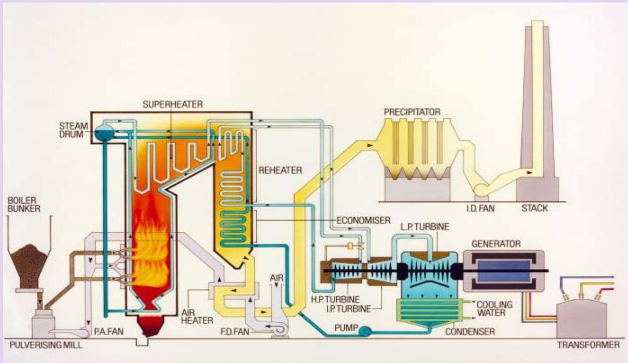
PROCEEDING

2-DAY CONFERENCE ON

"DESIGN, ENGINEERING, ERECTION, TESTING, COMMISSIONING, OPERATION & MAINTENANCE OF THERMAL POWER PLANT"

AT FEDERATION OF GUJARAT INDUSTRIES (FGI),
GOTRI - SEVASI ROAD, GOTRI, VADODARA, GUJARAT.



Jointly Organized By:

THE SOCIETY OF POWER ENGINEERS (I) VADODARA CHAPTER &
GUJARAT STATE ELECTRICITY CORPORATION LTD. - GSECL

The Society of Power Engineers (India) Vadodara Chapter

414-415, B–Wing, Monalisa Business Centre, Near Samanvay Saptarshi Complex, Manjalpur, Vadodara 390 011.
GSTN: 24AABAT3247Q1Z4
e-mail: spevadodara01@rediffmail.com,
WhatsApp: M – 9328658594 Web: www.spevadodara.in

	2 – DAY CONFERENCE ON **"Design, Engineering, Erection, Testing, Commissioning, Operation & Maintenance of Thermal power plant"** The Society of Power Engineers (I) Vadodara Chapter & Gujarat State Electricity Corporation Limited	

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TENTATIVE PROGRAM

2-DAY CONFERENCE ON

"DESIGN, ENGINEERING, ERECTION, TESTING, COMMISSIONING, OPERATION & MAINTENANCE OF THERMAL POWER PLANT"

21&22 MAY 2026 (THURS-FRI), AT FGI, GOTRI, VADODARA

SOCIETY OF POWER ENGINEERS (I), VADODARA CHAPTER

TIME	DESCRIPTION
Day - 1	21ST MAY 2026 (THURSDAY)
08.00 To 09.30	**REGISTRATION & HI-TEA**
09.30 To 11.00	**INAGURATION**
11.00 To 11.15	**NETWORKING TEA BREAK**
11.15 To 13.00	**TECHNICLE SESSION – I Chairman: Dr. Satish Chetwani Director [ERDA]**
	1) Feasibility Studies & Project Planning of Thermal Power Plant (Er K.C.Yadav) 2) Vibration Severity Analysis of Rotary Equipment (Motor) & Case Studies (Mr. Robert Macwan, Mr. Umesh Soni & Dr Anil Khopkar) 3) Grounding Risks and Hidden Electrical Hazards in Generating Stations (Er D.B.Gour) 4) RENOVATION, MODERNISATION & CONDITION MONITORING OF THERMAL POWER STAION SWITCHYARD. (Er S.M.Takalkar) 5) PLATINUM SPONSOR'S PRESENTATION – GSECL
13.00 To 14.00	**NETWORKING LUNCH BREAK**
14.00 To 15.30	**TECHNICLE SESSION – II Chairman: Dr. Anil Khopkar**
	1) Role of Instrumentation and Control in Thermal Power Plants And Recent Advancements. (Er Aaditya Bhatt and Er SMS Baxi) 2) Design & Engineering of Thermal Power Plant Main Plant & Balance of Plant (BOP) (Er D.J.Parmar) 3) Bare Inspection of Package Boiler & Fit for Services Inspection of Pressure Vessel (Mr. Robert Macwan Mr. Umesh Soni & Dr. Anil Khopkar) 4) Boiler Remaining Life Assessment (RLA) & Condition Assessment Comprehensive Approach. (Er. Nikhil Sabhaya & Er Deepak Chandarana) 5) PLATINUM SPONSOR'S PRESENTATION – ADANI POWER
15.30 To 15.45	**NETWORKING TEA BREAK**
15.45 To 17.30	**TECHNICLE SESSION – III Chairman: Er K.C.Yadav.**
	1) Contract Labour Information Management System (CLIMS) (Mr Devansh Shah) 2) Gujarat Power Sector in a Net-Zero 2047 Scenario Demand, Resource Adequacy and the Strategic Role of Concentrated Solar Power. (Er Nitesh Bidarkar) 3) Modelling and analysis of duct path using Computational fuid dynamics. Pressure Loss in Fuel Gas. (Mr. Arunesh Dwivedi, Mr. Shubham Kumar & Mr. Kuldeep Ruprelia) 4) Auxiliary power consumption reduction in Coal fired Thermal Power Plants (Prof. Awdheshkumar Singh) 5) Renewable Energy Integration and Thermal Flexibilization Costs: Evidence from GSECL Thermal Power Plants. (Er Rutvij Patel , Er. Kandarp Mistry, Er. Nitesh Bidarkar) 6) PLATINUM SPONSOR'S PRESENTATION – NTPC
	End of Day 1

Day - 2	22[ND] MAY 2026 (FRIDAY)
08.00 To 09.00	**HI-TEA**
09.00 To 10.45	**TECHNICLE SESSION – IV Chairman: Prof. Awdheshkumar Singh**
	1) Civil Design & Engineering of Thermal Power Plant (Main & Balance Of Plant) (Er. S S Sheth) 2) Construction and Project Management in Thermal Power Plants.(Er D.J.Parmar) 3) Significance of Pole Slipping Protection for Generator and Protection Setting Guidelines. (Mr. Shailesh Modi & Dr. Anil Khopkar) 4) Feasibility Assessment of Fast Motor Bus Transfer for Critical Motor Loads Using EMTP Simulation. (Er Chinmay Jani & Er Sumit Mehta) 5) Use of Pipe Conveyor System in Transportation of Minerals.(Er. Hitesh Harigovind Gulbani) 6) SILVER SPONSOR'S PRESENTATION – ERDA
10.45 To 11.00	**NETWORKING TEA BREAK**
11.00 To 13.00	**TECHNICAL SESSION – V Chairman: Er P.H.Rana.**
	1) Automatic Generation Control (AGC) in Thermal Power Plants (Er. Aviral Anurag Tripathi) 2) Safety Standards & Regulations including Electricity Safety (Er. Samir A Chaudhari) 3) Exergy Analysis of an 800 MWSuper Critical Coa - FiredThermal Power Plant (Mr. Kuldeep Ruprelia & Mr. Arunesh Dwivedi) 4) Coal Size and its importance in AFBC BOILER OPERATION (Gohil Devpalsinh I) 5) COMMERCIAL GOVERNANCE FRAMEWORK EPC Contract Closure & Dispute Resolution in Power Sector Projects (Er R H Kahar) 6) SILVER SPONSOR'S PRESENTATION – Durga Infra Mining Pvt. Limited
13.00 To 14.00	**NETWORKING LUNCH BREAK**
14.00 To 15.45	**TECHNICAL SESSION – VI Chairman: Er. Y.V.Joshi.**
	1) Statutory requirement for safety Training Thermal Power Plant which is the value - not just priority. (Mr. S.V.Sapre & Er P. A Shah) 2) High Voltage Gas Insulated Switchgear (HV GIS) Technology (Er Anil C Shah) 3) Feasibility and Project Planning of Thermal Power Plant (Er Jay Parmar.) 4) Technical Paper on Power Trading and LPS Rules (Er Kalpendra Rathaur.) 5) Fuel Management. (Er D.J.Chaudhary) 6) SILVER SPONSOR'S PRESENTATION – Maruti Clean Coal & Power Ltd.
15.45 TO 16.00	**NETWORKING TEA BREAK**
16.00 TO 17.30	**CONCLUDING SESSION – VII Chairman: Er. S.M.Takalkar**
	1) Renovation and Modernization of GSECL Thermal Units GSECL (Er J.K.Sandhi) 2) Advance Steam Chemistry (Chief Chemist D.S.Gamit & K.L.Paramar.) 3) Environmental Norms & Compliance. (Er Rina Parmar) 4) SILVER SPONSOR'S PRESENTATION – P.C. Patel Mahalaxmi Simplex Consortium Pvt Ltd. **5) Concluding Remarks**

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2 – DAY CONFERENCE ON "Design, Engineering, Erection, Testing, Commissioning, Operation & Maintenance of Thermal Power Plant" at FGI, Vadodara

The Society of Power Engineers (I) Vadodara Chapter
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414-415, B–Wing, Monalisa Business Centre, Near Samanvay Saptarshi Complex, Manjalpur, Vadodara 390 011. GSTN: 24AABAT3247Q1Z4

e-mail: spevadodara01@rediffmail.com, WhatsApp: M – 9328658594 Web: www.spevadodara.in

Role of Instrumentation and Control in Thermal Power Plants and Recent Advancements

Er. Aditya Bhatt
Deputy Engineer,
GSECL

Er. Sanjay M Shilearbaxi
Former EE GSECL,
Associate Engineer, TPEC

Abstract

Every megawatt-hour generated by a thermal power plant depends on hundreds of measurements and control actions happening simultaneously — from combustion air dampers responding to flame signals, to feed-water pumps reacting to drum-level sensors, to emission monitors reporting to regulators in real time. Instrumentation and control (I&C) is the infrastructure that makes all of this possible. Over the past two decades, it has transformed from simple regulatory hardware into an intelligent, connected platform built on AI, Machine Learning, IIoT, and Digital Twins — and the impact on Indian thermal generation has been tangible. This paper traces that journey and grounds it in practice through five Indian case studies: NTPC Vindhyachal's AI-based combustion optimisation programme, NTPC Korba's physics-informed digital twin for boiler pressure-part health, Adani Power Mundra's IIoT-based predictive maintenance at India's second-largest single-site coal station, Tata Power Mundra's CEMS integration for continuous CPCB compliance, and NTPC Dadri's WirelessHART retrofit for balance-of-plant monitoring. Published benchmarks for these technologies document heat-rate improvements of 0.6–2%, significant NO_x reductions, and measurable reductions in forced-outage rates — outcomes now being pursued across India's 215 GW coal fleet. The paper also covers cybersecurity requirements and the I&C outlook for India's thermal fleet through 2031.

1. Introduction

Walk into the control room of a modern thermal power plant and you are surrounded by data — thousands of measurements streaming from field instruments, dozens of control loops responding autonomously, and alarm systems watching for anything that drifts outside safe limits. This is instrumentation and control (I&C) at work, and without it a plant cannot run safely, efficiently, or in compliance with India's tightening emission regulations. India's coal fleet — roughly 215 GW and still the backbone of national grid reliability — is under pressure from two directions at once: CPCB emission deadlines that many stations are racing to meet, and grid operators asking for faster ramp rates as solar and wind capacity grows. Smart I&C, AI/ML analytics, and IIoT architectures are the tools operators are reaching for. This paper reviews how those tools work and, more importantly, what they have actually delivered at five Indian power stations.

2. Role of Instrumentation and Control in Thermal Power Plants:

Think of I&C as doing four things for a thermal plant simultaneously (Figure 1). First, it watches — measuring temperature, pressure, flow, level, vibration, and chemical composition continuously and feeding that data to controllers that respond faster and more consistently than any operator could manually. Second, it protects quality — catching parameter drift early, before a small deviation becomes a trip or a generation shortfall. Third, it drives efficiency — automating the routine adjustments that optimise fuel burn, water chemistry, and auxiliary power consumption, taking the guesswork out of operations. And fourth, it keeps people safe — monitoring for dangerous conditions and triggering interlocks or emergency shutdowns the moment something goes wrong. These four roles are not independent; they reinforce each other, and a well-designed I&C system delivers all four at once

Figure1-PRIMARY ROLES OF I&C

3. Evolution of Industrial Instrumentation

Industrial instrumentation has evolved across five generations — pneumatic signals, analog 4–20 mA loops, digital DCS/SCADA, Advanced Process Control, and today's AI-enabled smart instruments and IIoT platforms (Figure 2). India's coal fleet spans all five simultaneously: 1980s subcritical stations still running legacy analog instruments sit alongside NTPC's 660 MW supercritical units equipped with Generation 4–5 I&C from commissioning. Managing this coexistence — retrofitting older plant without shutdown while deploying AI on newer units — defines the central I&C challenge for Indian utilities today.

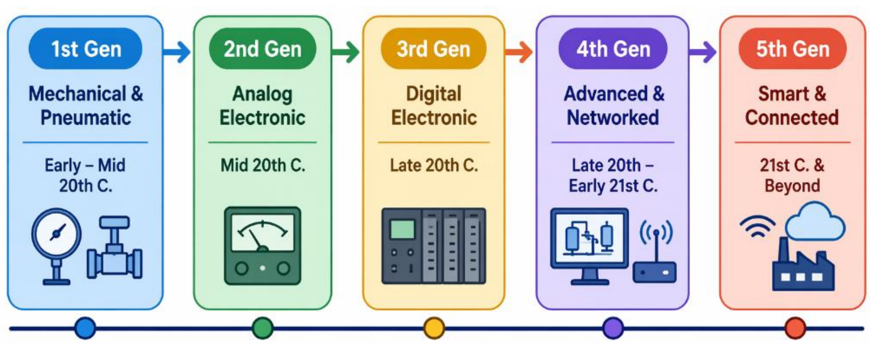


Figure 2. Evolution of industrial instrumentation across five technology generations.

4. Advancements in Instrumentation and Control Systems

Four mutually reinforcing technologies define the current I&C frontier: smart instruments generating richer data at source, AI/ML converting that data into foresight, IIoT connecting plant assets into a unified information fabric, and digital twins enabling virtual testing before live action. Their operating principles and Indian plant applications are summarised below.

4.1 Smart Instruments

Smart transmitters embed a microprocessor at the sensor, transmitting diagnostics and calibration data alongside the process variable via HART — making each device a self-validating networked node. Smart valve positioners add auto-calibration, HART/Fieldbus compatibility, and partial-stroke testing for SIL compliance.

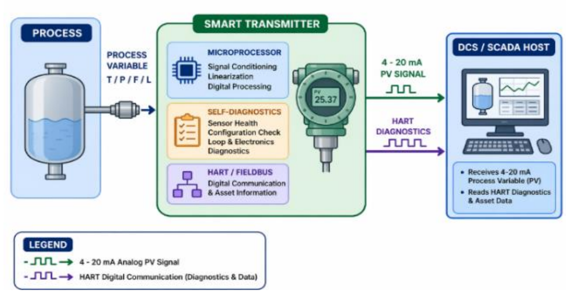


Figure 3. Smart transmitter architecture with HART

Wireless HART (2.4 GHz mesh, IEC 62591) enables cost-effective monitoring in brownfield plants where new cabling is impractical — applied at NTPC Dadri (Section 8.5). Fieldbus (H1 at 31.25 kbps; HSE at 100 Mbps) replaces parallel wiring with a single digital bus, cutting panel space and enabling on-bus diagnostics.

4.2 Artificial Intelligence and Machine Learning

A 660 MW unit generates tens of thousands of data points per second — historically archived but rarely mined. AI/ML converts this data deluge into actionable intelligence through three high-impact use cases in Indian plants:

- Predictive maintenance — vibration, temperature, and acoustic signatures fed to supervised-learning models detect incipient bearing wear, tube leaks, or fouling weeks before failure (see Sections 8.2–8.3).
- Combustion optimisation — reinforcement-learning agents trim excess O_2, burner tilts, and mill loading in real time to minimise heat rate and NO_x simultaneously (see Section 8.1).
- Anomaly detection — unsupervised models flag deviations from the unit's normal operating manifold, catching sensor drift, cyber intrusions, and process upsets that rule-based alarms miss.
- In practice, AI operates in an advisory or supervisory role — presenting recommendations or nudging setpoints within pre-approved ranges — while the DCS retains full authority over control loops and protective interlocks.

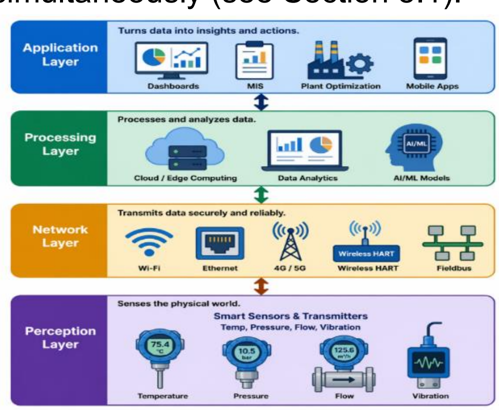


Figure 4 Four-layer IIoT

4.3 Industrial Internet of Things (IIoT)

IIoT connects smart sensors through wired networks, Wireless HART, and 4G links to edge gateways, cloud analytics, and operator dashboards — giving a maintenance engineer bearing temperatures at a remote pump from a tablet while a plant manager tracks fleet-wide heat-rate trends in a browser. Edge gateways process high-frequency vibration data locally, transmitting only meaningful features upstream — minimising bandwidth, reducing latency for time-critical alerts, and keeping raw data within the plant's OT boundary.

4.4 Digital Twin

A digital twin pairs physics-based models with ML surrogates, fed continuously by live sensor data, enabling engineers to see not just current asset state but predicted future behaviour. In Indian thermal plants, twins are now in commercial operation on boilers, turbines, and key auxiliaries.

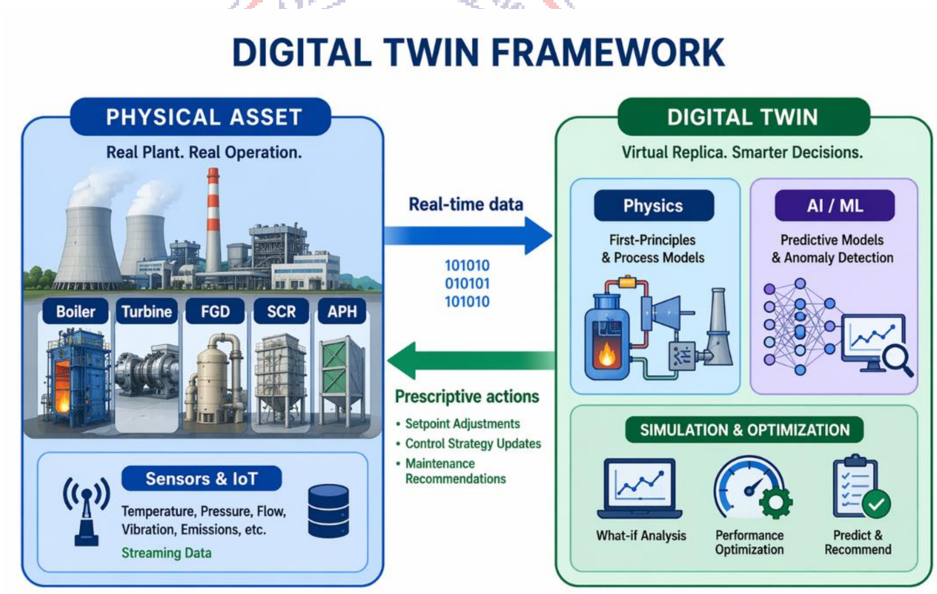


Figure 5. Digital twin framework for thermal power plant assets.

Three asset classes have seen the most traction:

- Boiler twin — watches tube-metal temperatures, slagging, and combustion stoichiometry to recommend sootblower sequences and burner trim before damage accumulates (see Section 8.2).
- Turbine twin — tracks HP/IP/LP efficiency trends, blade creep consumption, and shaft-vibration health, flagging degradation before it shows up in output.
- FGD/SCR/APH twins — model reagent chemistry, catalyst deactivation, and air-preheater fouling to keep SO_2 removal above 95% and stretch catalyst life without wasting

consumables (see Section 8.4). Quantified benefits are summarised in Section 7; Indian outcomes are detailed in Section 8.

5. Sustainability and Emissions Monitoring

India's MoEFCC norms ($SO_2 \leq 200$ mg/Nm³, $NO_x \leq 300$ mg/Nm³, PM ≤ 30 mg/Nm³) have made CEMS mandatory at all coal-fired stations above 500 MW, with real-time data streaming to the CPCB portal. Modern CEMS deploy in-situ and extractive analysers for continuous SO_2, NO_x, CO, CO_2, PM, and opacity measurement — and feed signals directly into closed-loop control: NO_x/O_2 readings trim combustion air, outlet SO_2 adjusts FGD limestone dosing (saving 5–10% reagent), and slip signals modulate SCR ammonia injection to protect catalyst life. Water-quality instrumentation on the condensate-feedwater cycle further guards boiler and turbine integrity while supporting zero-liquid-discharge obligations.

6. Cybersecurity of Instrumentation and Control Systems

OT connectivity widens the attack surface — the Ukraine 2015 grid attack, Triton/TRISIS, and global ransomware events confirm that cybersecurity is now a core I&C discipline. Two standards provide the framework:

- IEC 61850 — the communication standard for electrical substations and increasingly for power-plant electrical auxiliaries. It defines object models (Logical Nodes) and protocols (MMS, GOOSE, Sampled Values) that enable interoperable, high-speed protection and control over Ethernet.
- IEC 62443 — the comprehensive framework for industrial automation and control system (IACS) security, specifying zones and conduits, security levels (SL1–SL4), secure development lifecycle requirements for vendors, and operational practices for asset owners.

Good OT security practice requires: OT Levels 0–2 isolated from enterprise IT; industrial firewalls and unidirectional gateways at zone boundaries; role-based access with MFA; HMI/historian application whitelisting; physical SIS–BPCS separation; and OT-SIEM monitoring. IEC 62443-4-2 device certification, secure boot, and encrypted field protocols (HART-IP/TLS, OPC UA with security profiles) are now standard procurement requirements in Indian utility tenders.

7. Quantified Benefits of Advanced I&C, AI/ML, and Digital Twins

The business case for I&C modernisation is well-evidenced. Indian operators — NTPC, Adani Power, Tata Power — report results broadly consistent with global OEM benchmarks (GE Digital, 2020; Siemens Energy, 2021; Emerson, 2022; IEA, 2023). The Indian evidence is detailed in Section 8; the aggregate picture from published deployments is summarised in Figure 6.

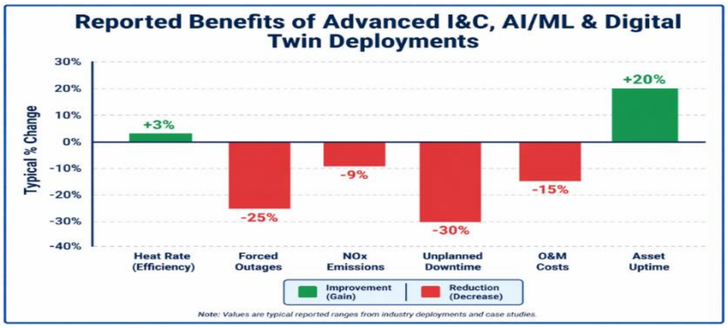


Figure 6. Typical benefits reported in thermal-plant digitalisation programmes.

Reported outcomes cluster consistently around:

- Heat-rate improvements of 1–3% from closed-loop combustion optimisation and neural-network soot-blowing control.
- Reduction in forced outages of up to 25% through predictive maintenance on critical rotating equipment.
- NOx emission reductions of 5–9% from SCR controller tuning and AI-based reagent dosing.
- Unplanned downtime reductions of 20–30% across boiler, turbine, and balance-of-plant assets following digital-twin deployment.
- O&M cost reductions of 10–15% driven by condition-based rather than time-based maintenance schedules.
- Asset uptime improvements of up to 20% for digital-twin-enabled units.

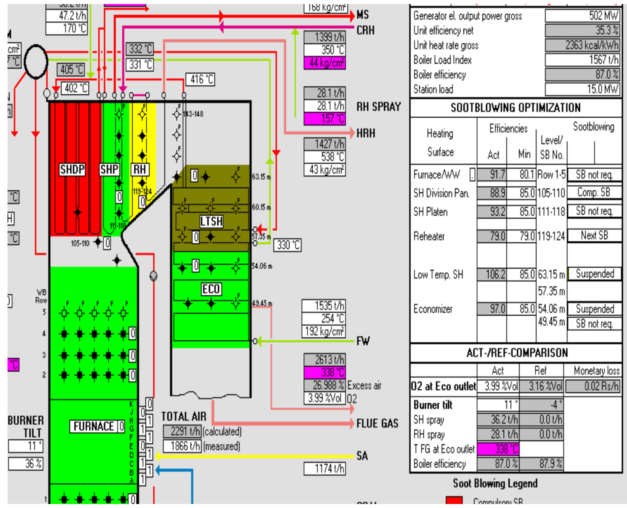
8. India Case Studies

Theory is only convincing when it translates into plant performance. The six deployments below span India's 215 GW coal fleet — from state-sector subcritical stations to NTPC's supercritical fleet and private-sector ultra-mega projects — and together illustrate how the I&C technologies described in Sections 2–7 are being deployed in Indian operating conditions.

8.1 GSECL Wanakbori Thermal Power Station — PADO System

The PADO (Performance Analysis, Diagnostics & Optimisation) System implemented in GSECL’s 800 MW thermal power unit is an advanced real-time monitoring and predictive analytics platform designed to improve plant efficiency, reliability, and asset health. The system integrates operational data from DCS and field instruments to enable continuous performance monitoring, fault diagnostics, and condition-based maintenance.Key Modules of PADO as mentioned below

Boiler Performance Monitoring: PADO continuously monitors combustion efficiency, excess air, APH performance, sootblower effectiveness, furnace conditions, flue-gas parameters, and mill performance. This enables optimisation of combustion, reduction in heat-rate losses, and improved boiler efficiency.



Condenser Performance Monitoring: The system tracks condenser vacuum, back-pressure, cleanliness factor, cooling-water performance, and air ingress, enabling early detection of fouling and vacuum degradation to improve turbine performance and reduce heat-rate penalties.

Turbine Performance Monitoring: PADO monitors HP/IP/LP cylinder efficiency, shaft vibration, bearing metal temperatures, differential expansion, and steam purity in real time. Predictive diagnostics help identify abnormalities and prevent major equipment failures.

Boiler Tube Condition Monitoring & Expected Life Assessment: PADO continuously evaluates superheater, reheater, and economiser tube health using metal-temperature monitoring, creep-life analysis, acoustic leak detection, and oxide-scale estimation. **The system estimates the remaining useful life of tube banks, enabling condition-based replacement planning and reducing forced outages due to tube failures.**

Key Benefits of PADO Implementation

- Improved plant heat rate and efficiency through continuous optimisation of boiler, condenser, and turbine performance.
- Reduced forced outages through early fault detection and predictive maintenance.
- Condition-based maintenance approach, replacing conventional time-based maintenance.
- Extended equipment lifespan through real-time monitoring of thermal stress, vibration, and creep conditions.
- Lower maintenance costs and improved availability via proactive intervention planning.
- Enhanced operational analytics and reporting through automated dashboards and MIS generation.

The successful implementation of PADO at GSECL's 800 MW unit demonstrates how digital performance analytics can modernise thermal power plants and improve operational excellence across critical generating assets.

8.2 NTPC Vindhyachal Super Thermal Power Station —Combustion Optimisation

Vindhyachal operates subcritical units at sustained high plant load factors on coal that varies in GCV and ash content consignment-by-consignment. The control problem is archetypal: the interactions between excess O_2, burner tilts, secondary-air damper positions, and individual mill loadings are too nonlinear and too fast-moving for manual optimisation to capture at the frequency required. NTPC confirmed AI/ML deployment across its fleet as part of its documented digital transformation programme, with combustion optimisation among the flagship applications.

The implementation deploys a deep neural network (DNN) trained on three years of DCS historian data — over 300 input features per 500 MW unit including individual mill fineness, coal GCV from online NIR analysers, and flue-gas O_2 at four elevations. The model runs in a supervisory advisory loop at five-minute intervals, recommending adjustments to excess air targets, burner tilt angles, and mill-biasing factors within DCS-enforced operating envelopes. An operator overrides log tracks acceptance rates, which exceeded 78% within six months of deployment, indicating confidence in the system's recommendations.

8.3 NTPC Korba Super Thermal Power Station — Digital Twin for Boiler Health Monitoring

Superheater and reheater tube-leak failures account for approximately 35–45% of all forced-outage hours at NTPC Korba. NTPC and BHEL jointly developed a physics-informed digital twin for the station's 500 MW boiler pressure parts, fusing 480 thermocouple readings on SH/RH headers, steam-flow measurements from venturi meters on individual tube circuits, and online coal-quality assays into a FEM-validated thermal model

The twin's core deliverable is a real-time Remaining Useful Life (RUL) map for every monitored tube bank — updated every ten minutes using the Larson–Miller creep model for SA-213 T91 material. The system integrates thermal and mechanical degradation physics (creep, low-cycle fatigue from thermal cycling, and flow-accelerated corrosion from wet-steam zones in the cold RH), giving operators foresight that routine inspection intervals cannot provide.

Operational outcomes: the twin identified localised heat-transfer anomalies on the secondary SH of Unit 3 attributable to sootblower sequencing errors — specifically, a recurrent blocked sootblower nozzle that increased local metal temperature by 18–22°C in the affected bank over an 8-week period. Correction of the sootblower programme prevented a tube failure that would have caused a 5–7 day forced outage. Coal consumption optimisation from the twin's combustion advisory reduced specific coal consumption by 3.5 g/kWh SCE, translating to approximately ₹4 crore in annual fuel savings per 500 MW unit (Xu et al., Clean Energy, 2019). Emerson's Ovation-platform predictive maintenance suite, which underpins Korba's DCS integration, is documented to reduce forced outage rates and optimise heat-rate efficiency fleet-wide and is now a standard specification in NTPC's technical procurement documentation.

8.4 Adani Power Mundra Thermal Power Plant — IIoT-Based Predictive Maintenance

Adani Power Mundra (4,620 MW, nine units: four × 330 MW subcritical and five × 660 MW supercritical) is India's largest private-sector single-site coal station. Its rotating-equipment fleet numbers several hundred assets — boiler feed pumps, condensate extraction pumps, ID/FD/PA fans, and bowl mills — and a forced outage on a 660 MW supercritical unit represents a generation loss of approximately 15 MUs per day at typical availability. Mundra's Unit 4 previously set a national 600-day continuous run record, but sustaining that reliability across nine units requires a shift from scheduled maintenance to predictive visibility.

The IIoT predictive maintenance deployment at Mundra integrates vibration transmitters (4–20 kHz bandwidth), bearing RTDs, motor-current signature analysers, and lube-oil particle counters on approximately 340 critical assets. Edge gateways at each equipment bay apply FFT-based signature analysis and transmit features to a cloud-hosted ML inference engine. **The ML model — a gradient-boosted ensemble trained on 18 months of historian data labelled with confirmed failure events — classifies each asset's health into a five-band risk tier every 30 minutes.**

Documented outcomes: bearing failures in boiler feed pump and ID fan drives are now detected an average of 12–18 days before failure, converting breakdown maintenance to planned interventions during load dispatch windows. GE Digital's published APM programme data for comparable supercritical deployments reports 1–2% heat-rate improvement at baseload and a 15–20% reduction in unplanned downtime (GE Digital, 2020). At Mundra's scale, a 1% heat-rate improvement on the five 660 MW units translates to approximately ₹35–40 crore of annual fuel savings. The IIoT platform also enables fleet-wide benchmarking: similar assets across the nine units are ranked by health index, identifying systematic underperformance in specific equipment batches and informing future procurement decisions.

8.5 Tata Power Mundra Ultra Mega Power Project — CEMS and Emissions Compliance under CPCB Norms

Tata Power's CGPL Mundra UMPP (4,150 MW, five × 830 MW, Gujarat) operates under import coal economics and a strict CPCB compliance regime — SO_2 ≤ 200 mg/Nm³, NO_x ≤ 300 mg/Nm³, PM ≤ 30 mg/Nm³ — with data streaming continuously to the CPCB online portal. Non-compliance triggers regulatory notices and financial penalties; at 4,150 MW, even a 48-hour shutdown carries a generation-loss cost of approximately ₹20–25 crore at merchant rates.

The CEMS architecture deployed at CGPL Mundra uses dual-channel extractive analysers for SO_2 and NO_x (continuous UV differential optical absorption spectroscopy), in-situ laser-backscatter PM monitors at the stack inlet and outlet, and CEMS data acquisition servers (DAS) that transmit 15-minute averages to the CPCB portal in the prescribed XML format. Tata Power additionally confirmed deployment of the Siemens SPPA-P3000 laser-based combustion optimisation system at one unit — using laser diagnostics to measure and homogenise the combustion flame cross-section, reducing local hot-spots that generate NO_x peaks beyond SCR design capacity.

Closed-loop integration: outlet SO_2 signals trim limestone slurry feed to the FGD system automatically, tracking actual stack conditions rather than worst-case design assumptions and reducing reagent over-dosing by an estimated 8–12%. NO_x slip signals modulate SCR ammonia injection to protect catalyst from ammonia slippage, extending catalyst service life from a nominal 16,000 hours toward 22,000 hours. PM readings feed the ESP voltage and rapping controller, preventing stack opacity excursions before the CPCB portal flags them. The Mundra UMPP architecture — continuous measurement, closed-loop control integration, and online regulatory reporting — is cited in CPCB's own best-practice guidelines for large plant CEMS implementation. **Tata Power reports zero CPCB violations at the station since full CEMS commissioning.**

8.6 NTPC Dadri — WirelessHART Retrofit for Balance-of-Plant Monitoring

NTPC Dadri (1,820 MW, Uttar Pradesh) hosts a mix of subcritical and gas-based units in a dense industrial corridor — a plant where adding wired instrumentation to operational BOP systems would require cable trays through live process areas at unacceptable risk and cost. Over 180 BOP measurement points — pipeline valve positions, auxiliary cooling-water supply temperatures, lube-oil header pressures, seal-water flows to pump mechanical seals, and heat-exchanger outlet temperatures — were being read manually on four-hourly rounds, creating a 4-hour detection blind spot for developing faults.

The WirelessHART retrofit programme deployed IEC 62591-compliant transmitters across these 180+ points. Each transmitter routes through a self-healing mesh network to one of four gateway nodes installed in weatherproof junction boxes on existing cable-tray brackets — requiring no civil works. The gateways connect to the DCS historian via Modbus TCP over the existing plant LAN. End-to-end latency for alarm conditions is under 4 seconds; routine monitoring updates transmit at 30-second intervals.

Outcomes: twenty-three slow-drift conditions — progressively rising auxiliary cooling-water outlet temperatures on condenser vacuum pumps, declining lube-oil header pressures on CEP drives, and valve-position deviations on feedwater isolation valves — were identified in the first year of operation that manual rounds had missed. In one instance, a 7°C rise in CEP bearing-cooler outlet temperature over five days, invisible between rounds, was flagged by the wireless network 38 hours before the bearing temperature itself reached alarm level; an emergency shutdown was avoided. The HART Communication Foundation publishes retrofit cost data showing WirelessHART installations deliver equivalent monitoring coverage at 25–40% of the cost of new wired instrumentation — validated by NTPC Dadri's experience. The programme is now cited in NTPC's annual digital transformation reporting as a replicable BOP monitoring model for its 21-station thermal fleet.

9. Challenges and 2026–2031 Outlook

9.1 Implementation Challenges

The case for I&C modernisation is clear — but anyone who has tried to execute it in a live thermal plant will recognise the following barriers:

- Legacy integration — DCS and PLC assets that are 15–25 years old, running proprietary protocols, do not talk easily to modern IIoT gateways. Protocol converters and middleware help, but they add latency and complexity.
- Cybersecurity exposure — increased connectivity widens the attack surface; retrofitting IEC 62443-compliant zones and conduits into brownfield plants is capital- and engineering-intensive.
- Data quality — AI/ML models are only as good as the data they consume. Tag-naming inconsistencies, missing metadata, sensor drift, and poorly documented process changes quietly degrade model accuracy, often without any obvious alarm.
- Skills gap — experienced I&C engineers are retiring; the incoming workforce requires cross-training in OT, IT, data science, and cybersecurity.
- Capital justification — AI and digital-twin projects compete against tangible reliability upgrades and mandatory compliance spend. The ROI is real but requires clear measurement frameworks; projects that cannot demonstrate sustained returns within two to three years risk cancellation.
- Regulatory ambiguity — emissions monitoring, cybersecurity reporting, and data-sovereignty requirements differ by jurisdiction and evolve faster than plant control systems can be updated.

9.2 Outlook: 2026–2031

Looking ahead to 2031, four trends are likely to reshape how thermal plants are instrumented and controlled:

- Edge-AI — ML inference embedded directly in DCS controllers eliminates the round-trip latency of cloud-based analytics and keeps OT data on-site. NTPC has already piloted this on supercritical units; expect it to become standard in next-generation controller specifications.
- Flexible operation — India's rapid solar and wind expansion means thermal plants that previously ran baseload will increasingly two-shift and fast-start. I&C architectures will need to prioritise ramp-rate control, start-stop cycle counting, and AI-based startup optimisation as competitive differentiators.
- Cyber-physical resilience — zero-trust architectures, signed firmware, and continuous OT monitoring (IEC 62443-3-3 SL 2+) will become mandatory in CEA and CERC procurement standards.
- Carbon-aware control — as India's carbon credit mechanism matures under the Energy Conservation Act 2022, operators will face financial incentives to minimise CO_2-per-MWh in

real time. Control systems that can integrate live carbon-intensity signals into combustion and load-dispatch decisions will have a measurable commercial advantage.

10. Conclusion

Advanced I&C — smart instruments, AI/ML analytics, IIoT, and digital twins — has crossed from aspiration into demonstrated commercial practice across India's thermal generation fleet. The five case studies in Section 8 are consistent in their message: peer-reviewed benchmarks confirm heat-rate improvements of 0.6–2% from AI combustion optimisation, digital twin deployments detect developing faults days to weeks before forced outage, IIoT predictive maintenance converts breakdown events into planned interventions, CEMS integration supports continuous regulatory compliance, and Wireless HART retrofits close BOP monitoring gaps at a fraction of wired cost — all with payback periods that compete with any conventional reliability investment. None of this is automatic. It requires clean data, IEC 62443-compliant cybersecurity architecture, engineers who can work across OT, IT, and data science, and management commitment that survives the first capital cycle. As India's coal fleet is called upon to run harder, cycle more flexibly, and meet progressively tighter CPCB emission limits, the case for I&C modernisation does not weaken — it intensifies. Operators who treat it as a strategic priority rather than a deferrable maintenance item will be the ones who keep thermal generation competitive, compliant, and safe through the remainder of this decade.

Name: Mr. Aditya Bhatt
Designation: Deputy Engineer
Organization: Gujarat State Electricity Corporation Limited (GSECL).

Work Experience:

- Over 17 years of experience in power generation, instrumentation & control systems, and plant operations.
- Currently posted at GSECL Corporate Office, working on Thermal Power Plant Flexibilization, and leading a centralized real-time performance monitoring system for all major GSECL power stations.
- Previous roles include Operation Engineer at Dhuvaran Gas-Based CCPP, Erection & Commissioning Engineer for the 800 MW Supercritical Unit at Wanakbori TPS, and Instrumentation & Maintenance Engineer at Kutch Lignite TPS.
- Experience in DCS upgradation, preventive maintenance, efficiency improvement, and implementation of advanced monitoring and control systems.

Certifications & Specialization:

- Certified Energy Auditor, Bureau of Energy Efficiency (BEE), Government of India.
- Industrial Control System (ICS)/Operational Technology (OT) Cyber Security Level - 2 Engineer – ISEA, Ministry of Electronics & IT.
- Associate CISO – ISEA, Ministry of Electronics & IT.
- Leadership Development Programs at IIM Lucknow, IIM Indore, and ISB Mohali.

	Education: • Bachelor of Engineering in Instrumentation & Control. • Diploma in Instrumentation & Control.
	**Name:** Er. Sanjay M Shiledarbaxi Former Executive Engineer, Gujarat State Electricity Corporation Limited (GSECL). • Passed BE (Electronics) in 1986 From M S University, Vadodara • SPE –LM and working as Finance Secretory of The Society of Power Engineers- Vadodara Chapter. M No. +91- 9909940562, mail: sanjaybaxi16@gmail.com **Work Experience:** • Over 32 years of experience in Power Generation, Instrumentation & Control system in erstwhile Gujarat Electricity Board (GEB) and Gujarat State Electricity Corporation Limited [GSECL] • Experience in maintenance of 210 MW Ukai and Wanakbori Thermal Power plant Instrumentation control systems, Planning and Project of various GSECL projects like Ukai # 500 MW, Dhuvaran # 375 MW GBPS, 250 MW Sikka Unit # 3&4 and 800 MW Wanakbori Supercritical Unit # 8 • Experience of PLCC (Power Line Communication System) of Wanakbori TPS. • Presently working as an Associate Engineer in Takalkar Power Engineers & Consultants Pvt Ltd. (TPEC), Vadodara.

Feasibility Assessment of Fast Motor Bus Transfer for Critical Motor Loads Using EMTP Simulation

By

Chinmay Y. Jani

Elcon Engineers Private Limited,

Vadodara-390020, INDIA – M +91 9979775100, emt@elconengineers.com.

ABSTRACT

Fast Motor Bus Transfer (FMBT) is an important strategy for maintaining supply continuity to critical motor loads within typical power plants during the loss of an incoming power source. This paper presents a detailed evaluation of the feasibility of implementing an FMBT scheme in a typical electrical network, considering the practical system configuration, operating philosophy, and available system data. An EMTP based model of the representative network is developed to study the transient behavior of interconnected motor loads during transfer conditions. The study focuses on key governing parameters such as residual bus voltage, phase angle difference between sources, frequency variation, transfer timing, motor speed, slip, electromagnetic torque, current, and V/Hz ratio during the transfer event. A practical operating scenario is simulated to assess the dynamic response of the motor loads, including their reacceleration capability and the influence of system strength and source characteristics. The results are evaluated against the limits specified in ANSI C50.41. The findings establish a clear operating envelope for the proposed scheme and identify the limiting conditions for reliable transfer. The study confirms that the proposed FMBT scheme is technically feasible and can ensure controlled and reliable transfer of motor loads without compromising the electrical parameters.

1. INTRODUCTION

The Fast Motor Bus Transfer (FMBT) is an important operational strategy used to maintain continuity of supply to critical motor loads when the normal power source is lost. In many industrial and utility installations, large motors such as boiler feed pumps, cooling water pumps, compressors, crushers, and process fans cannot tolerate even brief supply interruptions without risking process instability, equipment stress, or plant shutdown. A properly designed bus transfer scheme allows these motors to remain in service by quickly transferring the motor bus to an alternate source.

Several motor bus transfer techniques are practiced in industry, namely fast transfer, in phase transfer, and residual voltage transfer. Among these, fast transfer is preferred when the alternate source is available, and the transfer can be completed within a few cycles, typically less than ten cycles, thereby minimizing motor deceleration and preventing stalling. However, the success of a fast transfer depends strongly on key parameters such as residual bus voltage, phase angle difference between the sources, frequency deviation, and transfer timing. If not properly controlled, the transfer can result in high transient currents, large electrical torque, and mechanical stress on the motors.

This paper addresses the technical feasibility of implementing an FMBT scheme for the existing electrical network under realistic operating conditions. The problem considered is to determine whether a fast transfer can be achieved without violating acceptable limits of voltage, current, torque, and V/Hz ratio during the transfer event. The study also aims to identify the limiting operating conditions and define the safe operating envelope for reliable implementation.

To achieve this, a detailed electromagnetic transient model of the representative power system is developed using an Electro-magnetic Transient Program (EMTP) based simulation platform. The dynamic behavior of interconnected motor loads is analyzed during transfer conditions, with particular attention to motor reacceleration, slip, electromagnetic torque, bus voltage profile, and phase angle variation between the sources. A practical operating scenario is simulated to represent a realistic disturbance and network condition.

The simulation results are evaluated against established engineering criteria, and the observed motor and system responses are found to remain within the acceptable limits defined by ANSI C50.41 [1]. The study demonstrates that, under controlled conditions of phase angle difference and transfer timing, the proposed fast motor bus transfer scheme is technically feasible and can be implemented without imposing undue electrical or mechanical stress on the motors.

The work presented in this paper provides a clear understanding of the governing parameters of FMBT, establishes its feasibility for the studied system, and offers practical guidance for reliable and controlled implementation in similar installations.

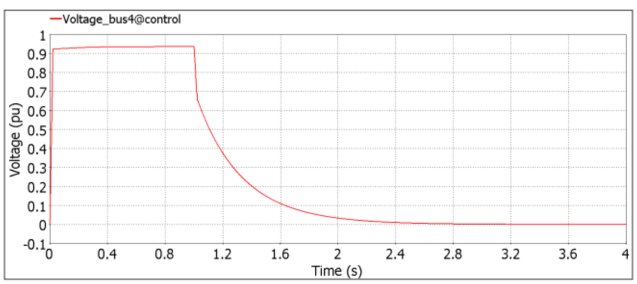
2. MOTOR BUS TRANSFER PRINCIPLE AND DYNAMIC RESPONSE

2.1 MOTOR BUS RESPONSE AFTER SUPPLY INTERRUPTION

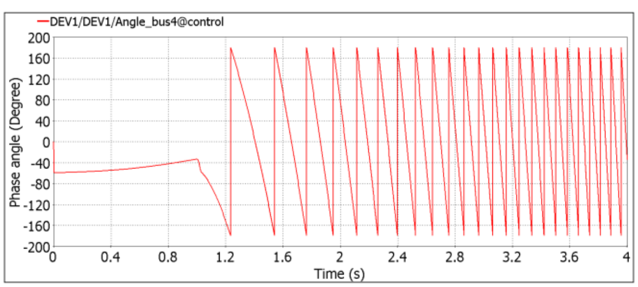
When the normal supply to a motor bus is lost, the connected motors do not stop immediately. Due to their rotational inertia, they continue to rotate for a short time and behave like generators, which keeps a residual voltage on the bus [2]. This residual voltage does not remain constant. Its magnitude, frequency, and phase angle gradually decay as the motors slow down [2], [3].

The rate at which this decay takes place depends on the motor characteristics and the connected mechanical load. In an induction motor, the decay of residual voltage is closely linked to the rotor open circuit time constant, which is influenced by rotor resistance, rotor reactance, and slip [3]. A higher time constant generally means the residual voltage remains present for a longer period, which may be useful for transfer if the alternate source can be connected quickly. On the other hand, a rapid decay shortens the available transfer window and makes synchronization more difficult.

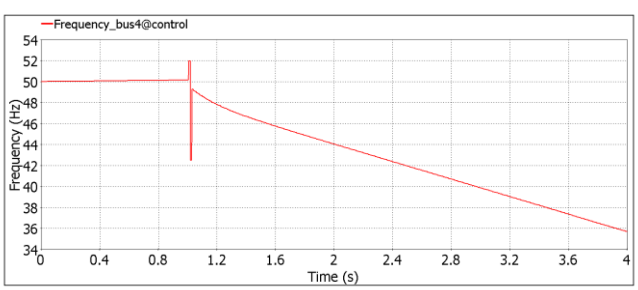
From the perspective of bus transfer analysis, the three most critical parameters following source loss are the residual voltage magnitude, phase angle displacement, and residual frequency as illustrated in Fig. 1(a)–1(c). These quantities determine whether the alternate source can be reconnected without producing excessive electrical stress on the motors [4], [5]. If the transfer is attempted too early or with a large phase mismatch, the closing action can produce high transient torque, large inrush current, and mechanical stress on the driven load [5], [6].



(a) Voltage profile



(b) Voltage angle profile



(c) Frequency profile

Figure 1. Spin-down/Coast-down characteristic of the motor, which suffers from the power outage

2.2 FAST MOTOR BUS TRANSFER

Fast motor bus transfer is intended to restore supply to critical motor loads within a very short time after the loss of the preferred source. In practice, this means that the alternate source should be connected before the residual voltage on the bus decays significantly, typically within the first ten cycles [1]. The main advantage of this approach is that motor speed is preserved as much as possible, which reduces the risk of stalling and helps maintain process continuity.

The major limitation of fast transfer is that the two sources may not be exactly synchronized at the instant of closing. If the incoming source is not sufficiently close to the residual bus voltage in magnitude and phase, a severe transient response can occur [4]. This is why the phase angle difference between the residual motor bus voltage and the incoming source voltage must be carefully controlled. A commonly accepted limit for fast transfer is that this difference should remain within 90 degrees [1].

The transient torque developed during a fast transfer depends on the magnitude of the bus voltage, the magnitude of the incoming source voltage, and the phase angle between them at the moment of closing [4], [6]. As this phase angle increases, the electrical torque applied to the motor also increases. In some cases, the transient current and torque can rise to several times the rated values of the motor, depending on the electrical parameters of the system, the connected load, and the switching instant [5]. The performance of a fast transfer scheme is therefore influenced by the following factors:

a) Motor loading condition: Heavily loaded motors decelerate more quickly after source loss, which causes the residual voltage to fall faster and the phase angle to change more rapidly. This reduces the time available for safe transfer. Lightly loaded motors retain residual voltage for a longer time, but the transfer is only successful if the initial phase angle difference is already small.

b) Motor Inertia: High inertia loads retain motion for a longer time and slow down more gradually. This can support fast transfer, provided the switching occurs within the available window. Low inertia systems decay more quickly and therefore provide less time for controlled transfer.

C) Types of Motor: In practical installations, a bus may feed both induction motors and synchronous motors. These machines do not behave in the same way during supply loss. Induction motors typically lose residual voltage faster [7], while synchronous motors can sustain voltage for a longer duration because of field excitation. This makes the transfer behavior more complex and must be considered during study [5].

For these reasons, fast transfer is best suited to systems where the transfer logic, breaker timing, and source conditions can be accurately coordinated.

2.3 IN PHASE TRANSFER

In phase transfer is used when immediate reconnection is not possible and the alternate source must wait until the bus voltage and source voltage align closely in phase [6]. In this method, a phase angle relay continuously monitors the angular difference between the residual bus voltage and the incoming source voltage. The breaker is allowed to close only when the predicted phase angle, frequency difference, and residual voltage all fall within the set limits [3], [6].

Compared with fast transfer, this method is more conservative. It reduces the chance of severe transient torque because the two voltages are brought into closer alignment before closing. However, the drawback is that the supply interruption is usually longer, since the system must wait for the proper closing instant. For this reason, in phase transfer is often selected where the electrical system cannot tolerate a severe out of phase closing, but a short interruption can still be accepted.

2.4 RESIDUAL VOLTAGE TRANSFER

Residual voltage transfer is based on allowing the motor bus voltage to decay to a low enough level before the alternate source is reconnected. In practice, the bus is transferred when the residual voltage falls below a preset threshold, typically around 0.25 to 0.3 per unit. At that point, the resultant V/Hz value must also remain within the accepted limit, commonly taken as 1.33 per unit [1].

This method is simpler than fast transfer because it does not require strict supervision of the phase angle difference. Since the residual voltage is already low, the risk of an out of phase closing is reduced [7], [8]. Because of this, residual voltage transfer is widely used in industry. At the same time, it is not always the best choice where uninterrupted operation is critical, since the bus must wait longer for the voltage to decay before reconnection [9].

Residual voltage transfer is therefore suitable for applications where simplicity and reliability are more important than very short transfer time. In systems that require tighter continuity of supply, however, it may not provide the speed needed to prevent process disturbance [9], [10].

2.5 PRACTICAL CONSIDERATIONS FOR TRANSFER SCHEME SELECTION

The selection of a motor bus transfer scheme depends on the operating duty of the plant, the nature of the connected motors, and the acceptable interruption time. Fast transfer offers the shortest restoration time, but it requires tight control of residual voltage, phase angle, and breaker closing time [1], [4]. In phase transfer provides a safer closing condition when synchronization is needed before reconnection [6]. Residual voltage transfer is easier to apply, but it can be too slow for sensitive processes [7], [8], [11].

A proper transfer study should therefore consider the following:

- decay of residual bus voltage after source loss
- frequency and phase angle variation during spin down
- motor loading and inertia
- mix of connected motor types
- breaker closing delay and relay logic
- acceptable electrical and mechanical stress during reconnection

A clear understanding of these factors is essential before finalizing any transfer philosophy. In practical terms, the bus transfer scheme must be chosen not only for electrical correctness, but also for process continuity and equipment safety [12]. These concepts provide the basis for the simulation and feasibility assessment carried out in the following chapter.

3. SIMULATION MODEL AND RESULT ANALYSIS

The electrical system under study is supplied from a 132 kV bus located at the plant switchyard. From this bus, two outgoing transmission lines feed a nearby substation. In addition, two dedicated 132 kV feeders from the same switchyard bus supply the plant station buses through station transformers. The two station bus sections are interconnected via a bus coupler that remains open under normal operating conditions.

Each station bus section supplies a group of critical motor loads that are essential for generation continuity and reliable plant operation. The specifications of the motors, M1 and M2, considered in the study are provided in Table 1. In addition to these motors, other auxiliary loads connected to the respective bus sections are represented as lumped loads for the purpose of system analysis.

Table 1. Parameters values critical motors

Parameters	Ratings	Parameters	Ratings
Power	4000 kW	*Cos φ*	0.91
Stator Volts	6.6 kV	*Degree of Protection*	IP 55
Stator Current	384 A	*Duty*	Continuous
Rated RPM	1490 RPM	*Insulation Class*	F
Efficinecy	96 %	*Rotor Type*	Cage

The Fast Motor Bus Transfer scheme is intended to maintain continuity of supply to these critical motor loads during feeder or transformer related disturbances by transferring the affected bus section to the adjacent healthy source through the bus coupler. The feasibility of such transfer is evaluated under one credible operating scenario.

3.1 CASE SCENARIO CONSIDERED

In the considered scenario, a fault is assumed to occur at t = 2 s on the high voltage side of the transformer, TR2, associated with Feeder 2, as illustrated in Fig. 2. Consequently, Feeder 2 is isolated by the protection system within 80 ms, including relay operation and circuit breaker clearing time, resulting in the loss of supply to the corresponding station bus section. The affected bus section begins to experience voltage decay driven by the spin-down characteristics of the connected motor, M2.

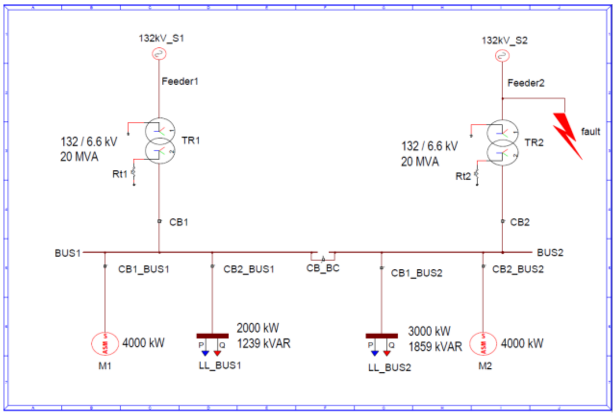


Figure 2. Typical SLD of case scenario considered

Under this condition, the bus coupler is commanded to close in order to transfer the de energized bus section to the adjacent healthy bus section that remains energized from its independent feeder, feeder 1. The study evaluates whether the transfer can be completed within the permissible time window for fast transfer, typically within the first few cycles after source loss, while ensuring that:

- The phase angle difference between the residual bus voltage and the incoming source voltage remains within acceptable limits
- The resulting transient current and electromagnetic torque in the motors remain within allowable limits defined by IEEE practice
- The voltage and V/Hz ratio during the transfer remain within safe limits for connected equipment

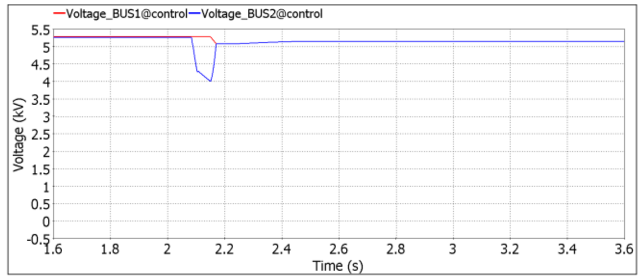
This case represents a typical source loss condition where the affected bus has only its normal connected motor and auxiliary loading at the instant of disturbance.

3.2 BUS VOLTAGE PROFILE AND PHASE ANGLE SYNCHRONISM

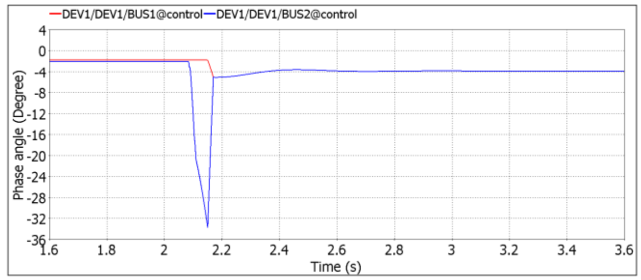
The Fig. 3 shows the bus voltage magnitude and phase-angle profiles derived at Bus1 and Bus2 during the transfer event. Before the disturbance, both buses remain close to their steady operating voltage. At the instant of source loss and transfer initiation, Bus2 voltage decays due to motor coast-down, falling from about 5.37 kV to approximately 4.0 kV, before recovering after the bus coupler closes. This corresponds to a temporary voltage drop of roughly 25% on the de-energized bus as seen from Fig. 3(a). As illustrated in Fig. 3(a), Bus1, which remains energized throughout the transfer event, experiences only a minor transient voltage dip of less than 5% and therefore does not exhibit any severe healthy-bus voltage sag.

The phase-angle plot indicates that the maximum phase angle difference between Bus1 and Bus2 is about 32 degrees during the transfer window as evident from Fig. 3 (b) and 3 (c). This is well within the ANSI C50.41 limit of 90 degrees. The recovery after transfer is smooth, and no large phase discontinuity is observed after closing.

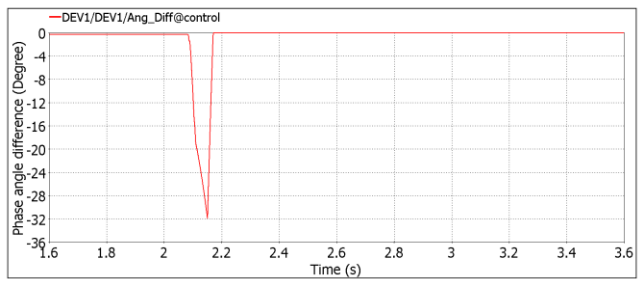
The synchronism condition is acceptable for fast transfer, and the phase separation remains comfortably below the ANSI threshold.



(a) Peak phase voltage profile of Bus1 and Bus2



(b) Voltage phase angle measured at Bus1 and Bus2



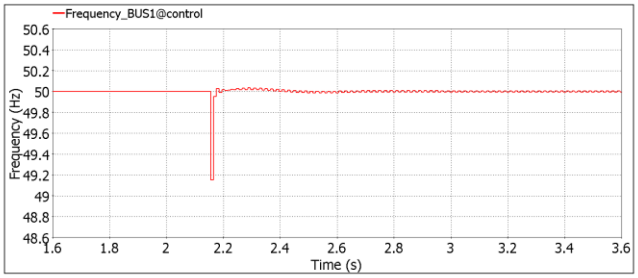
(c) Voltage phase angle difference between Bus1 and Bus2

Figure 3. Bus voltage and phase angle profiles

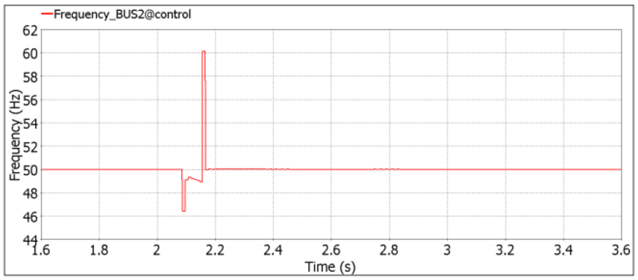
3.3 FREQUENCY STABILITY AND V/HZ RESPONSE

This section presents the frequency profile of both buses and the corresponding volts-per-hertz (V/Hz) response. As illustrated in Fig. 4(a), the frequency of Bus1 experiences only a brief transient dip to approximately 49.1 Hz before recovering to the nominal value of 50 Hz, indicating that the healthy source remains stable throughout the transfer event. In contrast, the frequency of Bus2 undergoes a comparatively larger transient excursion, briefly decreasing to around 46.5 Hz and subsequently rising to approximately 60.3 Hz during the switching interval, as shown in Fig. 4(b). This is a transient measurement associated with the loss/reconnection state and then quickly damps out.

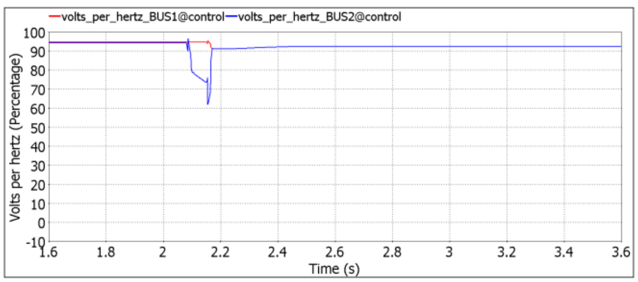
The V/Hz profile is more important for equipment stress. According to Fig. 4(c), the V/Hz ratio of Bus1 remains within approximately 93–95% of the rated value, whereas the residual V/Hz ratio of Bus2 decreases to about 62% before recovering to nearly 92–93% following the transfer. The healthy receiving bus does not experience any excessive rise in V/Hz, and the observed voltage depression on the energized bus remains well within the acceptable healthy-bus voltage dip limit of 10–15%.



(a) Frequency profile at Bus1



(b) Frequency profile at Bus2



(c) Volt per hertz profile of Bus1 and Bus2

Figure 4. Frequency and V/Hz profiles

Under ANSI C50.41, a fast transfer is acceptable when:

- Phase angle difference does not exceed 90 degrees,
- Resultant V/Hz at transfer does not exceed 1.33 pu,
- Transfer occurs within 10 cycles or less.

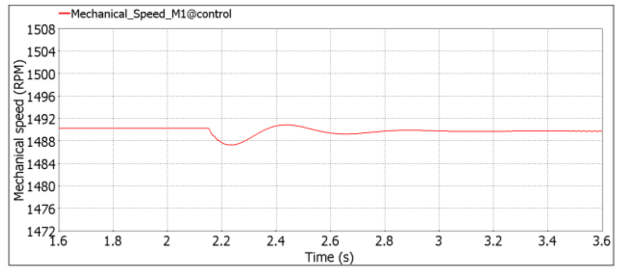
From the above results, the transfer appears to occur within only a few cycles, and the measured phase-angle, frequency, and V/Hz responses are consistent with the fast-transfer criteria specified in ANSI C50.41, while also confirming stable operation of the healthy bus throughout the transfer interval.

3.4 MOTOR SPEED AND SLIP RECOVERY

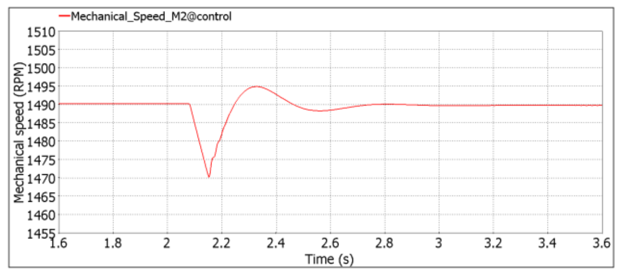
As illustrated in Fig. 5(a), the speed of M1 exhibits only a marginal transient dip from approximately 1489 RPM to 1487 RPM, followed by recovery to its original operating point. This indicates that M1 experiences only a mild disturbance during the transfer event. This indicates that M1 is only mildly disturbed by the transfer.

As depicted in Fig. 5(b), the speed of M2 exhibits a comparatively larger transient reduction to approximately 1470 RPM, followed by an overshoot to around 1495 RPM before gradually damping back to its nominal operating speed. This behavior is consistent with the transient torque response observed in the previous section.

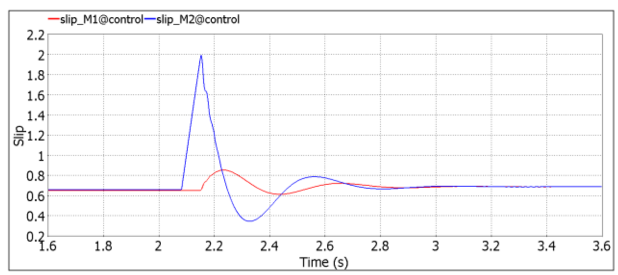
The slip characteristics further support the same conclusion. As illustrated in Fig. 5(c), the slip of M1 undergoes only a moderate transient variation, whereas M2 exhibits a comparatively larger transient slip excursion before gradually settling to its steady-state value. The important observation is that both motors recover to a stable running condition, and no sustained slip growth is visible.



(a) Mechanical speed of M1



(b) Mechanical speed of M2



(c) Slip profiles of M1 and M2

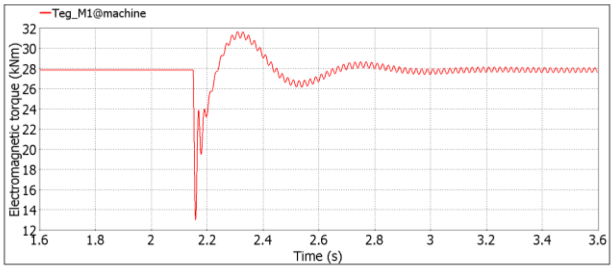
Figure 5. Speed and slip profiles of the motors

From the above analysis, it can be concluded that the motors successfully ride through the transfer event, and the post-transfer speed and slip responses remain stable with satisfactory recovery to steady-state operating conditions.

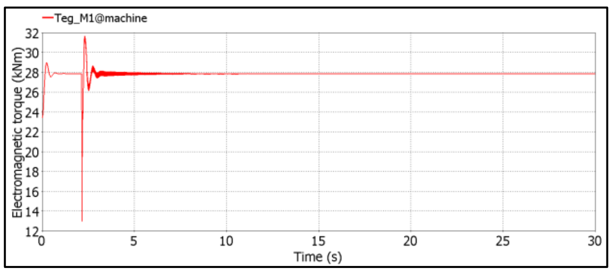
3.5 MOTOR ELECTROMAGNETIC TORQUE RESPONSE

This section shows the electromagnetic torque of motors M1 and M2 during and after the transfer. For M1, torque is steady at about 28 kNm before the event. At the transfer instant, torque briefly drops to around 13 to 14 kNm, then rises to a peak of about 31 kNm before settling back near the pre-transfer value as illustrated in Fig. 6(a). The oscillation is effectively damped and subsides within a short duration without exhibiting sustained transient behavior as depicted in Fig. 6(b).

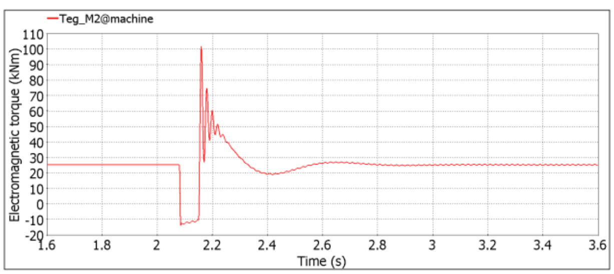
For M2, the response is much more severe, which is expected because it is the motor more directly affected by the source interruption and re-energization. As shown in Fig. 6(c), the motor torque initially drops to a small negative value and subsequently rises sharply to a peak of approximately 100–105 kNm, followed by a damped oscillatory response that gradually settles toward the steady-state value of about 28 kNm.



(a) Electromagnetic torque profile (zoomed) of M1



(b) Electromagnetic torque profile (normal) of M1



(c) Electromagnetic torque profile (zoomed) of M2

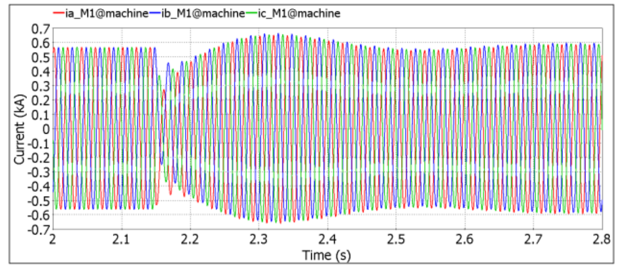
Figure 6. Electromagnetic torque profiles of motors

This is the main transient stress seen in the study. However, the important point is that the torque excursion is short-lived and self-damping, with no indication of loss of synchronism or unstable hunting.

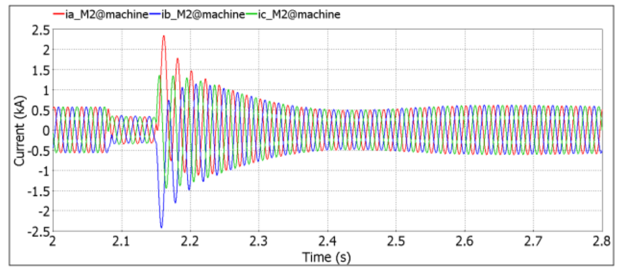
3.6 THREE-PHASE CURRENT AND VOLTAGE

This section shows the current waveforms of M1 and M2 and the three-phase voltage waveforms at Bus1 and Bus2. For M1, the current disturbance is relatively modest, with only a temporary waveform distortion observed around the transfer instant, as illustrated in Fig. 7(a). The waveform quickly returns to a steady sinusoidal form.

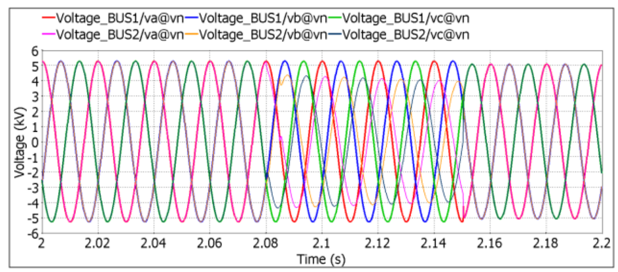
For M2, the current transient is comparatively more severe. As illustrated in Fig. 7(b), a short-duration inrush-like current peak of approximately 2.3–2.5 kA is observed, followed by a damped oscillatory response. This is expected when a motor bus is transferred onto a healthy source while residual voltage and motor slip are still present. The waveform then settles without long-duration overcurrent.



(a) Current profile of M1



(b) Current profile of M2



(c) Three phase RMS voltage profiles of Bus1 and Bus2

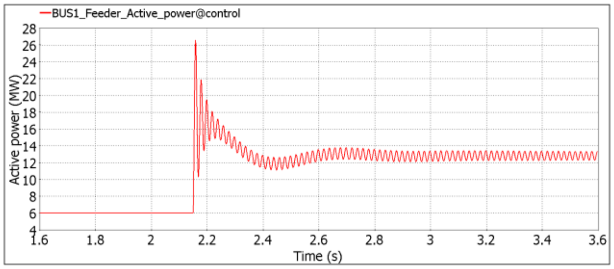
Figure 7. Three phase current and voltage profiles

The three-phase voltage waveforms shown in Fig. 7(c) indicate that the phase sets of Bus1 and Bus2 are sufficiently synchronized at the instant of transfer to permit a controlled bus closure, with no significant phase discontinuity observed in the waveform window.

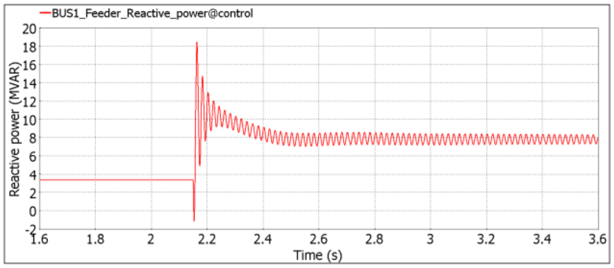
3.7 ACTIVE AND REACTIVE POWER MEASUREMENT

This section shows how the healthy feeder picks up the transferred load in terms of active and reactive power. Before transfer, feeder active power is around 6.5 MW. At the instant of transfer, the active power rises sharply to approximately 27–28 MW and subsequently decays to a steady-state value of around 13.5–14 MW, as indicated in Fig. 8(a). The reactive power exhibits a similar transient response, increasing from about 3.5 MVAr to approximately 19 MVAr before settling near 8–9 MVAr, as illustrated in Fig. 8(b).

The results indicate that the healthy feeder successfully accommodates the transferred load and subsequently reaches a stable operating condition without overloading of transformer, TR1. Although a transient over-response is observed immediately after the transfer, no evidence of sustained overloading or progressive loading instability is observed within the simulated time window.



(a) Active power profile of Feeder 1



(b) Reactive power profile of Feeder 1

Figure 8. Active and reactive power profiles of feeder 1

4 CONCLUSIONS

Based on the simulation results, the fast motor bus transfer in this case is technically feasible. The critical ANSI C50.41 checks are satisfied as follows:

- **Maximum phase angle difference:** Approximately 32 degrees, which is well below the ± 90-degree limit.
- **V/Hz condition:** The healthy bus remains near nominal V/Hz, while the residual bus decays as expected during motor coast-down. The plots are consistent with a compliant fast-transfer operation, as shown from the respective plots.
- **Transfer time:** The event appears to complete within a few cycles, and therefore within the 10-cycle ANSI requirement.
- **Healthy-bus voltage dip:** The receiving healthy bus does not show a severe dip and remains within the 10 to 15% allowable range.
- **Motor torque/current response:** Transient excursions are present, especially on M2, but they are short-lived and damped, with stable recovery.

The Bus2 voltage show a 25% dip which is exceeding the allowable range. However, this excursion is short-duration and do not adversely affect system recovery, motor re-acceleration, or operational continuity, and are therefore considered acceptable from a practical system performance perspective.

The simulation supports the feasibility of the Fast Motor Bus Transfer scheme. The transfer is completed within an acceptable window, the phase displacement remains well within ANSI limits, the healthy bus remains stable, and the motors recover without loss of synchronism or sustained instability.

REFERENCES

[1] ANSI/NEMA. (2012), "Polyphase induction motors for power generating stations," (ANSI/NEMA C50.41-2012).

[2] P. Kundur, Power System Stability and Control (1st ed.). McGraw-Hill, 1994

[3] Balamourougan, V., Sidhu, T. S., Kasztenny, B., & Thakur, M. M. (2006), "Robust technique for fast and safe transfer of power plant auxiliaries," IEEE Transactions on Energy Conversion, 21(2), 541-551.

[4] Muralimanohar, P., Haas, D., McClanahan, J. R., Jagaduri, R. T., & Singletary, S. (2016, September), "Implementation of a microprocessor-based motor bus transfer scheme," In 2016 Petroleum and Chemical Industry Technical Conference (PCIC) (pp. 1-9). IEEE.

[5] IEEE Standards Association. (2000), "IEEE guide for AC motor protection," (IEEE Std C37.96-2000).

[6] Chang, C. K. (2015), "A new MV bus transfer scheme for nuclear power plants," EPJ Nuclear Sciences & Technologies, 1, 12.

[7] Beckwith, T. R., & Hartmann, W. G. (2005, May), "Motor bus transfer: considerations & methods," In IEEE Systems Technical Conference on Industrial and Commercial Power 2005. (pp. 62-76). IEEE.

[8] P. Ledesma and E. Muljadi, "Transient Behaviour of Large Induction Motors During Power Transfers," IEEE Trans. Ind. Appl., vol. 37, no. 5, pp. 1325–1332, 2001.

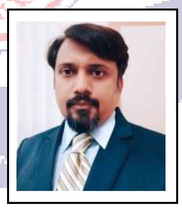
[9] J. Taylor and R. M. Nelms, "Phase Angle Based Motor Bus Transfer Scheme," in Proc. IEEE Power & Energy Soc. Gen. Meeting, 2015, pp. 1–6.

[10] Zamani, M. A., Zadeh, M. D., & Sidhu, T. S. (2014), "A compensated DFT-based phase-angle estimation for fast motor-bus transfer applications," IEEE Transactions on Energy Conversion, 30(2), 569-577.

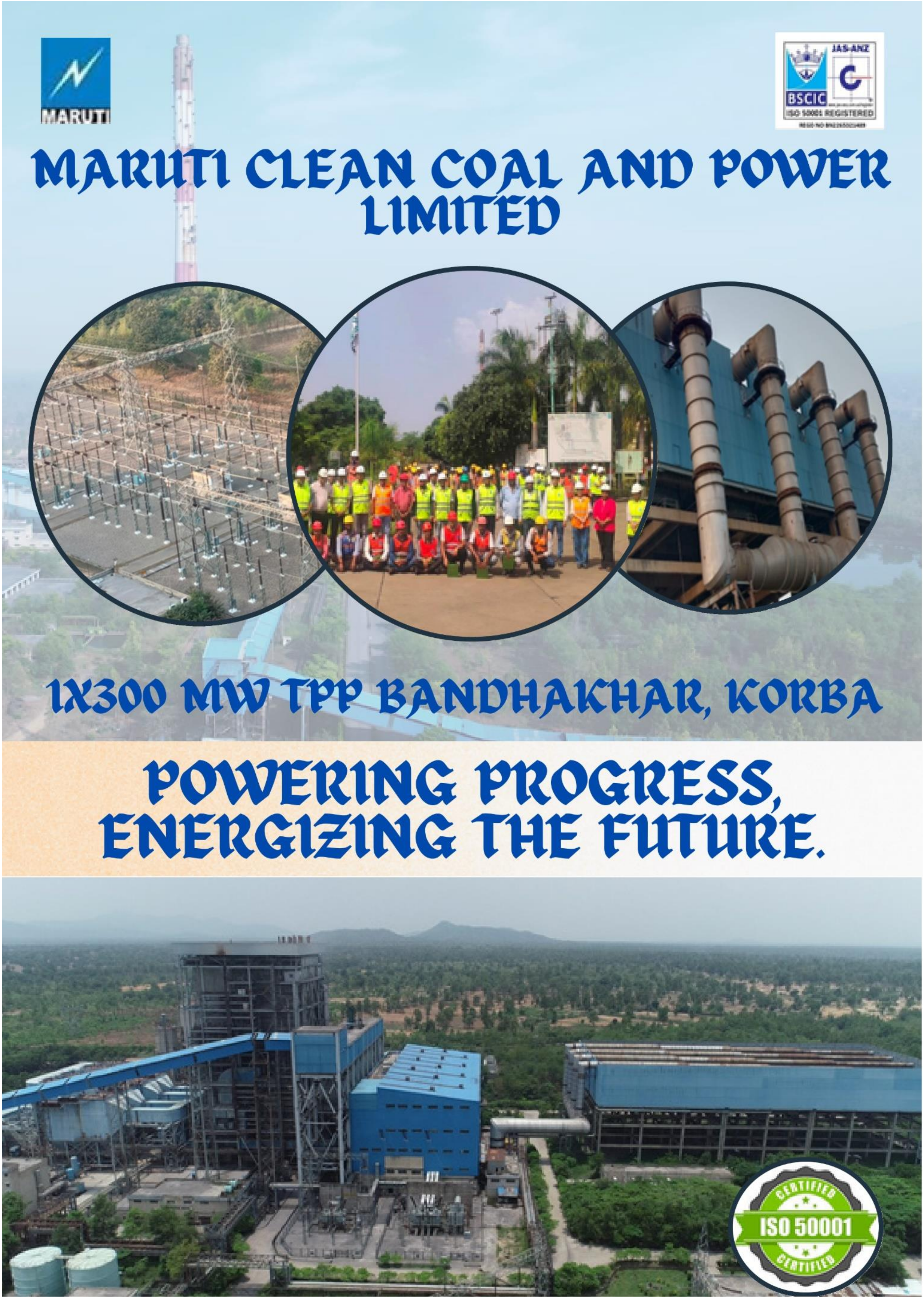
[11] Thiam, F. B., Urbina, M. D., & Wisniewski, J. B. (2017, July), "Fast bus transfers for open phase analysis at nuclear power plants," In 2017 IEEE Power & Energy Society General Meeting (pp. 1-5). IEEE.

[12] NEMA. (2021), "Motors and generators," (NEMA MG 1).

AUTHOR'S BIOGRAPHY



Chinmay Y. Jani received the B.E. degree in Electrical Engineering from Gujarat University in 2009 and the M. Tech. degree with specialization in Electrical Power Systems from Nirma University in 2013. He is currently pursuing his Ph D in the Department of Electrical Engineering at the Institute of Technology, Nirma University, Ahmedabad, India. Presently, he is working as a manager at Elcon Engineers Private Limited, where he leads EMT-based power system studies and associated engineering activities. His areas of interest include power system transient analysis, insulation diagnostics of power apparatus, power system studies, and mathematical modeling and simulation of electrical power systems.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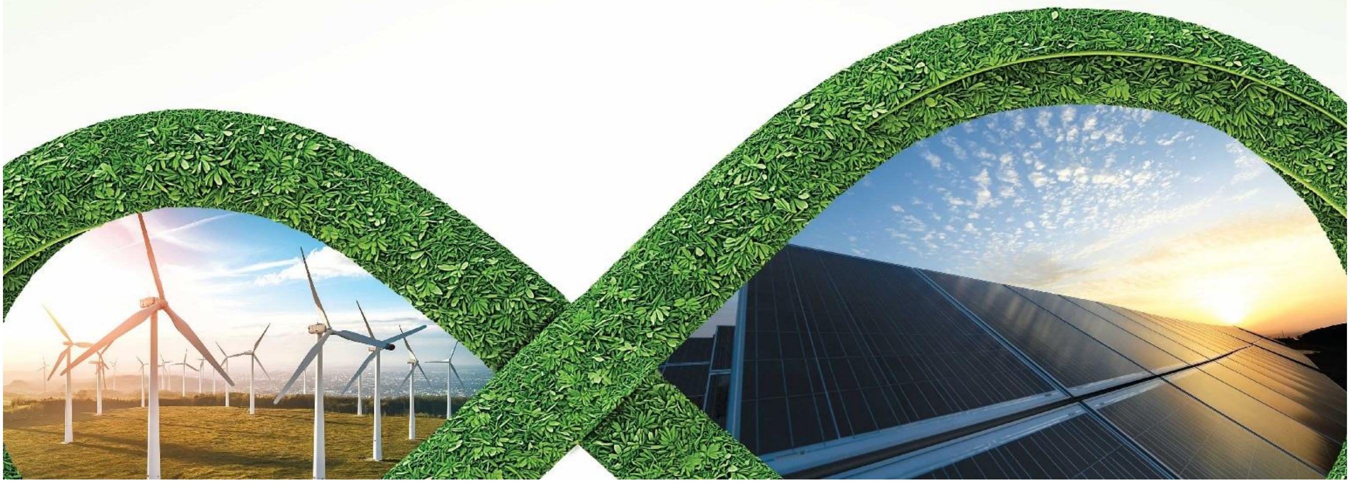

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Transportation of lignite from Ghogha Surka Lignite Mine to BLTPS (Captive Power Plant) through Pipe Conveyor of 2.18 KM long having Capacity of 1500 TPH.

VIBRATION SEVERITY ANALYSIS OF ROTARY EQUIPMENT (MOTOR) & CASE STUDIES

Robert Macwan, Umesh Soni & Anil Khopkar,
Electrical Research and Development Association, INDIA,
robert.macwan@erda.org

ABSTRACT:

In Competitive, the industries are approaching to predictive maintenance from traditional preventive maintenance approach. Vibration Severity Analysis is the one of the most crucial Condition Monitoring tool used to check the healthiness of plant machinery and diagnose mechanical causes of failure or unavilabity of equipment. The health of machine can be monitored by routine or continuous vibration monitoring with sophisticated vibration instruments, which will give you prior indication of the fault and can take countermeasures to avoid catastrophic failure and avoid unavailability of equipment for operations. This paper represents the common causes that produce excessive vibrations in rotating machines & their specific spectrum pattern which can be identified with frequency and phase analysis. This paper explains details about frequency analysis, common cause of excessive vibration in motor. Also the vibration measurement and data collection equipment as well as acceptance standards are discussed.

Keywords— Condition Monitoring, Vibration Severity Analysis, Amplitude, Frequency analysis (Spectrum analysis or Fast Fourier Transform), Vibration Measurement instrumentation, Acceptance criteria, Case studies

I. INTRODUCTION

Condition Monitoring is the assessment of certain parameter on a continuous or periodic interval basis of the machinery, equipment and systems, If the parameter are based on Mechanical condition like vibration, Noise, NDT then it is called mechanical condition monitoring & if the parameter is based on Electrical condition like current, voltage, Partial discharge then it is called Electrical condition monitoring. Condition monitoring is a systematic & modern approach to keep any equipment health & available for operation any time rather than replacing parts of equipment. Condition Monitoring has Four stage as 1. Detection or Measurement 2. Analysis of Measured Data 3. Rectification after analysis 4. Confirmation after rectification

Vibration is the cyclic or oscillation motion of any machine or machine component from its original position of rest. It is response of a system to an internal or external stimulus causing it to oscillate or pulsate. Vibration can be measured in amplitude (Displacement, Velocity and Acceleration) with respect frequency (Spectrum Domain) or time (Time wave form). Frequency is an essential for pinpointing the cause of a machine problem. Most of the defects encountered in the rotating machinery give rise to a distinct vibration pattern (vibration signature analysis). Most vibration problems exhibit frequencies related to the rotational speed(s) of the machine. The FFT Record of "vibration signature" & its analysis with modern software with reach experience of expert & immediately diagnoses of faults makes Vibration Monitoring technique so powerful for condition monitoring rotating machinery.

II. ACCEPTABLE CRITERIA FOR VIBRATIONS

A. ISO – 20816 Part 3:

The ISO 20816 standard provides guidelines for Mechanical vibration-Evaluation of machine by measurement on non-rotating Parts. The ISO 20816-3 provides guidelines for the Industrial Machines with Nominal Power above 15 kW and Nominal Speed between 120 rpm and 15,000 rpm when measured in-situ condition. These guidelines consists of machines which are small (Class – 1 :Speed between 120 RPM to 600 RPM & Motor rating between 15 kW to 300 kW), medium (Class – 2:Speed above 600 RPM & Motor rating between 15 kW to 300 kW), large with rigid foundation (Class – 3 :Speed between 120 RPM to 600 RPM & Motor rating between 300 up to 50 MW),), large with soft foundation (Class – 4 : Speed above 600 RPM & Motor rating between 300 kW up to 50 MW) direct coupled, motors, pumps, generators, turbomachinery fans and compressors. Some rotary machines are in coupled with motor directly or by some gear boxes. The orientation of machine are inclined or horizontal or vertical depends upon applications with rigidly mounted or flexible mounts. As per ISO 20816-3, vibration velocity is sufficient to characterize the zone boundary values & the limits apply to the broad band R.M.S values of velocity in the frequency range of 10 Hz to 1000 Hz (600 to 60,000 cpm).

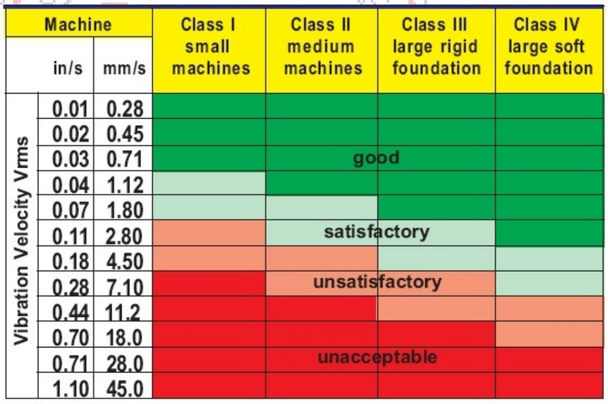

Figure I: ISO 20816 standards chart

B. Manufacturers Recommendations:

Generally OEM provides specific vibration limit along with equipment manual at the time of purchasing new equipments. The measured vibration values can be matched to these vibration limit for the safe operation of equipment. Thus overall vibration limits provided by the manufacturer can be used as a guilde line for vibration severity.

C. Comparison of Similar Equipment:

Whenever Two or more identical machines are operating under the same conditions, Vibration measurement can be comapred with each other for safe operation of equipment.

D. Baseline Comparison:

Aa per the acceptance test or history of machine or after machine overhauling, vibration severity limits can be set on baseline reading of machine. We can use this reading as a vibration severity limits in case relevant standards are not there.

E. Experience of Manufacturers /Suppliers /Vibration Experts.

III. VIBRATION MEASUREMENT INSTRUMENTATION

A. Transducers:

A transducer converts physical variables values of machine into corresponding electrical signals during measurement. There are many types of transducers are available in the market. Accuracy, application & measurement range along with cost is very important in selection of transducer. The types of measurement devices used include accelerometers, velocity and displacement transducers. Some of the transducers commonly used for vibration measurement are variable Resistance Transducers, Piezoelectric Transducers, Electrodynamic Transducers, Linear Variable Differential Transformer Transducer etc.

B Vibration Pickups:

Vibration pickup are the vibration transducer used in combination with another device to measure vibrations. These types of transducers have a mass, a spring and a damper inside a enclosure, which is affixed to the vibrating body. The displacement of the mass relative to the cage can be measured if we attach a pointer to the mass and a scale to the cage.

C. Accelerometer:

The acceleration of a vibrating body can be measured by accelerometer. Simple constuction, small size, high frequency range, long life and robustness are the main features of accelerometers. Due to this, it is used widely all overth world. The velocity and displacements are integrated by measured acceleration. The acceleration is directly proportional to frequency's square, accelerometers can be used for higher frequency measurement in case of Bearing, Gear Box etc.

D. FFT Analyzer:

Fast Fourier Transform (FFT) analyzers are used widely for signal analysis in vibration severity measurement. This type of digital analyzers is also called real-time signal analysis. Depends upon the requirement of vibration, these types of analysers are measured signal either in the frequency domain or in time domain. The vibration signal is constantly analyzed over all the various frequency Bands in real-time frequency analysis by analyzer. In morden days, Machine health monitoring is done by real-time analyzers as a minor change in machine relavant parameter measuring can be measured in real time by analyzer. The the real time measruing data is in the plot of Amplitude Vs. time while FFT data is in the plot of Frequency Vs Amplitude. By the Amplitude of measurement we can find the severity of the fault and by the frequency we can find the origin of the fault.

IV. LOCATION OF MEASUREMENT:

In three direction – Horizontal, Vertical, Axial at drive & Non drive end of the equipment on Non-rotating parts as near as possible towards Bearing.

V. CASE STUDY I

Table V-I Motor Details:

MOTOR DETAIL:		BEARING DETAIL:	
Name	RAW WATER MOTOR	DE Bearing	6313-C3
Rated	37 KW	NDE Bearing	6313-C3
Speed	1480 RPM	Motor Speed	24.66 Hz

Table V-II Observation Table & FFT Graph:

MEASUREMENT LOCATION		VELOCITY (RMS)(MM/SEC)
RAW WATER MOTOR - Drive End (DE) Side	Horizontal	**4.108**
	Vertical	2.296
	Axial	1.766
RAW WATER MOTOR - Non Drive End (NDE) Side	Horizontal	**6.545**
	Vertical	3.820
	Axial	0.650

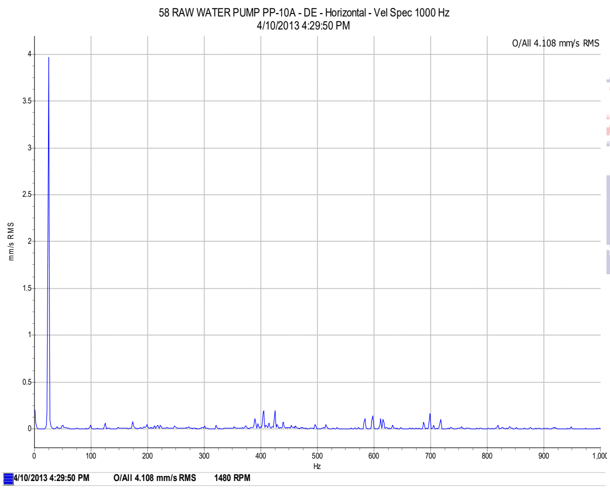

Figure V-1 FFT graph at NDE with Horizontal Position

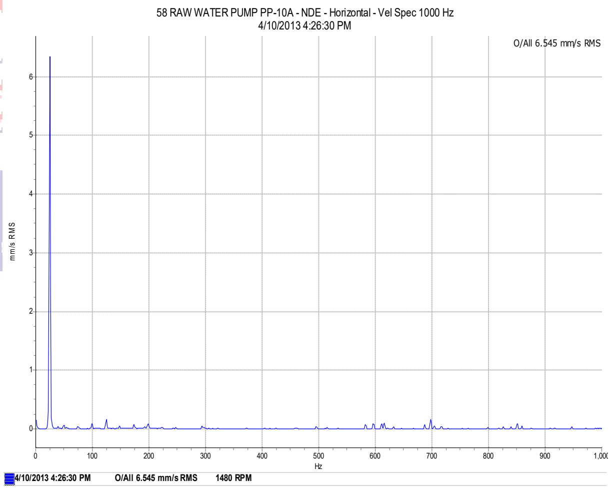

Figure V-2 FFT graph at DE with Horizontal Position

V-III Observation for Case Study – I:

The Motor DE & NDE velocities indicate “Alert zone” and “Danger zone” as per ISO 20816-3 respectively. From the FFT Spectrum of motor, Major frequency of vibration is approximately 1× RPM in the horizontal direction. This shows Unbalance in the motor.

VI. CASE STUDY II

Table VI-I Motor Details:

MOTOR DETAIL:		BEARING DETAIL:	
Name	11-PM-05B	DE Bearing	6313
Rated KW	37	NDE Bearing	6313
Speed	2940 RPM	Motor Speed	49.00 Hz

Table VI-II Observation Table & FFT Graph:

MEASUREMENT LOCATION		VELOCITY (RMS)(MM/SEC)
11-PM-05B - Drive End (DE) Side	Horizontal	**4.735**
	Vertical	**4.374**
	Axial	1.047
11-PM-05B - Non Drive End (NDE) Side	Horizontal	**5.107**
	Vertical	**2.101**
	Axial	1.874

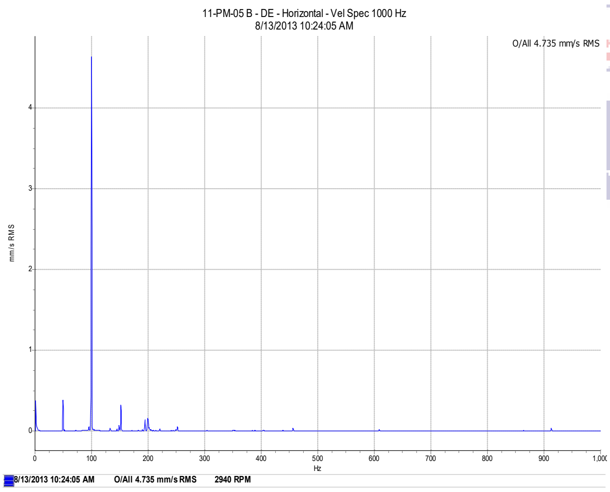

Figure VI-1 FFT graph at DE with Horizontal Position

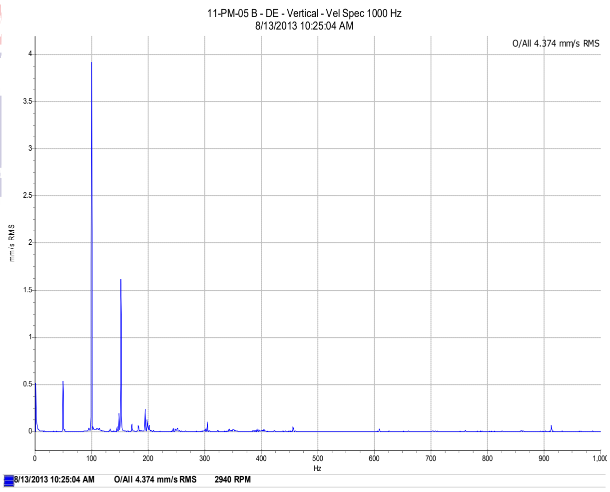

Figure VI-2 FFT graph at DE with Vertical Position

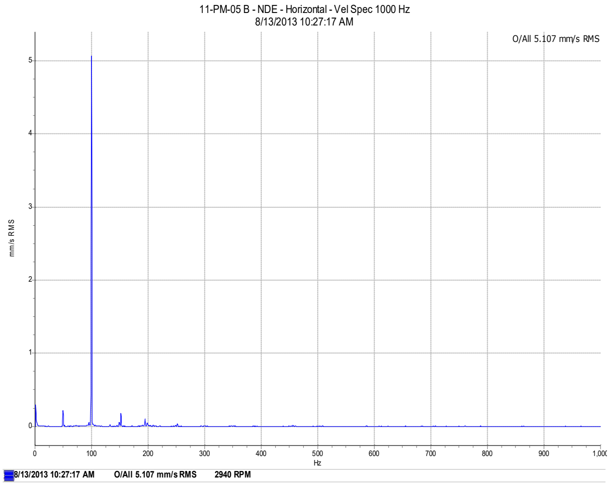

Figure VI-3 FFT graph at NDE with Horizontal Position

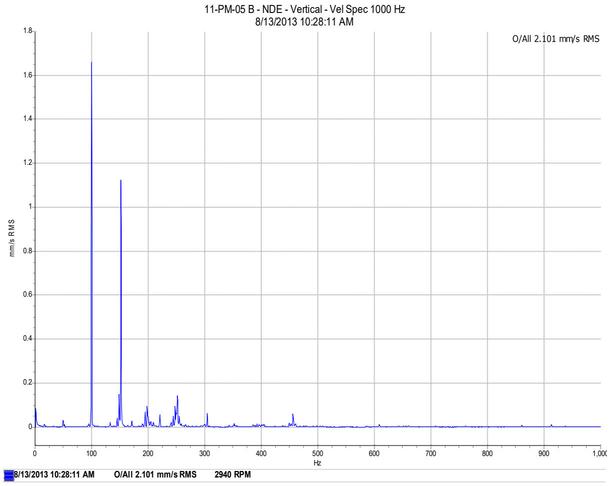

Figure VI-4 FFT graph at NDE with Vertical Position

VI-III Observation for Case Study – II:

From the FFT Spectrum of motor, Major frequency of Vibration is approximately 2× RPM as per ISO 20816-3. From the FFT Spectrum of motor shows mechanical looseness.

VII. CASE STUDY III

Table VII-I Motor Details:

MOTOR DETAIL:		BEARING DETAIL:	
Name	A/C COMPREESSOR	DE Bearing	NU 318
Rated KW	110	NDE Bearing	6314
Speed	1480 RPM	Motor Speed	24.66 Hz

Table VII-II Observation Table & FFT Graph:

MEASUREMENT LOCATION		VELOCITY (RMS)(MM/SEC)
A/C COMPREESSOR - Drive End (DE) Side	Horizontal	**4.444**
	Vertical	2.139
	Axial	1.758
A/C COMPREESSOR - Non Drive End (NDE) Side	Horizontal	**7.363**
	Vertical	2.284
	Axial	1.106

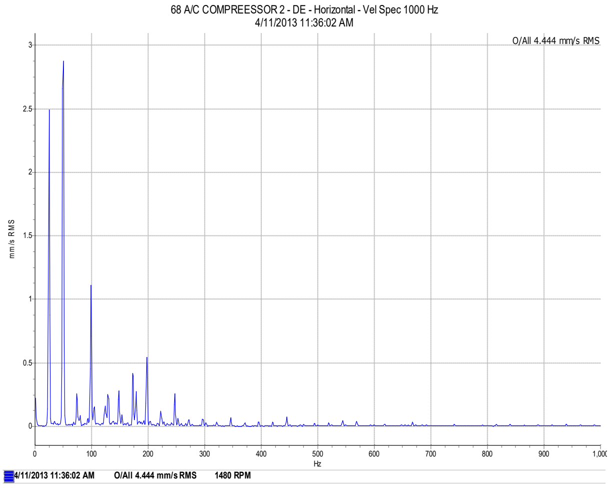

Figure VII-1 FFT graph at DE with Horizontal Position

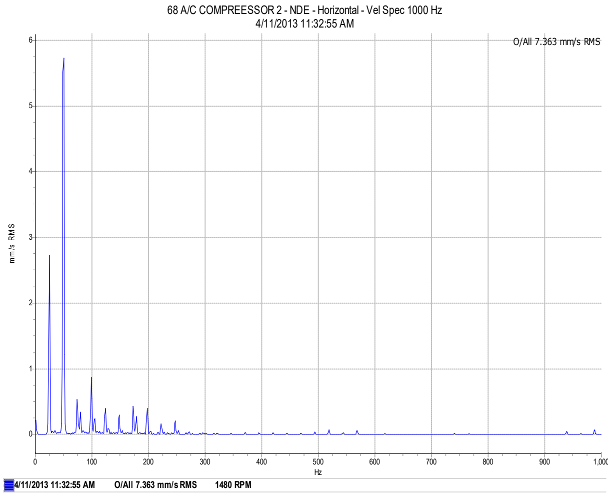

Figure VII-2 FFT graph at NDE with Horizontal Position

VII-III Observation for Case Study – III:

The Motor DE (Horizontal & Axial) velocity measurements indicate" Alert zone" as well as" Danger zone" of Vibration. From the FFT Spectrum of motor, Major frequency of vibration is approximately 1× RPM, 2× RPM, 3× RPM and so on as per ISO 20816-3. From the FFT Spectrum of motor shows mechanical looseness, Unbalance or misalignment.

VIII. CONCLUSION:

The different case studies that carried out at different industries contains the Unbalance, mechanical looseness and misalignment problem, which we removed by Balancing, soundness and alignment across coupling and dynamic vibration absorbers.

IX. REFERENCES:

[1] ISO - 20816
[2] "Mechanical Vibrations" by Singiresu S. Rao.5th edition Prentice Hall page 870 - 924
[3] "Mechanical Vibrations" by S.K. Bhave
[4] www.vibrationschool.com

Bio-data of Authors:

Mr. Macwan Robert Advin is Working as Head of Section- Mechanical Diagnostic at Electrical Research and Development Association (ERDA), Vadodara. He is responsible for activities related to Remaining Life Assessment (RLA) & Nondestructive Testing (NDT) of Thermal Plant, Process plant & Refineries. He has vast knowledge related to Remaining Life Assessment (RLA) of Boiler & Turbine through various Nondestructive Testing, Bare Inspection, Fit for Service (FFS) Inspection, Vibration Severity Analysis of Motor, Thermography and Energy Audit of plants. He has reach experience in the asset management through the various special mechanical diagnostic technique like Bare Inspection, Fit for Service, Vibration Severity Analysis, Finite Element Analysis (FEM), Various Remaining Life Calculation Techniques etc. He has published more than 15 research papers in national and international conferences and journals. He can be contacted at email: robert.macwan@erda.org.

Mr. Umesh N. Soni is Working as Head of Section- Diagnostic at Electrical Research and Development Association (ERDA), Vadodara. He is responsible for activities related to electrical diagnostic section. He has vast knowledge related to electrical diagnostic of various HT electrical equipment including Power transformer, Rotating machine, Switchyard equipment & HT cables. He has reach experience in the asset management through the various special diagnostic technique like C&TD, SFRA, ELCID, Partial discharge measurement. He has published more than 25 research papers in national and international conferences and journals. He can be contacted at email: umesh.soni@erda.org.

Dr. Anil S. Khopkar is PhD in electrical engineering, working as “Asst. Director & Head of Division – R&D and Expert Services at Electrical Research and Development Association (ERDA), Vadodara. He is responsible for various research activities and technology development in areas of Power Systems, Renewable Energy, Product Development and Advanced Materials in field of electrical engineering. He also headed, High voltage Impulse laboratory, Extra High Voltage Partial Discharge laboratory, Cable laboratory, Instrument Transformer Laboratory, Transformer Laboratory as well as calibration laboratory. He has established various test laboratory like, HV Impulse, HV PD lab, Transformer test laboratory etc. He is Member of BIS technical committee of India for High Voltage Testing techniques (ETD 19) and chairman of BIS technical committee of India for Surge Arrester (ETD 30). He is also a member of IEC Technical committee “TC 99/JWG 13 – Insulation co-ordination for HVDC System”. He has published 45 research papers in national and international conferences and journals. He can be contacted at email: anil.khopkar@erda.org

BARE INSPECTION OF PACKAGE BOILER & FIT FOR SERVICES INSPECTION OF PRESSURE VESSEL

By

Robert Macwan, Umesh Soni & Anil Khopkar, Electrical Research and Development Association, INDIA,

robert.macwan@erda.org

ABSTRACT:

At the time of designing of Boilers or pressure vessel, mostly ageing process of the materials used in the construction is considered for the safely, reliability and profitability. But the actual condition of the boiler or vessel varies significantly due to variation of various operation parameters, environmental factors, statutory requirements & human aspect/experience at the time of operation. Various component deteriorate constantly during their service due to time dependent material degradation process which included creep, fatigue, corrosion and oxidation. In general practice material damage results from interaction between two or more of damage mechanisms, causing unexpected failures. Such failures may be sudden in nature and may lead to huge loss. With this concept, the condition assessment of boiler or vessel needs to be evaluated regularly with high importance. Depth guideline has been mentioned for thermal power plant boiler in Indian boiler regulation, but for package boiler or pressure vessel, we have to follow rules for bare inspection or Fit for service inspection respectively. More over Cost, risk and time consumed for new installations as well as environmental demands have given rise for existing boilers.

Looking to the above situation, the main idea of this paper is to develop awareness & knowledge for conditional assessment of package boiler through bare inspection and condition assessment of pressure vessel through Fit for service (FFS) inspection.

A. CASE STUDY OF BARE INPSECTION OF BOILER

As the name suggests, the bare inspection of boiler means removal of all insulation/cladding for in-depth examination of all pressure parts of boiler by visually as well as physically by various Non-destructive Tests. After taking necessary care of boiler shut down, all insulation and cladding should be removed for bare inspection. As per the IBR guide line bare inspection is very important & mandatory for package boiler after every 10 years after commissioning. Schematic diagram of package boiler shown in photo no. 1 while photo 2 shows actual photo of package boiler along with all pressure parts or component of package boiler.

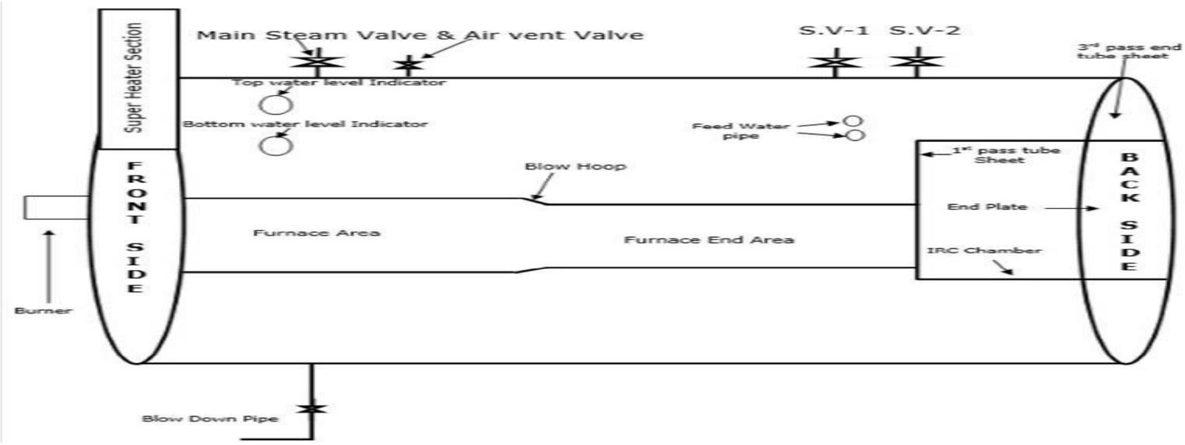

Photo 1: Schematic diagram of Package Boiler

Photo 2: Boiler in bare conditions.

The Package boiler has been made bare for the inspection and various NDT like Visual Inspection (VI), Liquid Penetrant Test (LPT), Magnetic Particle Test (MPI), Ultrasonic Flaw Detection (UT), Dimension Measurement (DM), Videoscopy Inspection (FO), In-Situ Metallography (IMG) and Hardness Measurement (HM) has been done on various component of package boiler. Following are the photographs of NDT outcome.

Photo 3: Externally surface shows minor corrosion, scaling. No cracks observed visually in fillet weld as well as long seams & circumferential seams weld.

Photo 4: Minor corrosion & Scaling observed inside furnace tubes in Videoscopy inspection. It is required to clean the tubes for good operation of boiler.

Photo 5: No surface indication observed in Circumference & Longitudinal weld joints of steam drum in Liquid Penetration Testing (LPT).

Photo 6: No surface / sub surface indication observed in Circumference & Longitudinal weld joints of steam drum in Magnetic Particle Inspection (MPI).

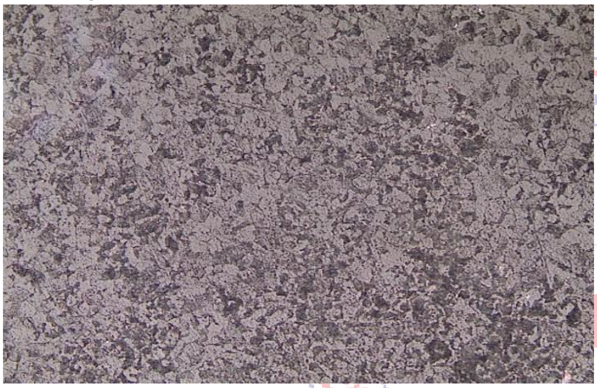

Photo 7: Microstructure of Steam Drum shows ferrite and pearlite. No significant degradation is observed.

Photo 8: In thickness Measurement, drum thickness found 5.45 mm which was less compare to design thickness of 8 mm.

Recommendation of Bare Inspection: Based on thickness reduction of steam drum of boiler, required allowable working pressure has been calculated & recommendation has been given to reduce 15 % of operating pressure than the rated operating pressure. Also Re-inspection of boiler has been recommended after 1 year to check the further reduction.

B. CASE STUDY OF FIT FOR SERVICE INSPECTION OF PRESSSURE VESSEL

Fit for Service (FFS) inspection is one of the important inspection of pressure vessel to know the actual operation condition of vessel as well as to know any damage or degradation occurs in any pressure parts after certain period of operation. Fit for Service (FFS) inspection has three different level namely level 1 or Basic level, level 2 or Engineering involvement level & level 3 or Advanced Investigation level. In level 1, competent or qualified person does simple visual examination and calculation of vessel in traditional way so data requirement is less. In level 2, competent or qualified person does calculation in depth with various NDT. So that we can gather more data. It is more precise in level 3, competent or qualified person with more experienced not only performs level 2 but along with it he does Finite Element Analysis (FEA) of vessel & estimates remaining life on condition as well as on operating parameter based. So the cost of level 3 is higher than level 2 & level 1. Photo 9 shows actual photo of pressure vessel on which fit for service (FFS) inspection has been performed.

Photo 9: Actual Photo of Pressure Vessel

In level 2 FFS inspection, various NDTs like Visual Inspection (VI), Liquid Penetrant Test (LPT), Magnetic Particle Test (MPI), Ultrasonic Flaw Detection (UT), Thickness Measurement (DM), In-Situ Metallography (IMG) and Hardness Measurement (HM) has been done on various component of pressure vessel. Following are the photographs of NDT outcome.

Photo 10: Internally surface shows minor corrosion & scaling. All weld joints are observed in good condition.

Photo 11: No surface indication observed in all weld joints of vessel in Liquid Penetration Testing.

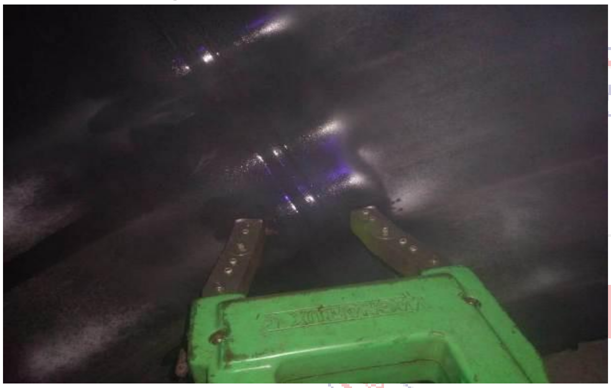

Photo 12: No surface / sub surface indication observed in all weld joints of vessel in Magnetic Particle Inspection.

Photo 13: No internal indications were observed in weld joints of vessel in Ultrasonic Testing (UT).

Photo 14: Micro-examination shows recrystallized fine-grained structure of ferrite & pearlite of Heat Affected Zone of weld joint.

Photo 15: Photographs shows hardness Measurement on outlet pipe of pressure vessel. Reading found with the range.

Recommendation of Fit for Service (FFS) Inspection of Pressure Vessel: Based on various Non-destructive tests carried out on pressure vessel, It was found that no major degradation / abnormality was observed, therefore, this pressure vessel can be continued in service following OEM guideline. However, it is recommended that this pressure vessel should be re-examined to determine the fitness for continual operation after one year.

C. CONCLUSION :

Both Bare Inspection of Package Boiler & Fit for Service (FFS) Inspection of Pressure Vessel are the important aspect of inspection which are based on systematic approaches & well planned productive maintenance tool for safety, reliability & availability. By these types of approaches, we can not only safeguard our plant & environment but also keep our plant from big hazard.

D. REFERENCE:

1. API – 570
2. API 579/ASME FFS-1
3. Indian Boiler Regulation, Act 1923 & Regulations 1950, Akalank Publications
4. R. Viswanathan, “Damage Mechanisms and Life Assessment of High Temperature Components”, ASM International, Metals Park.

Bio-data of Authors:

Mr. Macwan Robert Advin is Working as Head of Section- Mechanical Diagnostic at Electrical Research and Development Association (ERDA), Vadodara. He is responsible for activities related to Remaining Life Assessment (RLA) & Nondestructive Testing (NDT) of Thermal Plant, Process plant & Refineries. He has vast knowledge related to Remaining Life Assessment (RLA) of Boiler & Turbine through various Nondestructive Testing, Bare Inspection, Fit for Service (FFS) Inspection, Vibration Severity Analysis of Motor, Thermography and Energy Audit of plants. He has reach experience in the asset management through the various special mechanical diagnostic technique like Bare Inspection, Fit for Service, Vibration Severity Analysis, Finite Element Analysis (FEM), Various Remaining Life Calculation Techniques etc. He has published more than 16 research papers in national and international conferences and journals. He can be contacted at email: robert.macwan@erda.org.

Mr. Umesh N. Soni is Working as Head of Section- Diagnostic at Electrical Research and Development Association (ERDA), Vadodara. He is responsible for activities related to electrical diagnostic section. He has vast knowledge related to electrical diagnostic of various HT electrical equipment including Power transformer, Rotating machine, Switchyard equipment & HT cables. He has reach experience in the asset management through the various special diagnostic technique like C&TD, SFRA, ELCID, Partial discharge measurement. He has published more than 25 research papers in national and international conferences and journals. He can be contacted at email: umesh.soni@erda.org.

Dr. Anil S. Khopkar is PhD in electrical engineering, working as "Asst. Director & Head of Division – R&D and Expert Services at Electrical Research and Development Association (ERDA), Vadodara. He is responsible for various research activities and technology development in areas of Power Systems, Renewable Energy, Product Development and Advanced Materials in field of electrical engineering. He also headed, High voltage Impulse laboratory, Extra High Voltage Partial Discharge laboratory, Cable laboratory, Instrument Transformer Laboratory, Transformer Laboratory as well as calibration laboratory. He has established various test laboratory like, HV Impulse, HV PD lab, Transformer test laboratory etc. He is Member of BIS technical committee of India for High Voltage Testing techniques (ETD 19) and chairman of BIS technical committee of India for Surge Arrester (ETD 30). He is also a member of IEC Technical committee "TC 99/JWG 13 – Insulation co-ordination for HVDC System". He has published 45 research papers in national and international conferences and journals. He can be contacted at email: anil.khopkar@erda.org

MODELING AND ANALYSIS OF PRESSURE LOSS IN FLUE GAS DUCT PATH USING COMPUTATIONAL FLUID DYNAMICS

By

Arunesh Dwivedi[-1], Shubham Kumar[-2], Kuldeep Ruparelia[-3]

[1]Accredited Energy Auditor, ERDA, :arunesh.dwivedi@erda.org[1]

[2]Engineer, ERDA, shubhams.kumar@erda.org

[3]Certified Energy Auditor, ERDA, kuldeep.ruparelia@erda.org

ABSTRACT

Energy Conservation is a continual process in any industry and can be achieved through various techniques including process modifications, adopting advance technologies, optimizing process operation and reducing wastage through recycle, reuse and recovery. This paper presents technique to adopt CFD analysis for process modification in Coal fire steam generator Flue Gas duct to reduce the pressure drop occurring in gas path. Thermal power stations burns fossil fuel to generate power but during the process TPS itself consumes auxiliary power which is around 8 to 15% of the total generation depending on the size and design of the plant. Therefore, net power export to grid may be less, depending on amount of auxiliary power consumed by itself. By adopting certain modifications techniques such as using CFD analysis in flue gas duct flow path and subsequent change in plant layout for more streamline flow, some Auxiliary Power Consumption (APC) can be saved in Induced drought fans, Forced drought fans and primary air fans power. This paper analyses flue gas duct path for more streamline flow to reduce pressure drop using CFD analysis resulting reduction in auxiliary power consumption.

Keyword: ANSYS Computational Fluid Dynamics (CFD); Flue Gas Duct; Reduced Pressure Drop; Energy Conservation

INTRODUCTION

In the era of energy crisis, energy efficient design plays a significant role in various industries and power plants. In case of pipe/duct, fluid flowing through major energy losses are due to friction and disruption in flow such as bends, valves, fittings, expansions etc. To overcome these problems, designers per sue to modify designs use baffles in flow or design more stream line body for continuous flow in which less pressure drops occurs. Baffles are mainly flow guiding vanes used in industrial power plant.

In this paper authors are using ANSYS fluent solver to simulate various geometrical change in design of flue gas duct using baffles and circular bend and calculate loss in pressure. Authors are interested in evaluation of energy saving due to less pressure drop in various cases of duct design.

OBJECTIVE AND METHODOLOGY

The main objective of this paper is to calculate pressure drop reduction in flue gas duct for two design aspects one is using circular baffles and another one is using circular steam line bend at corner of Flue Gas (FG) path using computational fluid dynamics (CFD) and analysis the design of flue gas duct with considering economic parameters and estimating the Energy Consumption of Induced drought fan for same output.

The main steps involved in simulation are developing a three dimensional model of pipe, meshing, setting up Boundary Conditions, solving and post processing. ANSYS Fluent solver have been used for analysis & space-claim for 3D modelling.

Figure 1: Boiler Duct Inner View

(Source: www. outselluar.com)

We have considered four cases in this paper for study of pressure drop as below:

1) Rectangular Flue gas duct with sharp 90^0 bend without circular baffles (Normally found in 210 MW design)
2) Rectangular Flue gas duct with sharp 90^0 bend with two round section baffle
3) Rectangular Flue gas duct with sharp round bend
4) Rectangular Flue gas duct with streamlines round bend (More Streamline Body)

PLANT OVERVIEW:

The dimension of flue gas duct and other relevant parameters are chosen for 210 MW coal based thermal power station for modelling and analysis. Location of the FG duct section is considered between Air Pre Heater (APH) outlets to Electro Static Precipitator (ESP) inlet with single bend for single duct section out of two parallel passes. The dimensions and operating parameters are as follows

Table 1: Flue Duct Design Data

1	FG duct dimension	L (m)	50
		W (m)	2.90
		H (m)	2.65
2	Cross sectional area	m^2	7.685
3	Mass Flow Rate for steam requirement of 210 MW Power Generation	kg/sec	118
4	Density of flue gas	kg/m^3	0.82
5	Pressure at flue gas duct section inlet	Pa (gauge)	2746

The flue gas duct have modelled in ANSYS Space-claim software for all four condition areas shown below:

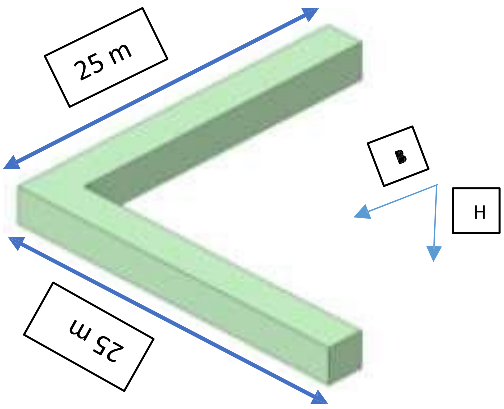

Figure 2: Rectangular Flue Gas duct with sharp 90^0 bend

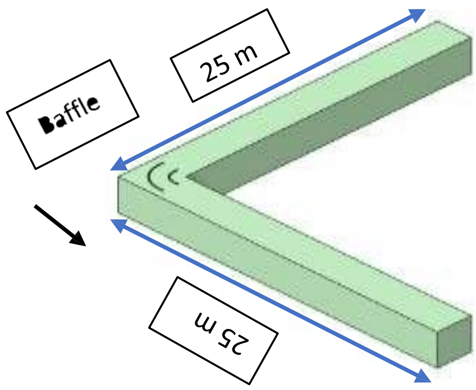

Figure 3: Rectangular Flue gas duct with sharp 90^0 bend with two round section baffle

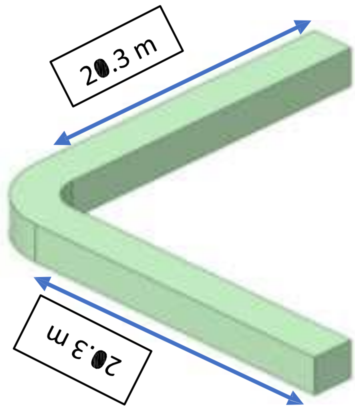

Figure 4: Rectangular Flue gas duct with round bend

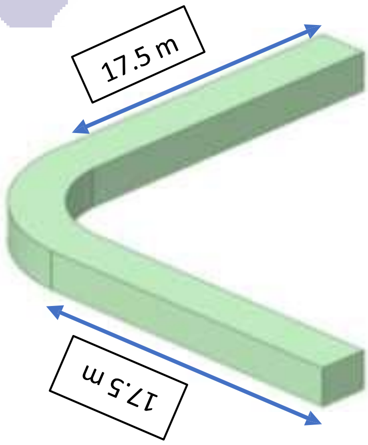

Figure 5: Rectangular Flue Gas duct with round bend having more streamline body

Remark: Dimension for all geometry is same (Height =2.9 m, Width 2.65 m are same for all 4 configuration)

Boundary Condition of the duct for various conditions used for simulation are as below mentioned in Table: 2

Table 2: Boundary Condition

Location	Parameters	
Inlet	Mass flow Rate	118 kg/s
	Pressure	2746 Pa (gauge)
Outlet	Opening	
Wall	Stationary wall with No Slip Condition and Roughness Constant 0.5	

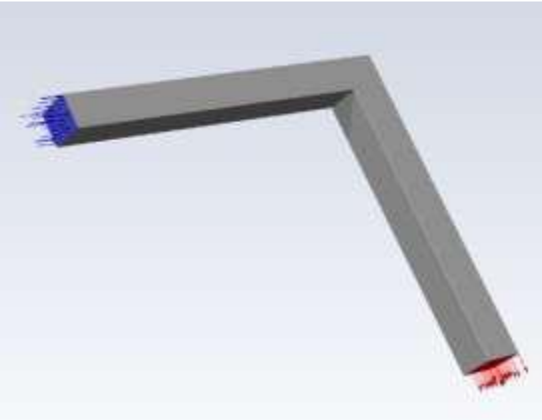

Figure 6: Inlet and outlet condition for sharp 90^0 bend

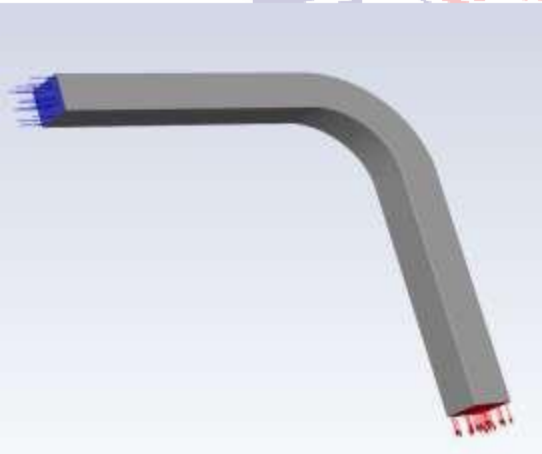

Figure 7: Inlet and outlet condition for round bend

Figure 6 and 7 shows inlet and outlet condition with inlet mass flow rate of 118 kg/sec and gauge pressure of 2746 Pa. Whereas, outlet condition is simply outflow and other faces are selected with no slip condition wall with standard roughness constant 0.5.

RESULTS AND DISCUSSION

Case 1: Rectangular Flue gas duct with sharp 90^0 bend

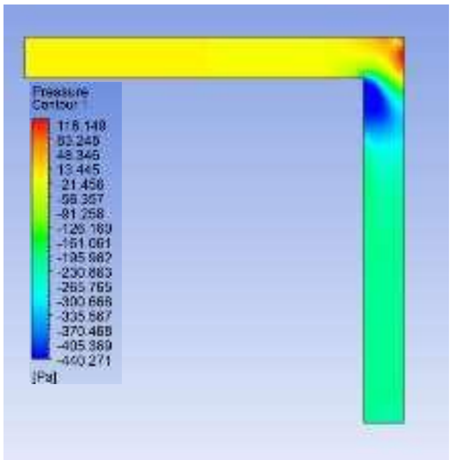

Figure 8: Pressure Contour for Sharp 90° Bend

Table 3: Pressure Values

Area avg. Pressure at Inlet (Pa)	-0.667715
Area avg. Pressure at outlet (Pa)	-208.532
Area avg. Pressure loss (Pa)	207.86

Case 2: Rectangular Flue gas duct with sharp 90^0 bend with two round section baffle

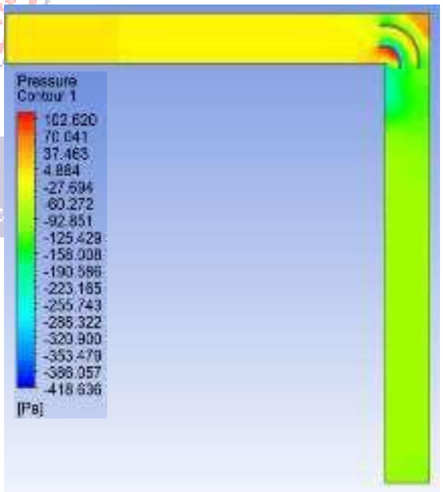

Figure 9: Pressure Contour for sharp 90^0 bend and round baffle

Table 4: Pressure Values

Area avg. Pressure at Inlet (Pa)	-0.666524
Area avg. Pressure at outlet (Pa)	-93.578
Area avg. Pressure loss (Pa)	92.91

Case 3: Rectangular Flue gas duct with round bend

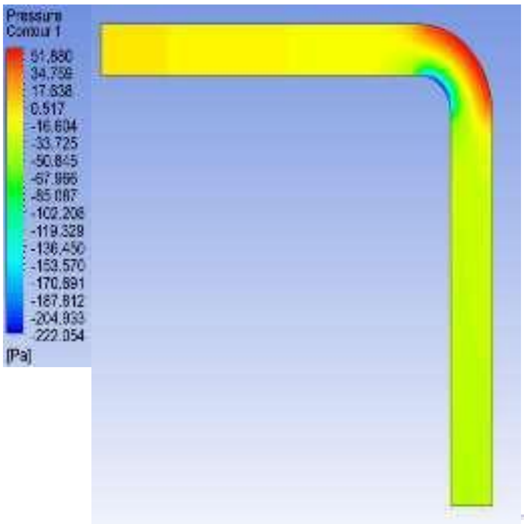

Figure 10: Pressure Contour for round bend

Table 5: Pressure Values

Area avg. Pressure at Inlet (Pa)	-1.81349
Area avg. Pressure at outlet (Pa)	-39.3631
Area avg. Pressure loss (Pa)	37.549

Case 4: Rectangular Flue gas duct with round bend (More streamline body)

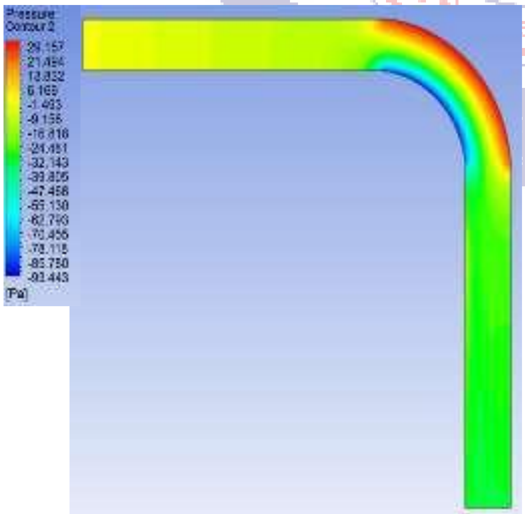

Figure 11: Pressure Contour for round bend (More streamline body)

Table 6: Pressure Losses at various condition

Area avg. Pressure at Inlet (Pa)	-0.666627
Area avg. Pressure at outlet (Pa)	-33.3718
Area avg. Pressure loss (Pa)	32.705

Table 7: Pressure drop at various condition

Sr No	Condition	Pressure drop in Pa
1	Rectangular Flue gas duct with sharp 90° bend	207.86
2	Rectangular Flue gas duct with sharp 90° bend and two round section baffle	92.91
3	Rectangular Flue gas duct with round bend	37.549
4	Rectangular Flue gas duct with round bend (More streamline body):	32.705

Table 8: Pressure Conversion

Case	Pressure drop in Pa	Pressure loss in Water Column(mm/WC)
Rectangular Flue gas duct with sharp 90° bend	207.86	21.20
Rectangular Flue gas duct with sharp 90° bend and two round section baffle	92.91	9.47
Rectangular Flue gas duct with round bend	37.549	3.82
Rectangular Flue gas duct with round bend (More streamline body):	32.705	3.33

CALCULATION OF POWER SAVING

Based on the pressure drop observed across the section for various configuration; the input power calculated for the existing 90° bend when compared with other configuration is presented in Table-9.

The formula used for calculation of input power is as follows:

Input Power = V [illegible] × [illegible] / 102 × [illegible] y

The annual energy savings potential have been calculated for 210 MW plant operating at 60% PLF (which is normally achieved by a 210 MW plant) with electrical energy generation cost of Rs. 3.2/kWh.

4

Table 9: Input Power of ID Fan and Energy savings calculation

Sr No	Condition	ID Fan Input Power	Annual Energy Savings (Rs. in Lakh)
1	Rectangular Flue gas duct with sharp 90° bend	705.39	Baseline
2	Rectangular Flue gas duct with sharp 90° bend and two round section baffle	677.81	4.64
3	Rectangular Flue gas duct with round bend	664.53	6.87
4	Rectangular Flue gas duct with round bend (More streamline body):	663.37	7.07

CONCLUSION

- Based on computational fluid dynamics analysis carried out using ANSYS software to estimate pressure drop occurring across flue gas duct section in various configurations; the best suited configuration was observed to be rectangular duct with round bend with more streamlined body; where pressure drop arrives to be 15.7% of original design.
- The energy savings observed to be around 6% of the original design suggesting the round bend with more streamlined body as the best configuration. Hence, it can be concluded that the rectangular flue gas duct with round bend should be preferred in comparison to sharp 90^0 bend.

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Significance of Pole Slipping Protection for Generator and Protection Setting Guidelines

By
Shailesh Modi & Dr. Anil Khopkar
Electrical Research and Development Association, Vadodara

ABSTRACT:

The objectives of electrical protection systems are improvement in system stability, system reliability, limit the extent & duration of interruption service, enhancement of equipment life and safety of personnel whenever equipment failure, human error, or adverse natural events occur on any portion of the Power System. The Protective relays has major role to play in this regards. Protective relays sense the status of power system and if any abnormality is detected due to some faulty operation they send the signal to the switching devices to operate and isolate the faulty section.

Protection system assessment is required at regular interval of time to determine the adequacy, healthiness, appropriateness of protection settings & schemes of individual elements associated with system protection. In Power Systems; Generator is very important and costlier equipment and protection of Generator unit is prime important. Various protections are being provided for the generator protection against various faults and network disturbances. In this paper; one of the main protection is pole slipping protection (which is used particular for large machines) and guidelines for the protection parameters setting are discussed. When a generator loses synchronism; the high magnitude currents and non-power supply frequency operation can be generated and it causes the stresses in the generator winding. The pulsating torques and mechanical resonances may occur that are potentially damaging to the turbine-generator unit. Therefore to minimize the possibility of damages, it is the requirement that generator unit get tripped without any delay preferably during the first slip of a loss of synchronism condition.

1. INTRODUCTION:

Generator is converting the mechanical energy into electrical energy. Generator is also providing other ancillary services like reactive power support for maintaining constant voltage, inertia for the frequency stability etc. There are various kind of faults in the power system like short circuit, loss of generator field (excitation supply failure) etc. Generator is very costlier equipment in power system. Any fault in power system network if it causes failure in the generator unit; it will result in the breakdown of the entire system and lot of time is required for the repairing of the unit or procurement of new generator. Hence there will be huge revenue loss for the generating company. In view of this; the adequate protection scheme and protection setting is required for protection from various kind of power system faults. Pole slipping is one of the major protection for generator which is mainly used for large size machines. Pole slipping occurs when the generator's rotor loses magnetic lock with the stator magnetic field and cause the rotor to rotate at a different speed (slip) than the desired frequency or grid frequency. In this paper Pole slipping protection of generators and its guidelines have been discussed in detail.

2. SIGNIFICANCE OF POLE SLIPPING PROTECTION:

Pole Slipping is caused by severe external faults, fault near the generator terminal, loss of excitation, excessive generator load etc. This leads to a change in rotor angular position beyond the generator transient stability limits. When generator experience the loss of synchronization (Pole slip) with the power system; it produce severe oscillation, high magnitude pulsating current and torque and stator overheating. This may result in electrical and mechanical damages of the generating unit. When the phenomena of loss of synchronism occurs, the rotor accelerates and change the speed of the rotor and hence the frequency. This change in the rotor frequency affects the grid frequency and governor of other generator units operating in the system. Thus it may cause disturbance to the entire network. This is not healthy condition of power system. Hence if pole slipping occurs inside the power plant, it is very essential to trip the unit before it affects the performance of other generator in the power system.

Pole slipping protection detects the rotor angle swinging and rapid changes in impedance. It initiate an immediate tripping of the circuit breaker within a slip cycle. Thus it protects the generator from stator overheating, rotor damage and turbine shaft fatigue by disconnecting the generator if it fails to re-synchronize after one or two slips.

3. POLE SLIPPING SETTING PARAMETERS:-

This protection monitors the impedance measured by the protective relay as it moves across the R-X plane. It monitors the crossing of the generator-transformer zone and analyzes the power system parameter changes. It can be triggered by severe faults near the generator terminal, loss of excitation, heavy system loading etc.

This protection see the impedance viewed from the generator terminal and sensed by the relay through the CT and PT connected to the generator terminal. As shown in Fig. (A); the generator is connected to the GT to step up the voltage and HV side of the GT is connected to the Grid/Power System network. The most important situation is that when power swing trajectory is produced in the power plant i.e in the region of the generator and GT. This is called Zone 1. The machine should be isolated from the network within 1st slip. If the power swing oscillations are there in the outside the power plant i.e in the grid network the generator should not switch off or at least not until 2 to 5 pole slip count have occurred.

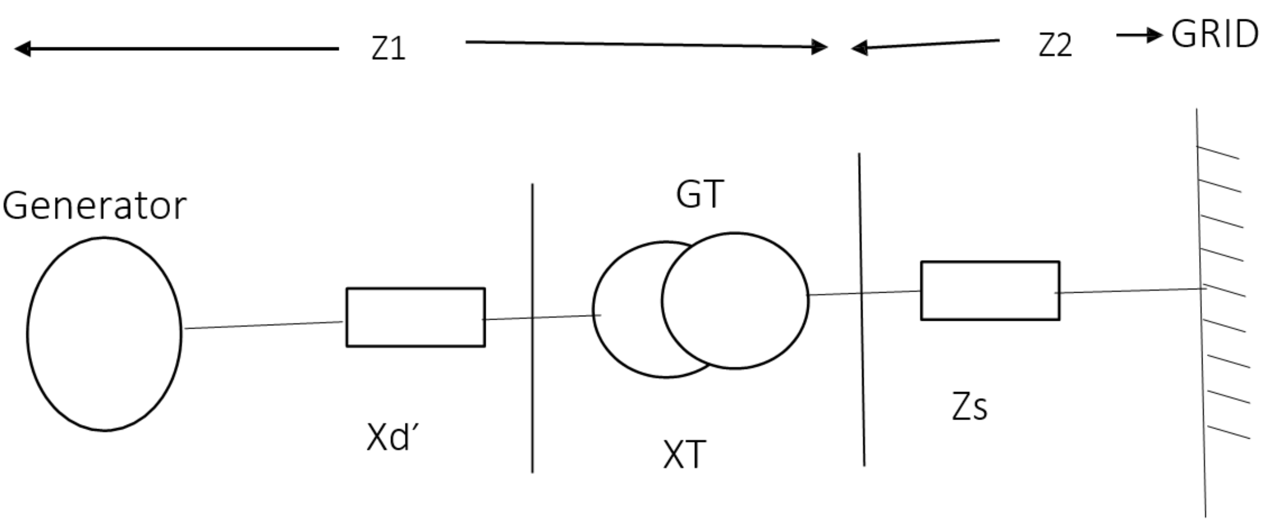

FIG (A)

The Impedance ZA is the forward impedance and it should be the sum of the transformer impedance XT and the equivalent impedance of the external system ZS.
The Impedance ZB is the reverse impedance and it should be equal to the generator transient reactance Xd′.
Thus the forward reach ZA and reverse reach ZB coincides with the system impedance (ZT + ZS) and the generator reactance (Xd′) respectively.
The Impedance ZC is the forward impedance and it is calculated based on the transformer impedance Z_T.

4. **LENTICULAR CHARACTERISTCS**:-

The lens characteristic (or lenticular characteristic) is impedance boundary used in pole slip relays to distinguish between stable power swings and actual out-of-step conditions. It acts as a monitoring zone in the R-X diagram, detecting when the generator's rotor angle increases beyond 90^0 (unstable region), allowing the relay to trip before damage occurs.

Protection against pole slipping condition can be given using a set of specific characteristics on R-X diagram. This characteristics as shown in fig (B) consists of (i) Lenticular (lens) characteristics (ii) A straight line (Blinder) that bisects the lens (iii) A reactance line which is perpendicular to the blinder.

The lenticular characteristics contain the blinder, lens and reactance line in the R-X plane. The blinder represents the impedance of three elements i.e Generator, Generator Transformer (GT) and the grid (source) impedance. The blinder crosses through the origin of the characteristics and origin is the terminal point of the generator. The protection relay provided for pole slipping protection sense forward impedance as well as reverse impedance i.e forward impedance is impedance of the GT and source (grid) impedance.

The reverse impedance is generator impedance. The reactance line is the intersecting the GT impedance and source impedance and divide the characteristics in two part i.e internal trajectory zone (below the reactance line – Z1) and external trajectory zone (above the reactance line-Z2). If the swing present inside the power plant i.e in the region of Generator and GT; it will follow the internal zone characteristics (Z1) and if the swing present outside the power station; it will follow the external zone characteristics (Z2).

In case of the internal swing; the voltage of the generator terminal may get reduced compared to the power system voltage and hence excitation system will try to maintain the generator terminal voltage constant. But due to heavy fault; the voltage may get collapse. When power swing occurs; the locus of the operating point will try to enter the lens characteristics. After a predetermined time duration and set counts; it will give the trip command. The relay setting angle can be set as 110^0-120^0 i.e less than the critical clearing angle to protect the generator from loss of synchronism condition. The width of the lens in lenticular characteristics depends on the Lens Angle (α). This should be set such that under all conditions, the load impedance remains safely outside the lens

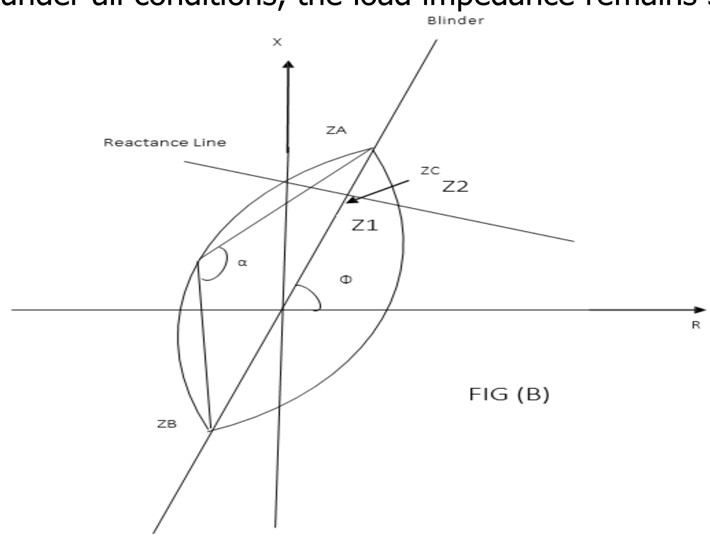

FIG (B)

5. **POLE SLIPPING PROTECTION SETTING GUIDELINES:-**

In normal condition; the generator operates synchronously with the power system. All the generators present in the power system network have the same angular velocity and approximately the same phase angle difference. This is called the stable generator operation. Now if the phase angle between the generators get changed significantly; the stable operation of the system cannot be maintained. In such a case the generator loses the synchronism (pole slip) to the external power system.

Due to the un-damped oscillations in the power system; generator located at different region oscillate with each other. If the connection between the generators is weak; the amplitude of the oscillations will increase until the angular stability is lost. At the moment of pole slip there will be a centre of this pole slip, which is equivalent with distance protection impedance measurement of a three-phase. If this point is situated in the generator itself, the generator should be tripped as fast as possible. If the locus of the out of step centre is located in the power system outside the generators; the generators should be kept in service.

If the excitation of the generator gets too low there is a risk that the generator cannot maintain synchronous operation. The generator will slip out of phase and operate as an induction machine. Normally the under-excitation protection will detect this state and trip the generator before the pole slip. For this fault the under-excitation protection and Pole slipping protection function will give mutual redundancy. The below are the guidelines for some protection parameters that can be set for the pole slipping protection of the generator. However; depending on the protection relay make and model; the nos. of setting parameters may vary.

Table: 1 Pole Slipping protection guidelines

No.	**Parameters**	**Protection Setting Guidelines**
1	Impedance ZA (Forward)	The Impedance ZA is the forward impedance and it should be the sum of the transformer impedance X_T and the equivalent impedance of the external system (Source Impedance) Z_S i.e. $ZA = Z_T + Z_S$. The source impedance can be calculated from the fault level of the power system network (grid impedance). If the oscillation present outside the unit (power plant) i.e in the grid network, the generator should not be switched off till few pole slips have occurred.
2	Impedance ZB (Reverse)	ZB can be set as Xd’ in the reverse direction where Xd’ is the transient reactance of the generator
3	Impedance ZC (Forward)	The Impedance ZC is the forward impedance and it is calculated based on the transformer impedance Z_T. The forward reach of the protection relay should cover Generator Transformer. The tripping in this zone should be in the first pole slip and the reach setting of this zone can be set as 0.7 X_T.
4	Lens Angle (α)	It define the boundaries to distinguish between a stable power swing and a pole slip (out-of-step) condition. The width of the lens in lenticular characteristics depends on the Lens Angle (α). This should be set such that under all conditions, the load impedance remains safely outside the lens. **The minimum setting for Lens Angle (α) on the relay is 90°.**
5	Blinder Angle (Φ)	The Blinder angle (ϴ) is set corresponding to the system angle
6	Slip Count Zone 1 (N1)	It is the number of pole slips crossing the zone 1 that should occur before issuing the trip command to the circuit breaker i.e. Pole slip

		is within the generator/GT region. Normally it can be set at 1 to minimize the stress on the generator at out of step conditions
7	Slip Count Zone 2 (N2)	This setting gives the number of pole slips crossing Zone 2 that should occur before trip issuing the trip command to the circuit breaker i.e. pole slip is in the external power system network. It can be set at higher values like 2-3 slips.
8	Start Angle	It is the setting angle at which the relay recognizes the start of a potential pole-slip condition. It detects that the generator is operating abnormally and initializes the counting of poles slips. When the impedance measured by the relay enters the operating zone; the protection starts to monitor the oscillation. **Normally the setting of start angle may be 110^0 to 120^0**
9	Trip Angle	It determines the specific rotor angle at which the relay issues a command to the circuit breaker. The trip angle ensures the generator is tripped when the angular separation between the generator and the grid exceeds a safe threshold, The "trip angle" is the setting at which the relay confirms an actual pole slip has occurred. It ensures the generator is disconnected if it fails to resynchronize (typically after one, two slips). The relay issues a trip command to the generator breaker, usually set for the 1st, 2nd, or 3rd slip depending on whether the center of the swing is inside or outside the generator. **The setting of Trip Angle can be between 90^0 to 120^0**
10	I1>	The positive sequence current release setting is normally required for generator pole slip protection to ensure the protection only operates during high-load, out-of-step conditions, avoiding unnecessary trips during stable, low-current swings. It is usually set above the generator rated current i.e about 120% to avoid the pickup on overload.
11	I2<	As the out-of-step conditions are symmetrical occurrences; the negative sequence current release normally set to 20% of the rated current to verify the symmetrical nature of the pole slip

6. CONCLUSION:

(1) Due to power swing when a generator loses synchronism, the resulting high magnitude currents and non-power supply-frequency operation may cause winding stresses, pulsating torques and mechanical resonances that are potentially damaging to the turbine-generator. The pole slip protection is used to operate under the power swing situation without delay, preferably during the first slip cycle of a loss of synchronism condition.

(2) The setting of the count of pole slip can be set as "1" when pole slip occurs inside the generator and GT region (Power Plant). The setting of count can be set more than "1" (2 to 5) for the pole slip generated outside the power plant i.e in the power system network.

(3) The review of protection setting at regular interval of time is essential to take care of the variation in the system parameters.

	Mr. Shailesh B. Modi is M.E. (Electrical Power Engineering) from M. S. University of Baroda. Presently he is working with Electrical Research and Development Association (ERDA), Vadodara. He is working at ERDA as Senior Manager in R&D Division. He worked at ERDA for various power system studies (Simulation & Analysis) like transmission planning study, FACT Solutions, Protection system audit of electrical network, Insulation Coordination study, Ferro Resonance Study etc. He also worked at ERDA for various distribution system projects like Design of HVDS system, Energy audit of the distribution network, R- APDRP project for verification of AT & C losses, Consultancy for electrification works (Project Management Agency), Preparation of detailed Project report (DPR) for electrification works under various government scheme, etc. He has also completed the assignments on Lightning Protection system study, Earhing Audit study, Third Party Inspection/Verification of Grid connected solar PV system installed on the roof top of government building/offices etc. He also worked in the field service division of ERDA for site testing & site calibration of electrical equipment, Third Party Inspection work etc.
	Dr. Anil S. Khopkar is PhD in electrical engineering, working as “Asst. Director & Head of Division – R&D and Expert Services at Electrical Research and Development Association (ERDA), Vadodara. He is responsible for various research activities and technology development in areas of Power Systems, Renewable Energy, Product Development and Advanced Materials in field of electrical engineering. He also headed, High voltage Impulse laboratory, Extra High Voltage Partial Discharge laboratory, Cable laboratory, Instrument Transformer Laboratory, Transformer Laboratory as well as calibration laboratory. He has established various test laboratory like HV Impulse, HV PD lab, Transformer test laboratory etc. He is Member of BIS technical committee of India for High Voltage Testing techniques (ETD 19) and chairman of BIS technical committee of India for Surge Arrester (ETD 30). He is also a member of IEC Technical committee “TC 99/JWG 13 – Insulation co-ordination for HVDC System”. He has published 45 research papers in national and international conferences and journals. He can be contacted at email: anil.khopkar@erda.org

Commercial Governance Framework - EPC Contract Closure & Dispute Resolution in Power Sector Projects

By

Dr. R. H. Kahar

Former Chief Engineer PSU, Gujarat

EXECUTIVE SUMMARY

India's power sector is anchored on a massive portfolio of Engineering, Procurement, and Construction (EPC) contracts, with cumulative project values exceeding Rs. 15-20 lakh crore across thermal, renewable, and hybrid power projects as of 2025-26. Yet the commercial governance of these contracts - particularly at the critical junctures of contract closure, claims management, and dispute resolution - remains one of the most neglected condition in the sector.

The paper integrates techno-commercial aspects - covering performance guarantees, delay apportionment, price escalation, and regulatory interface - with business development strategy, recognising that commercial governance is ultimately about preserving and enhancing project realization and institutional relationships

Drawing on the author's 35+ years of direct experience in EPC project management, commercial contract administration, and formal arbitration practice across India's thermal and renewable energy sector, the paper presents Indian examples, regulatory frameworks, quantified commercial cases, and actionable recommendations. It argues that disputes are primarily a failure of governance - and that a structured Commercial Governance Framework (CGF), consistently applied, can support the majority of India's power sector EPC disputes before they crystallise, saving the sector thousands of crores annually in direct dispute costs and hundreds of crores more in deferred project value.

Key Dimension	Data / Finding & Recommendations
EPC Portfolio at Risk	₹15–20 lakh crore; 60%+ contracts face disputes
Root Cause of Disputes	Contract deficiencies (40%), Claims management failure (35%), regulatory gaps (25%)
Resolution at Negotiation	70% of disputes are resolvable at Senior Management Negotiation - without arbitration
Annual Dispute Cost	₹3–8% of disputed value in direct costs; ₹8,000–12,000 Cr/year nationally
ROI of CGF Adoption	10–25x return on governance investment (₹4–6 Cr investment → ₹50–120 Cr savings)

1. INTRODUCTION*:* The Governance Deficit in India's EPC Power Sector Projects

1.1 The Scale and Complexity of India's Power Sector EPC Market

India's installed power generation capacity has surpassed 530 GW as of March 2026, of which coal-based thermal power accounts for approximately 249 GW, renewable energy (solar, wind, hydro, biomass) accounts for approximately 250 GW, and the balance comprises nuclear, gas, and other sources. The National Electricity Plan (NEP 2023) targets total installed capacity reaching over 900 GW by 2032, implying an investment pipeline of Rs. 25-30 lakh crore in new generation, transmission, and storage assets over the next decade.

Every major power project - whether a 800 MW supercritical thermal station in Gujarat, 30 GW RE Hybrid Park at Khavda Kutch, 500 MW floating solar project on a reservoir, or a 2 GW offshore wind project at the Tamil Nadu coast - is delivered through an EPC contract or a cluster of EPC packages. The EPC contract is therefore not merely a procurement instrument; it is the primary commercial mechanism through which India's energy future is being built.

The EPC market in India's power sector is characterised by:

- Contract Values: Rs. 500 Cr to Rs. 15,000 Cr for a single EPC package; multi-package thermal projects of Rs. 8,000-12,000 Cr; RE park infrastructure contracts of Rs. 3,000-8,000 Cr
- Execution Periods: 3-7 years for thermal; 18-36 months for RE; 5-7 years for offshore wind
- Technical Complexity: Multi-discipline integration (civil, structural, mechanical, electrical, C&I, IT/IOT) with interdependent critical paths
- Regulatory Overlay: Continuous interface with CEA, CERC/SERC, MoEF&CC, State PCB, PGCIL, SLDC / RLDC, CIL, GAIL Authority - each with independent timelines
- Multi-Stakeholder Finance: Project finance structures involving 5-15 lenders, equity investors, government guarantors, and export credit agencies - each with their own reporting and compliance obligations

1.2 THE CONTRACT GOVERNANCE DEFICIT: The Engineering Challenge- Why EPC Contracts Fail Commercially

Despite the enormous scale and commercial importance of EPC contracts in India's power sector, commercial governance - the systems, processes, and institutional capabilities that ensure EPC contracts are managed, closed, and disputed in a commercially rational, legally sound, and strategically intelligent manner - remains profoundly attended.

The consequences are visible as:

- Over 60% of large EPC contracts in India's infrastructure sector face formal disputes (KPMG Infrastructure Disputes Survey, 2022)
- The cumulative value of arbitral claims pending in India's power and infrastructure sector exceeds Rs. 2.5 lakh crore (Niti Aayog estimates)
- Average time to resolve a complex EPC dispute through arbitration: 3-7 years
- Average direct cost of arbitration (legal fees, arbitrator fees, expert witnesses): 3-8% of disputed amount
- Indirect costs say management bandwidth, lender relationship stress, reputational damage, delayed project commissioning, often exceeding direct costs.

The Five Most Common Root Causes

Root Cause	Why It Matters in Engineering Projects
Inadequate Scope Definition	Ambiguous contract scope creates asymmetric expectations - Owner believes comprehensive scope; Contractor priced narrow scope. Every ambiguity becomes a dispute.
No Dedicated Contract Management team	Project Manager is not a Contract Manager. Commercial issues accumulate unaddressed when the same person manages both - until they become intractable disputes at closure.

Claims Notice Neglect	Valid claims lost because notice was not given within 15/28 days as required by FIDIC/GCC. Statutory rights silently waived during execution.
Undefined COD Matrix	Commercial Operation Date triggers numbers of simultaneous obligations. Without a precise COD definition, both parties operate on different assumptions for years.
Holding BG After DLP Expiry	Retaining Bank Guarantees beyond legitimate expiry triggers disputes, damages contractor liquidity, and creates arbitral liability for the Owner.

These outcomes are not inevitable. They are the product of identifiable governance failures and treated as a sub-function of Project Management; disputes escalated to arbitration without exhausting genuine settlement options; and post-closure documentation neglected.

1.3 The Business Development Dimension

Commercial governance is not merely about managing disputes - it is about creating and protecting project value. An efficiently closed EPC contract - where all claims are resolved, all guarantees honoured, all documentation complete, and all relationships preserved - creates several categories of business development values as under:

- Repeat Business:
- Lender Confidence:
- Regulatory Goodwill:
- Capitalized Reputation Competitive RE Auction empanelment
- Institutional Credit Rating

2. The Commercial Governance Framework: Architecture and Pillars

2.1 Framework Overview

The Commercial Governance Framework (CGF) is a structured, five-pillar system for the commercial management of EPC contracts from contract award through post-closure. Unlike traditional project management frameworks that treat commercial management as a support function, the CGF positions commercial governance as a strategic, integrated discipline with its own processes, responsibilities, tools, and performance metrics.

CGF Pillar	Scope	Key Deliverables	Business Value
I) Contract Architecture	Risk allocation, Commercial terms, Regulatory interface design	Balanced contract, Clear risk matrix, Regulatory timeline plan	Fewer disputes at source, Competitive bid environment
II) Claims Management	Real-time variation tracking, Notice management, Quantum documentation	Claims register, Variation Order log, Contemporaneous records	70% dispute prevention, Preserved claim rights

III) Contract Closure	Final account, BG management, Performance certification	Final Account Statement, Completion Certificate, Deed of Release	Clean project closure, Lender reporting, Tariff certainty
IV) Dispute Resolution	Negotiation through arbitration, DAB/DRB, Conciliation, Enforcement	Settlement agreements, Arbitral awards, Enforcement decrees	Minimum cost resolution, Relationship preservation
V) Business Development Intelligence	Closure analytics, Market positioning, Contractor relationship management	Closure KPI reports, BD pipeline, Market intelligence	Repeat business, Opportunities, Competitive advantage, Sector leadership

Table: The Commercial Governance Framework - Five Pillars

The Commercial Governance Framework presented in this paper is therefore both a dispute management tool and a business development strategy - two dimensions that are, in the author's experience, inseparable in India's competitive and relationship-driven power sector.

2.2 Commercial Governance Structure

Effective CGF implementation requires a dedicated governance structure within the project owner organisation, distinct from - but integrated with - the Project Management function:

- Commercial Director / Chief Commercial Officer
- Contract Manager (per project)
- Commercial Management Team
- Independent Commercial Advisor (ICA)
- Board-Level Commercial Governance Committee -projects above Rs. 500 Cr

The author's experience heading EPC projects across the thermal and RE sectors confirms that the single most common root cause of commercial disputes is the absence of a dedicated, empowered Contract Management during project execution - a gap that allows commercial issues to accumulate unaddressed until they become intractable disputes.

3. PILLAR I - Contract Architecture: Building Governance in to the Contract

3.1 Contract Model Selection **-** most consequential commercial governance decision

3.2 Critical Commercial Terms

3.2.1 Scope Definition - The Root of Most Disputes

- Detailed Scope Matrix - Contractor S, Owner or Interface Scope
- Employer's Requirements (ER) Document - performance outcomes
- Exclusions Register - preventing constructive inclusion claims
- Drawing Issue Schedule – Owner / Contractor developed

3.2.2 Risk Allocation Matrix

Commercial governance requires explicit allocation of every material project risk to either the Owner or the Contractor. Risks allocated to the Owner are 'compensable' and Contractor are 'non-compensable'.

The following risk categories reflects international best practice adapted for India's power sector regulatory environment:

- Design adequacy
- Ground conditions
- Grid connectivity delay
- Forest/Env. clearance delay
- Coal/fuel quality deviation
- Price escalation (materials)
- default/insolvency

3.2.3 Liquidated Damages: Calibration and Enforceability

Liquidated Damages (LD) clauses are the most litigated commercial provision in Indian EPC contracts. The Supreme Court of India has consistently held that LD clauses are enforceable as a 'genuine pre-estimate of loss' - provided the LD rate is not a 'penalty' in the legal sense.

3.2.4 Dispute Resolution Clause - Designing for Efficiency

The Dispute Resolution (DR) clause is, paradoxically, the most important commercial provision in the contract - and the most neglected. Defined clause of Institutional arbitration (ICA, IEI, IDAC) rather than ad hoc - at least one arbitrator must have power sector engineering and commercial credentials - Fast-track arbitration for claims below Rs. 25 Cr.

3.3 Regulatory Interface Planning

India's power sector EPC projects operate at the intersection of multiple regulatory timelines each outside the contractor's control and often outside the Owner's direct control. A governance-first contract design includes a Regulatory Interface / approvals:

- CEA Techno-Economic Clearance
- MoEF&CC Environment Clearance
- CERC/SERC Tariff Order / PPA
- State PCB Consent to Establish/Operate
- PGCIL/STU Grid Connectivity
- SHAKTI Coal Linkage / FSA
- CEA Boiler/TG Inspection
- Explosive Act Licence / IBR

4. PILLAR II - Claims Management: The Commercial Nervous System of EPC Execution

4.1 The Claims Management Imperative

Claims management is the most commercially consequential activity in EPC project execution - and the most under-resourced. A 'claim' in the EPC context is any assertion by either party that the other has failed to perform an obligation, or that a change in circumstances entitles a party to additional time, money, or relief unmeasured, undocumented, or untimely claims become disputes; well-managed claims become negotiated settlements.

The commercial principle is straightforward: every contractual entitlement - whether a Variation Order, an Extension of Time, a Change-in-Law claim, or a performance LD deduction - must be identified, documented, quantified, and notified in accordance with the contract's procedural requirements at the time it arises, not retrospectively at contract closure.

4.2 The Claims Register: Real-Time Commercial Intelligence

The Claims Register is the central commercial management tool in the CGF. It is a live, continuously updated database of all potential claims and counter-claims on the project - maintained & reviewed by the Contract Management.

4.3 Variation Order (VO) Management

Formal instructions to the Contractor to change the scope, specification, or sequence of work - are the most frequent source of disputes in Indian EPC contracts.

4.4 Delay Analysis and Extension of Time

Delay management is the most technically and commercially complex claims management activity. A governance-first approach requires a disciplined delay analysis framework:

- 4.4.1 Programme Management as Claims Defence
- 4.4.2 Concurrent Delay - India's Most Contested Issue
- 4.4.3 India-Specific Compensable Delay Events

4.5 Price Escalation: Commercial Management of Volatility

India's EPC market has experienced extraordinary material cost volatility in recent years: steel prices increased 60-80% between 2020 and 2022; copper prices increased 40-50%; silicon (solar PV) prices collapsed 70% between 2022 and 2024. For multi-year EPC contracts with fixed Lumpsum turn key pricing, this volatility creates enormous commercial stress and disputes.

4.6 Performance Management: The Technical-Commercial Interface

Performance claims - heat rate shortfall, capacity shortfall, generation shortfall, auxiliary consumption excess, emission limit exceedance - sit at the boundary of technical and commercial management. They require specialist integration of power plant engineering knowledge with contractual interpretation.

5. Pillar III - Contract Closure: The Structured Commercial Protocol

5.1 CONTRACT CLOSURE - THE FIVE-DIMENSION MATRIX

Contract closure is NOT an event - it is a structured, multi-dimensional process. Engineers understand commissioning checklists. This is the commercial commissioning checklist: the project is not truly complete until all five dimensions are closed.

Technical	Financial	Commercial	Legal / contract	Documentation
Performance tests - Net Guaranteed Output, NHR, Auxiliary, Emissions	Prepare Final Account - reconcile original price vs. all adjustments	Settle all pending VOs and scope change claims	Issue Taking-Over/Completion Certificate with exact COD date	Compile Quality Dossiers - weld maps, NDT, inspection certificates
Clear punch list, Sign Punch List, Completion Certificate	Compute LD deductions - Delay LD & Performance LD with audit trail	Negotiate all counter-claims by Owner (LD, short-supply, rectification)	Return / encash Bank Guarantees per contractual trigger dates	Submit As-Built Drawings - civil, structural, mechanical, electrical, C&I
Submit As-Built drawings, O&M Manuals, Vendor	Compute & reconcile price escalation - IEEMA/WPI	Execute Full & Final Settlement Agreement -	Execute Deed of Release - permanently	File all Test Records - hydro, pneumatic, FAT,

Manuals (complete set)	indices, correct base date	ALL claims discharged	extinguishes all further claims	SAT, performance reports
Handover spare parts, special tools, consumables per SOR	Release retention - 1st tranche at COD, 2nd at DLP expiry	Settle sub-contractor/ vendor dues - prevent third-party lien on Owner	Obtain Lien Waiver from Contractor - protect Owner from sub-contractor claims	Handover Insurance documents, OEM warranties and performance guarantees
Obtain DLP commencement confirmation - 12-24 months clock started	Recover advance payment fully - confirm nil balance, cancel APG	Agree post-warranty support terms in writing beyond DLP	CERC/SERC: include settled EPC costs in allowed capital cost application	Archive ALL records - statutory minimum 10 years (IBR, CEA, MoEF&CC)

Table: Contract Closure – five dimension matrix: Protocol

6. PILLAR IV - The Dispute Resolution Ladder: From Dialogue to Award

6.1 The Governance Principle: Disputes as Commercial Failure

The fundamental principle on dispute resolution is that a formal dispute - one that reaches arbitration - represents a commercial governance failure. It means that the contract was inadequately drafted, that claims were not managed proactively.

6.2 The Six-Rung Dispute Resolution Ladder

The Dispute Resolution Ladder is escalation protection scheme - exactly like an electrical protection system. Each rung provides protection, the next rung activates only if the previous one fails to clear the fault. The system is designed so that 85–90% of disputes are resolved before reaching the last two rungs.

Rung	Mechanism	Timeline	Cost (% of Claim)	Resolution Rate	When to Use
1	Contract Manager / Engineer Decision	7–14 days	<0.1%	~30% of issues	Site-level technical disputes; minor variations; measurement disagreements
2	Senior Management Negotiation	21–60 days	0.1–0.5%	65–70% of remaining	All disputes above Rs. 1 Cr; structured commercial brief required
3	Conciliation / Mediation	30–90 days	0.5–2%	Most technically complex cases	Technical disputes needing expert facilitation; ongoing relationships
4	Dispute Adjudication Board (DAB)	84 days	1–3%	Binding during project	Projects above Rs. 500 Cr; constituted at contract award, not when dispute arises

5	Institutional Arbitration (ICA/IEI/IDAC)	12–36 months	3–10%	Binding award	When Rungs 1–4 are genuinely exhausted; legal rights require formal determination
6	Court Challenge (Section 34/36)	2–10 years	10–25%	Narrow grounds only	LAST RESORT - grounds are narrow; courts do not re-examine merits post-2015 amendment

Table: The Dispute Resolution Ladder - Six Rungs

6.3 Legal Framework: Key Provisions of India's Arbitration Law

6.3.1 The Arbitration and Conciliation Act, 1996 (as amended 2015 & 2021)

India's Arbitration and Conciliation Act 1996, amended 2015 and 2021, governs domestic and international arbitration. Key provisions of governance relevance:

- Section 11: Court appointment of arbitrators where parties cannot agree - available as a fallback; courts have significantly reduced involvement post-2015
- Section 17: Interim orders by arbitral tribunal - powerful commercial tool; tribunal can order continuation of contract, preservation of evidence, or interim payment
- Section 29A: Mandatory 12-month completion for domestic arbitration (18 months with party consent); extensions require court application. Critically important for commercial planning
- Section 31(7): Interest on arbitral awards - RBI commercial rate from date of award; compounded interest post-award if not paid; critical for NPV analysis of settlement vs. arbitration
- Section 34: Challenge to award - narrow grounds; courts cannot re-examine merits post-2015 amendment; Section 34 challenge stay does not automatically stay enforcement
- Section 36: Enforcement as court decree - post-Section 34 period; attachment of assets available

7.0 REAL Case STUDIES - CGF IN ACTION

Case Study | GST Change-in-Law - RE EPC Contracts, India (2017–2020)

The Event	The Dispute	Resolution Pattern	Undisclosed Point
GST introduced 1 July 2017 mid-construction for projects bid in 2015–16 under VAT/Service Tax.	MERC & one of the Developer's **Claim:** Developer sought compensation for higher project costs due to GST rate increases (from 5% to 12%/13.8%) in late 2021	MERC rejected a Rs. 477.5 million Change- in – law compensation claims as per PPA	The petition was dismissed because the developer failed to submit their claim to MSEDCL within the stipulated time mentioned as per PPA.

The Event	The Dispute	Resolution Pattern	Undisclosed Point
In one of the Contract: Issue due to the enhancement of work amount than the original order issued amount.	Owner: Non-payment of enhanced work amount & penalty raised for time delay.	Commercial Court-directed the Owner herein to deposit 100% of the amount awarded by the Arbitral Tribunal as per award. Owner to deposit both, principal amount as well as interest and cost.	process: Contractor claims from Owner under civil work contract to Arbitration – all time-to-time proceedings & intimated to owner for conatrct closure.

Table: Relevant Indian Case Law for Power Sector EPC Dispute Resolution

8.0 PILLAR V - Business Development Intelligence from Contract Closure

8.1 Why Closure Performance is a Business Development Asset

The fifth pillar of the CGF - Business Development Intelligence - transforms contract closure from a terminal administrative event into a strategic input for future project development, contractor relationship management, and competitive market positioning. This dimension of the CGF is uniquely important in India's power sector, where the same Owner-Contractor relationships repeat across multiple projects, where sector reputation determines bid competition, and where lender and regulatory relationships are shaped by project delivery track records.

Closure KPI	Target	Business Value
Final Account Settlement Time	< 18 months post-COD	Contractors bid more competitively for owners with fast, fair closure history - bid savings of 5–10%
Dispute Cost as % of Contract Value	< 1%	Low dispute cost signals commercial capability - attracts better contractors, better lenders
LD Recovery Rate	60–80% of justified LD	LD discipline creates credible performance signals in the bid market
VO Value as % of Original Contract	< 8%	VO creep above 12% signals scope definition weakness - input for next tender design improvement
Performance Guarantee Achievement	95–100%	Supplier qualification data - OEM capability benchmarking for next project
BG Return Timeliness	Within 14 days of trigger	BG efficiency directly affects contractor participation rates in future tenders

Table: Closure Performance Analytics Dashboard

9. Digital Governance Tools for CGF Implementation

9.1 Contract Management Information Systems (CMIS)
9.2 AI-Assisted Commercial Analytics
9.3 Online Dispute Resolution and Digital Arbitration

10.0 Ten Undisclosed and Challenging Points - What the Textbooks Don't Tell You

These are the points that experienced EPC practitioners know from battle - points that are not in any standard contract management course: Say

1. The 'Practical Completion' Illusion
2. The Sub-contractor Trap at Closure
3. The Latent Defect Time-Bomb
4. The DAB Award Compliance Trap
5. PSU Settlement Authority Paralysis
6. The Section 29A Trap
7. Performance Guarantee Re-Test Rights
8. The Change-in-Law Double-Claim Risk
9. The Abandoned Project Scenario
10. The Offshore Wind Governance Gap

11.0 Conclusion: Commercial Governance as Strategic Imperative

India is building the largest power sector investment programme in its history - Rs. 25–30 lakh crore over the next decade in RE expansion, thermal R&M, transmission modernisation, and energy storage. Every megawatt of this programme will be delivered through an EPC contract. The commercial governance of these contracts will determine not just the financial outcomes of individual projects, but the pace and quality of India's energy transition.

The core message of this paper is simple: commercial disputes are, in the majority of cases, engineering failures before they are legal failures.

They arise because:

- The scope was not engineered clearly enough at the contracting stage.
- The schedule baseline was not maintained with the rigour of a CPM critical path.
- The claims notice discipline was not applied with the rigour of a safety checklist.
- The COD definition was not specified with the precision of a commissioning test protocol.
- The Final Account was not prepared with the systematism of a plant performance report.

The five pillars of the CGF - Contract Architecture, Claims Management, Contract Closure, Dispute Resolution, and Business Development Intelligence - are mutually reinforcing. CGF adoption is not a compliance exercise but a strategic business development investment. For India's power sector state PSUs, central sector utilities, IPPs, and RE developers alike - the time to build this commercial governance capability is now, before the next wave of large projects is contracted, not after the disputes have already begun.

India's energy future will be built on contracts. The quality of those contracts - and the governance that surrounds them - will determine whether that future is built efficiently and equitably, or through a decade of disputes that consume the capital, talent, and time that India can ill afford to waste.

ABOUT THE AUTHOR

	**Dr. R. H. Kahar** is a Former Chief Engineer (Projects) State PSU, Gujarat. Qualifications: Ph.D. (RE Projects), MBA (Finance), LLB (Special), Degree in Engineering, Panel Arbitrator - ICA, IEI & IDAC, Valuer (IoV), Certified Energy Auditor & Manager (BEE, GoI), Advisor - Corporate & PSU, On Board Independent Director (MCA, GoI), Chartered Engineer. He is a result-driven professional with 35+ years of cross-functional expertise spanning the full lifecycle of thermal and renewable energy projects. He majorly superheated: (i) development of an 800 MW Supercritical Thermal Power Project; (ii) R&M and performance improvement of a 210 / 500 MW TPS including FGD installation; and (iii) development of India's 3.3 GW RE Hybrid Park at Khavda Kutch, Gujarat & Land acquisition & development of more than 1200MW of Solar Projects one of India's largest integrated RE development programmes. He has been honoured as ``***Scroll of Honor***`` from The Institution of Engineers (India) Alumni Association for his exceptional Contribution to Electrical Engineering``

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Civil Design & Engineering of Thermal Power Plant (Main Plant & Balance of Plant)

Use of M-Sand & Self compacting concrete

By

Er. S. S. Sheth

S.E. (Civil) GSECL Vadodara.

Introduction

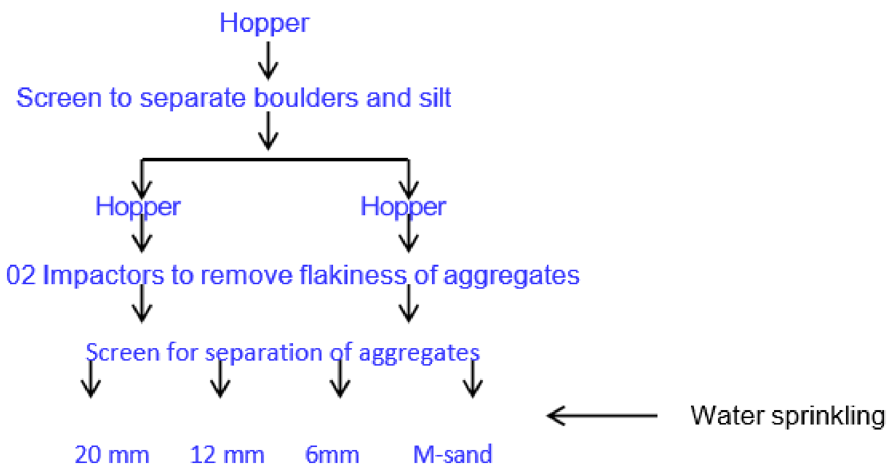
The presentation is in reference to observations of the Author related to construction of extension units in existing Power Plants of GSECL. Various changes / adoption of new trends are suggested for review; to enable good and long lasting performance of the new units, maintaining timeline and Environment protection.

1. Use of M-sand:

Use of M sand is debatable from technical aspects, specifically where river sand is available in required quantity. However, use of M-sand as a replacement of river sand can be considered preferable from environment point of view. As is known, natural resources are now a days depleting fast due to population growth, rise in new construction and increase in purchase power by majority class of the population. This needs the use of M sand in place of river sand a review. Also, it is moral duty to preserve natural resources for upcoming generations, as the use of river sand may damage the river basin ecology in longer run.

Technically, river sand particles are rounded as compared to M-sand having flaky particles requiring more cement for binding the particles. As per IS 383, aggregates most of which passing through 4.75 mm IS sieve are defined as fine aggregates. In case of M sand, permissible limit of 150 micron sieve passing is increased to 20%, which is 0 to 10% in case of natural sand of zone I, II and III.

Natural rocks are crushed to required grain size distribution as per (IS 383-1970) to manufacture M-sand. Stones are crushed in various stages and screened to form M-sand as per desired grain size distribution. The flow chart of Production line is as follows



In case of use of M-sand, specific gravity and void proportion remains almost same.

However, M-sand particles are comparatively flaky or angular and offer less workability as compared to river sand. To overcome this, use of appropriate plasticizer can be made. Also, it is required to use 15-20 Kg more cement as compared to concrete with river sand.
Use of M-sand in Power Plant projects can be made in paving / flooring / grade slab, static buildings like Service Building / Chemical Lab / ESP Control Room etc., static foundations, cable trenches, rigid pavement roads for connection of buildings / structures, storm water drains etc. Also, M sand can be used in architectural works like tiles fixing, masonry, plaster, IPS etc.

By this way, for a Power Plant project, huge quantum of river sand can be saved, and a lot can be contributed towards Riverbed ecology and Environment.

2. **Use of Self-Compacting Concrete:**
Self-Compacting Concrete was first developed in 1988 to achieve durable concrete. Since then, many investigations have been done and now a days, use of SCC is gaining preference in spite of cost factor.
Traditional concrete, even with the use of concrete pumps and transit mixers, requires labour in large numbers. Further, proper placing and compaction requires skilled labours and due to development everywhere, skilled labours availability is decreasing day by day. Further, trend of high rise structures and structures / buildings with concrete shape to make architectural view is increasing. This promotes use of self-compacting concrete instead of conventional concrete. Major benefits of self-compacting concrete are as follows:
   1. Increase in speed of construction is significant, reducing timeline of the project.
   2. Eliminates the need of mechanical vibration, thereby saving on labour and reduction in noise pollution at site and surroundings.
   3. Provides superior durability and superior surface finish, essential in modern

infrastructure.

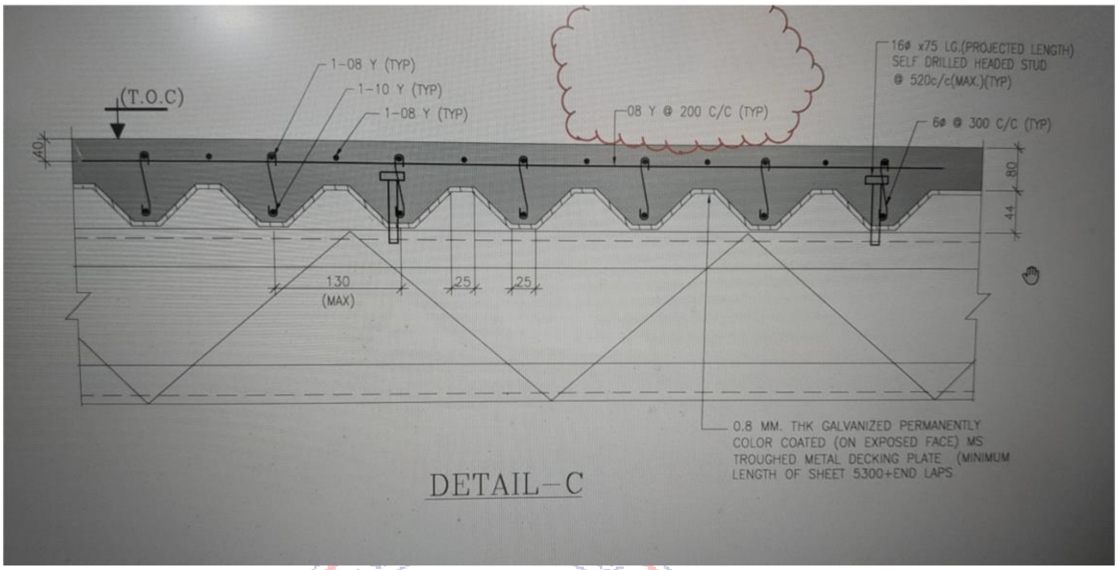
The ingredients of self-compacting concrete are cement, water, sand and coarse aggregates (usually less than 20 mm). Over and above, fine particles like fly ash, stone powder, blast furnace slag are added for voids packing (typically 400 – 600 Kg per m^3 of concrete). Also, Viscosity maintaining agents and super plasticizers are added to achieve free flow. Research has found that energy required for flowing is consumed by increase in internal stress, resulting in blockage of aggregates. In case of self-compacting concrete, high viscosity and internal packing due to finer particles lowers the internal stress and allows free flow of concrete according to shape of form work. Due to higher flow ability, it is compacted even in congested reinforcement as well as in compacted shapes.

In Power Plant, water retaining structures like CW Sump / Forebay, Clarified Water Sump, CW Channel etc. are constructed. Use of SCC in these structures will ensure proper compaction and elimination of leakages and the cost of post concrete treatments will be reduced. This will lower hampering in plant running.

In case of Power Plant construction, Turbine generator is very crucial structure and it requires great quality control and good compaction. Generally, proportion of reinforcement is 50-60 Kg per M^3, which is further raised to 80 Kg per M^3 in Boiler foundations, tall structures like Chimney. In case of TG deck slab, proportion of reinforcement is > 240 Kg per M3, over and above many inserts, bolts, sleeves etc. are making it fully congested. Use of conventional concrete with temperature control requires very strict supervision, even though it becomes difficult in many cases to achieve 100% compaction. Use of self-compacting concrete will ensure proper placing of concrete and compaction and enhance the life of the structure even after sustaining vibrations 24 x 7 from the generator rotating at 3000 RPM. Further, SCC can be used in ID, FD, PA, SA Fans and decks, Boiler foundations, Wagon Tippler, PH Building foundations and various floors, which are subjected to heavy loads / vibrations.

3. Casting of metal deck roof over Turbine floor

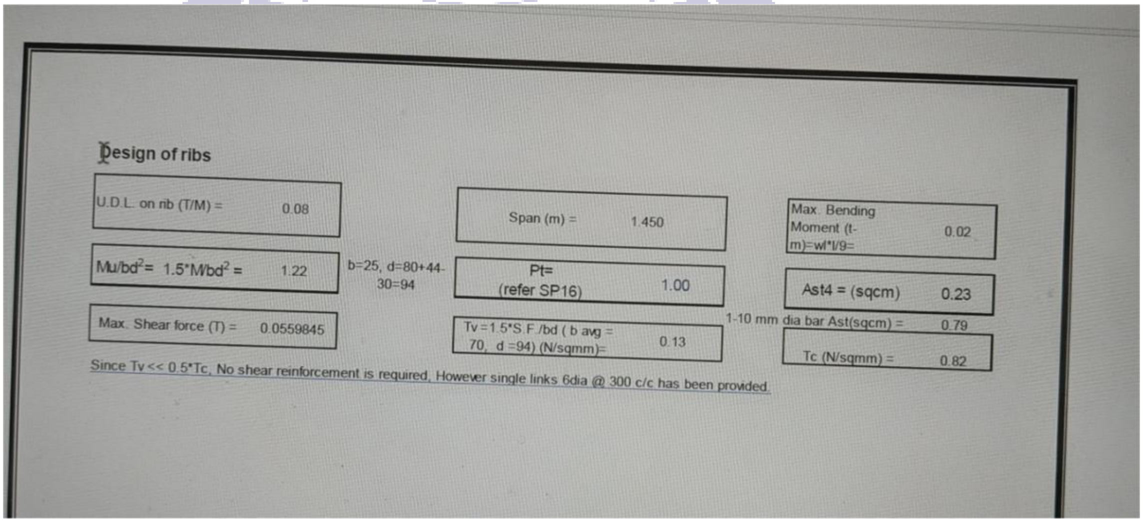
Casting of metal deck roof over Turbine floor is very important aspect, for housing of Turbine and operating floor of powerhouse. General dimensions are > 100 m in length and @ 35 m in width, with metal deck slab of 124 mm over 0.8 mm thick galvanized permanently colour coated metal decking plate.



Details are as follows:

The shear lugs are provided of 6 mm dia bar, at 300 c/c distance. Now the size of the lug is 65 mm long and 32 mm hooks at both ends. Cutting of 6 mm diameter bar in 130 mm length and bending hooks of 32 mm on either side is very cumbersome and time taking activity, with chances of minor injury on fingers. Even, binding is also time taking activity. This activity delays the roofing of dpowerhouse area and turbine floor.

As per design calculations, shear reinforcement is not required.



However, provision of shear lugs is essential to keep the bars in position; hence suitable spacing of 600 – 750 mm can be decided. This will definitely gear up the roof work, subsequently housing of Turbine.

4. Conclusion

- Use of M-sand is gaining importance to reduce the use of River sand and ultimately reduce impact on environment due to damage to river bay

- Use of self-compacting concrete reduces the time of construction and avoids dependence on mechanical vibrations
- For casting metal deck root turbine floor shear and reinforcement is not required

	Er. SS Seth presently working as Superintending Engineer (Civil) at Gandhinagar TPS- GSECL since November 2022. He joined GEB in May 1994 as a JE (Civil) and posted at Kadana HEP. Thereafter, he worked with various TPS i.e. Wanakbori TPS (13 years), Sikka TPS (02 years), Ukai TPS (06 years), Corporate Office (05 years) and Gandhinagar TPS (03 years and running). For most of the time, He was associated with construction of new units and during his tenure at Corporate Office, he is looking after design/ engineering of Wanakbori TPS extension unit # 8 and Solar projects executed by various TPS of GSECL.

#####

STATUTORY REQUIREMENT FOR SAFETY TRAINING THERMAL POWER PLANT WHICH IS - THE VALUE - NOT JUST PRIORITY

By

Mr. S. V. Sapre
Chief Executive Officer
Gujarat Safety Council
Vadodara

Mr. P. A. Shah
Associate
Takalkar Power Engineers & Consultants, Vadodara

1. INTRODUCTION

To Motivate & educate work force of any industry to build up safety consciousness for eradicating accidents. It is very essential to impart them effective tailor made, work related training. This will inspire and encourage them to make significant & contributory change in their attitude toward safety, which will improvise safety standards and increase productivity.

2. STATUTORY REQUIREMENT:

Statutory requirement for training to the employees of power plant in India is mandated by the Electricity Act 2003 and Central Electricity Authority (CEA) Regulations. It is mandatory to impart annual training in respect of safety focused curricula to all employees including Operation and Maintenance personnel.

- **Mandatory Training Duration:** Organizations must adopt a formal policy ensuring at least **one week of training annually** for all personnel.
- **Safety Training Requirement:** The CEA (Safety Requirements for Construction, Operation & Maintenance of Electrical Plants & Electric Lines) Regulations, 2011 mandate special safety training for employees, including contractors, particularly for high-risk activities like electrical work, hot work, and confined spaces.
- **Mandatory Training for O&M Staff:** Engineers and technicians engaged in operation and maintenance (O&M) of generation, transmission, and distribution systems must complete training programs specified in CEA guidelines.
- **Institutional Training:** Training must be imparted through any National or Local State Institute or other institutes recognized by the CEA or Central / State Governments.
- **Training Plan & Budget:** A Comprehensive Training Plan based on Need Analysis (TNA) is required. A minimum of **1.5% of the salary budget** should be allocated for training, aiming for 5%.
- **Induction Training:** For new employees, specialized on boarding training on plant operations and safety.
- **Refresher Training:** Regular training to update knowledge and skills for existing staff.

  Specialized Topics: Disaster management, fire safety, Hazard Identification & Risk Assessment (HIRA), and handling hazardous substances. Others are Theoretical & Practical Training on Behavior Based Safety Training, Occupational Safety, Training on PPEs Personnel Protective Equipment, Accident Prevention Techniques, Accident investigation & Root Cause Analysis, Chemical Safety, Electrical Safety, Disaster Management and Need Based Training.

3. **TRINING INSTIUTES IN INDIA:** The following are the training institutes in India.

   a. **National Power Training Institute (NPTI):** As an ISO-certified organization under the Ministry of Power, NPTI is the apex body. Main institute is at Faridabad (Corporate Office), Badarpur (New Delhi), Nagpur, Neyveli, Durgapur, Guwahati, Nangal, Bengaluru, and Alappuzha. NPTI also Offers 500 MW and 210 MW thermal plant simulators for hands-on operation training. NPTI running c**ourses like** Post Graduate Diploma Course (PGDC) in Thermal Power Plant Engineering, Post Graduate Certificate Course, and short-term courses.
   b. Central Board of Irrigation and Power (CBIP): Offers specialized training for power sector professionals, often in collaboration with organizations like BHEL.
   c. Iqony Solutions (STEAG (Signals Technology Evaluation and Adaptation Group) Power Plant Learning Centre): Provides specialized training on power plant operation and efficiency.
   d. TPSDI (Tata Power Skill Development Institute): Offers training for technicians and engineers in thermal power operations.
   e. Torrent Power Limited, Ahmedabad: 362 MW AMGEN Thermal Power Plant training centre.
   f. Nabha Power Limited: Provides specialized training in thermal power.
   g. Also NTPC, GETRI, Power Generation Utilities provides In-house training as Induction Training as well as Refresher Training.
   h. The training shall be imparted in the topics of Main Plant consists of Turbine and Generator and Balance of Plant comprises DM Plant, CW Pump House, AHP including EHP, CHP, WTP, Chlorination Plant, FGD, etc.
   i. The training shall also include the topics related to HR like (a) Leadership Development - Programs for managers on supervision and building a strong safety culture. (b) Communication & Conflict Management - Enhancing collaboration among shifts. (c) Stress Management: Specifically for employees handling critical operations.

4. **OCCUPATIONAL, HEALTH & SAFETY MANAGEMENT SYSTEM (OHSMS):**
   OHSMS is a structured set of policies, procedures, responsibilities & controls used to prevent workplace injuries, ill health and improve safe performance. The OHSMS activities / documentation includes

   a. OH&S Policy & Clear objectives
   b. Hazard Identification & Risk Management - HIRM.
   c. Legal & Regulatory Compliance Checks.
   d. Incident Reporting, Investigation & Corrective Action.
   e. Workers Participation, Training, Audit (Safety) & Continues Improvement (PDCA Cycle). The PDCA cycle (Plan-Do-Check-Act) is a four-step, iterative management method used for continuous improvement, problem-solving, and process control. It involves planning a change, testing it on a small scale, checking results, and acting on learning to improve processes systematically.

5. **HOW IT WORKS (ISO 45001 i.e. PDCA CYCLE)**
   Most OHSMS frameworks follow a continues improvement Cycle

P – P stands for plan - Identity risk and then set object
D – Do: Improvement Processes
C – Check: Monitor & Evaluate
A – Act Improve continuously
(Repeat this Cycle)

6. BEHAVIORAL APPROACH TOWARDS SAFETY (BBS)

Behavior Based Safety is a proactive approach to workplace safety that emphasizes, observing & modifying employer behavior to prevent accident, injury and loss of property. It shifts focus from equipment or conditions or environment to human actions using data driven feedback to reinforce safe practice.

7. PREVENTIVE ACCIDENTS: Normally, 98% of accidents are preventive while only 2% accidents are un-preventive. The accidents are purely due to Hyman Error or Environment Conditions. Some of them are listed below:

Unsafe Act of Employee		Unsafe working conditions	
1.	Operating machineries without authority	1.	Unguarded absence of guard or (Flying)
2.	Operating or working at unsafe speed	2.	Inadequate Support or guards, improper height, strength etc.
3.	Making Safety device inoperative	3.	Defective rough, sharp Slippery, decayed Cracked Surface.
4.	Using unsafe or defective equipment	4.	Unsafe design of machine, tools, plans, equipment etc.
5.	Unsafe loading, Placing, mixing etc.	5.	Unsafe arranged housekeeping, condition, blocked exit etc.
6.	Taking unsafe position or passive	6.	Inadequately lighted or Slare etc.
7.	Working on moving or dangerous equipment	7.	Inadequate ventilation impure air (Polluted Air).
8.	Without Distracting, teasing, abusing, at workplace	8.	Unsafe PPE e.g. Gloves or mask, high shoes
9.	Failure to use PPE	9.	Unsafe processes, Electrical, chemical, Medicines, hazard etc.
10.	Use of prohibited drugs, alcohol	10	High noise, vibration, discharges or hazards, dust, gases, vapors.
11.	Improper lifting operating	11.	Fire & Explosion Hazards

8. SAFETY TAG & SAFETY AUDIT:

As per sec. 111 A of the Factory Act 1948, every worker shall have right to:

a. Obtain from occupier, information relating to worker's health & safety at work.

b. Get trained within the facing or ger himself sponsored by the occupier for getting trained at duly approved training Centre (GSC, Mali etc.) by DISH – Directorate of Industrial Safety and Health.

Following Trainings are required for Prevention of Accidents

Sr. No.	Name of Training
1.	Fire Prevention & Protection
2.	અગ્ની પ્રતિબંધ અને નિયંત્રણ
3.	Compliance of HSE Legislation – Practical Approach
4.	Accident Prevention Techniques (APT)
5.	Behaviour Based Safety (BBS)
6.	First Aid Training
7.	Safety in Warehousing Material Handling & Transportation
8.	Process Safety Management in Manufacturing Industry
9.	Electrical Safety
10.	Managing Electrical Risks in Industry
11.	Electrical Safety Audit & CEA Regulation
12.	વિજળીના જોખમો.
13.	Electrical Safety in Industry
14.	Working at Height & Work Permit System
15.	Safety in Tank Farm
16.	Confined Space Entry
17.	Safety – A Cost Efficient Technology for Industry
18.	Safety in Scaffolding
19.	Role & Responsibilities of Safety Committee
20.	Safety in Chemical Industries
21.	Working at Height & Confined Space
22.	Disaster Management
23.	Fire & Explosion in Chemical Industries
24.	Statutory Provisions Pertaining to Safety Management
25.	Factory Act & legal Statutory Provisions for Handling of Hazardous Chemicals
26.	Storage & Handling of Hazardous Chemicals
27.	Statutory Requirement – Factory Act, Explosives Act, SMPV Rules, Petroleum Rules, Electrical Rules, 2005
28.	Crane – EOT crane Safe operation
29.	Forklift safe driving

9. SAFETY AUDIT AS PER IS 14489 – 2018:

Recently Labor Skill Development & Employment Department Government of India has amended the rules for Safety Audit in Factory Act. Major amendments are discussed below:

Category I – Factories involving major accidents or hazardous installation, once in two years.

Category II – Factories where in hazardous process is involved and having storage and manufacturing of hazardous chemicals, once in three years.

Category III – Factories not covered under Category I & Category II above, once in four years. In this amendment, Occupational and Safety Auditor must possess required qualification, with age limit and experience. He / She shall get recognition from DISH as certified auditor. An Organization or an Individual can apply for recognition in prescribed format. The validation of registration of Safety Auditor is valid for two years and can be renewed subsequently.

10. ABOUT AUTHORS:

 **S. V. Sapre**	**Mr. S. V. Sapre Born in 1953 with present age of 73 years. He is BSc, LLB (LL), LLB (Special), MLW and Post Diploma (I.R&P.M). He is having Experience of 40 years in the field of HR, Industrialization, Personnel Management and Administration, Labour Litigation and Training & Development in reputed industries, public sector undertaking and government as well. He also worked as Welfare Officer in Textile Mill, Ahmedabad. Further, as Labour Officer GSRTC (Gujarat State Road Transport Corporation) and Assistant Labour Commissioner: Government of Gujarat. H.R. Head: Atul Ltd., Valsad. He retired as Chief General Manager (HR): GETCO (Erstwhile Gujarat Electricity Board). Presently he is holding the position of Chief Executive Officer CEO in Gujarat Safety Council, Vadodara since 2017.**
 **P. A. Shah**	**Er. P. A. Shah** born in 1953. He is Post Graduate in Electrical Power System and Graduate in Electrical Engineering from MS University of Vadodara. He is having diplomas in Commerce, Electrical and Mechanical. He is CMA (Inter) and Chartered Engineer (IE). He is having total experience of 52 years in various organizations including erstwhile GEB, SSNNL, Parul University, TPEC and other Companies. Presently he is working as Associate with TPEC and Visiting Professor in Parul University. He is also imparting Trainings and delivering lectures on various topics to State / Central Government organizations, NGOs, Companies, Industries, Power Utilities, Colleges, etc. He is active Life Member of SPE (I), LM of Institution of Engineers and LM of IIMM Vadodara.

#######

HIGH VOLTAGE GAS INSULATED SWITCHGEAR (HV GIS) TECHNOLOGY - Historical Development, Technical Evolution and Industry Analysis

By
Anilkumar C Shah
B E (Electrical)

1. Introduction to HV GIS Technology

1.1 Definition and Fundamental Principles

Gas Insulated Switchgear (GIS) is a compact, metal-enclosed switchgear assembly wherein the major electrical components such as circuit breakers, disconnectors, earthing switches, busbars, current transformers, and voltage transformers are enclosed in a sealed environment and insulated with sulfur hexafluoride (SF_6) gas or alternative insulating gases.

The fundamental principle leverages the superior dielectric properties of SF_6 gas, which has approximately 2.5 times the dielectric strength of air at atmospheric pressure. This enables significant size reduction while maintaining equivalent electrical performance and safety standards as conventional air-insulated equipment.

1.2 Key Technical Advantages

HV GIS technology offers multiple technical and operational advantages:

- Space Efficiency: Requires only 10-15% of the footprint needed for equivalent AIS installations
- Enhanced Safety: Enclosed design eliminates risks from external environmental factors and unauthorized access
- Reliability: Typical failure rates of 0.02-0.05 failures per bay-year, significantly lower than AIS
- Minimal Maintenance: Sealed compartments reduce maintenance requirements to once every 15-30 years
- Environmental Independence: Unaffected by pollution, humidity, salt fog, or extreme temperatures
- Reduced Electromagnetic Interference: Metal enclosures provide effective EMI shielding.

2. Historical Development of HV GIS Technology

2.1 Early Beginnings (1960s)

The commercial development of GIS technology began in the late 1960s, driven primarily by space constraints in urban substations across Europe. The first commercial GIS installations were commissioned in 1968-1969:

- 1968: Siemens installed the first commercial 60 kV GIS in Germany
- 1969: Sprecher & Schuh (later acquired by ABB) commissioned 145 kV GIS installations in Switzerland

- 1969: BBC (Brown Boveri) deployed three-phase enclosed GIS in European metropolitan areas

These pioneering installations operated at voltage levels ranging from 60 kV to 145 kV. Early designs faced significant technical challenges including SF6 gas purity management, particle contamination control, and developing reliable sealing technologies for long-term gas containment.

The initial market reception was cautious due to the technology's novelty, higher capital costs compared to conventional AIS, and limited operational experience. However, utilities in space-constrained urban areas recognized the transformative potential of compact switchgear designs.

2.2 Technology Maturation Era (1970s)

The 1970s marked a period of rapid technological advancement and geographic expansion. Key developments during this decade included:

2.2.1 Voltage Level Escalation

Manufacturers successfully demonstrated GIS operation at progressively higher voltage levels:

- 1972: First 245 kV GIS installations in Japan and Europe
- 1975: 420 kV prototype testing completed successfully
- 1978: Commercial 420 kV GIS deployed in high-power transmission networks.

2.2.2 Geographic Expansion

GIS technology spread from Europe to other regions facing similar urbanization challenges:

- Japan: Rapid adoption driven by extreme space constraints and seismic design requirements
- North America: Initial installations primarily in major metropolitan areas (New York, Chicago, Los Angeles)
- Middle East: Early adopters due to harsh environmental conditions (sand, extreme temperatures)

2.2.3 Design Philosophy Evolution

Two competing design philosophies emerged during this period, each with distinct advantages:

- Three-Phase Designs: Single enclosure housing all three phases, offering maximum compactness but requiring larger gas compartments
- Single-Phase Designs: Separate enclosures per phase, providing better fault isolation and maintenance flexibility

Industry consensus gradually favoured single-phase designs for high-voltage applications (≥245 kV) due to superior fault containment, while three-phase configurations remained popular for distribution voltage levels.

2.2.4 Reliability Data Accumulation

By the end of the 1970s, approximately 5,000 GIS bays were in operation worldwide. Systematic reliability data collection began, establishing baseline performance metrics that would guide future design improvements. Early field experience identified particle contamination as the primary cause of dielectric failures, leading to enhanced manufacturing cleanliness protocols.

2.3 Rapid Growth and Ultra-High Voltage Development (1980s-1990s)

2.3.1 Ultra-High Voltage Achievements

The 1980s and 1990s witnessed remarkable progress in ultra-high voltage GIS development:

- 1984: First 550 kV GIS installation at Shin-Shiobara Substation, Japan
- 1988: 800 kV GIS prototype testing initiated by Japanese manufacturers
- 1992: Standardization of 550 kV GIS designs for widespread deployment
- 1997: First commercial 800 kV GIS commissioned in Japan's long-distance transmission network

2.3.2 Circuit Breaker Technology Innovations

Significant advancements in circuit breaker mechanisms improved reliability and reduced maintenance:

- Puffer-Type Breakers: Utilized mechanical compression to generate high-pressure SF6 for arc quenching
- Self-Blast/Auto-Expansion Mechanisms: Leveraged arc energy to create pressure rise, reducing operating energy requirements
- Spring Operating Mechanisms: Replaced hydraulic and pneumatic systems, eliminating auxiliary systems and reducing failure points

2.3.3 Market Expansion and Installed Base Growth

The global GIS installed base expanded dramatically during this period:

Year	Installed Bays	Primary Regions	Avg. Voltage Level
1980	~15,000	Europe, Japan	145 kV
1990	~120,000	Global	245 kV
2000	~350,000	Global + Asia	420 kV

2.3.4 Standardization and Quality Improvements

International standards organizations established comprehensive specifications:

- IEC 62271-203: High-voltage switchgear and controlgear – Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV
- IEEE C37.122: IEEE Standard for Gas-Insulated Substations Rated Above 52 kV

- CIGRE Working Groups: Published technical brochures on GIS design, testing, and operation based on accumulated field experience

2.4 Digital Era and Smart Integration (2000s-2010s)

2.4.1 Digital Substation Integration

The adoption of IEC 61850 communication protocol revolutionized GIS integration into digital substations:

- Process Bus Architecture: Replaced conventional copper wiring with fiber optic communication between intelligent electronic devices (IEDs)
- Merging Units: Digitized analog signals from current and voltage transformers directly at the GIS
- GOOSE Messaging: Enabled high-speed peer-to-peer communication between protection relays and circuit breakers
- Sampled Values: Transmitted digitized waveforms replacing conventional current and voltage transformers' analog outputs

2.4.2 Condition Monitoring Systems

Advanced monitoring capabilities were integrated into modern GIS designs:

- Partial Discharge Monitoring: Ultra-high frequency (UHF) and acoustic sensors detect incipient insulation defects
- Gas Quality Monitoring: Continuous measurement of SF_6 purity, moisture content, and decomposition products
- Gas Density Monitoring: Electronic density monitors with trend analysis and predictive alerts
- Temperature Monitoring: Infrared sensors and fiber optic distributed temperature sensing
- Circuit Breaker Operations Counter: Mechanical wear tracking with maintenance scheduling algorithms

2.4.3 Seismic Design Advancements

Following major earthquakes in Japan (1995 Kobe, 2011 Tohoku), seismic qualification requirements were substantially enhanced:

- Shake Table Testing: Full-scale seismic qualification at 0.5g to 0.7g peak ground acceleration
- Flexible Interconnections: Bellows and expansion joints between rigid GIS sections
- Foundation Design: Isolated mounting systems and base isolation technologies

Post-earthquake field inspections demonstrated exceptional GIS resilience, with minimal damage even in severely affected areas, validating enhanced seismic design approaches.

2.4.4 Compact and Hybrid Designs

Continuing demand for space optimization drove development of ultra-compact configurations:

- Integrated Solutions: Combined circuit breakers and disconnectors in single compartments
- Compact GIS: Achieved 40-50% size reduction compared to conventional GIS through optimized gas pressures and field distribution
- Hybrid Switchgear: Combined GIS circuit breakers with AIS busbars for cost-performance optimization in specific applications.

A view of all between equipment with a picture of 380KV GIS substation in KSA. Environmental Awareness and Modern Developments (2010s-Present)

2.5 VARIOUS CONCERNS

2.5.1 SF6 Environmental Concerns

Sulphur hexafluoride (SF6), while possessing excellent dielectric and arc-quenching properties, has a global warming potential (GWP) of 23,500 times that of CO2 over a 100-year period. The Kyoto Protocol classified SF6 as a greenhouse gas requiring reduction, prompting the industry to develop alternatives.

Environmental regulations in the European Union (F-Gas Regulation 517/2014) and California (AB-32) established phase-down schedules for SF6 emissions, accelerating development of eco-efficient alternatives.

2.5.2 Alternative Insulating Gases

Major manufacturers developed and commercialized SF6-free GIS technologies:

Technology	Manufacturer	Gas Mixture	GWP
Blue GIS / g³	GE Grid Solutions	C5-PFK + CO2 + O2	<1
Air Plus	ABB	C4-FN + CO2 + O2	<1
Clean Air	Siemens Energy	C5-FK + CO2 + O2	<1
Vacuum Technology	Multiple	Vacuum + Air	0

These alternative gas mixtures utilize fluor nitrile or fluor ketone compounds mixed with natural gases (CO2, O2, N2) to achieve dielectric performance comparable to SF6 while reducing GWP by over 99.99%. As of 2024, over 5,000 eco-efficient GIS installations have been commissioned globally.

2.5.3 Digital Twin and Predictive Analytics

Advanced analytics and simulation capabilities are transforming GIS asset management:

- Digital Twin Models: Virtual replicas of physical GIS installations for simulation, testing, and optimization
- Machine Learning Algorithms: Pattern recognition for anomaly detection in partial discharge signatures
- Predictive Maintenance: Data-driven maintenance scheduling based on condition indicators rather than fixed intervals
- Cloud-Based Monitoring: Centralized fleet monitoring across multiple substations with automated alert systems

2.5.4 Modular and Prefabricated Systems

Factory-assembled, pre-tested modular GIS systems reduce on-site installation time and improve quality control. Containerized mobile substations utilizing compact GIS enable rapid deployment for emergency power restoration, renewable energy interconnection, and temporary events. Installation times have been reduced from 12-18 months for conventional on-site assembly to 3-6 months for modular systems.

3. Industry Analysis and Market Trends

3.1 Global Market Overview

3.1.1 Market Size and Growth Projections

The global GIS market has demonstrated robust growth, expanding from approximately USD 15.2 billion in 2020 to an estimated USD 22.8 billion in 2025. Market research firms project continued expansion at a compound annual growth rate (CAGR) of 8.2% through 2030, reaching approximately USD 34.5 billion by decade's end.

Year	Market Size (USD B)	Units Shipped	YoY Growth	Leading Region
2020	15.2	~45,000	5.8%	Asia-Pacific
2023	20.5	~58,000	9.1%	Asia-Pacific
2025 (Est.)	22.8	~64,000	7.5%	Asia-Pacific
2030 (Proj.)	34.5	~92,000	8.2% CAGR	Asia-Pacific

3.1.2 Regional Market Distribution

Regional market dynamics vary significantly based on infrastructure development stage, urbanization rates, and regulatory environments:

- Asia-Pacific (48% market share): Dominated by China and India's massive infrastructure buildout, with annual installations exceeding 30,000 bays
- Europe (22% market share): Focus on aging infrastructure replacement and SF6-free technologies driven by environmental regulations
- North America (15% market share): Accelerating adoption in urban centres and renewable energy interconnection points
- Middle East & Africa (10% market share): Expansion driven by population growth and oil/gas sector electrification
- Latin America (5% market share): Emerging market with growing investments in transmission infrastructure

3.2 Market Drivers and Growth Factors

3.2.1 Urbanization and Land Scarcity

Rapid urbanization, particularly in developing nations, continues to be the primary driver for GIS adoption. Urban land costs ranging from USD 50-500 per square foot make the 85-90% space savings offered by GIS economically compelling. In metropolitan areas like Mumbai, Singapore, and Hong Kong, land acquisition costs can exceed the equipment costs, making GIS the only viable technical solution.

3.2.2 Renewable Energy Integration

The global transition to renewable energy sources requires extensive transmission network expansion and reinforcement. Wind farms, solar installations, and energy storage facilities frequently utilize GIS for collector substations and interconnection points. The International Energy Agency (IEA) projects renewable capacity additions of 3,700 GW between 2023-2028, driving substantial GIS demand for grid integration.

3.2.3 Aging Infrastructure Replacement

Developed nations face widespread replacement of aging AIS installations commissioned in the 1960s-1980s. Approximately 40% of North American and European transmission substations exceed their design life expectancy of 40-50 years. Utilities increasingly choose GIS for replacements to gain space for additional equipment, enhance reliability, and meet modern environmental standards.

3.2.4 Environmental and Safety Regulations

Stringent environmental regulations regarding electromagnetic field (EMF) exposure, noise levels, and visual impact Favor GIS over outdoor AIS installations. Enclosed metal compartments provide superior EMF shielding and eliminate visual pollution concerns in residential areas. Safety regulations in jurisdictions like the European Union and California increasingly mandate enclosed switchgear for new urban substations.

3.3 Competitive Landscape

3.3.1 Major Manufacturers and Market Share

The global GIS market exhibits moderate concentration, with the top five manufacturers controlling approximately 65% of market revenue:

Manufacturer	Market Share	Primary Region	Key Strengths	Eco Tech
ABB (Hitachi Energy)	~22%	Global	UHV, Eco-efficiency	AirPlus
Siemens Energy	~18%	Europe	Technology innovation	Clean Air
GE Grid Solutions	~15%	Americas	Installed base	g^3 Blue
Schneider Electric	~10%	Europe	Digital integration	SM AirSeT
Chinese Manufacturers (XD, Pinggao, TBEA)	~25%	China	Cost, Volume	Emerging

3.3.2 Technology Differentiation Strategies

Manufacturers compete through multiple differentiation vectors:

- Environmental Leadership: SF6-free alternatives represent key competitive advantage in environmentally regulated markets
- Digital Capabilities: IEC 61850 integration, condition monitoring sophistication, and analytics platforms
- Reliability Track Record: Documented field performance data spanning decades builds customer confidence
- Total Cost of Ownership: Life-cycle cost optimization through extended maintenance intervals and modular designs
- Technical Support Services: Global service networks, spare parts availability, and training programs

4. Current Technical Specifications and Standards

4.1 Voltage Ratings and Applications

Modern GIS technology covers a comprehensive voltage range from medium voltage distribution to ultra-high voltage transmission:

Voltage Class	Standard Ratings	Primary Application	Typical Config	Market Share
Medium Voltage	12-36 kV	Distribution	Three-phase	25%
High Voltage	72.5-145 kV	Sub-transmission	Mixed	35%
EHV	245-420 kV	Transmission	Single-phase	30%
UHV	550-1100 kV	Bulk Transmission	Single-phase	10%

4.2 Performance Characteristics

Modern GIS installations demonstrate exceptional performance across multiple metrics:

- Reliability: Failure rates of 0.02-0.05 failures per bay-year, significantly superior to AIS (0.10-0.15)
- Availability: Typical availability exceeding 99.95% when including scheduled maintenance
- Maintenance Intervals: Major inspections every 15-30 years, compared to 3-5 years for AIS
- Operating Life: Design life of 40-50 years with proper maintenance
- Short Circuit Current: Ratings up to 80 kA for EHV applications
- Seismic Performance: Qualified to IEEE 693 and IEC 62271-203 standards for high seismicity zones

5. Conclusions

⇨ High Voltage Gas Insulated Switchgear technology has evolved from experimental installations in the late 1960s to become the preferred solution for space-constrained and environmentally challenging substation applications worldwide. The technology's journey reflects continuous innovation across electrical engineering, materials science, digital systems, and environmental stewardship.

⇨ Current market dynamics indicate sustained growth driven by urbanization in developing nations, renewable energy integration requirements, and aging infrastructure replacement in developed markets. The global installed base exceeding 1.5 million bays demonstrates the technology's maturity and acceptance across diverse operating environments.

⇨ Environmental consciousness has catalysed development of SF6-free alternatives, representing perhaps the most significant technological shift since GIS inception. These eco-efficient designs maintain performance standards while dramatically reducing greenhouse gas impact, positioning GIS technology for continued relevance in an increasingly sustainability-focused industry.

- ⇨ Digital transformation through IEC 61850 integration, advanced condition monitoring, and predictive analytics fundamentally enhances GIS value proposition beyond simple space savings. These capabilities enable proactive asset management, optimized maintenance strategies, and integration into evolving smart grid architectures.
- ⇨ Looking forward, GIS technology continues advancing along multiple vectors: environmental sustainability through alternative gases and circular economy principles, digitalization enabling autonomous operation and AI-driven optimization, and materials science innovations yielding further compactness and performance improvements. The convergence of these trends ensures GIS will remain central to electrical infrastructure development for decades to come.

6. CASE STUDY

380KV Sub Station Qurayyah Power Plant at Eastern Province in Saudi Arabia.
The Substation was a directly connected to Generating to Power evacuation from 380KV Transmission lines.

Following Major issues came up while Consulting the above said Project.

On the Protection side, Major relay settings for the bus bar Protection was broadly discussed among the Protection and client Engineers. Even through, there were two main companies M/S ABB Switzerland and M/S Siemens AG Germany. As the different settings of their corresponding relay was done. The main sequence of events with the protections for the various buses, contractor could not convince the client.

After lot of discussions among parties, the issue could be amicably resolved. This was after seven to ten days of working with the respective Protections Engineers. This was a major bottle neck faced for the Sub Station Project.
B) The second Major hurdle was faced as the 380KV Transmission Line to 380KV Busing i. e. (Interfacing Accessories) Termination material not included in the contract by the either Parties, Therefore the scope while tendering was not considered by the client. After some negotiations client revised the scope of work for the work and that the project got delayed by a week or so.

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Auxiliary Power Consumption Reduction in Coal-fired Thermal Power Plants

By

Prof. Awadhesh Kumar Singh

FIE, FSPE, MISNT, MIIW, MIIM

Vice President-Asset Integrity Management & Training

TCR Advanced Engineering PVT Ltd., Vadodara

E-mail: awadhesh@tcradvanced.com

INTRODUCTION: Thermal Power Plants produce electrical energy and also consume a substantial amount of energy in the form of auxiliary power consumption required for various plant equipment and services. Most of the thermal power plant utilise 30-40% of energy value of primary fuels for power generation and remaining 60-70% is lost during generation, transmission and distribution of which major loss is in the form of heat. Auxiliary Power Consumption (APC) in thermal power plants is the electricity the plant itself uses to run equipment like pumps, fans, mills, precipitators, lighting, etc. National level average auxiliary power consumption is around 8%-12%. Reduction of even 0.5 - 1.0 % can result in huge savings and additional output of a few Megawatts.

1.0 AUXILIARY POER CONSUMPTION: As we can see there is massive impact of Auxiliary power consumption (APC) which plays an important role in EBITDA and Saving of Natural Resources. Following steps can be taken for APC Reduction:

1. By analysing energy saving potential areas, energy can be conserved efficiently.
2. Performance monitoring of each unit should be carried out which includes auxiliaries such as coal handling plant, ash handling plant, water treatment plants and compressors.
3. Monthly performance tests should be conducted to evaluate boiler efficiency, condenser performance, turbine cylinder efficiency, LP/HP heater performance, turbine heat rate etc.
4. Installation of Variable Frequency Drive (VFD) should be done which can save 15% to 25% of energy.
5. Flue gas leakage can be minimized by replacing metallic joints with fabric joints.
6. Use of soft starters can save considerable energy for the motors which operate continuously on variable load.
7. The moisture of coal should be removed before use otherwise it increases the load on boiler and hence decreases its efficiency.
8. Proper crushing (pulverizing) of coal should be done which reduces the unburnt carbon and bottom ash.
9. Monitoring of Oxygen and CO to ensure complete combustion and control combustion air to limit the dry gas losses.
10. Regular monitoring operating controllable parameters to gain efficiency and availability.
11. Monthly performance monitoring of the station should be reported in meting to the head of department.
12. Annual overhaul of units and auxiliaries should be done regularly based on the performance deterioration due to ageing.

2.0 APC REDUCTION OPPORTUNITIES IN A THERMAL POWER PLANT:

1. Air & Flue Gas Circuit:

a. Optimizing excess air ratio: - It reduces FD fan & ID fan loading.

b. Replacement of oversize FD and PA fan: - Many thermal power plants have oversize fans causing huge difference between design & operating points which leads to lower efficiency. Hence, fan efficiency can be improved by replacing correct/proper size of fan. If replacement is not possible, Use of HT VFD for PA & ID fan can be the other solution.

c. Attending to the air & flue gas leakages: - Leakages in air & flue gas path increase fan loading. Use of Thermo-vision monitoring can be adopted to identify leakages in flue gas path. Air preheater performance is one crucial factor in leakage contribution. If APH leakage exceeds design value, then it requires corrective action.

2. Steam, Feed-Water and Condensate Circuit:

a. BFP scoop operation in three element mode instead of DP mode: - In three element mode throttling losses across FRS valve reduce leading to reduction in BFP power.

b. Optimization of level set point in LP & HP heater: - Heater drip level affects TTD & DCA of heater which finally affect feed water O/L temp. Hence, it requires setting of drip level set point correctly.

c. Charging of APRDS from CRH line instead of MS line: -APRDS charging from cold reheat (CRH) is always more beneficial than from MS line charging.

d. Isolation of steam line which is not in use: - It is not advisable to keep steam line unnecessary charged, if steam is not utilized since there energy loss occurs due to radiation. For example, deaerator extraction can be charged from turbine Extraction/CRH or from APRDS. In normal running, APRDS Extraction is not used. So, same can be kept isolated.

e. Replacement of BFP Cartridge: - BFP draws more current if cartridge is worn out, causing short circuit of feed water flow inside the pump. It affects pump performance. Hence, regular and periodic cartridge replacement is necessary.

f. Attending to Passing Recirculation Valve of BFP: - BFP Power consumption increases due to passing of R/C valve. It requires corrective action.

g. Installation of HT VFD for CEP: - CEP capacity is underutilized and also there is pressure loss occuring across Deaerator level control valve. There is large scope of energy saving which can be accomplished by use of HT VFD for CEP or impeller trimming.

3. Coal & Ash Circuit:

a. Optimized ball loading in Ball tube mill: - Excessive ball loading increases mill power. Hence, ball loading is to be optimized depending upon coal fineness report.

b. Use of Washed Coal or Blending with A- grade coal: - F-grade coal has high ash content. Overall performance can be improved by using washed coal or blending of F-grade coal with A- grade imported coal instead of only using F-grade coal.

c. Avoiding Idle Running of Conveyors & Crusher in CHP

d. Use of Dry Ash Evacuation instead of WET Deashing System: - Dry deashing system consumes less power & also minimizes waste reduction.

e. Optimize Mill Maintenance:- Mill corrective/preventive maintenance is to be optimized depending on parameters like- running hrs, mill fineness, bottom ash unburnt particle, degree of reject, pipe chocking etc.

4. Electrical & Lighting System:

a. Optimizing Voltage Level of Distribution Transformer: - It is found that Operating voltage level is on higher side than required causing more losses. It is required to reduce the voltage level by tap changing.

b. Use of Auto Star/Delta/Star Converter for Under loaded Motor Lighting: - Use of electronic chock instead of conventional use copper Chock, Use of CFL, Replacement of mercury vapor lamp by metal Halide lamp. Use of timer for area lighting are the methods that can be used. Lighting has tremendous potential of saving.

5. ECW & ACW System:

a. Isolating ECW supply of Standby Auxiliaries: - Many times standby coolers are kept charged from ECW side. Also Standby equipment's auxiliaries like Lube oil system are kept running for reliability. We can isolate Standby cooler from ECW system & switching of standby auxiliaries, doing trade-off between return & reliability.

b. Improving Condenser Performance by Condenser Tube Cleaning & Use of Highly Efficient Debris Filter: - Tube cleaning by bullet shot method increases condenser performance, condenser tube cleaning is necessary which is to be carried out in overhaul. Also highly advanced debris filter contributes to better condenser performance.

c. Application of Special Coating on CW Pump Impeller: - It improves pump impeller profile condition, increasing pump performance.

6. Compressed Air System:

a. Optimizing Discharge Air Pressure by Tuning Loading/Unloading Cycle: It is helpful to reduce Specific Power consumption.

b. Use of Heat of Compression Air Dryer instead of Electrically Heated Air Dryer: - Heat of compression air dryer uses heat generated in compression cycle, thus reduces Specific Power consumption.

c. Use of Screw Compressor instead of Reciprocating Compressor: - Specific Power consumption of screw compressor is less than that of a reciprocating air compressor and leads to reduced auxiliary power consumption.

7. Other Areas:

a. Cooling tower performance improvement.

b. Installing absorption refrigeration system instead of vapor compression system.

c. Use of wind turbo-ventilators instead of conventional motor driven exhauster.

d. Monitoring the power consumption of each equipment before and after overhaul and also carrying out the trend analysis.

3.0 QUICK WINS — LOW / NO INVESTMENT

1. Reduce excess air: 1% excess O_2 raises FD/ID fan load ~1%.
2. Tight O_2 control at 2.5-3% vs. 4-5% saves APC.
3. Condenser vacuum improvement: Every 1 kPa better vacuum cuts BFP power ~1% and boosts efficiency. Clean condenser tubes reduce air ingress.
4. Optimize CW flow: Many plants run CW pumps at 100% year-round. Link VFD to CW inlet temp and load — 10-15% savings.

5. Switch off standby equipment: Ensure auto-standby logic works. Lots of plants have 2-3 pumps/fans running when 1 would do at part load.
6. Compressed air leaks: Fix leaks. 1 mm hole at 7 bar wastes ~0.5 kW continuously.

4.0 MAJOR RETROFITS — HIGH ROI

1. VFDs on large HT motors: 500 MW unit: VFD on BFP or ID fan can save 3-5 MW. Payback is 2-4 years at ₹4/kWh.
2. Replace BFP hydraulic coupling with VFD: Cuts losses from 5-8% to <3%.
3. Intelligent Soot Blowing: Run based on furnace heat transfer, not timer.
4. Reduces steam + air compressor load.
5. Motor Rewinding with Energy-efficient Design: Old motors have 88-90% efficiency → 94-96% IE3/IE4 motors.

5.0 OPERATIONAL BEST PRACTICES:

- Sliding pressure operation at part load vs. throttle control — big BFP savings.
- Coal Quality Management: High ash/moisture increases mill + APC load. Blending (with imported coal) to design coal helps.
- APC monitoring per unit: Track kWh/ton steam or % of generation daily. Target: Supercritical <5.5%, Subcritical <7.5%.
- Unit heat rate vs. APC trade-off: Don't chase 0.1% heat rate gain if it costs 0.5% APC.
- For Belt-driven utilities like Air Compressor etc., 7-10% of Motor Power can be saved by using FLAT BELTS in place of V-BELTS.
- FLAT BELTS may in general be used wherever V-BELTS are used. The cost of V-BELTS and FLAT BELTS are almost the same as far as the belt alone is concerned. However, V-BELT Pulleys are reported to be about 25% costlier than similar Pulleys for FLAT BELTS.
- MAINTAINING OPTIMUM VOLTAGE: In a Power Plant of size, 1000 MW, 80 to 100 MW Power is absorbed in the form of Electrical Energy, out of which 10 to 15% goes as the copper losses in the transformers, bus ducts, motors, cables etc.
  These losses may increase by 10% if the voltage at buses is say, 95% which is Permitted as per standard and the control room staff will not bother about it.
  In view of this, proper awareness needs to be generated about the importance and benefits of maintaining the optimum voltage.
- REDUCTION IN TRANSFORMER LOSSES
  In the Power Plant, a number of transformers are just kept charged as standby and continuously incur losses. The transformer losses can be minimized by designing such transformers for low no-load losses and for this necessary provisions are required to be made into specifications.
  It is well established that Cast Resin transformer has lower no-load losses than the oil-filled one. Since, they are being manufactured in India now, their use must be encouraged,
- CABLE LOSS REDUCTION
  In a Power Plant of say 2 x 500 MW capacity, approximately 250 km of LT and 80 to 100 km of HT POWER CABLES are used.
  The copper losses in these cables, could be of the order of 20 to 30 million units of energy per year.
  If savings to the tune of 5 to 10% in cables is achieved by way of improving the layouts, cabling, optimizing the route length etc., not only saving in the initial investment towards these cables will be achieved but also 2 to 3 million units of energy will be saved each year on a recurring basis.
- STEAM TURBINE DRIVEN BFP

There is approximately a saving potential of 1 MW in a 500 MW unit, when a steam turbine driven BFP is selected in place of electrical motor driven BFP.
In a motor driven BFP, there is a loss of around 800 kW in the hydraulic coupling due to slip loss and another loss of around 200 kW in the motor.
A steam turbine provides variable speed operation without an additional component such as hydraulic coupling which in turn also eliminates the coupling losses resulting in a substantial energy saving.
Thus, in other words, 6.5 MW of power generated at the shaft of the BFP steam turbine will be able to pump the same amount of feed water as an electrical motor driven pump drawing a power of 7.5 MW.

6.0 BEST PRACTICES FOR CONSERVING ENERGY IN LIGHTING:

- Reducing single phase voltage to 220-230 V by Transformer tap setting (in most of the generating stations the single phase voltage has been observed to be in the range of 250-260V).
- Use of Electronic Ballasts.
- Incorporation of CFL's.
- Incorporation of Lighting Energy Savers.
- Use of Metal Halide Lamps by replacing HPSV lamps.
- Incorporation of Timers.
- Incorporation of Photo Sensors etc.
- Typical Results: Indian 500 MW subcritical plants run at 7-9% APC. Best-in-class supercritical units do 4.5-5.5%. So, there's 2-3% net output gain on the table.
- NTPC Tanda reduces Ash Slurry Pumps in usage from eight to four and Cooling Water Pumps from four to two.
- NTPC Dadri saves 6500 units per day in power consumption of BFP.
- NTPC Unchahar reduces energy in coal conveyor by 10%.
- NTPC Singrauli saves 10% in BFPs.
- NTPC Tanda predicts coal mill breakdown.

7.0 NATIONAL BENCHMARK FOR AUXILIARY POWER CONSUMPTION (APC) – FY 2024-25

1. **CERC Normative Benchmark (Coal Thermal >200 MW)**
   8.5% of gross generation remains the Central Electricity Regulatory Commission norm for units 200 MW and above.
   This is the regulatory target used for tariff calculations and performance evaluation.
2. **Actual National Averages**
   Indian coal fleet average: **~8.34% to 9.48%** depending on unit size/age
   Min: 4.79%, Max: 14.79%, Mean: **9.48%** for 69 coal plants under PAT scheme
   Plant Audits: A 210 MW unit showed **11.59% actual** APC vs **8.5% benchmark**, but best achievable was **8.5%**

3. **Global Range**
   ScienceDirect study of 69 coal plants: APC ranged from 4.79% to 14.79%, average 9.48%
   Large, efficient units: Can get down to 4.86–6.62% for in-house auxiliaries with best practices.
4. **National National Benchmark (for the Year 2007-08):**
   - TROMBAY- Tata Power Co. Ltd: 4.3%
   - Central Sector: TALCHAR STPS - NTPC: 5.34%
   - State Sector: CHANDRAPUR STPS-MahaGenco: 7.40%

5. **International Benchmark:**
"Shanghai Shidonhkou Power Plant": 3.66% **(2 x 600 MW-Coal fired) (for the Year 2000)**

8.0 AUXILIRY POWER CONSUMPTION REDUCTION:
Cutting APC by even 1% directly boosts net output and profit, since that power can be sold instead. Here's how plants reduce it: Major APC Equipment & Typical Fixes:

EQUIPMENT	% OF TOTAL	REDUCTION STRATEGIES
ID/FD/PA FANS	25-35%	Variable Frequency Drives (VFDs). Inlet Guide Vanes, Impeller Trimming, Duct Pressure Optimization. VFDs alone save 20-40%.
BOILER FEED PUMPS (BFPs)	20-30%	VFDs, Throttling Control → variable speed, proper sizing, maintaining design clearances
COAL MILLS / PULVERIZERS	10-15%	Optimize grinding fineness, reduce reject rate, VFD on primary air fans, maintain ball/roller wear
COOLING WATER PUMPS	10-20%	VFDs based on condenser vacuum, CW system optimization, pump impeller trimming
ESP + ASH HANDLING	5-10%	ESP field optimization, intermittent energization, dense-phase ash conveying vs lean-phase
LIGHTING + HVAC	2-5%	LED retrofit, occupancy sensors, efficient chillers

9.0 CONCLUSION:
Reducing auxiliary power consumption is one of the fastest, highest-ROI ways to improve a thermal plant's profitability and efficiency. Key Points:

- ⇨ Direct bottom-line impact: APC is 5-10% of gross generation. Cutting it by just 1% in a 500 MW plant saves ~5 MW = ~120 MWh/day = ₹17-20 lakh/day at ₹4/kWh. The saved power is sold, not just "not used."
- ⇨ Biggest levers are fans & pumps: ID/FD fans, boiler feed pumps, and CW pumps make up 60-75% of APC. VFDs, optimization of excess air, condenser vacuum, and sliding pressure operation deliver 20-40% savings on those systems alone.
- ⇨ It's both technical and operational: Equipment retrofits like VFDs and IE3 motors matter, but so does daily discipline — fixing air leaks, switching off standby drives, optimizing soot blowing, and tracking APC/kWh daily.
- ⇨ Benchmark to compete: Best-in-class supercritical units run at 4.5-5.5% APC. Most Indian subcritical plants are at 7-9%. Closing that 2-3% gap is achievable without new capacity addition.
- ⇨ Co-benefit for decarbonization: Lower APC = lower coal burned per MWh net, which cuts specific CO_2 emissions. Critical as grids tighten carbon norms.
- ⇨ Bottom line: APC reduction isn't just an O&M issue — it's a no-regret profit centre. Start with measurement, target the big motors first with VFDs and control logic, then enforce operational best practices. A focused APC program typically pays back in 1-3 years and keeps giving returns for the life of the plant.

#######

Gujarat's Power Sector in a Net-Zero 2047 Scenario Demand, Resource Adequacy and the Strategic Role of Concentrated Solar Power

By

Er. Nitesh Bidarkar

Abstract: *Gujarat's aspiration to become a $ 3.5 trillion economy by 2047 and a net-zero economy in the same timeframe creates a distinctive planning challenge for its power sector. The state must simultaneously sustain industrial growth, electrify end-use energy, substitute fossil fuels in transport and process heat, support green hydrogen production, and preserve grid reliability under very high shares of variable renewable energy. Drawing on the State's Vision 2047 energy security roadmap, this paper examines Gujarat's present energy-consumption profile, the implied electricity and peak-demand requirements under a 2047 net-zero scenario, the generation mix needed to support this transition, and the strategic role of CSP as a firm, dispatchable and grid-supportive renewable resource. The analysis shows that Gujarat's final energy consumption remains fossil-fuel-dominated: coal, oil, and gas together account for nearly four-fifths of the energy mix, while electricity contributes only around one-sixth. In a net-zero scenario, electricity demand is projected to increase to about **1,852 billion units** (BU) by FY47, compared with about **647 BU** under the current-policy pathway. This implies not merely incremental renewable capacity addition but a structural reconfiguration of the electricity system, requiring around 706 GW of generation capacity, 120 GW of energy storage systems, and nearly 20 GW of pumped storage or long-duration energy storage by FY47. The scale of solar and wind capacity envisaged under the net-zero case also reveals resource constraints: the onshore wind requirement exceeds the estimated wind potential, while solar approaches 86% of the mapped potential. CSP therefore deserves policy attention not as a substitute for PV and wind, but as a strategic complement that provides thermal storage, synchronous inertia, reactive power support, firm capacity and a credible transition pathway for coal-based power plant assets and workers*.

1. Introduction

Gujarat's power sector has historically been shaped by industrial demand, relatively high electricity consumption, strong grid infrastructure and early adoption of renewable energy. The next phase, however, is qualitatively different. The Vision 2047 framework does not merely call for higher power supply; it places the power sector at the centre of an economy-wide decarbonisation strategy. A state seeking to reach USD 3.5 trillion in gross domestic product by 2047, while also aspiring to become net-zero by that year, must treat electricity as the primary driver of future economic growth. In such a scenario, the electricity sector will not serve only conventional loads. It will also absorb new demand from electric mobility, industrial electrification, green hydrogen, electric cooking, data centres, semiconductor manufacturing and other forms of digital and industrial growth.

This paper argues that Gujarat's net-zero power sector cannot be built solely by expanding current solar PV and wind capacities. Solar PV and wind will remain the backbone of decarbonised electricity supply, but their variability introduces challenges related to adequacy, ramping, curtailment, voltage, inertia, and reserves. The strategic question is therefore not whether Gujarat should expand renewable energy; that is settled. The question is: what kind of renewable portfolio is required to support a high-growth, high-reliability, net-zero electricity system by 2047?

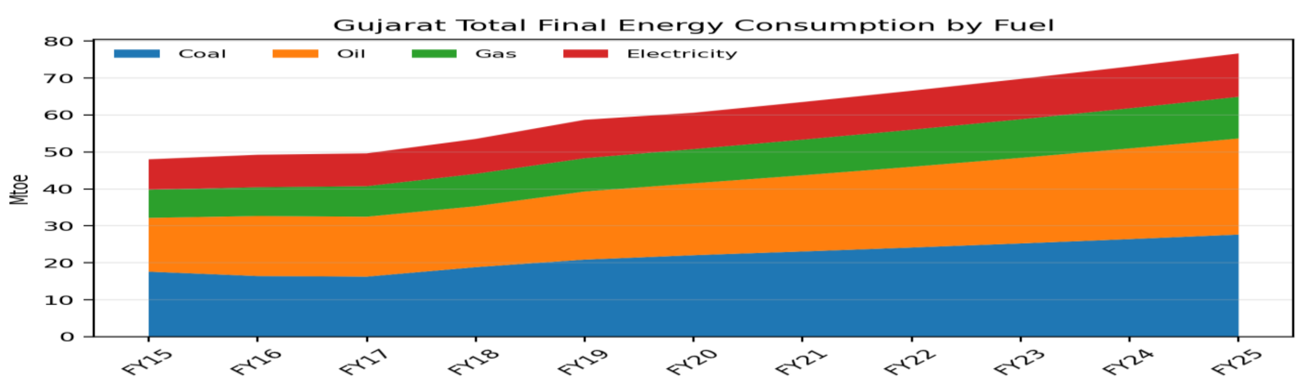
The paper is organised around eight sections: (1) the current total final energy consumption (TFEC) scenario; (2) Gujarat's 2047 economic and net-zero vision; (3) the operational meaning of net-zero by 2047; (4) electricity and indicative peak demand under the net-zero pathway; (5) the generation capacity mix required; (6) the mapping of renewable resource potential against required capacity; (7) the critical role of CSP; and (8) the investment opportunity to coal-generating plants to switch over to CSP-led firm renewable power.

2. Current energy-consumption and power sector baseline

Gujarat's current energy system remains overwhelmingly fossil-fuel-based. The State’s energy independence roadmap reports that total final energy consumption increased from 48.00 million tonnes of oil equivalent (Million ton of oil equivalent - Mtoe) in FY15 to 60.60 Mtoe in FY20, and further to an estimated 76.62 Mtoe in FY25. Coal consumption increased from 17.60 Mtoe in FY15 to 27.63 Mtoe in FY25, while oil increased from 14.56 Mtoe to 26.01 Mtoe over the same period. Electricity increased from 8.24 Mtoe to 11.73 Mtoe, but its share remains modest relative to direct fossil-fuel use. The FY20 energy profile indicates coal at 36%, oil at 32%, gas at 15% and electricity at 16% of final energy consumption. Thus, the decarbonisation task is not confined to cleaning electricity generation; it requires a progressive substitution of direct fossil-fuel consumption by clean electricity and green molecules.

The existing installed and contracted generation capacity provides the starting point for this transition. As of March 2026, the total generation capacity of about 78 GW meets Gujarat's electricity requirement, including central-sector shares and contracted medium- and short-term capacity. Coal remains the largest component at 25.50 GW, followed by gas at 5.89 GW, solar at 22.24 GW, distributed solar at 6.88 GW and wind at 15.6 GW. Nuclear and hydro together contribute less than 2 GW. This baseline shows that Gujarat has already begun diversifying its supply mix, but the system remains materially dependent on thermal capacity for adequacy, ramping and reliability.

Figure 1. Gujarat Total Final Energy Consumption by source, FY15-FY25



Source: Vision 2047 Energy Security Roadmap of Gujarat.

3. Gujarat's 2047 vision and the meaning of net-zero

The Vision 2047 framework aims for Gujarat's economy to expand rapidly, with gross state domestic product reaching Rs 55-60 lakh crore by 2030 and Rs 435 lakh crore by 2047, equivalent to approximately USD 3.5 trillion. The same framework projects a population of 8.5 crore by 2047, with 66% living in urban centres. These assumptions matter for electricity planning because demand is driven not only by income growth but also by urbanisation, industrial structure, transport behaviour, building energy use and the pace of electrification.

Becoming net-zero by 2047 should not be interpreted as eliminating all emissions or eliminating all fossil-fuel use instantaneously. In technical terms, net-zero requires that economy-wide greenhouse gas emissions be reduced as far as technologically and economically feasible, and that residual emissions be offset through credible removals or carbon sinks. For Gujarat's power sector, however, the practical implication is more direct: electricity must become substantially non-fossil and serve as the decarbonization engine for other sectors. This means that power-sector planning must shift from a narrow electricity-demand forecast to an integrated energy-system view.

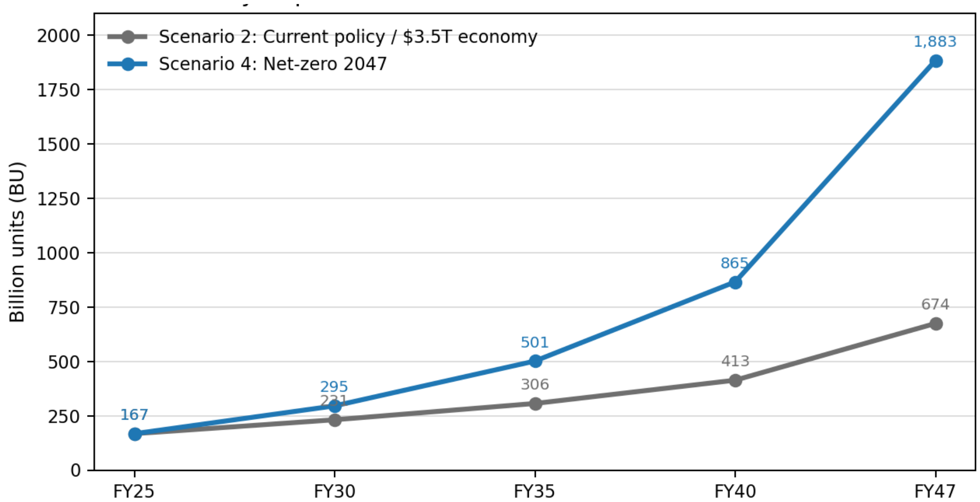
In this framework, electricity demand grows because fossil fuels are displaced from end-use applications. Transport electrification shifts petrol and diesel demand to the grid. Industrial heating is increasingly shifting away from coal and gas toward electric boilers, heat pumps, electric furnaces, and, in selected applications, green hydrogen. Household cooking is shifting away from firewood, LPG, kerosene, and other fuels. New high-value industrial loads, such as data centres and semiconductor manufacturing, add further to electricity demand. Net-zero is therefore an expansionary electricity scenario, not a demand-suppression scenario.

4. Electricity and indicative peak-demand requirement

As per the State government's energy security road map, under the current policy pathway (Business-as-Usual), electricity consumption increases from about 184 BU in FY26 to about 674 BU in FY47. Under the net-zero scenario (where states aspire to become net-zero economies by 2047), the electricity consumption rises to about 1,852 BU by FY47, with a reported compound annual growth rate of 11.4% from FY26 to FY47. The difference between these two pathways is central to planning. The net-zero pathway requires around 2.74x more electricity in FY47 than the current-policy pathway, largely because electricity becomes the substitute for fossil fuels in transport, industrial heat, cooking and green-hydrogen production.

For a reliable power supply along with energy requirements, the peak demand must be treated as a planning variable. At an annual demand of 1,852 BU, peak demand is projected to reach 324 GW. This is 1.26x India's current peak demand. A reasonable planning range for FY47 is therefore 320-350 GW, subject to end-use load shapes, storage dispatch, demand response, green-hydrogen operating strategy and time-of-day tariffs. This range is not a substitute for resource-adequacy modelling. In a deeply electrified economy, the peak may be influenced by evening EV charging, industrial process heat, seasonal cooling loads, green-hydrogen electrolyser operation and residual agricultural demand. More granular modelling, focusing on hourly or sub-hourly demand forecasts on a long-term basis, is essential to quantify loss-of-load probability, the effective load-carrying capability of renewables, reserve requirements, and storage duration needs.

Figure 2. Current-policy and net-zero electricity-demand pathways for Gujarat



Source: Vision 2047 Energy Security Roadmap, Tables 3 and 5.

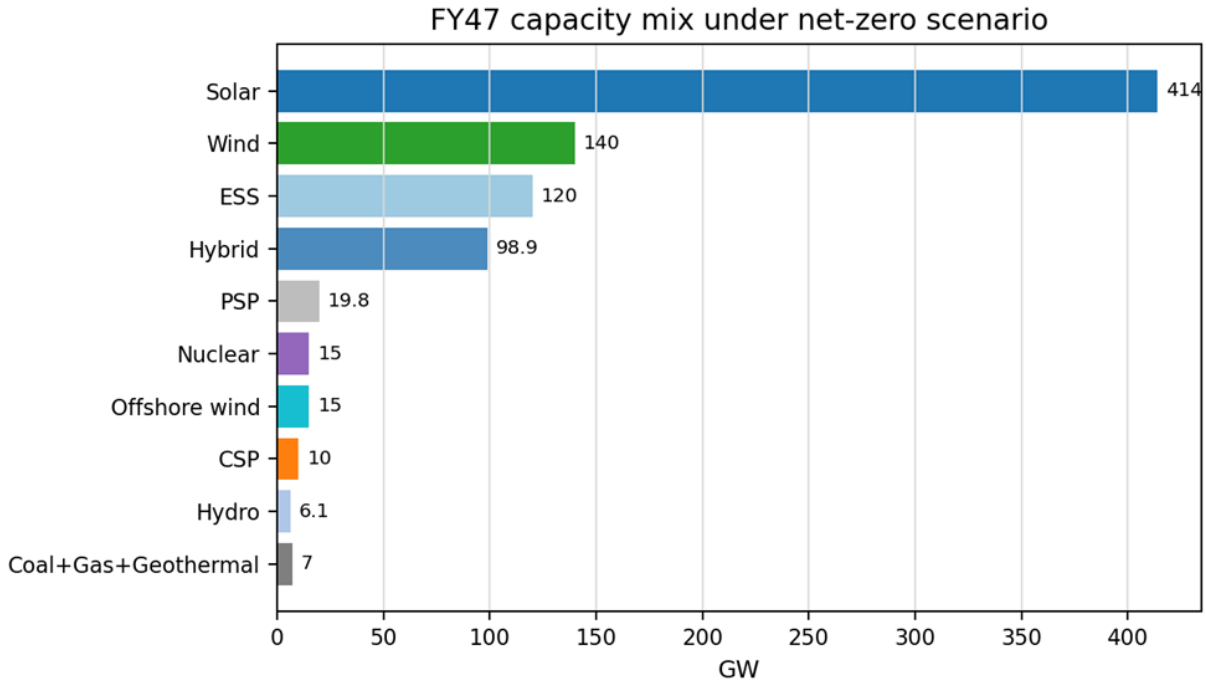
5. Generation mix required under the net-zero pathway

The net-zero generation mix is ambitious and reveals the magnitude of the system transformation. By FY47, the required generation capacity is estimated at about 706 GW, excluding 120 GW of battery or other energy storage systems and ~20 GW of pumped storage or long-duration energy storage. The generation portfolio includes 414 GW of solar, 140 GW of wind, 15 GW of offshore wind, 98.9 GW of hybrid capacity, 15 GW of nuclear, 6.1 GW of hydro, 1.5 GW of geothermal and 10 GW of CSP. Coal falls sharply to 4 GW and gas to 1.5 GW.

This mix is technically meaningful because it recognizes that a net-zero grid needs both bulk low-cost energy and firm capacity. Solar PV supplies large volumes of daytime energy; wind contributes seasonal and diurnal diversification; offshore wind adds resource diversity and potentially higher utilization; nuclear provides clean baseload; hydro and pumped storage provide flexibility; and storage supports balancing across hours. CSP occupies a distinct position because it combines renewable generation with long-duration thermal storage and synchronous generation.

The mix also raises practical questions. A system with more than 400 GW of solar, 140 GW of wind and 120 GW of storage will require large-scale transmission expansion, land-use coordination, grid-forming inverter standards, forecasting, ancillary-service markets and sophisticated dispatch. Gujarat's planning architecture must therefore integrate resource adequacy, transmission planning, distribution readiness and market operations.

Figure 3. FY47 capacity mix under the net-zero scenario



Source: Vision 2047 Energy Security Roadmap

6. Mapping renewable potential against required capacity

The resource-potential mapping in the energy-security roadmap is one of its most important policy signals. Gujarat's solar potential is estimated at 714 GW when ground-mounted and floating solar are combined, while the net-zero pathway requires 611.6 GW of solar-equivalent capacity. This represents 86% of mapped potential, indicating that solar availability is large but not unlimited. Land, evacuation, environmental constraints, competing economic uses, and local acceptance will become binding considerations as deployment scales increase.

The wind constraint is more serious. Against an estimated 182 GW of wind potential at 150 m hub height, the net-zero capacity requirement is 240 GW, or 131% of the potential. This indicates that the current resource allocation is over-dependent on wind relative to Gujarat's mapped onshore potential. It implies that the state must either increase reliance on solar, offshore wind, CSP, nuclear, imported renewable energy, green hydrogen imports, or other firm and low-carbon resources.

In light of the above, CSP is mapped more conservatively. Considering a conservative estimate of 149 GW of CSP potential in high-DNI regions and only 10 GW of capacity in the net-zero policy pathway, equal to about 7% of potential. This under-utilization is analytically important. If onshore wind is resource-constrained and solar approaches the upper bound of mapped potential, CSP becomes one of the few firm renewable resources that can be scaled without exhausting the mapped technical potential. Geothermal, by contrast, is projected at 1.5 GW against 5 GW potential and is useful but not a system-shaping resource.

7. Critical role of CSP in Gujarat's net-zero scenario

CSP deserves a specific place in Gujarat's net-zero planning because it addresses weaknesses that solar PV and wind cannot fully resolve on their own. CSP converts direct normal irradiance into high-temperature heat, stores that heat in thermal energy storage, and generates electricity through a steam turbine. This configuration gives CSP four attributes that are systemically valuable: dispatchability, long-duration storage, synchronous inertia and reactive power capability.

The high CSP potential offers Gujarat as India's leading CSP opportunity. Depending on the DNI threshold used, Gujarat's potential is estimated at around 182 GW for areas with DNI of 1,800 kWh/m2/year or more and around 149 GW for areas with DNI of 2,000 kWh/m2/year or more. Kutch, Patan and Banaskantha are particularly suited due to high DNI, semi-arid land, and proximity to transmission infrastructure. CSP's global average capacity utilisation factor increased from about 30% in 2010 to 55% in 2023, with advanced projects reaching up to 80%, and the average thermal storage duration expanded from 3.5 hours in 2010 to 11.7 hours by 2023.

The economics of CSP should be evaluated based on system value, not just energy LCOE. The global weighted-average installed cost declined by 37% from 2010 to 2023, and the CSP LCOE declined by 70% over the same period, reaching USD 0.117/kWh in 2023. Noor Energy 1 hybrid CSP-PV project in Dubai, with 700 MW CSP, 250 MW PV and 15 hours of thermal storage, at an estimated LCOE of USD 0.073/kWh, roughly Rs 6.02/kWh. While such costs may still exceed merchant solar PV, CSP supplies dispatchable renewable energy during evening and morning peaks, precisely when PV output is unavailable, and the marginal value of electricity is higher.

CSP also offers grid services. It operates through synchronous turbine-generators and can provide inertia and reactive power support. The CSP plants can operate across a broad range of 40% to 100%, enabling ramping, spinning reserve and balancing support. This is particularly relevant for Gujarat because very high PV penetration will increase midday surplus, evening ramps and curtailment risk. The NREL analysis suggests that, in inflexible systems, high solar penetration can lead to significant PV curtailment, whereas CSP with storage can materially reduce curtailment and improve the value of PV.

Finally, CSP has environmental and safety advantages relevant to Gujarat. The 100 MW CSP plant with 10 hours of storage and 65% CUF with solar PV and wind on land-use intensity, showing CSP to be more efficient per MWh generated than both. With dry cooling, CSP's water use can fall to 80-100 litres/MWh, making it more suitable for arid regions. Molten-salt thermal storage also avoids the thermal-runaway risks associated with lithium-ion BESS, which is material when storage deployment reaches utility scale.

Table 1. Strategic value stack of CSP for Gujarat.

CSP attribute	System relevance
Thermal energy storage	Long-duration firming beyond short-duration BESS
Synchronous generation	Inertia and reactive power support
Dispatch during non-solar hours	Evening/morning peak supply and curtailment reduction

High-DNI resource in Gujarat	Kutch, Patan and Banaskantha can support utility-scale CSP
Lower mineral dependency	Concrete, steel, nitrate salts, glass and HTF dominate material needs
Coal-workforce transition	Rankine-cycle similarity enables reskilling and plant-transition pathways

8. Future investment choice for coal-based generating plants

The coal-to-CSP transition is not a simplistic replacement of coal boilers by mirrors. It requires site-specific engineering, grid studies and economic appraisal. Nevertheless, it is one of Gujarat's most credible just-transition opportunities because CSP and coal plants share the Rankine cycle. Coal plants convert fossil heat into steam to drive turbines; CSP converts solar heat into steam for the same broad purpose. This technical similarity creates opportunities in three areas: asset repurposing, workforce transition and grid-node utilization.

First, existing thermal power plant locations often possess valuable infrastructure: grid interconnection bays, switchyards, water systems, access roads, control rooms, trained O&M teams and large land parcels for coal yards. Not all assets will be reusable, and coal-handling systems, ash ponds and boilers may become redundant or require remediation. However, turbines, balance-of-plant systems and evacuation infrastructure may be evaluated for repowering, hybridization or phased redevelopment. Second, coal-plant workers already possess operational skills in steam-cycle management, turbine operation, electrical systems, safety protocols and plant maintenance. CSP systems use the Rankine cycle, as do coal plants, and therefore require relatively limited reskilling for many operators and technicians.

Third, CSP can be introduced as a transition technology before full coal retirement. Solar thermal augmentation of existing plants, hybrid CSP at or near retiring coal stations, and use of thermal storage to provide evening peak support can reduce fossil-fuel consumption while preserving grid reliability. Gujarat's roadmap expects existing coal plants to be gradually retired after 2035, with coal capacity declining to around 4 GW by FY47 in the net-zero scenario. The transition should therefore begin well before retirement dates. Waiting until plants are stranded will convert an orderly transition into a crisis of reliability, labour displacement and sunk-cost recovery.

More importantly, Gujarat should reassess the logic of adding new coal capacity in a system that is expected to move rapidly toward a high-renewable, net-zero architecture. Instead of investing in new coal-based generating stations with long economic lives, new investment should increasingly be directed toward **hybrid CSP–Solar PV projects with 10–12 hours of thermal energy storage**. Such projects can provide firm renewable power during evening and morning peak periods, reduce dependence on imported or domestic coal logistics, avoid future carbon-related risks, and deliver system services such as inertia, reactive power support and dispatchability that solar PV alone cannot provide. When evaluated only on energy cost, CSP may appear costlier than standalone solar PV; however, when evaluated on **firm capacity, storage duration, grid-support value, fuel-price**

risk avoidance and decarbonization value, CSP coupled with Solar PV becomes a far more strategic and economically resilient investment than new coal capacity.

Coal-based power-generating companies should therefore treat CSP not as a competing technology but as their natural next-generation business opportunity. Their existing strengths, (large-scale project execution, steam-cycle operation, grid integration, plant maintenance and availability management); are directly relevant to CSP development. By investing in CSP–PV hybrid projects now, coal generators can protect their institutional capabilities, redeploy their workforce, utilize existing grid nodes, and participate in Gujarat’s net-zero power system without locking themselves into assets that may face declining utilisation, regulatory pressure and carbon-transition risk over the coming decades.

9. Policy and implementation agenda

The immediate policy task is to convert CSP from a concept into a bankable resource class. Gujarat should initiate a techno-economic feasibility study for a 100 MW CSP plus 100 MW solar PV pilot with 10-12 hours of thermal storage. The pilot should evaluate dispatch value, storage duration, water requirements, land intensity, reactive-power contribution, inertia value, integration with solar PV, and compatibility with existing transmission corridors.

Procurement design is critical. CSP should not be compared with standalone daytime solar PV through a flat LCOE metric. The bid product should specify dispatch windows, minimum availability, storage duration, ramping requirements, reactive-power obligations and performance during peak periods. A tariff design based on capacity availability plus scheduled energy may better capture CSP's value than an energy-only tariff. The same principle applies to storage, pumped hydro and demand response: Gujarat needs procurement products that value reliability attributes, not only energy volume.

Gujarat should also use CSP to develop local manufacturing. The CSP supply chain, comprising mirrors, receivers, heat-transfer fluids, storage tanks, heliostats, turbine-generator units, and nitrate salts, is a major component. Gujarat's industrial base in chemicals, salt processing, glass, steel, fabrication and port logistics creates a plausible manufacturing ecosystem.

Finally, the net-zero roadmap must be embedded in electricity-market reform. Storage, pumped hydro, CSP, demand response, green-hydrogen electrolysers and flexible thermal units should participate in markets that reveal the value of flexibility. The 324 GW peak demand cannot be handled through generation planning alone; it requires an integrated demand, grid, storage and market strategy.

10. Conclusion

- ✓ Gujarat's net-zero 2047 aspiration transforms electricity planning into economy-wide energy planning. The state begins with a fossil-dominated final energy system, where coal, oil and gas still dominate direct energy use. The strategic task is therefore twofold: decarbonize electricity supply and expand electricity's role in end-use sectors. Under the current policy pathway aligned with the USD 3.5 trillion economy vision, Gujarat's electricity requirement reaches 674 BU and peak demand reaches 116 GW by FY47. Under the net-zero pathway, the electricity requirement reaches 1,883 BU, and the peak demand reaches 324 GW.

- ✓ The capacity mix required under the net-zero scenario is unprecedented: around 706 GW of generation, 120 GW of storage and nearly 20 GW of pumped storage / long-duration energy storage by FY47. Solar and wind will dominate, but they cannot alone provide all the reliability services needed by such a system. The resource-potential mapping shows that solar approaches a large share of the mapped potential, and wind exceeds the mapped onshore potential. This makes diversification into nuclear, offshore wind, CSP, storage, demand response and possibly imported renewable energy strategically necessary.
- ✓ CSP's strategic value lies in firm renewable capacity, long-duration thermal storage, synchronous inertia, reactive power, ramping capability, reduced curtailment and a credible transition route for coal-plant workers. In Gujarat, with high-DNI regions, manufacturing capability, and thermal-generation experience, CSP should be treated as a system resource rather than a niche technology. The prudent next step is a structured pilot and feasibility programme that tests CSP under Gujarat-specific conditions.

About Author:

	***Nitesh Bidarkar*** *is an Executive Engineer with over 29 years of experience in the power sector, currently leading the* Centre for Net-Zero Energy Transition (C-NET) *at the Green Energy Transition Research Institute in Vadodara. His professional journey encompasses distribution system planning, energy accounting, distribution loss analysis, energy efficiency, grid management, system operation and regulatory and policy analysis. He is a certified Energy Auditor and holds two postgraduate master's degrees: one in Business Administration and the second in Energy Policy and Regulation from IIT Gandhinagar.*

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FEASIBILITY STUDIES & PROJECT PLANNING OF THERMAL POWER PLANT

By
Er. Kailash C Yadav
Chief Engineer Civil (Retired)
Gujarat State Electricity Corporation Ltd.

Introduction

The purpose of conducting a feasibility report or study for any thermal power plant is to assess the key components of project feasibility and ensure that the proposed planned project is technically, economically, and environmentally viable or not.

On completion of pre-feasibility / site selection & study of Demand-Supply Scenario of the particular region, the planning for a thermal power plant starts, which involves a proposal for the land acquisition, environmental impact assessment (EIA) permissions and statutory approvals, soil investigation, focus on the selection of technology, engineering design, invitation of EPC base tender, scope of work package-wise, contract for major equipment (Boiler, Turbine, Coal Handling Plant), etc. Initial infrastructure development and construction sequence, financing, micro planning, commissioning.

Following are the key factors for site selection prior to starting the planning for the installation of a thermal power plant:

1. **Land:** The overall total land requirement may vary depending on the availability of coal linkage, water source and ash utilization. It is also influenced by the type and capacity of the thermal power plant, cooling technology and the proposed plant's design, it may be super thermal power plant with super critical technology either pithead or with older technology small capacity without pithead. To minimize the land requirement, plant should be proposed near to mine (Pithead). The main factors impacting the land requirement area are.

   - **Land requirement per MW:** For a new proposed supercritical or ultra-supercritical thermal power plant in India, the total land requirement, including the main plant, balance of plant, township, ash pond and coal handling plant, generally ranges from 0.5 to 0.8 acres per megawatt for pit-head plants.
   - Coal Type and Location: The preferred coal of good quality Indigenous (domestic) coal or imported coal with a lower percentage of ash content and high calorific value.
   - **Ash disposal &Utilization:** Fly ash should be utilized for cement manufacturing, road embankment filling, de-coaled mine filling, low-level land filling and fly ash bricks manufacturing. Recently new technology is developed to dispose of ash from thermal power plant in paste form is called High Concentration slurry disposal (HCSD) / paste disposal, it reduces consumption of water & require less area for ash pond. Particularly in Indian coal which contains 20-35% ash.
   - **Plant of higher capacity MW:** The establishment of a supercritical thermal plant is cost-effective, utilizing new highly efficient supercritical technology with capacities of 800 to 1000 MW. For the proposed Greenfield new thermal power plant, the land to acquired is large, flat, and non-agricultural (barren or waste). The Ministry of Coal encourages the use of de-coaled land for new projects as well as extension unit to avoid using agricultural, forest land and redundant or filled-up ash dykes.

2. **Fuel:** For any proposed thermal power plant, the choice of fuel (coal or lignite) is very important & a critical factor that directly impacts the cost of generating megawatts

(MW). The quality of the fuel and its proximity to the proposed plant location should be optimized to minimize transportation costs. The installation of thermal power plants in India near the coal mines is increasing. Pit-head power plants are typically installed directly at or adjacent to a coal mine which reduces transportation costs. Major Pit-head thermal power plants in India are under construction by NTPC, NLCIL and Coal India Ltd with higher megawatt capacities. There are now many private players who have ensured the market of coal base power plant. Adani, Aryan Coal, Maruti clean coal, Reliance, Tata Power etc. The plant should be located near a mine to minimize the land required for unnecessary coal storage for long time.

3. **Water Requirement:** A thermal power plant requires a reliable and sufficient source of good quality potable water for plant operations. This includes the main plant systems, the ash handling system with ash dyke, and the associated Township. Most large thermal power plants in India are therefore located near a perennial water source to ensure a continuous and dependable supply. A major and sustained water source such as a river, lake or canal is essential for the long-term operation of the plant. The selected site should maintain a minimum distance of 500 meters from the riverbank to ensure safety and regulatory compliance. In addition, the bottom level of drain disposal point of the plant area should be maintained at least 1.5 to 2.0 meters above the historically recorded highest flood level of the river/ waterbody. This is necessary to safeguard the plant infrastructure from flooding and to ensure uninterrupted operation during extreme conditions.

4. **Transportation of Materials:** The plant location should be well-connected to nearby railway and or road networks including the right of way from a major state or national highway for the transportation of construction materials, heavy machinery and coal from mines as well as large size plant equipment. During the plant’s operation period good connectivity also facilitates in maintenance work.

5. **Plant Location:** The plant site should be situated away from metropolitan cities, wildlife and ecologically sensitive areas as per MOEF&C guidelines. The township should be located away from the main plant area to avoid coal dusting in residential areas. The power plant should preferably be situated near coal or lignite mines to reduce transportation costs and thereby lower the cost of generation. The plants to be located away from the pit head need to ensure coal linkage through Railway.

6. **Utilization of Local Construction Materials:** To reduce construction cost, locally available raw materials should be used for civil works after confirming their suitability through proper testing. Materials from nearby areas such as fly ash bricks, stone chips, gravel, sand, hard murum, rubble, red bricks, timber, steel sections and precast concrete elements may be considered for this purpose. In addition, water reuse from ash ponds should be considered as part of efficient resource utilization.

7. **Topography and Geological Condition& strata of Soil:** The selected site for a thermal power plant should possess suitable soil strata with adequate bearing capacity to safely support dead loads, dynamic/vibratory loads and forces generated by heavy equipment such as turbines, boilers, bowl mills and coal handling systems, as well as high-rise structures including chimneys and cooling towers. Sites with a high groundwater table or shallow hard rock strata should preferably be avoided, as these conditions can significantly increase foundation complexity and cost. Furthermore, uneven terrain necessitates extensive cutting and filling operations for site grading, leading to additional expenditure and potential delays in project execution.

8. **Local Manpower Availability:** The proposed project site should have access to an adequate workforce during the construction, operation, and maintenance phases, encompassing unskilled, semi-skilled, and skilled labour. However, with advancements in technology and the increasing use of modern equipment and machinery, the dependence on unskilled labour has significantly reduced.

Higher MW Capacity Plant in India Commissioned / Under Construction

Sr. No	State & Ownership of Plant	Name of Power plant	MW Capacity	Fuel Linkage from Mine	Water Source	Remark
1	Madhya Pradesh District Singrauali (NTPC)	Vindhyachal Thermal Power Station	4760 MW	Nigahi Mines Northen Coal fields Limited (NCL)	Discharge Canal	All units have already been commissioned of 210 & 500 MW.
2	Telangana State Power Generation Corporation Limited with BHEL	Yadradi Thermal Power Plant District Nalgonda (TSPGCL)	4000 MW (5X800) supercritical Coal base	SCCL coal 50 Imported 50 transporta-tion by rail Not Pit head.	Krishna River about 6.0 KM from Plant by pipeline	Two units commissioned & balance three next year Supercritical Thermal Power Plant
3	Chhattisgarh JSW owned power Plant	KSK Mahanadi Thermal Power Plant	3600 MW (6X600) Super thermal power plant	Coal from nearby mines long term agreement from Odisha & Chhattisgarh	Mahanandi River 11 KM from Plant Water nearby Nariyara	First phase 3 units commissioned & balance 3 under construction
4	Odisha Neyveli Lignite Corporation India Limited (NLCIL)	Talabira Thermal Power Plant District Jharsuguda /Sambalpur	3200 MW (4x800) ritical Power plant	Odisha NLC open cast mine Telangana II & III Pit-head Plant	Hirakund Reservoir 6 to 8 KM from Plant	First phase under construction
5	Chhattisgarh NTPC	Korba Super Thermal Power Plant	2600MW (3x220+ 4x500)	Gevra Mine Kusmunda Block (SECL)	Hasdevo River or Subsidiary of the Mahanadi River	Super thermal power plant

- Dropped or stalled several thermal power plants in India due to improper feasibility reports on weak planning, financial issues, environmental constraints, inadequate water supply, could not acquire required land & failed due to lack of power purchase agreements. For example some thermal Power Plant which are as under.

Power Plant Dropped due to improper feasibility report

Sr. No	State & Name of Power plant	MW Capacity	Reason for dropping	Fuel Linkage from Mine
1	Jharkhand Tori Power Plant	1200 MW	Financial Constraints, water unavailability & Clearances from Gov authorities	Not conducted in detail proper feasibility report before planning
2	Lanco Amarkantak Power Plant	1320 MW Phase - II	Financial Constraints & Land acquisition	Not conducted in detail proper feasibility report before planning
3	Chhattisgarh Athena Power Plant	1200 MW	Financial Constraints, Land acquisition issue & slow progress	Not conducted in detail proper feasibility report before planning
4	Maharashtra Nasik Thermal Power Plant	1350 MW Phase - II	Financial Constraints	Not conducted in detail proper feasibility report before planning
5	Odisha Babandh Power Plant	1320 MW	Financial Constraints	Not conducted in detail proper feasibility report before planning
6	Bihar Banka Power Plant	2640 MW	Coal supply issue	Not conducted in detail proper feasibility report before planning

- As per reports available up to 2020, approximately 20 thermal power plants, with a combined capacity of around 20,000 MW, were abandoned due to the aforementioned issues, involving an estimated investment of about ₹1,00,000 crore.

9. Conclusion:

- Prior to the establishment of a thermal power plant in any region, it is imperative to undertake a comprehensive feasibility study to mitigate the risks of cost overruns and project delays.
- Meticulous planning of critical components, coupled with the deployment of high-quality equipment, is essential to ensure reliable, efficient and sustainable power generation.

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RENOVATION, MODERNISATION & CONDITION MONITORING OF THERMAL POWER STATION SWITCHYARDS

By
Er. S. M. Takalkar
(Managing Director)
Takalkar Power Engineers & Consultants Pvt. Ltd. Vadodara
Email:- smtkalkarpca@gmail.com

1. INTRODUCTION

1.1 The coal based Thermal Power plants suffer from humidity, moisture and pollution. The sub-station (switchyard) equipment, structures & foundations suffer from deterioration. If not attended, there can be a catastrophe.

1.2 The coal dust flew gases fly ash and vapor from cooling towers cause lot of deposition of particles on the switchyard structures, busbars & equipment. The coal handling plants are also responsible for pollution.

1.3 The location of thermal power plant may also be some time responsible for such depositions. For example, the power station along the seashore, desert or near mining area.

1.4 When additional units to existing installed capacity or dismantling of old inefficient units & replacement by new one (mostly by higher capacity) is done, the switchyard equipment and bus-bar arrangement need to be modified.

1.5 Similarly, when technological development takes place, it becomes necessary to make changes in the switchyard.

1.6 The presentation tries to cover some of the aspects of the subject matter in brief as follows.

2. IMPACT OF ELECTRICITY ACT 2003

2.1 The Indian Electricity Act 2003 brought lot of reforms in power sector. For the first time since independence the government accepted that power is not a charity. If it is given as free or at subsidized rate due to a political compulsion, the public exchequer has to compensate for the power utility.

2.2 Unbundling of the power sector in different segments such as Generation, Transmission, Distribution, Power management and load dispatch brought a sense of responsibility to each constituent of the parent government owned Electricity Boards.

2.3 The power companies formed out of the unbundling are now independently accountable in terms of services, quality Power, finance, Statutory compliances and manpower management.

2.4 Open access and giving permission for generation, transmission & distribution of energy to private sector has forced the unbundled Government driven entities to compete with such private players and improve performance of their constituent company.

Thus, efficient running of power plant by thermal power generators has become an order of the day. This includes technical efficiency & financial efficiency.

3. RENOVATION IN SWITCHYARD

3.1 The switchyard in the TPS has step up generator transformer mostly placed next to the wall of the TPS Building. The switchyard is generally little away from the generator Transformer due to road for the transportation of generator transformers.

3.2 Depending upon the steam cooling scheme and raw water intake source, the cooling towers are located. Similarly, coal yard and coal handling equipment depend upon the rail head & the position of boiler.

3.3 Under the circumstances, the coal, smoke, dust, fly ash and the humidity from cooling tower is bound to make thick layers on the generator transformers, busbars, sub-station equipment and the switchyard structures. In case of lignite based TPS the situation is still alarming. This is due to high ash contents in the lignite.

3.4 In spite of good maintenance, hotline washing and condition monitoring, the generator transformers and switchyard equipment/structures are bound to experience deterioration.

3.5 Renovation and modification in switchyard may include the following

3.5.1 Addition of Line bays & Transformer bays.

- The TPS is getting connected to more load centers and/or getting connected to other power station. Extension of bus and addition of line bays are required.
- When a unit is added to the existing installed capacity of TPS, additional generator transformer and bay are required. No doubt, bus needs to be extended.
- While adding a new unit it may become necessary to extend cable trenches, earth mat, A.C.D.B. /D.C.D.B extensions and revise the relay co-ordination. The fault level of Switchyard goes up thus revision in system study is necessary.
- Sometimes the direction of new line (for evacuation of power or connectivity to new load center) is such that the shifting of existing lines to new bays may be required. Such modification may sometime need shutdown of the bus.

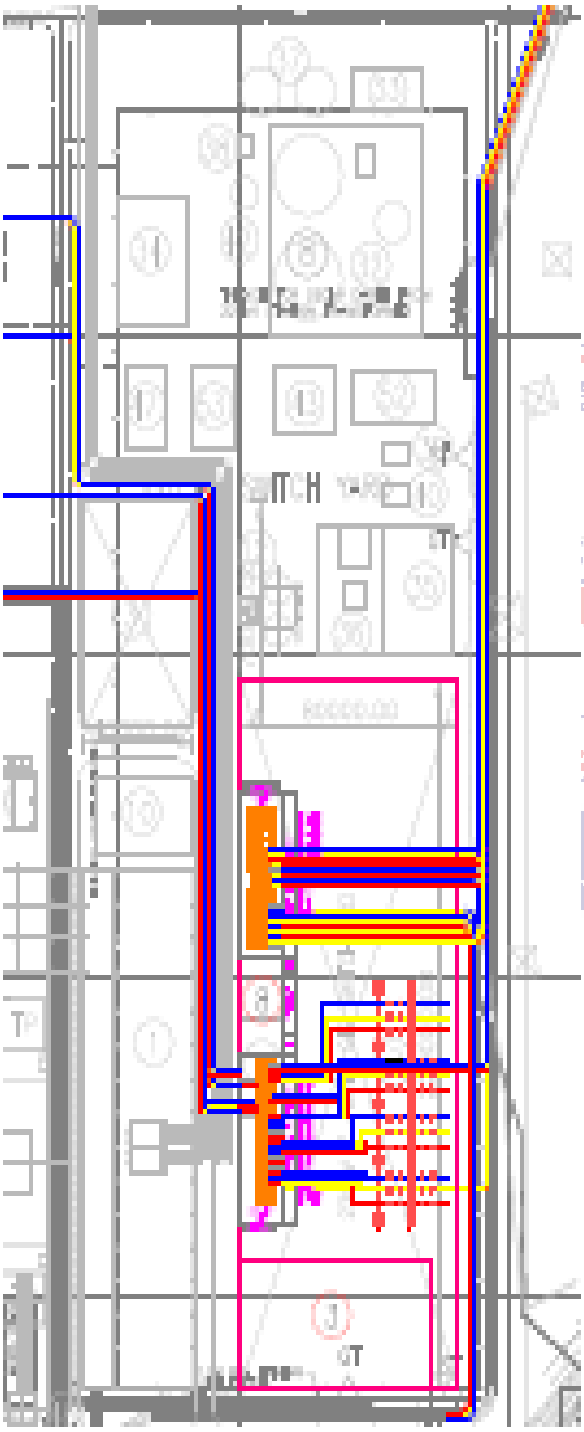
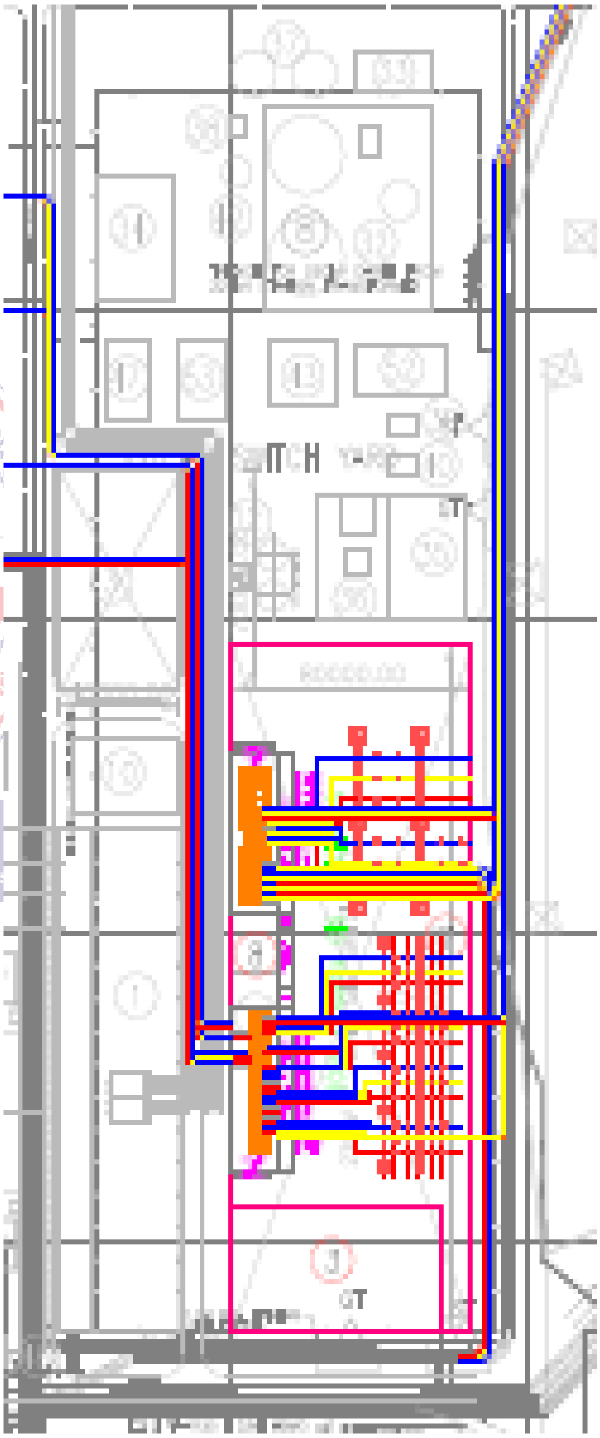
3.5.2 Switchyard Equipment and Generator Transformers

- If the Generator Transformer (GT) fails many years after commissioning, it becomes very difficult to get identical GT with regards to dimensions and technical parameters as well as cooling system auxiliaries. This requires modification in bus-duct (Generator side) and pedestals for cooling gadgets (Fans, force oil cooling etc.).
- Addition of units may need bus-reactor and also augmentation of station transformer.
- Addition of units to the existing plant may also need review of the protection system of the generator switchyard.

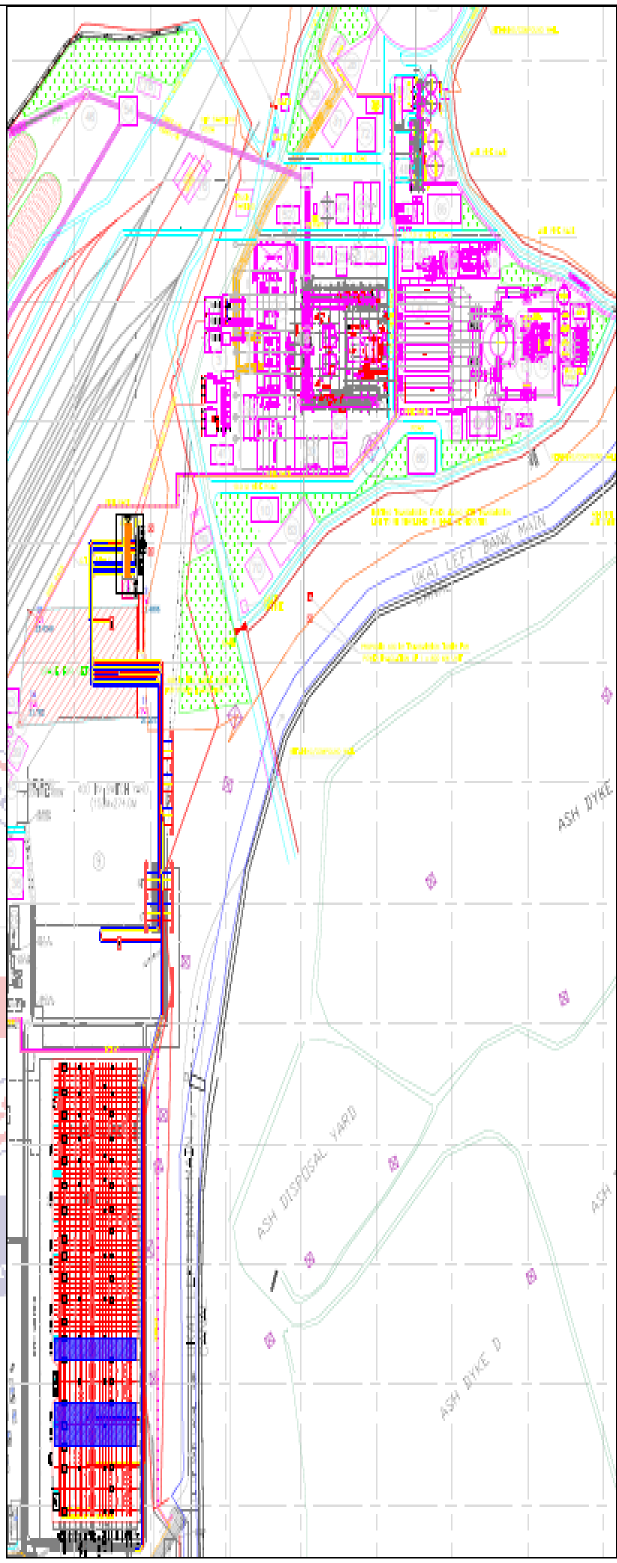
3.5.3 Case Study of Ukai TPS

- At Ukai TPS of GSECL, there are five units. Unit Nos. 1 & 2 are of 120MW each. Unit Nos. 3 & 4 are 200MW each. Unit No. 5 is 210 MW and Unit No. 6 is 500MW. The existing 120MW Unit Nos. 1 & 2 are required to be dismantled because of low heat rate. The existing Unit Nos. 3 & 4 (200MW each) have undergone refurbishment may work for few years more but may be dismantled later on. Unit No. 5 (210MW) and may also follow soon. It is planned to add one unit of 800 MW into existing Thermal Power Plant. For evacuating this power into the grid, there is 220KV network and also 400KV network. It was found necessary to make changes in existing switchyard. The authority of GSECL required various alternatives for making changes to optimize the cost of land, and or resources. Keeping this in view various alternatives were worked out as described below:
- Proposal 1 - Construction of 220kV GIS & 400KV GIS in the existing 220kV Switchyard with Common Control Room and 400KV Cable from GIS to gantry of existing 400KV AIS.
- Proposal 2 - Construction of 220kV GIS & 400KV GIS in the existing 220kV Switchyard with Common Control Room by re-routing of existing 400KV Transmission Line
- Proposal 3 - Construction of 220kV GIS in the existing 220kV Switchyard with 220KV Control Room & Construction of 400KV GIS at new proposed location near existing 400KV Switch Yard of AIS with 400KV Control Room.
- Proposal 4A - Installation of Yard Kiosk in the Existing 220kV Switchyard for the Operation and Control with New 220KV Control Room & Construction of 400KV GIS at new proposed location near existing 400KV AIS Switch Yard of AIS with New 400KV GIS Control Room.

- Proposal 4B - Installation of Yard Kiosk in the Existing 220kV Switchyard for the Operation and Control with New 220KV Control Room & Construction of 400KV GIS at new proposed location near existing 400KV AIS Switch Yard of AIS with New 400KV GIS Control Room.
- Proposal 4C - Installation of Yard Kiosk in the Existing 220kV Switchyard for the Operation and Control with New 220KV Control Room & Construction of 400KV GIS at new proposed location near existing 400KV Switch Yard of AIS with New 400KV Control Room only for 800MW Power Evacuation.

	
PROPOSAL 1	PROPOSAL 2

PROPOSAL 3



PROPOSAL 4

3.5.4 CASE STUDY OF GANDHINAGAR TPS:

In Gandhinagar TPS it was decided to shut down 2 units each of 120MW due to low heat rate. However, the management of GSECL wanted to modify the switchyard for shifting control and substation equipment by modification in switchyard.

The scope of work included Complete Electrical & Civil Design of New Control Room and other facilities for shifting of existing control rooms to a new location for 220kV Switchyard at Gandhinagar Thermal Power Station.

Since there was constraints of space and change in bus bar configuration was required, the work was required to be done under EPC.

3.5.5 CASE STUDY OF WANAKBORI TPS:

The Wanakbori TPS has installed capacity of 7 x 210MW and 1 x 800MW unit. One of the 210MW units, the generator transformer developed a major snag and was not repairable. New GT was ordered by GSECL, however the dimensions and alignment of busduct of new GT did not match with the original alignment of the bus duct of the unit. A short length of Aluminum Bus Duct was required to be designed and installed to re-align the bus duct. The design, fabrication and installation of insertion piece of the Bus Duct was challenging.

4. CONDITION MONITORING:

4.1 When switchyard of TPS becomes older, the condition monitoring of electrical equipment and the civil structure becomes important.

4.2 Condition monitoring of electrical equipment is done as per the laid down practices of O&M. However civil and steel structures sometimes do not receive priority in condition monitoring.

4.3 Condition monitoring of steel structures and foundations is done as under:

4.3.1 Steel structures:

4.3.1.1 Loss of thickness due to rusting and pitting. This is done by using ultrasonic thickness gauge.

4.3.1.2 Condition of welded / bolted joints.

4.3.1.3 Condition of anchor bolts on foundation top.

4.3.1.4 Loss of geometry of beams, columns and equipment support structures.

4.3.2 Foundations:

4.3.2.1 Rebound hammer test for testing of soundness of concrete. Fast rebound indicates good concrete slow rebound indicate poor concrete.

4.3.2.2 Ultra pulse velocity test using transducers and pulse generator. Higher velocity of the pulse across two transducers indicates good concrete work and lower velocity of pulse indicates poor concrete work.

4.3.2.3 Carbonation test is performed by extracting sample powder from the concrete work and subjecting the sample powder to chemical test to ascertain extent of corrosion of steel reinforcement.

4.4 Change in technology leads to modification in switchyard. Earlier control & relay panel used to be separate. This was due to the use of electro-magnetic relays. Over the years these relays have been replaced by static relays. The latest version is numerical relays. Use of fiber optic and introduction of SCADA have compelled the power station operations (management) to switch over to new technology leading to modernization of protection system.

4.5 CASE STUDY OF SABARMATI TPS OWNED BY TORRENT POWER:

- The 132kV switchyard is evacuating power from the Torrent TPS. The switchyard is located close to the power station which is more than 50 years old. As the power station augmented its capacity, it had become necessary to extend the switchyard periodically.
- Due to the presence of coal particles (Fly ash) and the condensation from the cooling towers of the thermal power station, the steel structures suffered from rusting and pitting.
- Due to periodical extension of the switchyard and replacement of damaged/unserviceable equipment, lot many structural changes were required to be made over a period of time. There was a structural mismatch at many places.
- Most of the structures were painted (not galvanized). Repeated painting created layers on the structure but could not prevent rusting and pitting.
- The number of welded joints had become weak.
- In some cases, the foundations of switchyard also suffer from settlement, inadequate concrete, corrosion etc.

- NDT on foundations included the following.
  Conducting Rebound Hammer Test in a grid of 30cm x 30 cm including surface preparation as per IS: 13311 PART 1 & 2.
  - Extraction of concrete cores from structural elements and testing for density, absorption, compressive strength, and carbonation as per requirement.
  - Half-cell potentiometer Test as per IRC-SP-40 in a grid of 300mm x 300mm in a 1M^2 area.
  - Photometer test, Cover meter test for determination of location and cover of rebars.
  - Chemical test, Chloride, Sulphate & Ph value
- Mechanical Test for Steel structures included the following.
  - Visual inspection and studying the condition of corrosion, painting condition, sagging of members.
  - Thickness survey using ultrasonic Thickness gauge.
  - Inspection of weld joints by DPT test

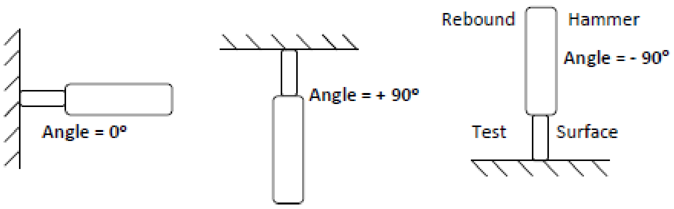
- Condition of bolted connection

- **Condition Monitoring of Foundations**

  Conducting Rebound Hammer Test in a grid of 30cm x 30 cm including surface preparation as per IS: 13311 PART 1 & 2.

  - Rebound Hammer Tests are carried out in accordance with I.S. 13311 (Part 2) – 1992 for assessing the likely compressive strength of concrete, the uniformity of concrete and the Quality of concrete with respect to standard requirements.
  - The apparatus used consists of a spring-controlled mass that slides on a plunger within a tubular housing. The impact energy required for rebound hammers is 2.25 Nm.

Rebound Hammer Testing



Schematic Diagram of Rebound Hammer Positions

  - For taking measurements, the rebound hammer is held at right angles to the surface of the concrete member. The test can thus be conducted horizontally on vertical surfaces or vertically on horizontal surfaces.
  - Large numbers of tests were done on concrete structures which lead to good precision regarding the homogeneity of the concrete. The detailed analysis of rebound hammer test leads to the decision regarding other types of NDT to be performed on the concrete or otherwise.

- **Half-cell potentiometer Test as per IRC-SP-40 in a grid of 300mm x 300mm in a 1M2 area.**
  - This technique is used for assessment of the durability of reinforced concrete members where reinforcement corrosion is suspected.
  - This is an invasive test. For performing this test, the RCC column are required to be damaged to expose a reinforcement bar so that both probes could be attached, and readings of voltage could be taken.

- **Photometer test, Cover meter test for determination of location and cover of rebars.**
  - Cover-meter test is a non-destructive test which is used to identify the location of reinforcement bars in the as built concrete work and to determine the exact concrete cover available and then compare with the specified cover.

Testing of cover by a meter

- **Carbonation Test**
  - ∗ The test for chloride content in concrete is very significant as when chloride is present in reinforced concrete it can cause corrosion of the steel reinforcement.
  - ∗ The test involves crushing a sample of the concrete to fine dust, extracting the chloride with hot dilute nitric acid, and then adding silver nitrate solution to precipitate any chloride present.
  - ∗ Sulphate Testing also involves an acid extraction and precipitation of the sulphate as barium sulphate with barium chloride solution. The resulting barium sulphate is filtered and weighed to determine sulphate gravimetrically.
- **Thickness survey** of corroded members using ultrasonic Thickness gauge.
  - ∗ An ultrasonic thickness gauge is a measuring instrument for non-destructive investigation of a material's thickness using ultrasonic waves. Ultrasonic thickness gauges are designed to improve safety and ensure reliability of materials which are subjected to corrosion or damage.
  - ∗ In this gauge, the thickness of a sample is evaluated using ultrasonic pulse echo method as a product of ultrasonic velocity in the sample and time of travel of waves. The gauge evaluates the time of flight basically and then multiplies it with some value of velocity. A timer or flip-flop circuit measures the time interval between the pulse that triggers the circuit on and the pulse that puts the circuit off. The method and equipment are exhibited below.
  - ∗ The recommended values for the thickness of any member are given in Indian Standard 802 (part 1) -1977 clause No. 11.

Ultrasonic thickness gauge survey at Leg of Column

5. CONCLUSION:

5.1 Thermal Power Plant switchyard need modification, condition monitoring and modernization.

5.2 The environment of Thermal Power Plants warrants proper attention to the electrical equipment and structural as well as civil assets.

#######

Automatic Generation Control (AGC) in Thermal Power Plants

By
Er. AA Tripathi
GSECL, Wanakbori TPS

1. Executive Brief

Central idea. Automatic Generation Control should be understood not merely as a dispatch-centre feature, but as a **grid-to-plant control layer**. It begins with frequency and reserve requirements at the system level, but its successful implementation depends heavily on plant-side C&I: communication reliability, MW feedback validation, DCS logic changes, operator HMI, cybersecurity, historian/event trails, and disciplined testing with the load despatch centres.

Anchor point	Usable conference statement	Source basis
AGC definition	AGC automatically adjusts SRAS provider generation in response to the secondary control signal.	CERC Ancillary Services Regulations, 2022
Signal periodicity	SRAS-Up / SRAS-Down secondary control signals are sent every 4 seconds to the SRAS provider control centre.	CERC Statement of Reasons / AS framework
National milestone	AGC was dedicated nationally in Jan 2022; POSOCO/NLDC sent signals every 4 seconds to more than 50 plants; 51 GW was operational at that milestone.	PIB release, 2022
Expanded reference figure	CERC DSM Expert Committee report records 185 generating units from 70 plants, total 67,337 MW, wired under AGC at the referenced time.	CERC DSM Expert Committee Report

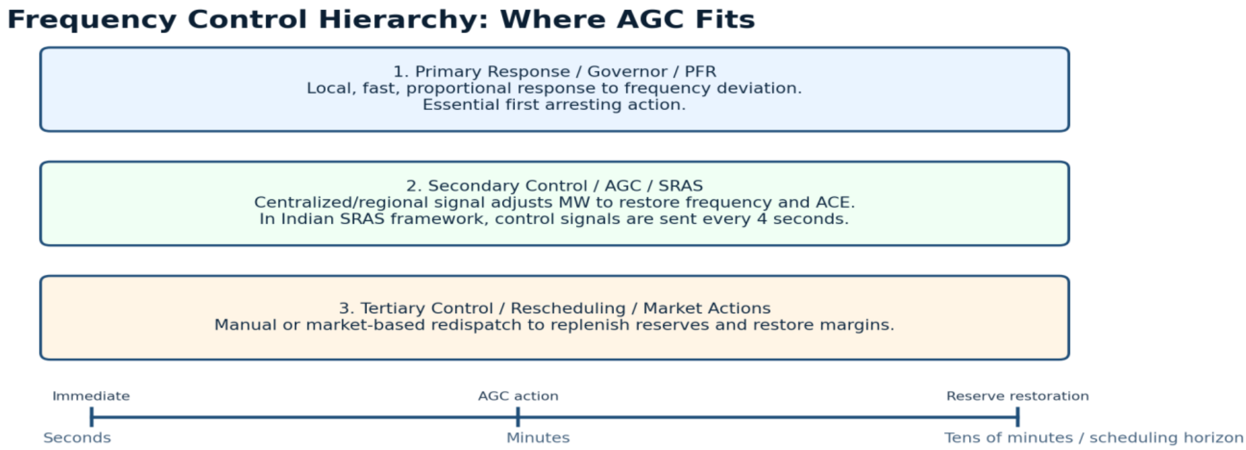


Figure 1. Control hierarchy showing AGC as the secondary frequency control layer between primary response and tertiary reserve action.

2. Opening: AGC as a Grid-to-Plant Control Layer

Core message: AGC should be introduced as a practical bridge between grid-level frequency control and plant-level MW response.

- **Presentation positioning.** This is a brief C&I-oriented overview of AGC in thermal power plants.
- **Audience premise.** The focus is on what AGC means for design, engineering, testing, commissioning, operation and maintenance.
- **Central theme.** AGC is a supervised MW regulation layer; it should not override plant protection or operator authority.

For a thermal plant, the real value lies in how that command is safely received, validated, displayed, integrated into DCS logic, and converted into a controlled MW response without compromising equipment safety or operator control.

3. GSECL and WTPS Context

Core message: A large state generating utility and a high-capacity supercritical unit have a natural role in supporting modern grid control.

- **GSECL role.** GSECL is a state generation utility supporting Gujarat's power demand through thermal and other generating assets.
- **WTPS relevance.** Wanakbori TPS is a major thermal station; Unit-8 is a 1 x 800 MW supercritical unit commissioned by BHEL.
- **Hybrid DCS context.** Unit-8 has TG-side Siemens SPPA-T3000 and boiler/BoP-side BHEL/Valmet maxDNA architecture, making DCS interface planning important.
- **Conference bridge.** AGC is directly connected with modern O&M, grid discipline, flexibilization, CMC performance and C&I reliability.

The audience is introduced to GSECL, 1X800MW Wanakbori TPS in particular, they need to see why GSECL's large thermal units matter for grid balancing, and why WTPS Unit-8 is a meaningful case for discussing real plant-side AGC implementation. Specifying the hybrid DCS architecture of Unit=8 because it is a real engineering issue: AGC must interface correctly with the unit load control path, the turbine/governing side and the boiler coordinated control side.

4. Why AGC Matters Now

Core message: AGC becomes more important as grid frequency control moves from slow manual correction toward faster, automated balancing.

- **Grid frequency quality.** Large, interconnected grids require continuous balancing between generation and demand.
- **Renewable variability.** Higher solar/wind penetration increases short-term variability and forecast error.
- **Thermal flexibility.** Thermal plants increasingly need to operate as grid-stabilizing flexible assets, not only base-load machines.
- **Operational discipline.** AGC helps implement dispatch-centre instructions in a measured, logged and performance-assessed manner.

Frame AGC as part of the modernization of power system operation. Earlier, thermal plants largely saw load changes through schedules, operator instructions or local controls. Now, system operators require faster secondary response to maintain grid frequency, absorb renewable variability and reduce deviation. The plant does not blindly chase every signal; it responds within agreed limits, available reserves and safe operating envelopes.

5. Regulatory and Government Framework

Core message: AGC in India is grounded in the ancillary-services and secondary-reserve framework, not an isolated OEM feature.

- **CERC Ancillary Services Regulations.** AGC is defined as a mechanism through which SRAS provider generation is automatically adjusted in response to the secondary control signal.
- **SRAS role.** AGC is part of Secondary Reserve Ancillary Services; it sits between primary governor response and tertiary redispatch.
- **Signal frequency.** SRAS-Up and SRAS-Down secondary control signals are sent every 4 seconds to the provider control centre as per the referenced regulatory reasoning/procedure.
- **Performance and accounting.** The framework depends on SCADA/EMS data, performance measurement and reconciliation of response.
- **Plant implication.** C&I design must ensure reliable telemetry, signal quality, command validation and archived evidence.

No need to overburden the audience with clauses. Can be explained with clean hierarchy: CERC defines ancillary services, SRAS provides secondary frequency control, AGC is the automation mechanism, and plant C&I must make it executable. The important point is that AGC has regulatory and commercial consequences, because performance is measured. Therefore, bad signal quality, poor MW feedback, missing event logs or unclear HMI are not small issues—they directly affect compliance, settlement and operator confidence.

6. What AGC Is: Primary, Secondary and Tertiary Control

Core message: AGC is the secondary-control layer that restores balance after the immediate primary response.

- **Primary control / PFR.** Local governor response acts quickly based on frequency deviation.
- **Secondary control / AGC.** Centralized/regional MW correction signal adjusts generation to restore frequency and area balance.
- **Tertiary control.** Manual or market-based rescheduling restores reserves and handles longer-duration imbalance.
- **Thermal plant interpretation.** AGC is not the first protection against disturbance; it is an automatic dispatch-following and reserve-deployment mechanism within plant limits.

This is the educational slide. Can be explained with simple analogy: primary response is the reflex, AGC is the coordinated correction, and tertiary control is the deliberate re-optimization. For thermal plant personnel, this distinction prevents confusion between governor response, CMC load control and AGC dispatch signals.

7. AGC Signal Path: From Dispatch Centre to Boiler-Turbine Response

Core message: The technical chain matters: a grid signal becomes useful only after safe plant-side integration.

- **Command origin.** Secondary control signal is generated by the nodal/dispatch system based on grid requirements.
- **Communication layer.** Secure wide-area communication carries the signal to the plant AGC control centre/gateway.
- **Plant AGC gateway.** Receives, validates, logs, quality-checks and passes the command to plant DCS.
- **DCS interface.** Command is applied as a bias or setpoint path into unit load control / CMC according to approved design.

- **Response and feedback.** Actual MW, limits, status and availability are sent back for monitoring and performance assessment.

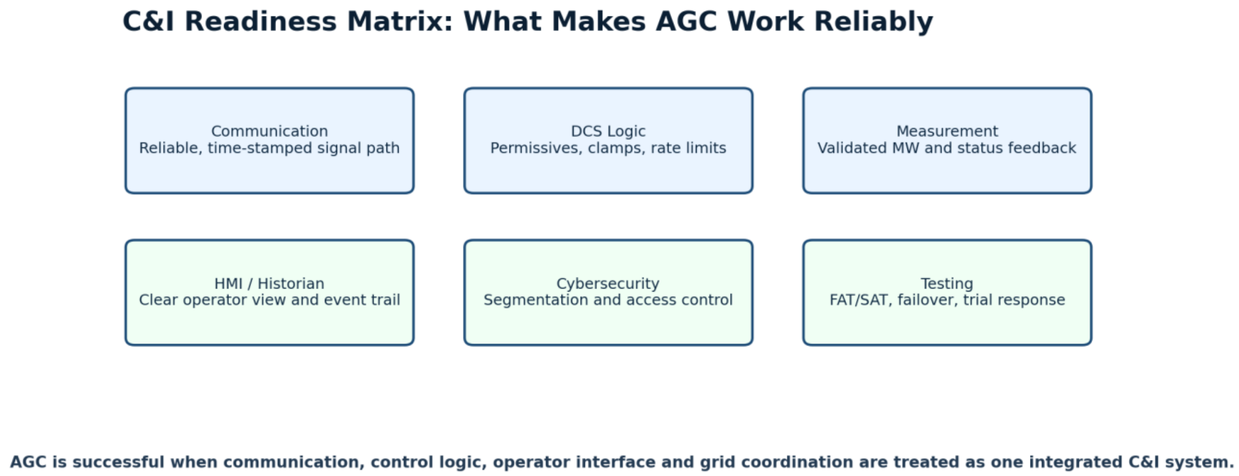
Signal path diagram to show that AGC is a chain of dependencies. A weak link anywhere—communication, gateway, DCS interface, feedback measurement, event logging—can cause either poor AGC performance or operator distrust. In hybrid DCS plants, the interface design must be especially clear: where exactly does the AGC command enter, which controller owns ramping, how is boiler-turbine coordination preserved, and how is manual takeover achieved?

8. C&I Requirements for AGC Implementation

Core message: AGC is a C&I-heavy project: success depends on instrumentation, controls, communication, HMI and cybersecurity.

- **Real-time data.** Validated actual MW, schedule/setpoint, breaker status, unit status, upper/lower limits, ramp rate and availability.
- **Signal quality.** Time stamps, bad-quality handling, stale-data detection, watchdog and communication health alarms.
- **DCS logic.** AGC enable, permissives, command range validation, rate limiter, high/low clamps, bumpless transfer and fallback.
- **Operator interface.** Clear HMI for AGC status, active command, accepted/rejected commands, limits, trends and alarms.
- **Cybersecurity.** Segmentation, access control, hardening, event logs and minimal trusted communication paths.

This slide should be practical and plant focused. Explain that AGC is not only a computer control room or an external communication panel. From a C&I standpoint it requires a complete system: field-worthy measurement, reliable SCADA/DCS data, hardened communication, defensible logic, operator HMI and historian evidence. If the plant cannot prove what command came, what was accepted, what was rejected and why, then AGC operation will not be robust.



9. AGC Components: What Typically Gets Supplied / Integrated

Core message: AGC implementation usually includes hardware, software, communication, logic, HMI, testing tools and documentation.

- **AGC server / gateway.** Dedicated computing platform, redundancy if specified, communication drivers and interface logic.
- **Communication interface.** IEC-60870-5-104 / approved LDC interface, plant switchyard integration, secure network path and time synchronization.

- **DCS engineering.** Signal mapping, logic modification, interface blocks, HMI graphics, historian tags and alarms.
- **Cyber and network items.** Firewall/segmentation, secure access, antivirus/whitelisting if applicable and backup/restore plan.
- **Documentation.** Signal list, logic write-up, FDS, FAT/SAT procedure, O&M manual, rollback plan and training material.

This slide is useful for engineers and management because it prevents under-scoping. A weak tender may only ask for "AGC system," but a successful project must define the complete interface: what comes from LDC side, what is done by the vendor, what is in GSECL scope, what is modified in DCS, what is tested during shutdown, and what documents will be handed over.

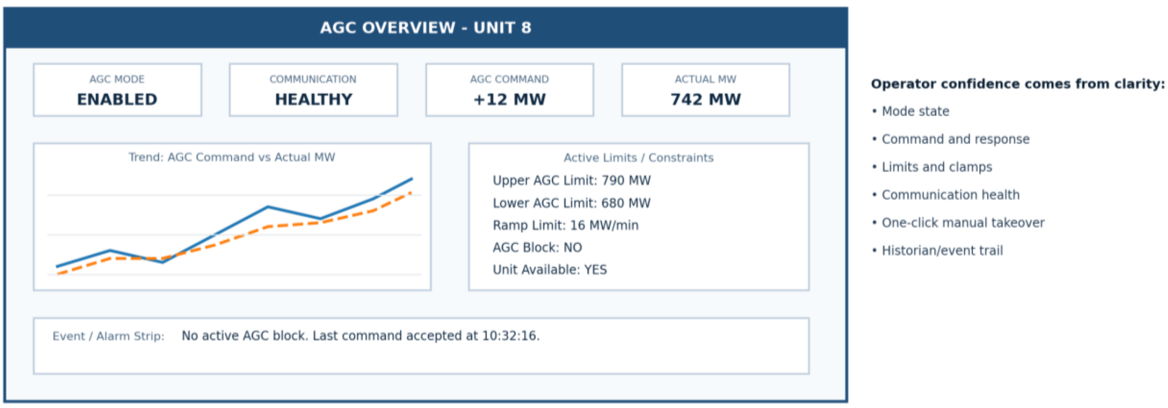
10. Operator HMI: What the Control Room Must See

Core message: Operators will trust AGC only if the HMI makes status, limits, commands and abnormal conditions are instantly visible.

- **Mode status.** AGC available / enabled / active / blocked / manual.
- **Command visibility.** Incoming AGC command, accepted command, rejected command and reason for rejection.
- **MW response.** Actual MW, schedule/load setpoint, AGC bias, ramp rate and deviation trend.
- **Limits.** Upper and lower AGC limits, technical minimum, ramp limit, boiler/turbine constraints.
- **Takeover.** Clear provision for operator disable/manual takeover with event logging.

This is one of the most important practical slides. HMI is not decoration; it is the operator's mental model of AGC. If the operator cannot immediately see whether AGC is active, healthy, limited, blocked or rejected, then the system will be distrusted. The HMI should show both engineering truth and operational simplicity.

Indicative AGC Operator HMI: What Must Be Visible at a Glance



11. DCS Logic Changes: Safeguards Before Control Action

Core message: The DCS must accept AGC command only through validated, limited and bumpless logic paths.

- **Permissive.** Unit synchronized, CMC healthy, AGC selected by operator, communication healthy, no trip/runback/block condition.
- **Validation.** Quality bit healthy, command in range, no sudden spike, sign/direction plausible and time stamp fresh.
- **Limits.** AGC upper/lower limits, technical minimum, ramp-rate limiter and equipment constraints.

- **Bumpless transfer.** No shock when entering or exiting AGC.
- **Fallback.** On fault, freeze/return safely to local setpoint path, alarm the operator and log the cause.

Non-negotiables can be shared. AGC should never be a raw signal wired directly to the load setpoint. It must pass through permissives, quality checks, clamping, ramp limits and bumpless transfer logic. The design philosophy must be fail-safe: loss of AGC should not create a plant disturbance.

12. Testing, Commissioning and Acceptance

Core message: AGC commissioning must be staged; closed-loop operation should come only after signal, logic and operator tests are proven.

- **Engineering review.** Freeze signal list, functional design, communication protocol, DCS logic and HMI.
- **FAT.** Simulate dispatch commands, validate range checks, bad-quality handling, logging, alarms and failover.
- **SAT.** Test live communication, time synchronization, MW feedback, DCS command path and operator screens.
- **Open-loop trial.** Receive AGC commands and monitor plant response calculation without applying to load setpoint.
- **Closed-loop trial.** Enable controlled response with agreed limits and continuous coordination with LDCs.
- **Acceptance.** Performance assessment, event review, training completion and documentation handover.

The commissioning sequence should be conservative. First prove communication and data quality. Then prove the logic with simulated commands. Then prove HMI and event logging. Then run open-loop observation. Only after that should the command be allowed into the load control path. The goal is not only to make AGC work once, but to make it explainable and maintainable for years.

13. AGC Penetration in India

Core message: India has already operationalized AGC at scale; the direction is toward wider and more diverse resource participation.

- **2021 reference.** Pan-India 24x7 AGC operations began on 21 July 2021 with 44 power plants and 41,900 MW in the CERC Expert Committee reference.
- **2022 national milestone.** PIB recorded 51 GW operational across all five regions and more than 50 plants receiving 4-second signals from NLDC/POSOCO.
- **Expanded CERC reference.** CERC DSM Expert Committee report records 185 units from 70 plants comprising thermal, gas and hydro resources, with 67,337 MW wired under AGC at the referenced time.
- **Forward direction.** The policy direction is broader participation, stronger ancillary-services framework and better frequency control in a renewable-heavy grid.

To be updated with latest official GRID-India/NLDC figures immediately before the May 2026 presentation.

This slide shows that AGC is not experimental anymore in India; it is an operational grid-control mechanism.

14. GSECL / WTPS AGC Plan

Core message: GSECL can position AGC as a planned modernization aligned with grid compliance, O&M discipline and flexible operation.

- **Current project status wording.** Comprehensive Open Tender NIT-RFQ No. 74818 has been floated for AGC implementation at 1 x 800 MW Unit-8 WTPS; technical bid scrutiny and tender process are to be presented only as per final approved status.
- **Offers and scrutiny.** Draft internal status indicates three offers received, technical bids under scrutiny and price-bid opening after technical qualification.
- **Implementation horizon.** Tender delivery period is understood as 12 months from order; implementation to be expedited where possible and coordinated with outage/shutdown opportunities.
- **Interface expectation.** Most offers are understood to include implementation up to plant switchyard IEC-104 communication card, with LDC connectivity responsibilities to be stated carefully as per final scope.
- **WTPS C&I complexity.** Hybrid DCS split between Siemens SPPA-T3000 and BHEL/Valmet maxDNA makes interface engineering, signal mapping and commissioning planning critical.

This slide should be handled diplomatically because it contains live project information.

Safe narrative is that GSECL is actively progressing AGC implementation at WTPS Unit-8 through a structured tendering and technical scrutiny process, with focus on proper DCS integration, communication reliability and commissioning coordination with the concerned load despatch centres.

15. O&M Risks and Controls

Core message: AGC reliability after commissioning depends on maintenance discipline, not only initial installation.

- **Communication failure.** Provide watchdog, stale-data alarm, fallback and periodic communication health checks.
- **Bad MW feedback.** Cross-verify metering/SCADA source, scaling, sign convention and quality bit handling.
- **Logic drift.** Freeze approved logic, maintain revision control and retest after DCS modifications.
- **Operator confusion.** Train operators on modes, blocks, limits, takeover and event interpretation.
- **Cyber exposure.** Maintain firewall rules, access logs, backup/restore, patching policy and vendor-access discipline.
- **Performance disputes.** Maintain historian data, event logs and reconciliation records.

This slide brings the presentation back to O&M. AGC is not finished at commissioning. Every subsequent DCS change, network change, meter replacement, CMC tuning change or cybersecurity update can affect AGC performance. A strong maintenance regime should include periodic signal verification, logic backup, HMI alarm review and mock failover checks.

16. Key Takeaways

Core message: AGC is a modern grid necessity, but its success at plant level is determined by rigorous C&I engineering.

- AGC is the practical mechanism for secondary frequency control and SRAS response.
- It must work through safe, constrained and auditable plant DCS paths.
- Operator HMI and manual authority are essential for trust.

- Testing must progress from simulation to open-loop to closed-loop operation.
- GSECL/WTPS implementation should emphasize interface clarity, cybersecurity, commissioning discipline and long-term maintainability.

17. CONCLUSION

- AGC is not a threat to plant operators; it is a tool that helps the plant participate in a more demanding modern grid.
- The C&I department is central because it converts the grid's requirement into a safe plant action.

Er. Aviral Anurag Tripathi working as Deputy Engineer in Gujarat State Electricity Corporation Limited (GSECL) -*Controls & Instrumentation | Thermal Power Plant Maintenance and Modernization Projects*

Work Experience:

1. Over 8 years of experience in power generation relevant Controls & Instrumentation engineering, DCS systems, and thermal power plant maintenance.
2. Worked in varied capacities as a Controls and Instrumentation Engineer at **1×500 MW Ukai TPS** and **1×800 MW Wanakbori TPS.**
3. Handled a wide range of instrumentation and controls related preventive, corrective, and breakdown maintenance tasks across plant-specific thermal power station systems.
4. Major hands-on experience with **BHEL maxDNA DCS** and **Siemens SPPA-T3000 DCS** systems, including plant troubleshooting, DCS maintenance coordination, logic-related support, and operational assistance.
5. Currently overseeing implementation and coordination of major modernization and advanced control initiatives at 1×800 MW Wanakbori TPS, including **Flexibilization**, **Automatic Generation Control (AGC), Simulator** implementation, and **Centralized Remote Performance Monitoring System**.
6. Actively conducting departmental training and lectures on field applications of Instrumentation and Controls to train junior subordinates at local plant level and at GETRI.

Professional Exposure:

1. Thermal power plant field instrumentation, control loops, DCS-based plant support, C&I maintenance practices, and system-level troubleshooting.
2. Practical exposure to modernization projects involving advanced monitoring, control integration, operational readiness, and plant performance support systems.

Education:

1. Bachelor of Technology (B.Tech.) in Instrumentation and Control Engineering, Nirma University, Ahmedabad.

Construction and Project Management in Thermal Power Plants

By:
Er. D J Parmar
Deputy Engineer, GSECL

Abstract

Thermal power plants remain one of the most significant sources of electricity generation worldwide. The construction of a thermal power plant is a highly capital-intensive and technically complex project that requires coordination among civil, mechanical, electrical, and instrumentation engineering disciplines. Efficient project management is essential to ensure project completion within schedule, budget, quality, and safety standards.

This paper presents a detailed study of construction and project management practices in thermal power plant projects. It explains the major phases of plant construction, project management methodologies, scheduling techniques, cost control measures, quality assurance procedures, risk management strategies, and safety practices. The paper also discusses challenges commonly encountered during project execution and highlights the importance of digital technologies such as BIM, PMIS, AI, and modular construction in improving project efficiency.

The study concludes that successful thermal power plant construction depends on systematic planning, proper resource allocation, modern project management tools, and continuous monitoring throughout the project lifecycle.

1. Introduction:

Electricity plays a vital role in economic growth, industrial development, transportation, healthcare, communication, and overall social progress. Thermal power plants continue to contribute a major share of electricity generation in developing countries such as India.

Thermal power plants generate electricity by converting heat energy obtained from coal, gas, or oil into mechanical energy and finally into electrical energy. Although renewable energy technologies are expanding rapidly, thermal power plants remain important because they provide continuous and stable base-load power.

The construction of thermal power plants is a highly complex engineering activity involving thousands of workers, multiple contractors, sophisticated machinery, and strict quality and safety standards. A delay in project completion may result in heavy financial losses and energy shortages.

Therefore, efficient construction planning and project management are essential for successful project execution.

2. **Objectives of the Study:** The objectives of this paper are:
   a. To understand the construction process of thermal power plants.
   b. To analyze project management practices in thermal power projects.
   c. To identify major challenges faced during project execution.
   d. To study modern technologies used in construction management.
   e. To explore future trends and sustainable practices.
3. **Overview of Thermal Power Plants**

A thermal power plant converts heat energy into electrical energy through a sequence of thermodynamic processes.

Types of Thermal Power Plants: 1. Coal-Fired Thermal Power Plants: Most common type used worldwide. 2. Gas-Based Thermal Power Plants: Use natural gas as fuel. 3. Oil-Fired Thermal Plants: Use diesel or furnace oil. 4. Combined Cycle Power Plants: Combine gas and steam turbines for higher efficiency.

Major Components of Thermal Power Plants

Boiler -The boiler is the heart of the thermal power plant. It converts water into high-pressure steam using heat generated from fuel combustion. Main Boiler Components, Economizer, Superheater, Reheater, Air preheater, Furnace,

Steam Turbine - he turbine converts thermal energy of steam into rotational mechanical energy. Types of Turbines - High-pressure turbine, Intermediate-pressure turbine, Low-pressure turbine,

Generator: The generator converts mechanical energy into electrical energy using electromagnetic induction. Condenser, The condenser converts exhaust steam from the turbine back into water.

Cooling Towers: Cooling towers remove excess heat from cooling water systems.

Water treatment Plant: Provides Desired Quality of water to produce Steam.(Very low PH value)

Coal Handling Plant: Responsible for receiving, storing, and supplying coal to boilers.

Ash Handling System: Handles disposal and transportation of fly ash and bottom ash.

Electrical Systems: Power control & switching, stepping up and transmission at desired output level efficiently.

Instrumentation and Control Systems: Modern plants use Distributed Control Systems (DCS) and SCADA for automation and monitoring.

4. **Construction Phases of Thermal Power Plants**

The construction of thermal power plants involves several sequential and overlapping phases.

4.1 Pre-Construction Phase: This phase determines project feasibility, Activities Involved are Feasibility Study, Technical feasibility, Economic feasibility, Environmental feasibility, Site Selection, Factors considered:, Availability of water, Coal transportation , Linkage), , Land availability & sub soil strata, Environmental impact, Grid connectivity, Road and rail connectivity , Environmental Clearance Environmental Impact Assessment (EIA) is mandatory. Financial Closure Project funding through banks, investors, and government support. Land Acquisition Acquiring land for plant construction and ash disposal.

4.2 Engineering and Design Phase: Detailed engineering work is carried out during this phase. Activities, Plant layout planning including GT, Switchyard & Soil Investigation, Structural design, Piping and instrumentation diagrams, Electrical single-line diagrams, Soil resistivity measurement, Foundation design, Equipment specification, 3D modeling and simulations, Importance, Good engineering design reduces future construction errors and delays.

4.3 Procurement Phase: –Procurement is one of the most critical phases because thermal power projects require heavy equipment with long manufacturing periods. Major Equipment Procured, Boilers, Turbines, Generators, Transformers, Pumps Control systems, Balance of plants. Procurement Activities, Vendor qualification, Tendering process, Bid evaluation, Contract management, Material inspection, Logistics management.

4.4 Construction and Erection Phase: –This is the most resource-intensive phase. Civil Construction, Excavation, Foundations, Cooling towers, Chimneys, Roads, Administrative buildings, Stores, Housing township, Structural Erection, Structural steel fabrication, Structural steel erection, Turbine hall & other pump house structures, Mechanical Erection, Boiler erection, Turbine installation, Piping systems, Coal handling systems, Electrical Installation, Cable laying, Generator installation, Transformer erection, Switchyard installation, Instrumentation Installation, Sensors, DCS systems, Control panels, Automation systems

4.5 Testing and Commissioning Phase: - This phase ensures all systems operate correctly, Activities, Hydrostatic testing, Steam blowing, Equipment calibration, Trial operation, Synchronization with grid, Performance guarantee tests, Instrumentation and SCADA. Objective, To confirm plant readiness for commercial operation.

5. **Project Management Framework: – Project management is the** process of planning, organizing, monitoring, and controlling project activities, Key Objectives, Timely completion, Cost control, Quality assurance, Worker safety, Efficient resource utilization

5.1 Scope Management: – Scope management defines project boundaries and deliverables, Benefits, Prevents scope creep, Improves coordination, Clarifies responsibilities

5.2 Time Management: – Time management ensures activities are completed according to schedule. Scheduling Tools, Gantt Charts, CPM, PERT, Primavera P6 & Microsoft Project, Critical Path Method (CPM), Identifies activities affecting project completion time. Program Evaluation and Review Technique (PERT) Used when activity durations are uncertain.

5.3 Resource Management: – Proper allocation of manpower, materials, and machinery. Resources Managed, Engineers, Skilled labor, Heavy equipment, Construction materials, Cranes and transport vehicles

6. **Planning and Scheduling Techniques Construction planning is** essential for coordinating activities. Work Breakdown Structure (WBS), Divides project into smaller manageable packages. Example WBS, Civil works, Boiler erection, Turbine erection, Electrical systems, Commissioning, Network Planning, Used for sequence optimization. Fast-Track Construction, Different activities are executed simultaneously to reduce duration.

7. Cost Management

Thermal power projects involve investments worth thousands of crores. Cost Components, Civil construction, Mechanical equipment, Electrical systems, Labor costs, Transportation, Taxes and duties,

Earned Value Management (EVM) Measures project performance. Important Indicators, CPI (Cost Performance Index), SPI (Schedule Performance Index).

Cost Control Measures, Budget monitoring, Resource optimization, Vendor negotiations, Avoiding rework

8. Quality Management

Quality management ensures reliability and long-term performance.

Standards Followed: ISO 9001, BIS Standards, ASME Codes, OEM Standards

Quality Assurance Activities: - Material testing, Welding inspection, Non-destructive testing (NDT), Calibration checks, Third-party inspection

Importance of Quality Management, Prevents equipment failure, Improves efficiency, Reduces maintenance costs

9.. Safety Management

- ⇨ Construction sites contain many hazards such as working at heights, heavy lifting, electrical systems, and confined spaces.

⇨ Safety Measures: - PPE usage, Safety induction programs, Permit-to-work systems, Fire safety systems, Emergency evacuation drills, Hazard identification.
⇨ Safety Standards: - OHSAS 18001 & OSHA Guidelines,
⇨ Importance: - Prevents accidents, Improves productivity, Reduces legal liabilities

10. Risk Management

- Risk management identifies and mitigates project uncertainties. Types of Risks
- Technical Risks: - Boiler failures, Turbine defects, Design errors
- Financial Risks: Inflation, Currency fluctuations, Cost overruns
- Environmental Risks: Floods, Cyclones, Extreme weather
- Regulatory Risks: Delayed approvals, Environmental restrictions, Risk Mitigation Strategies Contingency planning, Insurance coverage, Alternate suppliers, Buffer schedules, Continuous monitoring

11. Challenges in Thermal Power Plant Projects

- Land Acquisition Problems Land acquisition can face legal disputes and public resistance.
- Environmental Clearance Delays Strict environmental laws may delay project approvals.
- Supply Chain Disruptions Transportation delays affect project schedules.
- Skilled Labor Shortage Lack of experienced welders and turbine specialists.
- Cost Escalation Inflation and design modifications increase costs.
- Political and Regulatory Issues Government policy changes affect project execution.

12. Modern Technologies and Innovations

Technology is transforming construction management.

- Building Information Modeling (BIM). BIM creates digital models for better coordination. Advantages are Clash detection, Better visualization and Reduced rework
- Modular Construction. Pre-fabricated modules are assembled at site. Benefits are Faster construction, Improved quality and Reduced labor requirements
- Project Management Information Systems (PMIS). Used for real-time monitoring. Functions are , Progress tracking, Resource management and Reporting & Documentation
- Artificial Intelligence and Analytics. AI predicts delays and equipment failures.
- Drone Technology. Used for site inspections and surveying.

13. Case Study

Case 1. GSECL WTPS #8 Thermal Power Project: Project Overview. Capacity: 1 × 800 MW. Technology: Supercritical

- Management Practices Used- MS Project Based Monitoring

- Timely progress tracking has highlighted delay and improved coordination.
- Modular Construction. Reduced construction duration.
- Parallel Activity Execution. Civil and mechanical works executed simultaneously.
- Contingency Arrangement. Past experience has given thoughtful contingency arrangement to provide Civil and mechanical works executed simultaneously. Deployed Experience Resource
- Ensured quality work with close monitoring and timely completion.
- Results are Reduced project delays, Improved work execution, Minimizing rework, System readiness well before requirement and Minimum disruption during commissioning

Case 2 NTPC Super Thermal Power Project:

- Project Overview - Capacity: 3 × 660 MW and Technology: Supercritical Management Practices Used PMIS-Based Monitoring and Daily progress tracking improved coordination.
- Modular Construction - Reduced construction duration.
- Parallel Activity Execution - Civil and mechanical works executed simultaneously.
- Strong Vendor Management - Ensured timely delivery of equipment.
- Results are Reduced project delays, Improved productivity, Better quality control and Enhanced safety performance.

14. Conclusion

- Construction and project management in thermal power plants involve multidisciplinary coordination, advanced engineering practices, and continuous monitoring.
- Successful execution depends on: Proper planning and scheduling, Effective cost control, , Quality assurance, Strong safety culture, Risk management and Adoption of modern technologies
- As the energy industry evolves, future thermal power plants will focus on higher efficiency, reduced emissions, digitalization, and sustainability.
- Therefore, project managers and engineers must continuously adapt to modern technologies and global standards to ensure successful project delivery.

######

Contract Labour Information Management System (CLIMS)
A Digital Platform for Contractor Labour Management and Compliance at GSECL

By
Er. Devang Shah, GSECL

1. Introduction:

Gujarat State Electricity Corporation Limited (GSECL) operates thermal, Lignite, Hydro and Gas based power stations across Gujarat and engages a large number of contractors and contract workers for operation, maintenance, project execution, housekeeping, security and support services. Managing contractor labour across multiple locations involves various activities such as worker registration, gate pass issuance, attendance management, wage processing, statutory compliance, medical records and approval workflows.

Traditionally, these activities are handled manually through paper registers, physical approvals and separate departmental coordination. This creates several operational challenges including delays in approvals, duplication of records, errors in calculations, lack of centralized monitoring and compliance risks.

To address these challenges, GSECL has developed the Contract Labour Information Management System (CLIMS), a centralized web-based platform for contractor labour management and statutory compliance.

2. Purpose of CLIMS

The main purpose of CLIMS is to digitize and streamline contractor labour management activities through a single integrated platform.

The system provides centralized management for:

- Contractor registration and onboarding
- Worker registration and verification
- Work order management
- Gate pass issuance and renewals
- Biometric attendance monitoring
- Wage and payroll processing
- Labour law compliance
- HR clearance certificate approval

CLIMS ensures transparency, accountability, operational efficiency and better governance across all power stations and departments.

3. Objectives of the System

The major objectives of CLIMS are as follows:

- To digitize labour management processes and reduce manual paperwork.

- To ensure compliance with labour laws, PF, ESIC, minimum wages, insurance and safety requirements.
- To improve transparency and accountability through online approval workflows.
- To prevent unauthorized entry through proper gate pass verification.
- To reduce errors in attendance and wage calculations.
- To provide centralized monitoring and management reporting.
- To improve coordination among contractors, HR, Safety, Medical, Security and Accounts departments.

4. **Overview of CLIMS**

CLIMS is a centralized digital platform accessible to various stakeholders including Contractors, Engineer-In-Charge (EIC), HR Department, Safety Department, Medical Department, Security Department, and Accounts Department.

The system operates through online workflows and integrates biometric attendance devices for real-time worker attendance monitoring.

The platform enables:

- Online contractor registration
- Worker profile management
- Online document upload and verification
- Gate pass approval workflow
- Attendance and wage integration
- HR clearance processing
- Digital records and statutory report generation

The system provides role-based access control to ensure security and accountability.

5. Major Modules of CLIMS

5.1 Contractor Registration Module

This module enables contractors to register themselves in the system by providing company details, statutory registration numbers, licenses, insurance details, PF, GST, ESIC, and other compliance documents.

5.2 Worker Management Module

The module is used for worker registration, validation of workers, skill category allocation, bank details, photograph upload and worker document management. Each worker receives a unique CLIMS ID.

5.3 Work Order Management Module

This module allows contractors to add work orders, define manpower requirements, upload insurance details, extend work orders and close completed work orders.

5.4 Worker Allocation and Gate Pass Module

Workers are allocated to valid work orders. Gate pass approvals are processed through EIC, Medical, Safety, Security and HR approvals.

5.5 Attendance Management Module

Biometric attendance data is integrated with CLIMS for real-time attendance tracking, overtime management.

5.6 Wage and Payroll Module

The system generates wages based on attendance and approved wage structures. Wage slips, advances, deductions, and multiple wage calculations are processed through the system.

5.7 HR Clearance Certificate Module

Contractor's upload wage registers, PF challans, ESIC challans, bank statements and attendance records for HR clearance approvals.

6. Workflow and Approval Process

The CLIMS system follows a structured workflow for contractor labour management.

Contractor Workflow:

Contractor Registration → Worker Registration → Work Order Creation → Worker Allocation → Gate Pass Approval → Attendance → Wage Processing → HR Clearance Certificate.

Gate Pass Approval Workflow:

Contractor → EIC → Medical → Safety → Security → HR → Gate Pass Issued.

HR Clearance Approval Workflow:

Contractor → EIC → HR → Issuance of HR Clearance Certificate. This workflow ensures proper verification, compliance checking, and transparency at every stage.

7. Attendance and Wage Management

Attendance management is one of the most important features of CLIMS. The system captures attendance through biometric devices installed at project locations.

Key Features:

- Real-time attendance monitoring
- Monthly attendance generation
- Overtime calculation
- Attendance correction facility
- Attendance reports

The attendance data directly integrates with wage processing modules. The system automatically calculates wages based on:

- Worker category
- Attendance days
- Overtime
- Wage revisions
- Advances and deductions

The system also supports:

- Generation of Wage slips
- Fine entries

- Advance salary entries
- Multiple worker wage calculations
- PF / ESIC related reports
- Generate required statutory compliance reports as per various codes.

CLIMS support minimizes manual errors and ensures proper processing of Payroll and compliances.

8. Reports and Compliance Management

CLIMS generates statutory registers and reports required under various applicable labour laws. Important reports generated by the system include:

- Employee Register
- Muster Roll
- Wage Register
- Wage Slip
- Register of Leave
- Register of Fines
- Register of Advances
- Overtime Register
- Attendance Reports
- Bonus Register
- Various quarterly/half yearly and Yearly reports for submission of statutory returns.

The system helps organizations to maintain legal compliance and supports audit and inspection requirements under various laws.

9. Benefits of CLIMS

The implementation of CLIMS provides several operational and administrative benefits.

Operational Benefits:

- Reduction in manual paperwork
- Faster approval processes
- Centralized worker database
- Better contractor management

Compliance Benefits:

- Improved PF and ESIC compliance
- Automated statutory register generation
- Better audit readiness

Security Benefits:

- Controlled gate pass issuance
- Worker verification and tracking
- Prevention of unauthorized entry

Management Benefits:

- Real-time dashboards and reports
- Better monitoring of manpower deployment

- Improved transparency and accountability

Financial Benefits:

- Accurate wage calculations
- Timely contractor payment processing
- Reduced administrative costs

10. Future Scope

The CLIMS platform can be further enhanced with advanced digital technologies such as:

- AI-based compliance monitoring
- Geo-fencing attendance system
- Integration with ERP and finance systems
- Advanced analytics and dashboard reporting

These enhancements can further improve operational efficiency and digital governance.

11. Conclusion

- Contract Labour Information Management System (CLIMS) is a comprehensive digital initiative developed for modern contractor labour management.
- The system integrates contractor registration, worker management, attendance, wage processing, gate pass approvals, statutory compliance, and HR clearance processes into a single centralized platform.
- CLIMS improves operational efficiency, transparency, security, and compliance while reducing manual work and administrative burden. The system supports better governance, real-time monitoring, and effective management control across all locations.
- Overall, CLIMS is an important step towards digital transformation and efficient contractor labour management in GSECL.

#####

Feasibility and Project Planning of Thermal Power Plant

By
Er. Jay Parmar
DE, GSECL

Step 1: Primary Requirement (New thermal plant required or not?)

- **Energy Requirement:** Energy requirement of the state and country is rising at growing pace resulted due to industrialization, urbanization as well as rising standard of living (Resource adequacy study as well as National Electricity Plan by CEA). Energy security is one of the most crucial factors for the developed India by 2047 and role of thermal is important in it.
- **Retirement planning of old plants:** Planning of old and inefficient plants in a phased manner replacing with the new advanced technology and more environmentally friendly plants
- **Government Positioning:** Government's view on conventional and renewable energy requirement in energy mix, employment generation, investment opportunities as well as environment positioning is important.
- **Grid Requirement:** Huge Variable Renewable Energy integration with the grid creates grid instability as well as huge requirement of reactor power and inertia in the grid. Thermal power plant will satisfy the base load as well as the reactor power and inertia requirement of the grid.

Step 2: Brown Field v/s Green Field Project (Which is better?)

- **Brown Field Project:**
  - Brown field projects are the expansion project in the existing power station.
  - It offers certain advantages like existing infrastructure, railway network, ash dyke structure,
- **Green Field Project:**
  - Green field projects are established at the completely new sites without any existing infrastructure.
  - All the major facilities like railway infrastructure, water availability, transmission network, transportation network, etc. are required to be established.

Step 3: Resource Availability Evaluation:

- **Land:**
  - One of the most important factors is the availability of the land for the new thermal plant.
  - For a Brown-field project:
    - The land will be available at the existing location as spare land or land vacant due to decommissioning of the old units.

- The orientation of the project must be adjusted according to the available parcel of land and existing facility.
- Further, the provision of the 33% Green belt area and compensatory afforestation is also one of the major hurdles.

o For a Green-field project:
- Land acquisition is a major constraint as there may be private, government or forest land.

- **Water:**
  - o Water requirement for the process and cooling purposes.
    - To meet cooling requirement for steam condenser which acts as a heat sink for the thermodynamic cycle and other auxiliary cooling such as bearing / lube oil coolers, compressors, generator stator etc.
    - To meet the heat cycle make-up and other process requirements.
    - For miscellaneous services like General services, Dust Extraction and dust suppression in coal yard, ash pond area, Fire Fighting etc.
- **Fuel:**
  - Quality of coal is major variant in the design of thermal power station.
  - For the coal based thermal power stations, the state must depend on transportation from central. It will be made available based on Revised Shakti policy.
  - For a Green-field thermal power plant, it will be difficult to achieve the fuel linkage from Ministry of Coal, Government of India.
  - Coal quality needs to be ascertained prior to taking up the design of the steam generator and other auxiliaries.
  - Fuel transportation cost also plays major role in the site selection decision for the thermal power plant.
- **Power Evacuation:**
  - o Power evacuation from the proposed thermal power plant is also important concern as these plants are mainly located at isolated places where there may not be available existing infrastructure for connectivity and evacuation of power.
  - o The timeline of establishment of the transmission network shall be coordinated with the project timeline.

Step 4: Cost Estimation:

- Cost estimates of the project are important factor as the levelized tariff can only be ascertained based on the project cost as well as other financial factors.
- For the projects established under Section 62 of the Electricity Act 2003, GERC MYT Regulations 2024 will be applicable for

the tariff determination. For the project established under Section 63, competitive tariff will be derived based on the competitive bidding.

Step 5: Statutory Approvals

To establish new thermal plant certain statutory approvals are necessary in the planning phase of the project.

- In-Principle Approval / Project Approval: Approval from the State Government or competent authority for setting up the project.
- Land Acquisition & Land Use Approval: Conversion of agricultural land to industrial use, land allotment, and related revenue permissions.
- Environmental Clearance (EC): Approval from the Ministry of Environment, Forest and Climate Change under the EIA Notification, 2006.
- Water Allocation / Water Withdrawal Permission: Approval from State Water Resources Department / Central Water Commission / river authority.
- Coal Linkage / Fuel Supply Agreement (FSA): Fuel allocation approval from Coal India Limited or other fuel supplier agencies.
- Railway Siding Approval: Approval from Indian Railways for coal transportation infrastructure.
- Power Evacuation Approval: Grid connectivity and transmission approvals from
- STU/CTU and Load Dispatch Centers.
- Forest Clearance (if applicable)
- Wildlife Clearance (if applicable)
- Coastal Regulation Zone (CRZ) Clearance (if applicable)

Step 6: Mode of Contract:

- Contract for the thermal power plants can be awarded based on Engineering, Procurement and Construction basis or package basis.
- There are very few agencies involved for the EPC contract and this creates monopoly or oligopoly in the market which may result in higher project cost and extended timeline of the project.
- For the package base contract, the integration of the various packages is awarded to different agencies in one of the biggest challenges for the developer.

#####

Power Trading and LPS Rules

By
Er. Kalpendra Rathaur
DE (Efficiency), Corporate Office GSECL

Introduction

India's electricity sector has transitioned from a completely regulated framework to a partially competitive electricity market structure. With increasing penetration of renewable energy, changing demand patterns, and the need for economic dispatch, power trading has become an essential tool for optimizing generation resources.

The establishment of power exchanges such as Indian Energy Exchange (IEX) and Hindustan Power Exchange (HPX) enabled generators and DISCOMs to buy and sell electricity competitively. The introduction of market mechanisms such as:

- Day Ahead Market (DAM)
- Real Time Market (RTM)
- High Price Day Ahead Market (HPDAM)
- Term Ahead Market (TAM)
- Ancillary Services
- Security Constrained Economic Dispatch (SCED)
- Security Constrained Unit Commitment (SCUC)

has significantly improved grid flexibility and economic efficiency.

However, one of the major concerns in the power sector remained delayed payments by distribution companies (DISCOMs), resulting in severe liquidity stress for generating companies. To address this issue, the Ministry of Power notified the Electricity (Late Payment Surcharge and Related Matters) Rules, 2022.

1. Overview of Power Trading in India

1.1 Definition of Power Trading

Power trading refers to the buying and selling of electricity through organized electricity markets or bilateral contracts. The objective is to optimize power procurement costs, improve utilization of generating assets, and ensure grid reliability.

1.2 Need for Power Trading

The major objectives of power trading are:

- Optimal utilization of generation resources
- Sale of surplus power
- Meeting peak demand economically
- Grid balancing and flexibility
- Competitive price discovery
- Efficient dispatch of generating stations
- Reduction in backing down losses
- Better integration of renewable energy

1.3 Power Exchanges in India

The major power exchanges operating in India are:

- Indian Energy Exchange (IEX)
- Hindustan Power Exchange (HPX)

- Power Exchange India Limited (PXIL)

These exchanges facilitate transparent and competitive electricity trading.

1.4 Market Segments

- Day Ahead Market (DAM): Electricity is traded one day in advance in 15-minute time blocks.
- Real Time Market (RTM): Allows trading closer to delivery time to manage real-time deviations.
- High Price Day Ahead Market (HPDAM): Designed for procurement during high demand periods.
- Term Ahead Market (TAM): Facilitates bilateral and contingency contracts.
- Green Markets: Specialized markets for renewable energy trading.

2. Evolution of LPS RulesBackground

Delayed payment by DISCOMs created huge outstanding dues for generating companies and transmission licensees. This resulted in:

- Cash flow problems
- Increase in borrowing costs
- Delayed coal payments
- Operational constraints
- Financial stress across the sector

To address these issues, Ministry of Power notified the Electricity (Late Payment Surcharge and Related Matters) Rules, 2022 on 03 June 2022.
Subsequently, amendments were issued on 28 February 2024.

2.2 Objectives of LPS Rules

The major objectives are:

- Ensuring payment discipline
- Reducing outstanding dues
- Implementing Payment Security Mechanism (PSM)
- Enabling generators to regulate supply in case of default
- Allowing sale of surplus power through exchanges
- Improving liquidity in power sector
- Promoting market-based operation

3. Rule 9 – Sale of Un-Requisitioned Surplus (URS) Power

3.1 Introduction

Rule 9 is one of the most significant provisions of the LPS framework.
It mandates generating companies to offer Un-Requisitioned Surplus (URS) power in power exchanges. If generators fail to offer URS power, they become ineligible for recovery of fixed charges corresponding to non-offered capacity.

3.2 Applicability

Applicable to:

- Interstate generating stations
- Intrastate generating stations
- State-owned generating stations

Exempted categories:

- Hydro generating stations
- Renewable generators under must-run status
- Energy Storage Systems (ESS)

3.3 Concept of URS Power

URS power means the power available but not requisitioned by beneficiaries.
Example:

- Declared Capacity = 500 MW
- Requisition by DISCOM = 350 MW
- URS Power = 150 MW

This 150 MW must be offered in power exchanges.

4. Operational Framework of Rule 9

4.1 Day Ahead Market (DAM)

Distribution licensees must declare requisition schedules before DAM closure.
Generators shall:

- Assess URS quantity
- Consider ramp constraints
- Offer URS in DAM

4.2 Real Time Market (RTM)

Any additional URS after DAM closure shall be offered in RTM considering:

- Ramp rate constraints
- Reserve shutdown (RSD)
- Technical minimum limits

4.3 Ceiling Price Limitation

Generators cannot bid above:
120% of Energy Charge Rate (ECR) + applicable transmission charges
If bid price exceeds this limit:

- Quantum is treated as non-offered
- Corresponding fixed charges become unrecoverable

5. NLDC Procedure for Implementation

Grid-India/NLDC issued detailed implementation procedure for LPS Rules and Rule 9.
The procedure covers:

- Information exchange
- Market participation
- Data submission formats
- Computation methodology
- Monitoring mechanism

6.1 Key Timelines

Activity	Timeline
DISCOM requisition declaration	Before DAM closure
Generator URS offer in DAM	D-1
RTM bidding	Before gate closure
ECR submission on NOAR	2nd day of month
PX submission of data	4th day
RLDC/SLDC computation	6th day

6.2 Data Formats

Format A
Power Exchanges submit:

- Quantum offered in DAM
- Quantum offered in RTM

- Quantum above 120% ECR
- Time block-wise details

Format B

RLDC/SLDC compute:

- URS available
- URS offered
- Non-offered quantum
- NOPAFM

7. NOPAFM Computation

7.1 Meaning

NOPAFM means:

Monthly Non-Offered Plant Availability Factor

This represents the percentage of declared capacity not offered in power exchanges.

7.2 Formula

The NOPAFM calculation is based on cumulative non-offered quantum during the month.

Key parameters:

- Non Offered Declared Capacity (NODC)
- Installed Capacity (IC)
- Auxiliary Consumption
- Time blocks

Higher NOPAFM results in:

- Reduction in fixed charge recovery
- Financial losses to generator

8. Power Trading Process Flow

8.1 Step-by-Step Process

1. Generator declares capacity.
2. Beneficiary declares requisition.
3. URS quantum identified.
4. Generator offers URS in DAM.
5. Un-cleared power offered in RTM.
6. PX communicates market clearance.
7. RLDC/SLDC validates schedules.
8. Monthly computation of non-offered capacity.
9. Fixed charge recovery adjusted.

9. Role of Different StakeholdersGenerating Companies

- Declare available capacity
- Offer URS power
- Submit ECR data
- Maintain compliance

9.2 Distribution Companies

- Declare requisition schedules
- Maintain PSM
- Make timely payments

9.3 RLDC/SLDC

- Schedule power
- Monitor compliance
- Compute non-offered quantum
- Ensure grid security

9.4 Power Exchanges

- Facilitate market transactions
- Submit transaction data
- Ensure transparency

9.5 NLDC/Grid-India

- Develop procedures
- Monitor implementation
- Coordinate stakeholders

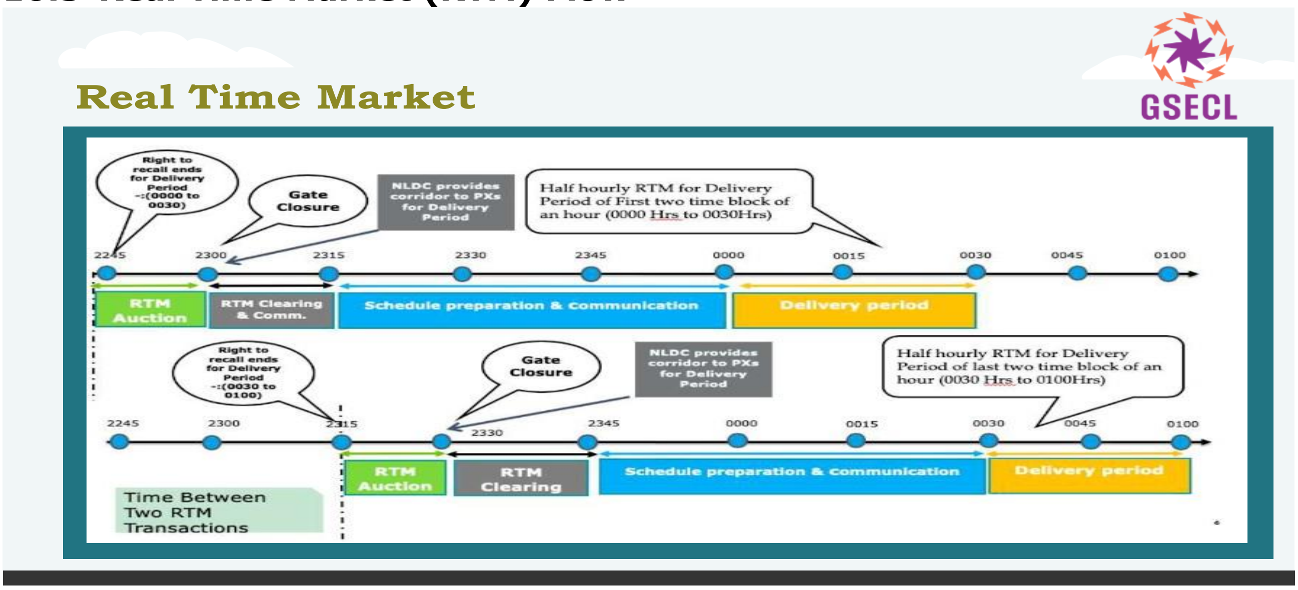
10. GSECL Experience in Power TradingInitiation of Trading

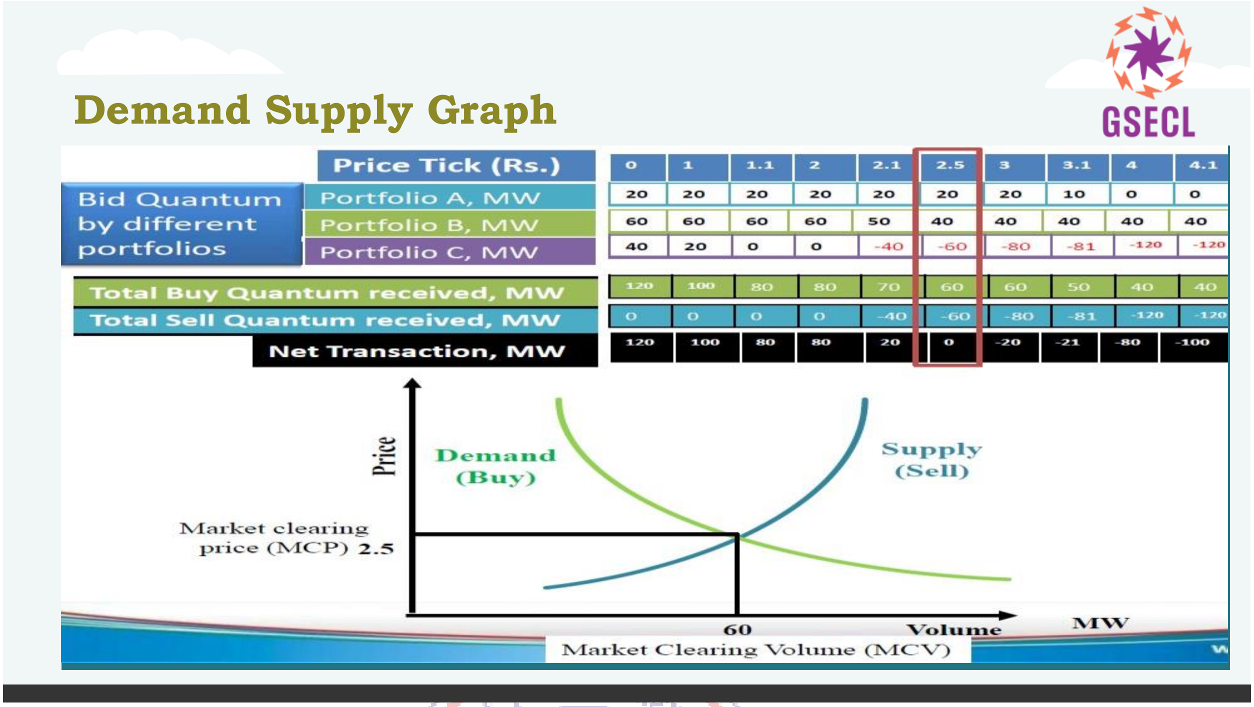
GSECL commenced offering URS power of thermal generating units in power exchanges on round-the-clock basis from October 2025.

10.2 Power Trading Operational Framework

Day Ahead Market (DAM) Flow

10.3 Real Time Market (RTM) Flow





Price Tick (Rs.)	0	1	1.1	2	2.1	2.5	3	3.1	4	4.1
Portfolio A, MW	20	20	20	20	20	20	20	10	0	0
Portfolio B, MW	60	60	60	60	50	40	40	40	40	40
Portfolio C, MW	40	20	0	0	-40	-60	-80	-81	-120	-120
Total Buy Quantum received, MW	120	100	80	80	70	60	60	50	40	40
Total Sell Quantum received, MW	0	0	0	0	-40	-60	-80	-81	-120	-120
Net Transaction, MW	120	100	80	80	20	0	-20	-21	-80	-100

10.4 FY 2025-26 Highlights

- Trading initiated from September 2025
- Total traded energy till March 2026: 30.53 MU
- Total traded amount: ₹28.19 Crore
- April 2026 traded energy: 33.67 MU
- Highest single day traded energy: 3.91 MU

11. Technical and Commercial Impacts

11.1 Positive Impacts

- Improved Market Efficiency: URS power gets economically dispatched.
- Better Asset Utilization: Generating stations can monetize surplus capacity.
- Enhanced Financial Discipline: DISCOMs are incentivized to maintain payment discipline.
- Transparency: Market-based price discovery improves transparency.
- Additional Revenue Opportunity: Generators can earn additional profits through market trading.

11.2 11.2 Negative Impacts

- Operational Complexity: Continuous market participation requires advanced coordination.
- Increased DSM Risk: Market uncertainty can increase deviation exposure.
- Technical Constraints: Thermal units face ramping and minimum load limitations.

12. Regulatory Challenges

Some important regulatory issues include:

- Alignment of IEGC and State Grid Codes
- Treatment of STU transmission losses
- Compensation mechanism for unsuccessful trades
- Harmonization of scheduling timelines
- Handling of RSD and forced outages

13. Future Outlook

The future of power trading in India is expected to expand significantly due to:

- Increasing renewable penetration
- Growth of real-time markets
- Energy storage integration
- Ancillary service markets
- Demand response programs

LPS Rules and Rule 9 are likely to accelerate market-based operation and financial discipline in the sector.

14. Conclusion

- The Electricity (Late Payment Surcharge and Related Matters) Rules, 2022 represent a landmark reform in the Indian power sector aimed at improving payment security and financial discipline.
- Rule 9 related to sale of Un-Requisitioned Surplus power has introduced a major shift in operational and commercial practices for generating companies. The mandatory offering of URS power in power exchanges has strengthened market participation and promoted economic dispatch.
- While implementation presents operational, technical, and regulatory challenges, it also provides significant opportunities for generators to optimize surplus power and improve revenues.
- The experience of GSECL demonstrates that effective market participation can generate substantial commercial benefits. However, successful implementation requires strong coordination among generators, DISCOMs, SLDCs, RLDCs, power exchanges, and regulators.
- With continued refinement of procedures, alignment of regulations, and enhancement of digital infrastructure, power trading and LPS framework are expected to play a crucial role in strengthening India's power sector.

*****

Design & Engineering of Thermal Power Plant
Main Plant & Balance of Plant (BOP)

By

D J Parmar, Deputy Engineer, GSECL

Abstract:

Thermal power plants are one of the most significant sources of electrical energy generation worldwide. These plants convert heat energy obtained from fossil fuels such as coal, oil, or natural gas into electrical energy through a series of thermodynamic and mechanical processes. The design and engineering of a thermal power plant involve the integration of various systems including boilers, steam turbines, generators, fuel handling systems, ash handling systems, cooling systems, and electrical control systems.

This paper presents a detailed study of the design and engineering aspects of thermal power plants, covering both Main Plant systems and Balance of Plant (BOP) systems. It discusses the Rankine cycle, plant layout, boiler engineering, turbine engineering, generator systems, environmental considerations, instrumentation and control, safety standards, and future technological advancements. The objective is to understand how efficient, reliable, and environmentally compliant thermal power plants are designed and operated.

1. Introduction

1.1 Overview of Thermal Power Plants

A thermal power plant converts thermal energy into electrical energy by using heat produced from fuel combustion. The heat energy converts water into steam, which drives a steam turbine connected to an electrical generator.

Thermal power plants are widely used because:

- They can generate large amounts of power.
- Fuel sources are readily available.
- Technology is mature and reliable.
- Suitable for base-load operation.

1.2 Objectives of Thermal Power Plant Design

The major objectives are:

- Maximum thermal efficiency
- Reliable operation
- Environmental compliance
- Reduced operational cost
- Improved safety and automation
- Long equipment life

1.3 Scope of Study

The presentation covers:

- Main Plant Design

- Balance of Plant (BOP)
- Engineering Methodology
- Thermal Cycles
- Environmental Engineering
- Future Trends in Thermal Power Generation

2. Working Principle of Thermal Power Plant

The operation of a thermal power plant is based on Rankine Cycle.

The Rankine cycle consists of:

- Boiler
- Steam Turbine
- Condenser
- Feed Water Pump

The sequence is:

- Water is heated in the boiler.
- Steam is generated at high pressure and temperature.
- Steam expands through the turbine.
- Turbine rotates the generator.
- Exhaust steam is condensed into water.
- Water is pumped back to the boiler.

Advantages of Rankine Cycle

- High efficiency
- Continuous operation
- Suitable for large-scale power generation

3. Main Plant Design & Engineering

3.1 Boiler Engineering: The boiler converts feed water into high-pressure steam using heat from fuel combustion. Types of Boilers

- Fire Tube Boiler
- Water Tube Boiler
- Pulverized Coal Boiler
- Supercritical Boiler
- Ultra-Supercritical Boiler

Boiler Components

- Furnace
- Economizer
- Superheater
- Reheater
- Air Preheater
- Drum
- Burners

Design Considerations Fuel Selection Common fuels:

- Coal
- Oil
- Natural Gas Steam Parameters Typical values:

- Pressure: 150–300 bar
- Temperature: 540–620°C Efficiency Improvement
- Economizer
- Air preheater
- Reheat cycle
- Superheating

Boiler Efficiency depends on:

- Combustion efficiency
- Heat transfer rate
- Fuel quality
- Excess air control

Boiler Safety Systems

- Pressure relief valves
- Flame scanners
- Emergency shutdown systems
- Water level monitoring

3.2 Steam Turbine Engineering:

Function Steam turbines convert thermal energy into mechanical energy.

Types of Turbines

- Impulse Turbine
- Reaction Turbine
- Condensing Turbine
- Back Pressure Turbine

Turbine Stages

- High Pressure (HP)
- Intermediate Pressure (IP)
- Low Pressure (LP) Turbine Design Factors Blade Design
- Aerodynamic efficiency
- Corrosion resistance
- High-temperature strength

Rotor Design

- Dynamic balancing
- Vibration control
- Thermal stress analysis

Governing System Controls:

- Speed
- Steam flow
- Load variation

Turbine Efficiency Factors affecting efficiency:

- Steam quality
- Blade profile
- Mechanical losses
- Leakage losses

3.3 Generator Engineering:
Function The generator converts mechanical energy into electrical energy.
Generator Type
Synchronous generators are generally used. Main Components

- Rotor
- Stator
- Exciter
- Cooling system
- Bearings

Cooling Methods

- Air Cooling
- Hydrogen Cooling
- Water Cooling

Voltage Regulation The excitation system maintains:

- Stable voltage
- Reactive power control
- Grid synchronization

Protection Systems

- Differential protection
- Overcurrent protection
- Earth fault protection
- Temperature protection

4. Balance of Plant (BOP)
Balance of Plant includes all auxiliary systems required for smooth operation.
4.1 Fuel Handling System:
Functions

- Coal unloading
- Crushing
- Conveying
- Storage
- Feeding to boiler

Equipment Used

- Conveyors
- Crushers
- Stackers
- Reclaimers
- Bunkers

Engineering Challenges

- Dust generation
- Fire hazards
- Material handling efficiency

Safety Measures

- Dust suppression systems

- Fire detection systems
- Emergency stop controls

4.2 Ash Handling System:

Types of Ash

- Fly Ash
- Bottom Ash

Ash Collection Methods

- Pneumatic conveying
- Hydraulic conveying
- Mechanical conveying

Environmental Considerations

- Ash utilization in cement industry
- Dust control
- Safe disposal methods

4.3 Water Treatment Plant:

Importance of Pure water is essential for boiler operation. Water Treatment Processes

- Filtration
- Softening
- Demineralization
- Reverse Osmosis
- Deaeration Cooling Water System Components
- Cooling towers
- Condensers
- Pumps

Cooling Tower Types

- Natural Draft
- Mechanical Draft

4.4 Electrical Systems:

Major Components

- Transformers
- Switchyard
- Circuit breakers
- Bus bars
- UPS systems

Switchyard Functions

- Voltage transformation
- Grid connection
- Protection and isolation Auxiliary Power System Supplies power to:
- Pumps
- Fans
- Control systems
- Lighting

4.5 Instrumentation & Control System:

Importance of Automation

Automation improves:

  - Efficiency
  - Reliability
  - Safety
  - Monitoring

Distributed Control System (DCS) Functions:

  - Real-time monitoring
  - Process control
  - Alarm management
  - Data logging

Sensors Used

  - Temperature sensors
  - Pressure transmitters
  - Flow meters
  - Level indicators SCADA Integration SCADA systems provide:
  - Remote monitoring
  - Data acquisition
  - Performance analysis

5. Plant Layout & Site Selection

- Site Selection Criteria
- Fuel Availability
- Plant should be near:
  - Coal mines
  - Fuel transportation routes
- Water Availability
- Large quantities of water are required. Land Availability
- Sufficient land is needed for:
  - Main plant
  - Ash ponds
  - Cooling systems
- Grid Connectivity
- Easy access to transmission network.
- Environmental Impact
- Minimum ecological disturbance.

6. Thermal Efficiency Improvement Techniques

- Methods to Improve Efficiency
- Superheating
- Increases steam temperature. Reheating
- Reduces turbine moisture content.
- Regenerative Feed Heating Improves cycle efficiency. Combined Cycle Technology
- Uses both gas and steam turbines. Supercritical Technology Advantages:
  - Higher efficiency

  - Lower fuel consumption
  - Reduced emissions

7. Environmental Engineering

- Major Pollutants
  - CO_2
  - SOx
  - NOx
  - Fly ash
  - Thermal pollution Pollution Control Equipment Electrostatic Precipitator (ESP) Removes fly ash.
- Flue Gas Desulfurization (FGD) Controls SO_2 emissions.
- Low NOx Burners
- Reduce nitrogen oxide formation. Wastewater Treatment
  - Neutralization
  - Filtration
  - Recycling Environmental Standards Plants must comply with:
  - CPCB standards
  - Environmental Protection Act
  - International emission norms

8. Safety Engineering

- Safety Objectives
  - Prevent accidents
  - Protect personnel
  - Ensure reliable operation
- Common Hazards
  - Boiler explosions
  - Electrical faults
  - Fire hazards
  - Steam leaks
- Safety Systems
  - Fire protection systems
  - Emergency shutdown systems
  - Safety valves
  - Alarm systems
- Personal Protective Equipment (PPE)
  - Helmets
  - Gloves
  - Safety shoes
  - Goggles

9. Engineering Challenges

- Efficiency vs Cost

- Higher efficiency requires expensive materials and technology. Water Scarcity
- Thermal plants consume large amounts of water. Emission Compliance
- Stringent emission standards increase engineering complexity.
- Renewable Energy Integration
- Thermal plants must operate flexibly with renewable energy sources.

10. Future Trends in Thermal Power Plants

- Ultra-Supercritical Technology Provides:
    - Higher efficiency
    - Lower emissions
    - Better fuel economy
- Carbon Capture & Storage (CCS)
- Captures CO_2 before release into atmosphere. Digital Twin Technology is used for:
    - Predictive maintenance
    - Performance optimization
    - Real-time diagnostics Artificial Intelligence & Automation AI helps in:
    - Fault prediction
    - Load forecasting
    - Energy optimization Hybrid Thermal-Solar Plants Combines:
    - Thermal power
    - Solar thermal energy

11. Advantages & Disadvantages

- Advantages
    - High power generation capacity
    - Reliable operation
    - Mature technology
    - Suitable for base load
- Disadvantages
    - Environmental pollution
    - High water consumption
    - Fossil fuel dependency
    - Greenhouse gas emissions

12. Conclusion

- Thermal power plants continue to play a critical role in global electricity generation. The design and engineering of thermal power plants involve multidisciplinary engineering principles including mechanical, electrical, civil, instrumentation, and environmental engineering.
- Modern thermal power plants focus on:
    - Higher thermal efficiency
    - Reduced emissions

- Improved automation
- Better safety standards
- Sustainable operation

➢ Future advancements such as ultra-supercritical technology, digitalization, and carbon capture systems are expected to make thermal power generation more efficient and environmentally friendly.

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Use of Pipe Conveyor System in Transportation of Minerals

By

Er. Hitesh Harigovind Gulabani

Abstract

Efficient mineral transportation logistics infrastructure is a cornerstone of sustainable power generation. As environmental regulations tighten and logistics costs rise, conventional methods like trucking, rail and open conveyor system face scrutiny for their emissions and inefficiencies. This paper examines the strategic implementation of Pipe Conveyor Systems (PCS) as a sustainable alternative to traditional mineral transportation methods. Using the Ghogha-Surka Lignite Mining project as a case study, the paper analyzes technical, commercial, and environmental parameters. It argues that while PCS requires higher initial CAPEX, its operational efficiency, zero-spillage design, and ability to navigate complex terrains provide a superior lifecycle value for the power and energy sector.

1. Introduction

Gujarat Power Corporation Limited (GPCL), incorporated in 1990, serves as a pivotal developer in Gujarat's energy sector. With major achievements including the Charanka Solar Park and the 30 GW Hybrid Renewable Energy Park, GPCL continues to lead in power generation infrastructure. A critical component of this infrastructure is the efficient movement of minerals, such as lignite from the GPCL's Ghogha-Surka Lignite Mine Project, Badi (2.25 MTPA capacity), to GSECL's 2x250 MW Thermal Power Plant at Padva, Bhavnagar.

2. Comparative Analysis of Mineral Transportation Modes

Mineral transportation selection is governed by technical feasibility, cost per ton-km, and environmental compliance. The following table summarizes the key parameters across common industrial methods:

Parameter	Pipe Conveyor	Open Conveyor	Truck (Road)	Rail (Rakes)
Estimated Cost/Ton-Km	₹0.80 – ₹1.00	₹0.60 – ₹0.80	₹2.50 – ₹4.50	₹1.36 – ₹2.00
Flexibility/Terrain	High (Curves/3D)	Low (Straight)	Very High	Fixed/Linear
Environmental Impact	Lowest (Enclosed)	Moderate (Dust)	Highest (Emissions)	Low
Operating Cost	Low-Moderate	Lowest	Highest (Diesel)	Moderate
Spillage Risk	Zero	High	Moderate	Low

3. Pipe Conveyor Systems: Technical Evaluation

Successful implementation requires adherence to strict design tolerances:

- **Design:** Belt overlap must be 3.5 to 4.0 times the belt thickness; Fill factors must remain between 60% and 75%.
- **Maintenance:** Specialized tracking control is needed to prevent 'belt twisting.' Use of electronic sensor loops for rip detection is recommended.

- **Economics:** Although drawing 15-25% more power due to friction, the 10-15 year lifespan and reduced material loss provide a superior long-term ROI.

3.1 Advantages

- **Environmental Protection:** Fully enclosed tubular belt eliminates fugitive dust (<1 mg/m³).
- **Terrain Adaptability:** Navigates tight horizontal and vertical curves (300-400x pipe diameter radius).
- **Material Conservation:** Prevents fuel degradation and moisture variations from weather exposure.
- **Operational Savings:** Reduces reliance on diesel and cuts cleanup labor by up to 85% due to zero spillage.
- **Two-Way Transport:** Capability to move materials on both top and return belt sections simultaneously.

3.2 Disadvantages & Challenges

- **High CAPEX:** Initial hardware costs are 20-40% higher than conventional open conveyors.
- **Energy Consumption:** Draws 15-25% more power due to constant idler friction and belt stiffness.
- **Complex Maintenance:** Risks of belt twisting or collapsing require specialized alignment and monitoring.
- **Specialized Training:** Requires technicians skilled in belt training and hexagonal idler centering.

4. Strategic Importance for Lignite Transportation

(From GPCL's Lignite Mine Project to GSECL's Thermal Power Plant at Bhavnagar)

2.20Km/1500TPH Pipe Conveyor System (PCS)

For the Ghogha-Surka Lignite Mine Project to the GSECL 2x250 MW Thermal Plant (Padva), the 2.20Km /1500TPH Pipe Conveyor System (PCS) is mission-critical. Lignite is highly fragile and prone to spontaneous combustion; the enclosed transit prevents rapid drying and self-ignition. It provides a direct, 24/7 automated delivery link straight to boiler stockpiles. Furthermore, by replacing traditional trucks, the system manages the 2.25 MTPA demand while protecting regional agricultural topsoil and avoiding groundwater pollution near local check dams in the Ghogha and Bhavnagar talukas from Lignite dust contamination.

Lignite Transportation Through Pipe Conveyor System (PCS)

Over Ground Reclaim Hoppers (OGRH)

Apron Feeder

Apron Feeder + Tail End (PCS)

Open Trough Belt Conveyor System (GPCL) (220 m/1500TPH) (To JNT-7 and GSECL Lignite Stackyard)

JNT-8 + Head End (PCS)

Pipe Conveyor Corridor (PCS) (2.2Km /1500TPH)

5. Future Outlook and Recommendations

The sector is moving toward 'Smart & Sensor-Driven' systems. For organizations adopting Pipe Conveyor System, the following are recommended:

1. **Two-Way Transport:** Utilize the return belt for light goods or return materials to maximize capacity.
2. **VFD Integration:** Use Variable Frequency Drives to optimize loading and maximize energy efficiency.
3. **Predictive Maintenance:** Integrate sensor loops to detect rips and alignment issues before failure which will replace reactive repairs.
4. **'Smart Conveying':** Using IoT, SCADA Systems and AI for real-time health monitoring and control belt.

6. Conclusion

Pipe conveyor technology is the superior & ideal choice for modern mineral logistics infrastructure. It successfully balances the high-capacity needs of 500MW+ thermal plants with the increasingly stringent environmental 'Zero Dust' mandates, ensuring long-term economic and ecological sustainability.

Er. Hitesh Harigovind Gulabani
He is a Mechanical Engineer & MBA in Infrastructure Management from (CEPT). Presently working in **Gujarat Power Corporation Ltd. (GPCL).** Email ID: hitesh.gulabani@rediffmail.com
Mobile No: 7228080507

Metallurgical Insights into Boiler Integrity: NDT, Remaining Life Assessment & Damage Mechanisms

By
Mr. Nikhil H. Sabhaya, Manager
Mr. Paresh U. Haribhakti, Managing Director
TCR Advanced Engineering Pvt. Ltd., Vadodara

1. Introduction: The Metallurgical Stakes of Boiler Operation

A boiler is not merely a pressure vessel, it is a dynamic metallurgical system operating at the intersection of extreme thermomechanical stress, aggressive chemical environments, and cyclic loading. For mechanical engineers tasked with operating and maintaining boilers in thermal power plants, understanding the metallurgical basis of component behaviour is not an academic luxury, it is an operational imperative.

Boiler components are designed to operate for a minimum of 100,000 hours under stipulated conditions. In practice, however, actual service life is governed by real-world variables that deviate significantly from design assumptions: fluctuations in fuel quality, variations in water chemistry, cyclic thermal loads from frequent start-stop operations, ash and slag deposition, and the relentless, time-dependent progression of creep at elevated temperatures. The result is that some boilers fail prematurely, while others, with intelligent inspection and life management programmes, operate safely at two to three times their design life.

This article presents the metallurgical perspective that bridges the gap between reactive maintenance and proactive asset management equipping boiler engineers with the foundational knowledge to make informed decisions about inspection timing, component replacement, and operational adjustments that extend plant life without compromising safety or reliability.

2. Boiler Classification and the Metallurgical Challenge of Evolving Technologies

Modern thermal power plants employ a spectrum of boiler technologies, each presenting a distinct metallurgical challenge. Understanding these differences is essential for maintenance engineers planning inspection strategies and material selections.

Type	Main Steam Pressure	Main Steam Temp.	Efficiency (HHV)	Key Material Challenge
Subcritical	< 221.2 Bar	Up to 565°C	33%–39%	Carbon/low alloy steels (SA-210, SA-213 T11/T22)
Supercritical	22.1–26 MPa	540–580°C	38%–42%	Advanced alloys T91/P91, T92/P92
Ultra-Supercritical	> 26 MPa	> 580°C	> 42%	Nickel-based superalloys, Inconel, HR6W

2.1 The P91/T91 Challenge in Supercritical Boilers

The adoption of Grade 91 (9Cr-1Mo-V) steels for main steam piping, headers, and superheater components in supercritical and ultra-supercritical boilers represents a significant metallurgical step forward in creep strength but also introduces new maintenance challenges that many operating engineers are inadequately prepared for.P91/T91 alloys are highly sensitive to improper heat treatment. Post-weld heat treatment (PWHT) must be performed within a narrow temperature window (730–760°C) and for a sufficient duration. Under-tempering produces a hard, brittle microstructure prone to stress relaxation cracking; over-tempering degrades the precipitate strengthening that gives P91 its superior creep resistance. In-situ metallographic examination particularly at weldments is the only reliable means of verifying heat treatment adequacy after years of service.

Furthermore, P91 components are susceptible to Type IV cracking, a form of creep damage that initiates in the fine-grained heat-affected zone (FGHAZ) adjacent to welds, a zone that is difficult to inspect by conventional methods and requires PAUT or TOFD for reliable detection.

3. Why Boilers Have a Limited Metallurgical Life

The design life of a boiler is a statistical construct based on allowable stress values derived from extensive creep rupture, tensile, and fatigue testing of materials at specified temperatures and pressures. Boiler designers select materials with creep rupture lives significantly exceeding the design operating hours, incorporating a safety factor typically a minimum factor of 1.5 on stress rupture life.

Many variables have impacts on microstructure degradation throughout operation time and transfers from design specifications to actual field installations. These variables include:

- Fuel quality variation: Higher sulphur and higher ash fuels will increase the rates of corrosive damage to heat transfer surfaces through fireside corrosion. This will result in tube wall thicknesses greater than the amount of wall thickness reduction originally designed.
- Metal Temperature Excursion: Even very brief periods of tube overheating will exponentially increase the rate of cumulative creep damage accumulation. A metal temperature increase of 10°C above the designed value will reduce the amount of remaining creep life by 30-50%..
- Non-uniformity of Fluid Distribution: Poor flow distribution in the tube panel results in localized overheating: "hot spots" that experience levels of creep and oxidation well above those expected and designed for.
- Cyclic Thermal Loading: Every time there is a start-stop cycle, thermomechanical fatigue will be placed on U-bends, bends, headers and tube-to-header junctions. In any event, the transition to improved load-following flexible operation required for integration with renewable energy sources has increased substantially the rate of thermomechanical fatigue damage being experienced by India's existing thermal generation base.
- Water Chemistry Excursion: Whenever feedwater quality is poor, there is a potential for corrosion due to introduction of corrosive agents that can attack the interior surfaces and create damage due to the deposition of scale and hydrogen. Scale acts as an insulator which will increase the amount of metal temperature.

- Ash and Slag Deposition: In general, variable ash coverage will create a variable heat flux and elevated metal temperatures in exposed areas and thermal fatigue of the metal at the edges of the deposit areas.

4. Boiler Damage Mechanisms: A Metallurgical Classification

A thorough understanding of damage mechanisms is the foundation of any effective RLA programme. Damage in boilers does not occur randomly, it follows metallurgical logic dictated by the material, the operating environment, and the thermal and mechanical loading. The following classification, drawing on both field experience and the comprehensive framework presented by Mr. Paresh Haribhakti in "Failure Investigation of Boiler Tubes," provides boiler engineers with a working reference for damage identification.

Category	Key Mechanisms	Affected Components
Water Side Corrosion	Oxygen pitting, caustic gouging, hydrogen damage, phosphate corrosion, flow accelerated corrosion (FAC)	Water walls, steam drum, economizer, headers
Fireside Wastage	Fireside oxidation, fly ash erosion, soot blower erosion, coal particle erosion, steam impingement, low-temperature dew point corrosion	Superheater/reheater tubes, water wall tubes, economizer coils
Stress Rupture Failure	Short-term overheating (stress rupture), long-term overheating (creep rupture), dissimilar metal weld (DMW) failures	Superheater/reheater coils, headers, main steam piping
Metallurgical Degradation	Graphitization (carbon & C-Mo steels), sigma phase embrittlement (austenitic SS), spheroidization of carbides	Economizer, main steam piping, superheater coils
Fatigue	Vibration fatigue, thermomechanical fatigue, waterside corrosion fatigue, fireside corrosion fatigue	Bends, U-bends, tube-to-header junctions, attemperators
Stress Corrosion Cracking (SCC)	Chloride-induced SCC, caustic stress corrosion, stress-induced corrosion	Austenitic stainless components, steam drum, boiler tubes

Water side corrosion

- Oxygen pitting
- Underdeposit corrosion—caustic gouging
- Underdeposit corrosion—hydrogen damage
- Underdeposit corrosion—phosphate corrosion
- Acid cleaning corrosion
- Internal deposit/corrosion product buildup
- Flow accelerated corrosion

Fireside wastage

- Fireside oxidation
- Fireside corrosion of super heater and reheater tubing
- Fly ash corrosion
- Soot blower erosion
- Coal particle corrosion
- Steam impingement
- Fireside corrosion of water wall tubing
- Erosion
- Low temperature (dew point) fireside corrosion
- Falling slag damage
- Tube rubbing

Stress Rupture Failure

- Short-term overheating (stress rupture)
- Long-term overheating (creep rupture)
- Dissimilar metal weld stress rupture

Metallurgical degradation

- Graphitization
- Sigma phase embrittlement cracking

Fatigue

- Vibration fatigue
- Thermo mechanical fatigue
- Corrosion fatigue—waterside
- Corrosion fatigue—fireside

SCC

- Stress-corrosion cracking
- Stress induced corrosion

Figure 1: Comprehensive damage mechanism categories for boiler components: from waterside corrosion to stress corrosion cracking (Source: TCR Advanced)

4.1 Creep: The Dominant High-Temperature Damage Mechanism

Among all the damage mechanisms operating in high-temperature boiler components, creep is the most consequential and the least amenable to simple visual detection. Creep is the time-dependent plastic deformation of metallic materials subjected to sustained stress at temperatures above approximately 40% of the absolute melting temperature of the alloy.

In carbon steel boiler tubes, the initial signs of creep can develop at temperatures as low as 400°C - 425°C, in low-alloy Cr-Mo steels (T11, T22) around 500°C, and in P91/T91 alloys at a temperature around 520°C - 540°C. Creep damage progresses through four different stages of metallurgical development, which can be seen by means of either optical or electron microscopy:

- Stage 1: Isolated Cavities - Void formation occurs at grain boundaries and particularly at triple points and from inclusions. At this stage, the component's structural integrity is still intact and its external dimensions are normal; thus, it cannot be detected by any other means than in situ metallography.
- Stage 2: Oriented Cavities - More cavities are formed, and they start to align with the grain boundaries that are perpendicular to the principal stress direction. Microhardness may begin to decrease during this stage.
- Stage 3: Microcracks - The coalescing of voids causes microcracking along the grain boundaries. Dimensional inspection will show swelling of the walls and a subsequent loss of hardness. The component will require either repair or replacement before the next inspection.
- Stage 4: Macrocracks - The microcracks will connect with other microcracks and create visible macrocracks that can be detected by surface non-destructive testing (NDT) techniques (e.g., magnetic particle inspection [MPI] or dye penetrant inspection [DPT]). Continued operation of the equipment is unsafe and must be repaired or replaced immediately.
- Stage 5: Fracture - Total failure due to rupture of the material and resulting catastrophic failure of the component. The Neubauer and Wedel damage classification system quantifies creep damage based on the ratio of cavitated

grain boundaries to total grain boundaries (the 'A' parameter), enabling remaining life to be quantified from in-situ metallographic observations made during planned shutdowns.

4.2 Flow Accelerated Corrosion (FAC): The Invisible Threat

Flow Accelerated Corrosion is a particularly insidious mechanism that has caused several catastrophic failures in thermal power plants worldwide, including the 1986 Surry Power Station feedwater line rupture and numerous industrial boiler failures in India. FAC operates when the protective magnetite (Fe_3O_4) layer on the internal surface of carbon steel pipework and headers is dissolved by the flowing water or wet steam at a rate faster than it can be regenerated.

FAC is strongly influenced by water chemistry (pH, dissolved oxygen, and reducing agent dosing), flow velocity, geometry (bends, tees, reducers, and orifice plates are high-risk locations), and alloy content (as little as 0.1% chromium dramatically reduces FAC susceptibility). The damage produces a characteristic orange-peel or scalloped surface on the internal bore, with wall thinning that can be detected by ultrasonic thickness measurement or internal videoscope. Periodic UT scanning at high-risk geometries, particularly the extrados of bends in low-pressure feed systems is mandatory for safe operation.

5. The RLA Methodology: From Data Collection to Life Estimation

Remaining Life Assessment is not a single test, it is a structured, three-phase engineering investigation that systematically integrates historical data, field observations, laboratory testing, and analytical calculations to arrive at a technically defensible judgement about the residual service life of boiler components.

5.1 Phase 1: Understanding the Existing Plant

An effective RLA begins in the control room and the maintenance office, not in the boiler itself. The historical investigation phase involves:

Review of original design documentation: material specifications, design pressure and temperature, fabrication records, and original inspection reports.

Operational history analysis: total operating hours, number of startups and shutdowns, episodes of abnormal operation (overheating, water hammering, tube failures), and any previous repairs or component replacements.

Water chemistry records: review of feedwater and boiler water quality logs to assess the historical risk of internal corrosion, scale deposition, and hydrogen damage.

Maintenance records: previous tube replacement statistics (quantity, location, frequency) particularly revealing of systematic damage patterns.

This phase establishes the 'grey areas' – the components and locations that deserve intensified attention during the field inspection phase.

5.2 Phase 2: Field Inspection – Non-Destructive and Destructive Testing

The field inspection phase integrates a matrix of NDT techniques selected based on the damage mechanisms identified in Phase 1 and the metallurgical characteristics of each component. TCR Advanced Engineering's standard boiler RLA inspection matrix applies the following techniques systematically:

Visual Testing (VT) and Remote Visual Inspection (RVI)

Visual testing remains the foundational NDT method and the most versatile diagnostic tool available to the boiler engineer. A methodical visual examination of the boiler structure assessing distortion and bowing of superheater and reheater coils, displacement of headers, condition of expansion joints, hangers and supports, and the overall structural integrity of the boiler frame provides a rapid qualitative assessment of the health of the entire system. Deformation patterns are particularly valuable: bowing of tube panels indicates flow maldistribution and potential overheating; displacement of headers suggests restraint forces from thermal expansion that may be inducing creep at header stubs.

Remote Visual Inspection (RVI), performed using videoscopes of varying probe diameters (4 mm to 90 mm), extends visual access to the interior of steam drums, headers, tubes, and piping where direct inspection is physically impossible. RVI is particularly effective for detecting internal corrosion, deposit accumulation, erosion, and localised pitting – as illustrated in TCR Advanced's Case Study 5, where videoscope inspection of water wall headers revealed severe clogging with debris, subsequently confirmed as a water quality-driven deposit accumulation problem that could have led to heat transfer blockage and tube overheating.

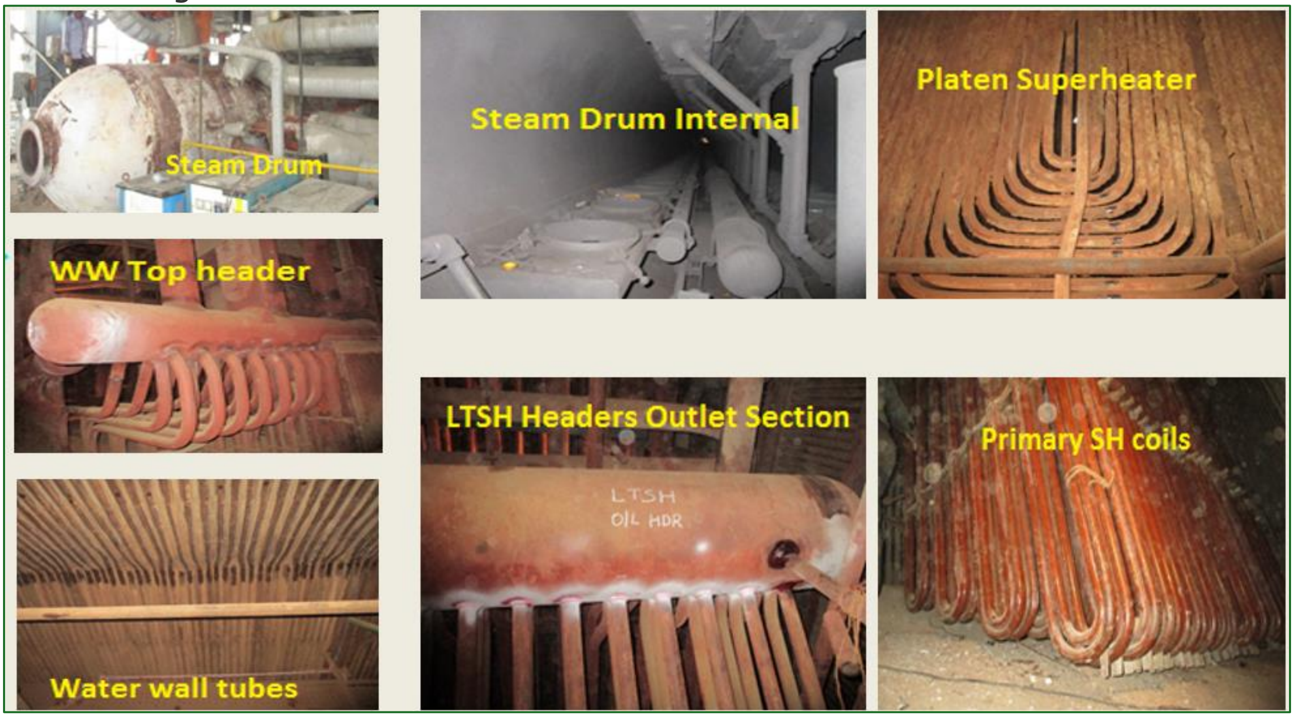

Figure 2: Visual examination photographs during RLA study — steam drum, water wall tubes, platen superheater, primary SH coils, WW top header, and LTSH outlet section (Source: TCR Advanced)

Ultrasonic Testing (UT) and Advanced UT Techniques

Conventional UT (using pulse-echo A-scan) provides wall thickness measurements and subsurface flaw detection. For boiler tubes, systematic UT thickness mapping identifies erosion and corrosion thinning in economizer coils, water wall tubes around soot blowers and burners, and in areas of confirmed FAC risk.

Phased Array Ultrasonic Testing (PAUT) and Time-of-Flight Diffraction (TOFD) have fundamentally transformed weld inspection capability in high-energy piping and headers. PAUT enables electronically-steerable beams that simultaneously sweep multiple angles through the weld volume, providing superior sensitivity to planar flaws (including fatigue cracks, Type IV creep cracks, and lack-of-fusion defects) and superior flaw sizing accuracy compared to conventional multi-angle UT. TOFD provides high-accuracy flaw depth sizing from diffracted signals, making it the preferred technique for fitness-for-service assessments of detected indications. In TCR Advanced's Case Study 3 (steam drum failure after 25 years), the combination of WFMPI and PAUT precisely characterised a 40 mm long, 43 mm deep crack at a drum nozzle, enabling targeted repair and return to service. Internal oxide scale thickness measurement using specialised high-frequency UT transducers is a critical technique for estimating the cumulative thermal exposure of superheater and reheater tubes. As the internal magnetite scale builds beyond 0.33 mm, it functions as a thermal insulator, progressively elevating metal temperature above the design value and accelerating creep damage. The scale thickness is directly correlated to the Larsen-Miller Parameter, allowing remaining tube life to be quantified non-destructively.

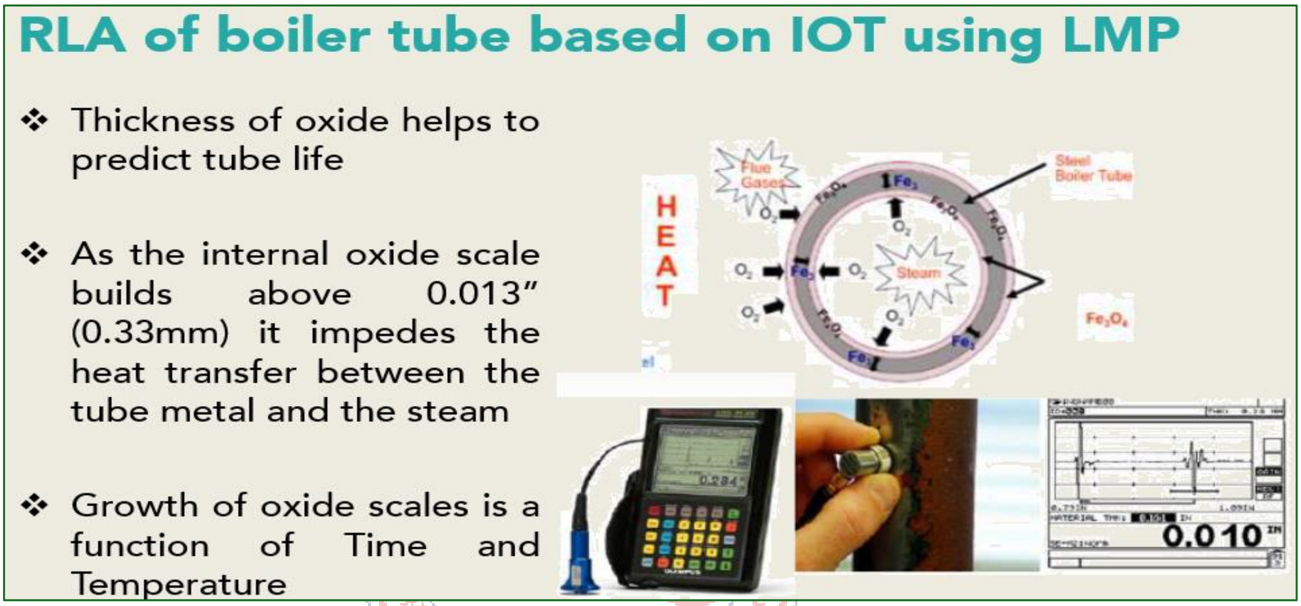

Figure 3: Internal Oxide Scale (IOT) – oxide growth mechanism in a boiler tube cross-section and UT-based scale thickness measurement; scale thickness > 0.33 mm signals elevated metal temperature history (Source: TCR Advanced)

Surface NDT: Dye Penetrant Testing (DPT) and Magnetic Particle Testing (MPT)

DPT and MPT are the workhorses of surface crack detection on boiler components. DPT, exploiting the capillary action of liquid penetrant into surface-breaking discontinuities, is applicable to any non-porous material and is particularly effective for detecting fatigue cracks, stress corrosion cracks, and thermal fatigue cracks on tube surfaces, header welds, and nozzle connections. Case Study 6 (main steam piping failure after 10 years) illustrates how DPT during a routine RLA study detected a critical crack at a nozzle-to-pipe junction that, if left undetected, would have led to a potentially catastrophic failure.

MPT, using the principle of magnetic flux leakage, is restricted to ferromagnetic materials but offers faster coverage and is particularly suited to the inspection of steam drums, water drums, and headers for stress corrosion cracks, hydrogen-induced cracking, and fatigue cracks at tube ligaments. Wet Fluorescent MPI (WFMPI) significantly enhances sensitivity – detectable in several of TCR Advanced's documented steam drum case studies.

In-Situ Metallography (ISM): The Metallurgical Microscope in the Field

In-situ metallography is the most powerful and distinctively metallurgical tool in the boiler RLA arsenal. It involves the preparation and examination of a metallographic replica of the component surface directly in the field – without removing the component from service or extracting a sample. The process involves mechanical polishing and chemical etching of a localised area of the component surface, followed by the application of a thin acetate film that captures the etched microstructure. The replica is subsequently examined under an optical microscope.

ISM provides direct observation of: creep cavity density and stage (Neubauer classification), carbide morphology (an indicator of averaging and high-temperature exposure), graphitisation in carbon steel components (a severe embrittlement mechanism), microcrack detection, and the characterisation of phase changes in stainless steel components (sigma phase embrittlement). In a comprehensive boiler RLA study, TCR Advanced routinely produces more than 125 metallographic replicas from a single 210 MW boiler – covering every significant high-temperature component from steam drum to main steam piping.

5.3 Destructive Testing: The Laboratory Evidence

For components where in-situ methods are insufficient or where a component has been retired from service (typically a tube sample extracted during shutdown), a comprehensive laboratory examination is conducted. This includes:

Chemical analysis by Optical Emission Spectrometry (OES): Verifies material identity and detects any deviation from the specified composition that may explain premature degradation.

Microstructural examination: Optical metallography at 100× to 400× magnification and Scanning Electron Microscopy (SEM) at higher magnifications for detailed characterisation of damage morphology, fracture surfaces, and phase identification.

Hardness and micro-hardness testing: Depletion of hardness below the design range indicates over aging (carbide coarsening) and reduced creep strength; elevation may indicate susceptibility to embrittlement or SCC.

Tensile testing: Verifies that retained mechanical properties (yield strength, UTS, elongation) meet the minimum specification requirements; reduced ductility signals embrittlement.

Accelerated creep rupture testing: The most direct measure of residual creep life test samples are subjected to elevated stress and temperature, and rupture time is extrapolated to service conditions using the Larsen-Miller or Monkman-Grant relationship. Mandatory for final superheater tubes and dissimilar metal welds in P91/T91 systems.

Internal scale characterisation: Scale deposit density measurement and EDS (Energy Dispersive X-ray Spectroscopy) analysis identifies the composition of internal deposits critical for diagnosing the specific corrosion mechanism and improving water chemistry control.

Figure 4: TCR Advanced Engineering's laboratory capability — SEM, creep testing machine, optical microscope, hardness testing, OES spectrometer, UTM, digital weighing, and image analysis software (Source: TCR Advanced)

6. Field Case Studies: Metallurgical Failures Averted by RLA

The following case studies from TCR Advanced Engineering's operational portfolio illustrate the range of defects detectable through systematic RLA all of which could have led to catastrophic failures had they remained undetected.

Case Study 1: Stress Corrosion Cracking in Waste Heat Boiler Shell (Petrochemical Plant)

Component: Shell and tube waste heat fired boiler, SA515 Gr. 70, 2088 mm OD × 28 mm thick. Operating at 26 bar and 225°C. **Finding:** During RLA, visual examination followed by Wet Fluorescent MPI revealed linear indications at inspection nozzles on the shell. Ultrasonic testing confirmed sub-surface discontinuities of 18–55 mm length at depths of 12–25 mm below the OD surface.

Metallurgical Analysis: In-situ metallographic examination showed fine-grained ferrite and pearlite with inter- and trans-granular crack morphology consistent with stress corrosion cracking originating from residual welding stresses in the heat-affected zone, promoted by the plant's water chemistry.

Resolution: Targeted repair of the affected nozzle zones with standard SMAW procedure, followed by PWHT to relieve residual stresses and post-repair WFMPI verification. A programme of water chemistry monitoring and periodic MPI of nozzle zones was instituted as part of the ongoing integrity management plan.

Case Study 2: Thermal Fatigue Cracking in Steam Drum – 17-Year-Old Power Boiler

Component: Steam drum, SA516 Gr. 70, design pressure 71.4 kg/cm², design temperature 287°C. **Finding:** WFMPI during the first RLA study at 17 years of service revealed a 52 mm long linear indication at 31 mm depth at a riser connection nozzle. **Metallurgical Analysis:** In-situ metallography showed fine-grained ferrite with trans-granular crack morphology filled with oxidation products classic thermal fatigue, driven by cyclic thermal stresses at the nozzle-to-drum junction during repeated startups and shutdowns. **Resolution:** Weld repair and PWHT. Review of startup procedures to limit thermal gradients during cold starts.

Case Study 3: Sub-Surface Drum Cracking at 25 Years — Detected by PAUT

Component: Steam drum, SA516 Gr. 70, design pressure 83 kg/cm², design temperature 526°C. **Finding:** WFMPI revealed a surface-breaking indication. PAUT characterised the defect as 40 mm long, 43 mm deep extending to within 30% of the drum wall thickness. Without PAUT, the true depth and criticality of this crack would have been significantly underestimated by conventional UT. **Resolution:** Repaired in-situ. The PAUT data supported a fitness-for-service assessment that confirmed the repair adequacy.

Case Study 4: HTHA Detection in Water Wall Tubes – Preventing Catastrophic Rupture

Component: Water wall tubes (carbon steel). **Finding:** During RLA, Advanced Ultrasonic Backscattering Technique (AUBT) detected back-scatter signals characteristic of High Temperature Hydrogen Attack (HTHA) at gooseneck tube welds at the 5th floor. HTHA occurs when atomic hydrogen diffuses into the steel and reacts with carbon to form methane (CH_4), creating internal voids and reducing ductility to near-zero. **Resolution:** Affected tube sections replaced immediately. Macroscopic examination of the removed tubes confirmed blister-like hydrogen damage on the external surface, validating the AUBT detection.

7. Deliverables of an RLA Study: What the Operating Engineer Should Expect

An accurate boiler RLA is much more than just a collection of inspection reports and testing statements, it is a detailed engineering document that allows the operating and maintenance staff to have a clear actionable path to follow for the upcoming life of the plant. The major deliverables should be:

Remaining Life Matrix - Component-by-component remaining service life estimates shown by different analytical methods (LMP, IOT, Neubauer, MAWP) including a confidence interval and the associated limiting damage mechanism per component.

Equipment Action Matrix - Each finding ranked and tabulated with four categories; (a) Immediate replacement necessary, (b) Conditional use and additional monitoring, (c) Replace recommended at planned outage, (d) Satisfactory - re-inspect when determined.

Recommendations for Repair and Remediation - Indicating the type of repair method that is required for each defective part (weld repair method, PWHT requirements, follow-up inspection method).

Recommendations for Operation - Suggested changes in the manner of operation - (steam parameters, startup curves, water chemistry goals, chemical cleaning frequencies,) so as to limit the rate at which the parts will degrade and to increase the useful life of the components.

Material Upgrade Recommendations: Where a recurring failure pattern points to a material deficiency (e.g., carbon steel tubes in a location where T11 or T22 is warranted by the thermal duty), material grade upgrades are formally recommended.

Inspection Plan for Next Outage - An inspection plan prioritised by risk for which components will require re-inspection prior to the next time the plant is shut down, and which non-destructive testing method should be applied, based upon the anticipated extent of damage.

8. Key Metallurgical Principles for Boiler O&M Engineers

The essence of metallurgically-informed boiler maintenance can be distilled into a set of principles that should guide the decision-making of every engineer responsible for keeping these critical assets operating safely and efficiently.

Key Takeaways for Boiler O&M Engineers

1. Understand your damage mechanisms: Every boiler has a unique degradation profile shaped by fuel type, water chemistry, operating cycles, and material selection. RLA is only as good as the engineer's understanding of the operative damage mechanisms.

2. Never substitute regulatory compliance for engineering insight: IBR compliance is a minimum legal requirement. Genuine integrity management demands metallurgical evaluation, microstructural analysis, and fitness-for-service assessment.

3. Quantify creep life proactively: For high-temperature headers and piping (particularly P91/T91), in-situ metallography and accelerated creep rupture testing must be routine — not reactive.

4. Internal oxide scale is your metallurgical logbook: For superheater and reheater tubes, IOT measurement is the most reliable, non-invasive indicator of thermal history and impending failure risk.

5. Advanced NDT is an investment, not a cost: PAUT, TOFD, HTHA detection, and videoscope detect latent defects before they become catastrophic failures, dramatically extending plant life and ensuring personnel safety.

6. Water chemistry is the silent lifecycle determinant: Poor feedwater quality is the root cause of under deposit corrosion, FAC, hydrogen damage, and internal pitting — all of which silently consume boiler life between shutdowns.

7. Document everything; trend what you measure: RLA delivers maximum value when successive inspections are compared against each other. Trending allows early intervention and transforms historical data into predictive intelligence.

9. Conclusion

- Boilers are not merely mechanical systems, they are metallurgical systems in which material science, thermomechanical loading, and chemical environment interact in complex, time-dependent ways. The engineer who understands these interactions – who reads a creep-cavitated microstructure as fluently as a pressure-temperature chart is equipped to make the decisions that separate safe, extended asset life from premature failure and unplanned outage.
- TCR Advanced Engineering's experience across more than 400 boiler RLA studies demonstrates conclusively that systematic, knowledge-based inspection integrating advanced NDT, in-situ metallography, and rigorous life assessment calculations consistently detects latent defects at early, repairable stages. The cases presented in this article from stress corrosion cracking in petrochemical boilers to HTHA in power plant water walls represent a fraction of the failures averted through proactive integrity management.
- The economics are unambiguous: a comprehensive RLA study, conducted at appropriate intervals, costs a fraction of a single unplanned boiler tube failure and an infinitesimal fraction of the catastrophic consequences of a steam drum rupture or main steam piping failure. For India's thermal power sector, which must extend the operational life of its existing fleet while integrating increasing renewable generation, the knowledge-driven approach to boiler integrity management is not optional, it is essential.

Mr. Nikhil H. Sabhaya | Manager – NDT & RLA, TCR Advanced Engineering Pvt. Ltd.

Mr. Nikhil Sabhaya holds a Post Graduate in Metallurgical Engineering and brings over 10 years of specialised hands-on experience in Non-Destructive Testing and Remaining Life Assessment of static equipment across the petrochemical, fertilizer, power, and chemical industries. He is certified as ASNT NDT Level III in VT, PT, MT, UT, and ET, and additionally holds API 510, API 571, and CSWIP 3.1 certifications.

At TCR Advanced Engineering, he leads shutdown inspections and RLA studies for boilers, reformer tubes, pressure vessels, piping, and storage tanks. His expertise encompasses in-situ metallography, creep analysis, accelerated life assessment, and a comprehensive range of advanced NDT techniques including Acoustic Emission (AE), Phased Array Ultrasonic Testing (PAUT), Time-of-Flight Diffraction (TOFD), Eddy Current Array (ECA), Magnetic Flux Leakage (MFL), and Videoscope.

He has successfully led numerous critical shutdown inspections across India, the Middle East, Africa, and Latin America, contributing to enhanced asset integrity, operational safety, and life extension.

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Exergy Analysis of an 800 MW Supercritical Coal-Fired Thermal Power Plant

By
Kuldeep Ruparelia,
Certified Energy Auditor, ERDA
Arunesh Dwivedi
Accredited Energy Auditor, ERDA

ABSTRACT

Coal-fired thermal power plants remain central to India's electricity generation, contributing nearly 70% of total output despite the rapid growth of renewables. Modern supercritical units of 660–800 MW capacity face new operational challenges such as flexible & rapid load ramping, two-shifting, low load stable operation, AGC and ancillary service participation, which increase heat rate deviations, equipment fatigue, and cycling losses. Plants also faces the challenges from availability of fuel with high ash content, lower GCV and variable moisture and quality; along with efficiency challenges.

Exergy analysis, based on the Second Law of Thermodynamics, provides a more realistic measure of plant performance by identifying where useful work potential is destroyed due to irreversibility. This study presents a detailed heat–mass–exergy analysis of an 800 MW supercritical coal-fired plant using reconciled field data from distributed control systems and local instrumentation. A rigorous iterative methodology was applied to ensure closure of mass, energy, and exergy balances across turbine extractions, heater drain cascades, deaerator, condenser, and boiler feed systems.

The present study paper focuses on detailed heat-mass-exergy analysis of an 800 MW supercritical coal fired thermal power plant operating under actual field conditions. The study has been carried out using real operating data collected from the Distributed Control System (DCS) performance monitoring systems, and local instrumentation installed across the plant as well as setting up temporary portable instruments. A rigorous iterative methodology has been adopted for reconciliation of turbine extraction flows, heater drain cascades, deaerator balance, condenser balance, boiler feed pump recirculation, gland steam system interaction, and overall steam- water cycle closure.

The study proposes an optimization framework prioritizing combustion control, air ingress minimization, soot blowing effectiveness, and LP heater overhauling. The methodology offers a practical tool for diagnostics, operational optimization, and energy auditing in large coal-based thermal power stations.

1. INTRODUCTION

The performance of coal-based thermal power plants has traditionally been assessed using first law (energy- based) methods, which ensure conservation and balance closure. However, these approaches do not capture the degradation in energy quality that occurs within various components of the cycle. As a result, they cannot fully identify the true thermodynamic losses or provide a reliable basis for optimization.

Exergy analysis, grounded in the Second Law of Thermodynamics, addresses this limitation by quantifying the useful work potential of energy streams and measuring irreversibility in each process. Exergy is destroyed whenever combustion, heat transfer across finite temperature differences, throttling, friction, or mixing losses occur. Thus, exergy provides a direct measure of thermodynamic imperfection and highlights where useful work potential is lost.

In large regenerative thermal cycles, this distinction is critical. For example, while the condenser rejects vast amounts of low-grade heat, its exergy contribution is minimal compared to the high-quality electrical energy produced at the generator terminals. Exergy analysis captures this difference, offering a more realistic assessment of component performance.

Second-law efficiency, or exergy efficiency, further strengthens this perspective by evaluating how effectively a component utilizes the available work potential. For turbines, it reflects the conversion of steam exergy into mechanical work; for boilers, the conversion of fuel chemical exergy into steam exergy; and for heaters or condensers, the degradation associated with heat transfer and mixing.

By directly linking exergy destruction to entropy generation, exergy analysis provides deeper insight into performance limitations and optimization opportunities than conventional energy analysis. It complements rather than replacing first-law methods, ensuring both conservation and quality assessment. Together, these approaches enable a comprehensive and realistic evaluation of thermal power plant performance.

The physical exergy of a flowing stream is expressed as:

$e=(h-h_0)-T_0(s-s_0)$ --- equation (1) Where,

e = specific exergy (kJ/kg)

h = specific enthalpy (kJ/kg)

h_0 = reference enthalpy (kJ/kg)

s = specific entropy (kJ/kg·K)

s_0 = reference entropy (kJ/kg·K)

T_0 = ambient reference temperature (K)

For turbines, second law efficiency represents the effectiveness of converting available steam exergy into mechanical work. In boilers, it reflects the effectiveness with which fuel chemical exergy is converted into useful steam exergy. Similarly, for regenerative heaters and condensers, second law analysis provides insight into the thermodynamic degradation associated with heat transfer and mixing processes.

2. IMPORTANCE OF EXERGY ANALYSIS IN THERMAL POWER PLANTS

Traditional performance evaluation of thermal power plants relies on heat rate, efficiency, and energy balance calculations. While these methods are useful for operational monitoring, they cannot reveal the true causes of thermodynamic degradation. Energy analysis treats all forms of energy equally, failing to distinguish between high-quality work and low-grade heat.

Exergy analysis, by contrast, evaluates both the quantity and quality of energy. It identifies where useful work potential is destroyed due to irreversibility such as combustion losses, heat transfer across finite temperature differences, throttling, pressure drops, moisture formation, and mixing. This makes exergy analysis a far more realistic tool for diagnosing inefficiencies and prioritizing optimization.

Key advantages of exergy analysis includes identification of irreversibility pinpoints components with the highest exergy destruction, such as boilers and condensers; optimization prioritization establishes a rational basis for focusing on the most thermodynamically significant losses; detection of hidden inefficiencies reveals performance issues not apparent in conventional energy balances, such as heater drain mismatches or condenser vacuum deterioration and complementary insights works alongside energy analysis to ensure conservation while exposing quality degradation.

3. MEASUREMENT AND CALCUALTION METHODOLOGY

The objective of the methodology was to develop a thermodynamically consistent and field-reconciled representation of the complete steam–water cycle of the 800 MW supercritical unit. Since plant instrumentation is subject to uncertainties such as sensor inaccuracies, calibration deviations, and operating transients, direct use of raw DCS data often leads to imbalances in cycle calculations. To overcome this, an iterative reconciliation approach was adopted to achieve closure of mass, energy, and exergy balances.

The reconciliation process involved sequential determination of turbine extraction flows, regenerative heater drain cascades, Deaerator and Hotwell mixing balances, Condenser closure and Boiler feed pump recirculation and team–water cycle convergence.

Actual operating temperatures, pressures, and flows were obtained from plant instrumentation, supplemented by portable measurements. Special emphasis was placed on regenerative feed heating systems, as even minor deviations in drain enthalpy or condensate entropy can lead to unrealistic exergy destruction values. Multiple iterations were performed to reconcile extraction flows, drain temperatures, and feedwater enthalpy rise across individual heaters. The reconciled model was accepted only after satisfying the following criteria:

1. Closure of overall steam–water mass balance
2. Closure of individual component energy balances
3. Positive exergy destruction values for all components
4. Consistency with actual plant operating conditions
5. Physically meaningful regenerative heater behaviour

This iterative methodology ensured a reconciled and physically consistent representation of the plant cycle, forming the basis for accurate exergy destruction and second-law efficiency calculations. The reference parameters measured for calculation of Exergies and Energy balances are as follows:

Parameter	Value
Ambient dry bulb temperature (DBT)	28.4°C
Relative humidity (RH)	54.90%
Atmospheric pressure	1.013 bar(a)

Table 1. Reference parameters (ambient parameters) for exergy calculation

The values of heaters parameters are as follows:

Equipment	FW/ Conden-sate Flow	FW Inlet Temp.	FW Outlet Temp.	Steam Pressure	Steam Temp.	Steam Flow	Drain Inlet Temp.	Drain Outlet Temp.
	TPH	0C	0C	kg/cm2(g)	0C	TPH	0C	0C
HPH-8	2462.27	259.2	293	83.6	400.4	228.22	--	283.0
HPH-7	2462.27	212.4	259.2	62.3	344	240.72	283.0	230.7
HPH-6 + DSH	2462.27	191.5	300.2	24.4	465.1	101.19	230.7	196.8
LPH-4	1765.81	129	149	4.5	262.5	63.9	--	149
LPH-3	1563.34	80	129	2.3	191	138.56	149	129
LPH-2	1563.34	67	80	-0.483	83.5	38.19	129	82.85
LPH-1	1563.34	54	67	-0.752	66.5	38.5	82.85	67.05
Deaerator	2462.27	149	187.3	11.5	364	126.33	--	--

Table 2. Parameters of Feed Water and condensate heaters

Flow was measured at condensate line to LPH 3 inlet. After carrying out iterative heat and mass balance, the flows are as follows:

Flow parameters (TPH)	Value
Main Steam Flow	2452
Feedwater Flow	2462.27
CRH Flow	1975.92
HRH Flow	1980.41
BFP Recirculation	228.05
GSC Recirculation	37.1
SH Spray	160.8
RH Spray	4.49
Boiler Blowdown	10.27
LP Exhaust to condenser	1335.53
TDBFP Steam Extraction	144.65
Gland Steam Extractions	0.701
Coal Flow	471.58

Table 3.Flow of various streams after carrying out heat mass balance iterations

The parameters of turbines are as follows: *Table 4. Parameters of Steam Turbines*

Section	Pressure	Temperature
HP Turbine Inlet	249.45 kg/cm2(g)	568°C
CRH	61.87 bar(g)	344.6°C
HRH	58.31 bar(g)	593.5°C
IP Turbine Exhaust	4.5 kg/cm2g	262.5
LP Exhaust-1	0.091 bar(a)	44.3°C
LP Exhaust-2	0.125 bar(a)	50.6°C

The gross power generation was 790 MW and the net power generation was 759.34 MW. The boiler flue gas parameters were observed as follows:

Parameter	**APH Inlet**	**APH Outlet**
Flue gas temperature	344.5°C	136.5°C
O_2 concentration	2.95%	5.80%
CO_2 concentration	16.05%	13.20%
Hot secondary air temperature	30.8	304.5
Hot primary air temperature	31.4	298.5

Table 5. Parameters of Air-preheater

Flue gas temperature observed across flue gas path are as follows:

Flue gas path location	Temperature °C
Superheater platen inlet	1240
Finish RH inlet	1000
Finish SH inlet	910
LT RH inlet	740
Economizer inlet / LT RH outlet	484
Economizer outlet / APH inlet A	339
Economizer outlet / APH inlet B	350
Economizer outlet / APH inlet average	344.5

Table 6. Parameters of Flue gas path

The ultimate analysis of coal was observed to be:

Coal ultimate analysis parameter	Value
Carbon, C	40.34 %
Hydrogen, H	2.61 %
Oxygen, O	10.72 %
Sulphur, S	0.8 %
Total moisture	10.8 %
Ash	33.76 %
GCV	3850 kcal/kg

Table 7. Ultimate analysis of Coal

4. CALCULATED PARAMETERS

Based on the data measured and calculations carried out, the performance parameters normally considered for analysis of a power plant are as follows:

Parameter	Value
Boiler heat input	2109.29 MW
Boiler heat absorbed (Main Steam)	1460.64 MW
Reheater heat absorbed	346.04 MW
Total heat supplied to cycle	1806.68 MW
Gross generation	790.00 MW
Net generation	759.34 MW
Gross turbine heat rate	1967.92 kcal/kWh
Net turbine heat rate	2047.38 kcal/kWh
Gross unit heat rate, fuel basis	2289.96 kcal/kWh
Net unit heat rate, fuel basis	2382.39 kcal/kWh
Net efficiency (First law)	35.999 %

Table 8. Calculated Performance Indicators of Power Plant

The component of Boiler performance are as follows:

Loss Component	**Loss, %**
Dry flue gas loss	4.53
Loss due to H_2 in fuel	3.97
Loss due to moisture in fuel	1.82
Loss due to moisture in air	1.58

Loss due to unburnt in ash	0.62
Loss due to blowdown	0.11
Loss due to sensible heat in ash	0.35
Radiation, convection and miscellaneous loss	1.5
Total losses	14.48
Boiler efficiency	85.52%

Table 9. Losses occurring in Boiler

The exergy parameters and second law efficiency of turbine system are as follows:

Turbine	**Exergy In MW**	**Exergy Out MW**	**Steam Exergy Drop MW**	**Shaft Power MW**	**Exergy Destruction MW**	**Second-law Efficiency**
HP Turbine	1034.24	777.12	257.13	249.94	7.19	97.21
IP Turbine	819.33	464.23	355.1	336.62	18.48	94.80
LP Turbine-1	171.36	36.21	135.15	127.15	8	94.08
LP Turbine-2	171.36	43.7	127.66	124.81	2.86	97.76
Total main turbine train	2196.3	1321.26	875.04	838.51	36.53	95.83

Table 10. Exergy destruction and second law efficiency of Turbines

The exergy parameters of TDBFP Turbines are as follows:

Turbine	**Steam Exergy In**	**Exhaust Exergy Out MW**	**Steam Exergy Drop MW**	**Useful Pump Work MW**	**Exergy Destruction MW**	**Second-law Efficiency %**
TDBFP-A	19.9	2.42	17.48	11.68	5.8	66.81
TDBFP-B	19.72	3.06	16.67	10.98	5.69	65.88
Total TDBFP	39.62	5.47	34.15	22.66	11.49	66.35

Table 11. Exergy destruction and second law efficiency of Turbine driving feed water pumps

The exergy parameters of heaters, deaerators and condensers are as follows:

Heater	**Exergy Gain/Input,**	**Exergy Destruction,**	**Second-law**
HPH-8	54.17	2.2	96.10
HPH-7	61.79	5.91	91.27
HPH-6 + DSH	36.69	4.89	88.24
LPH-1	2.3	1.82	55.79
LPH-2	2.67	3.58	42.73
LPH-3	18.92	4.26	81.62
LPH-4	10.47	2.71	79.44
Deaerator	122.6	20.1	85.90
Condenser	47.3	46.2	2.30

Table 12. Exergy destruction and second law efficiency of feed water and condensate heaters and condenser

The exergy parameters of boiler system are as follows:

Component	**Exergy Destruction / Loss MW**	**Second-law Efficiency, %**
Boiler + Reheater overall	1103	48.4
Air Preheater	25.7	73.88

Table 13. Exergy destruction and second law efficiency of Boiler Components

The chemical exergy of coal was calculated as 2147.93 MW. This leads to overall second law efficiency being
35.35%.

5. ANALYSIS OF CALCULATED PARAMETERS

The reconciled analysis indicates that the 800 MW supercritical coal-fired unit is thermodynamically performing reasonably well, but the dominant inefficiencies are concentrated in the boiler combustion and high-temperature heat-transfer regions. The biggest component of exergy destruction are Boiler + Reheater, Turbine train, Condensers, Heaters and Deaerator. This is as per expectation because combustion is highly irreversible, high furnace temperature, high ash content and moisture content in coal and large temperature gradients being existing between flue gas and steam/water surfaces. The overall second law efficiency of turbine being 95.8% indicating good expansion process, no significant internal loss in turbines, no significant aging of turbines. The low value of second law efficiency in condenser is because it destroys low-grade thermal exergy by rejecting heat near ambient temperature. In case of heaters, the LPH 1 and 2 comes to be a weaker performing heaters. The possible causes may be lower extraction flow, air ingress in heaters or degraded heat transfer surfaces. The flue gas side exergy destruction indicates opportunity of combustion optimization, excess air control, air ingress reduction in APH and furnace heat transfer management.

6. CONCLUSION

- This paper demonstrates that the maximum exergy loss is occurring in Boiler system and less exergy is lost in turbine cylinders.
- Based on the analysis carried out, the highest priority should be given to optimize combustion efficiency of the boiler by optimizing excess air supply, minimizing false air/air ingress in boiler system, maximizing release of inherent chemical energy of coal by improving coal quality and fineness, improve soot blowing effectiveness.
- The medium priority should be given to performance improvement of LP Heaters 1 & 2, drain cascade; whereas the least priority should be given to work on turbine as the turbine train is performing comparatively well.

About Authors

Er. Kuldeep Ruparelia received his Graduate in Electrical Engineering from Gujarat Technological University, India and is a Certified Energy Auditor from Bureau of Energy Efficiency, Ministry of Power, Government of India and Lead Verifier for ISO 14064. He is currently associated with R&D and Expert Services division of Electrical Research and Development Association (ERDA), Vadodara and has practical experience of around 14 years in the field of power plant performance analysis, energy auditing, thermodynamic energy balance study and exergy analysis, boiler-turbine efficiency evaluation, and operational diagnostics of coal-based thermal power plants. He has carried out more than 80 energy audits in energy intensive industries and power plants. His research interests include performance of energy intensive processes and instruments, pinch technology, power system study, power system operation under ABT/DSM mechanisms.

Er. Arunesh Dwivedi is Manager and Accredited Energy Auditor at the Electrical Research & Development Association, Vadodara. He obtained his M. Tech Honors in Energy Management from School of Energy and Environmental Studies (DAVV Indore), and BE Chemical Engineering from National Institute of Technology, Raipur. He is Accredited Energy Auditor from Bureau of Energy Efficiency, Government of India and Lead Verifier for ISO 14064. He has been working in Energy conservation field for the last 19 years and conducted more than 300 energy audits of various process industries, cement sector and power plants. His professional interest includes Thermodynamics, Fluid Mechanics, Transport phenomenon, Heat and Mass Transfer, Process Optimization and Energy Conservation. He has also worked for process and energy optimization of Cement plants.

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Renewable Energy Integration and Thermal Flexibilization Costs: Evidence from GSECL Thermal Power Plants

By

Er. Rutvij Patel, Er. Kandarp Mistry & Er. Nitesh Bidarkar

Abstract: The surge of intermittent renewable energy (RE) in India is forcing coal-based thermal plants, designed for stable baseload operation, into flexible ”load-following” roles. This shift triggers significant performance degradation, specifically increased Station Heat Rate (SHR) and Auxiliary Power Consumption (APC). This paper analyzes the operational and economic impacts on the Gujarat State Electricity Corporation Limited (GSECL) fleet. Unlike typical fleets, many GSECL units have historically faced low Plant Load Factors (PLF) due to merit-order displacement, resulting in ”path-dependent” degradation that predates the current RE boom. Analyzing data across multiple stations, the study finds that backdown costs range from INR 0.17/kWh to INR
0.54/kWh, with older subcritical units suffering the most. The findings suggest that current regulatory framework based on benchmarks of central generators might be inadequate and formulation of new regulatory compensation frameworks must be considering benchmark costs of regional fleet operating under similar conditions.

1. Introduction:

India’s aggressive push toward 500 GW of non-fossil fuel capacity by 2030 has fundamentally altered the grid’s operational DNA. In Gujarat, a leader in solar and wind deployment, this transition is particularly acute. While RE expansion is a climate necessity, its inherent variability forces conventional thermal plants to abandon their design as baseload generators in favor of frequent ramping, low-load operation, and reserve shutdowns.

This transition from ”steady state” to ”flexible” operation comes at a high technical cost. Operating at low PLFs deteriorates the Gross Heat Rate (GHR) and increases APC, while frequent cycling accelerates equipment wear and reduces residual life. Recognizing these burdens, the Central Electricity Regulatory Commission (CERC) has established compensation mechanisms; however, these rely on generic normative assumptions that fail to capture the unique degradation trajectories of individual plants.

The GSECL fleet presents a critical case study. Many of its units, particularly older subcritical ones, have operated under flexible conditions for years—not just due to RE integration, but because of merit-order displacement driven by higher variable costs. Consequently, these plants entered the high-RE era with significant accumulated stress.

This paper argues that RE integration impacts are not uniform. By evaluating GSECL operational data, this study quantifies the relationship between PLF reduction and efficiency loss, calculates specific backdown costs, and highlights why regulatory frameworks must evolve to incorporate plant-specific historical data and technology profiles.

2. Renewable Energy Integration and Flexible Thermal Operation:

Renewable energy integration introduces variability and uncertainty into the operation of modern power systems. Solar generation follows a pronounced diurnal pattern and is highly sensitive to cloud cover and weather conditions. Wind generation similarly fluctuates depending on meteorological conditions and seasonal variability. Unlike thermal generators, renewable sources generally cannot be dispatched according to operator requirements.

Consequently, thermal power plants increasingly serve as balancing resources responsible for maintaining supply-demand equilibrium in real time. This balancing role requires thermal units to:

- Operate at lower loading levels
- Ramp generation rapidly
- Undergo frequent start-stop cycles
- Accommodate reserve shutdowns
- Respond to renewable generation variability

Flexible operation significantly affects thermal plant performance. At lower loading levels, the efficiency of boiler and turbine systems deteriorates due to reduced heat transfer efficiency, unstable combustion conditions, and non-optimal steam parameters. Auxiliary systems such as pumps, fans, and mills continue consuming power even at reduced generation levels, thereby increasing Auxiliary Power Consumption (APC) as a percentage of output.

The primary operational impacts of flexible generation include:

Gross Heat Rate Degradation Gross Heat Rate (GHR) measures the thermal efficiency of a generating unit and indicates the amount of heat energy required to generate one unit of electricity. Thermal units are typically designed for optimal operation near rated capacity. At lower Plant Load Factors (PLFs), boiler efficiency, steam cycle efficiency, and turbine performance deteriorate, leading to increased GHR.

Higher GHR implies increased fuel consumption for the same electrical output, resulting in increased energy charges and reduced operational efficiency.

a. Increase in Auxiliary Power Consumption:

Auxiliary Power Consumption refers to the electricity consumed internally by thermal plant equipment including pumps, fans, pulverizes, cooling systems, and pollution control equipment. While generation output decreases during part-load operation, many auxiliary systems continue operating at near constant loads. Consequently, APC rises disproportionately at lower PLFs.

Mechanical and Thermal Stress Frequent cycling and low-load operation create thermal fatigue in critical boiler-turbine components. Repeated expansion and contraction of metal surfaces accelerate equipment wear, increase maintenance requirements, and reduce residual equipment life.

Increased Maintenance and Overhauling Requirements Flexible operation accelerates degradation of thermal plant equipment, necessitating more frequent overhauling and maintenance interventions. These impacts are particularly severe for older subcritical units that were not originally designed for flexible operation.

The increasing operational burden associated with renewable integration has therefore created a new category of system balancing costs that are increasingly relevant in high renewable power systems.

b. CERC Regulations on Compensation for Flexible Operation:

Recognizing the operational burden imposed on thermal generating stations due to flexible operation and backing down, the Central Electricity Regulatory Commission (CERC) introduced provisions for compensation associated with operation below normative loading levels.

The compensation framework primarily addresses:

- Increase in Station Heat Rate (SHR)
- Increase in Auxiliary Energy Consumption (AEC)
- Additional secondary fuel oil consumption
- Additional start-stop requirements

The framework is intended to compensate thermal generators for additional operational costs arising from renewable integration and grid balancing requirements. SHR Compensation Mechanism CERC regulations prescribe admissible degradation bands in Station Heat Rate based on loading levels.

For coal/lignite-based generating stations. Percentage Permissible Unit Heat Rate of Degradation as per CERC are as under:

Sr. No	Unit loading	Subcritical	Supercritical
1	85-100	Nil	Nil
2	80 - 85	2.1	1.8
3	75 - 80	3.0	2.5

4	70 - 75	4.0	3.3
5	65 - 70	5.1	4.1
6	60 - 65	6.1	4.9
7	55 - 60	7.6	6.0
8	50 - 55	9.2	7.1
9	45 - 50	11.3	8.3
10	40 - 45	13.8	9.9

Table 1: Permissible Heat Rate Degradation as per CERC

For supercritical units, lower admissible degradation levels are specified owing to superior operational efficiency. The compensation mechanism computes the revised Energy Charge Rate (ECR) considering increased SHR and APC due to part-load operation. APC Compensation Mechanism CERC regulations similarly recognize degradation in Auxiliary

Energy Consumption at lower loading levels.

Unit APC Degradation Permissible (%)		
Sr. No.	**Unit Loading (%)**	**Admissible APC (%)**
1	85 -100	Nil
2	80 - 85	0.5
3	70 - 80	1.1
4	60 - 70	1.8
5	50 - 60	2.5
6	40 - 50	3.2

Table 2: Permissible APC Degradation as per CERC

The regulations provide for computation of compensation in terms of incremental energy charges attributable to deterioration in SHR and APC.

Energy Charge Rate Based Compensation - The compensation methodology calculates revised energy charges based on:

- Gross Heat Rate
- Auxiliary Energy Consumption
- Primary fuel prices
- Secondary fuel oil consumption
- Calorific value of fuel

The incremental Energy Charge Rate resulting from degradation in operational parameters is compensated to the generating station.

Regulatory Significance - The CERC framework represents an important regulatory acknowledgement that renewable integration imposes measurable operational costs on thermal generators. However, the framework primarily adopts normative degradation assumptions applicable generically across thermal stations.

This raises important questions regarding whether generic compensation methodologies adequately capture plant specific operational history, legacy degradation, technology differences, and accumulated thermal stress.
These issues become especially relevant in the case of older thermal fleets such as GSECL, where prolonged historical flexible operation predates large-scale renewable integration.

3. GSECL Thermal Fleet and Historical Flexible Operation:

Gujarat State Electricity Corporation Limited (GSECL) operates one of the largest state-owned thermal generation fleets in India. The fleet comprises a combination of aging subcritical units and newer supercritical units.
Historically, several GSECL thermal stations have operated under low PLF and flexible generation conditions due to relatively higher variable generation costs compared to central generating stations which is demonstrated below.

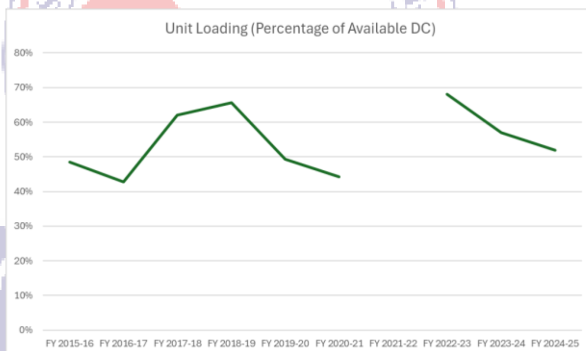

Figure 1: GSECL thermal fleet Loading

Merit Order Displacement In the merit-order dispatch framework followed by Indian power systems, generating stations with lower variable costs are dispatched preferentially. Older GSECL units, particularly subcritical coal units with higher heat rates and aging equipment are often faced with merit order displacement by:

- Central sector coal plants
- Supercritical generating stations
- Renewable energy generation
- Low-cost private generators

As a result, GSECL plants increasingly operated under:

- Reduced PLFs
- Reserve shutdown conditions
- Cyclic operation
- Frequent backing down

- Variable loading patterns

Importantly, these operational conditions existed even before large-scale renewable energy penetration accelerated in Gujarat.

Legacy Operational Stress The prolonged exposure of GSECL plants to flexible operation has resulted in:

- Higher accumulated wear and tear
- Efficiency degradation
- Lower availability levels
- Increased maintenance intensity
- Higher sensitivity to low-load operation

This historical operational burden distinguishes GSECL's fleet from many newer generating stations that historically operated closer to baseload conditions.

Consequently, the incremental impact of renewable integration on GSECL stations must be under- stood within the context of pre-existing operational degradation.

a. Analysis of Flexibilization Costs in GSECL Thermal Stations:

This section evaluates the operational and economic impacts of part-load operation across selected GSECL thermal stations using operational data for FY 2022–23.

The analysis primarily examines:

- Gross Heat Rate degradation
- Auxiliary Power Consumption degradation
- Cost implication of flexible operation

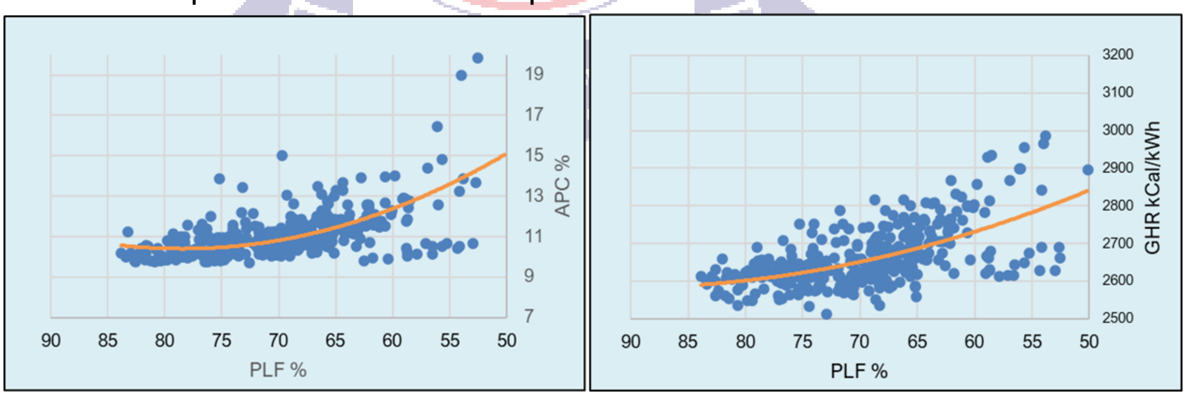

Figure 2: WTPS Unit 1-6 GHR, APC Degradation with Loading

WTPS Units 1-6 and GTPS 3-4 with their high variable costs as compared to other Central Generating stations, have historically been subjected to varying loads and have steeper degradation profiles for GHR and APC as compared to that allowed by CERC compensation mechanism.

The table below enumerates Cost Implication of APC and GHR degradation on GSECL's legacy units.

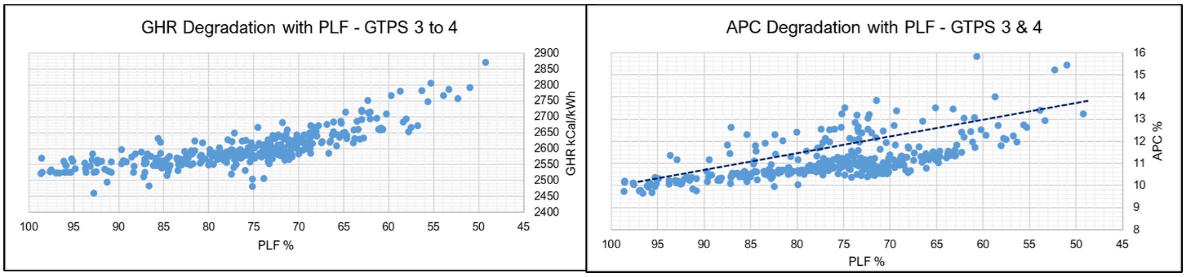

Figure 3: GTPS Unit 3 - 4 GHR, APC Degradation with Loading

WTPS Unit-1-6

Parameter	PLF 85%	PLF 55%	Degradation %	Cost ₹/kWh
GHR	2600	2830	8.85	0.38
APC	10	13.75	3.75	0.16
Overall Cost implications				**0.54**

Gandhinagar TPS Unit 3,4

Parameter	PLF 85%	PLF 55%	Degradation %	Cost ₹/kWh
GHR	2550	2750	7.84	**0.33**
APC	9.7	12.7	3.00	**0.13**
Overall Cost implications				**0.46**

Figure 4: Enter Caption

4. Key Observations:

The analysis of GSECL stations reveals several important trends:

- Older subcritical units exhibit significantly higher degradation under flexible operation.
- Newer supercritical units demonstrate superior flexibility performance and lower operational degradation.
- Historical operational stress materially affects current operational efficiency.
- Plant maintenance and overhauling significantly influence flexibilization costs.
- Flexible operation costs are highly plant-specific and depend strongly on technology vintage and operational history.

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SAFETY STANDARDS & REGULATIONS INCLUDING ELECTRICAL SAFETY – GSECL

By
SAMIR A CHAUDHARI,
Safety Officer, GSECL, Ukai Thermal Power Station

Introduction

Power stations are high-risk industrial environments. Safety is critical to Protect human life, Ensure equipment reliability & Prevent environmental damage. Thermal power plants involve High voltage systems, High temperature & pressure & Complex machinery

1. Objectives of Safety Standards in GSECL:

- Minimize accidents and hazards
- Ensure compliance with legal requirements
- Promote safe culture among employees, workers & their family.
- Ensure generation of reliable, uninterrupted & affordable power from its plants meeting stakeholder's requirements.
- Achieve sustainability in power generation by producing energy, ensuring environmental protection, economic viability and social responsibility.

2. Safety Regulations & Standards and General Safety Practices in GSECL:

a. Key Safety Regulations & Standards

- International Electrotechnical Commission (IEC)
- National Fire Protection Association (NFPA 70E – Electrical Safety)
- Bureau of Indian Standards (IS codes) & Another International Standard
- Central Electricity Authority (CEA Regulations)
- The Occupational Safety, Health and Working Conditions Code (2020)
- Occupational Safety and Health Administration (OSHA)
- ISO 9001:2015, ISO 14001:2015 & ISO 45001:2018

b. General Safety Practices

- Use of Personal Protective Equipment (PPE)
- Daily Meeting Start with Safety in Each Power Plants
- Proper training and certification
- Safety signage and labelling
- Emergency preparedness plans
- Tool box Safety Talk
- Use of Permit to Work
- Daily Safety Observation & Compliance
- Regular safety audits and inspections

c. Hazards in Thermal Power Plants

- Electrical hazards (shock, arc flash)
- Mechanical hazards (moving parts)
- Fire and explosion risks
- Chemical exposure (coal dust, ash, gases)
- Thermal hazards (steam, hot surfaces)

3. Electrical Safety – Overview:

- High voltage systems (up to 400 kV and above)

- Complex distribution networks
- Critical need for insulation and grounding
- Strict operational procedures required

4. Electrical Safety Hazards & Safety Measures:
- Electric shock and electrocution
- Arc flash and arc blast
- Short circuits and overloads
- Equipment failure and insulation breakdown

5. Electrical Safety Measures:
- Proper earthing and grounding systems
- Proper Testing of Electrical Equipment & Relays etc
- Use of insulated tools and equipment
- Installation of circuit breakers and relays
- Provide Rubber Mat front & backside Panel
- Regular maintenance and testing
- Lockout/Tagout (LOTO) procedures

6. Highly Hazard & Risk Activities in Coal Based Thermal Power Plants:
- Clinker formation in Boiler & its removal operation
- Bottom Ash Hopper Operation & Maintenance
- Steam leakages (High Temp. & Pressure) attending Work
- Work at Fire Smoke area when fire catchup i.e., Coal Bunker etc.
- Work at Confined Space
- Work at Height Activities
- Work at Slippery place due to Oil / wet ash area
- Switchyard Operation & Maintenance
- Workers working at Coal Handing Plant O&M- e.g., Conveyor Belt System, unloading wagons etc.
- Men Works at Coal Dust & Ash Dust Area-Health hazards
- Work at Chemical Storage Area and O&M of Chemical Plant including Chlorine, Acid, Caustic etc.

7. Safety PPEs (Personal Protective Equipment): PPEs Provided in Thermal Power Plant in line with IS Standards and International Standards

a. Personal Protective Equipment (Common)
- Helmets
- Safety goggles
- Gloves
- Ear protection
- Safety shoes

b. Personal Protective Equipment (Electrical)
- Insulated gloves and boots
- Flame-resistant clothing (Electrical Arc Suit)
- Face shields and arc-rated helmets
- Safety goggles

8. Safety Standards & Safety Issues in Coal Based Thermal Power Plant:

a. Safety in Boiler & Turbine Areas

- Pressure relief systems
- Regular inspection of boilers
- Safe handling of steam systems
- Monitoring of temperature and pressure
- Standard O&M practiced in GSECL

b. Issues in Boiler & Turbine Areas

- Furnace Explosion / Boiler Explosion
- Clinker Formation (Slagging)
- Boiler Tube Leakage / Tube Burst
- Coal Dust Explosion
- High Pressure Steam Leakage
- Furnace Positive Pressure
- Soot Blower Hazards
- Ash Handling Hazards
- ID/FD/PA Fan Hazards
- Confined Space Hazards

9. Safety in Turbine Safety Issues:

- Steam pipe burst
- Turbine overspeed trip failure
- Generator hydrogen explosion
- Lube oil fire
- Rotor blade failure
- Arc flash incident
- Condenser confined-space accident

10. Fire Protection System in Coal Based Thermal Power Plant-GSECL & Fire Safety:

- Fire detection systems
- Fire suppression systems (CO_2, foam, water)
- Proper cable management
- Regular fire drills

11. Environmental safety measures in a Coal-based Thermal Power Plant:

a. **Air Pollution Control:** Electrostatic Precipitator (ESP), Flue Gas Desulfurization (FGD), Low NOx Burners, Tall Chimneys, Continuous Emission Monitoring System (CEMS)

b. **Ash Handling and Disposal**: Fly Ash Collection System, Ash Dyke Management, Fly Ash Utilization, Dust Suppression

c. **Water Pollution Control:** Effluent Treatment Plant (ETP), Sewage Treatment Plant (STP), Cooling Water Management, Zero Liquid Discharge (ZLD)

d. **Coal and Fuel Handling Safety:** Covered Coal Storage, Fire Detection and Suppression Systems, Proper Ventilation, Conveyor Belt Protection

e. **Noise Pollution Control:** Acoustic enclosures around turbines and generators, Use of silencers, Green belt development around the plant, Personal protective equipment (ear plugs/ear muffs)

f. **Climate and Environmental Management:** Green Belt Development, Carbon Reduction Measures, Environmental Monitoring

12. Safety Standards in Thermal Power Plant in GSECL:

a. Emergency Response Plan-GSECL Done -

- Crisis Management Plan for GSECL (In line with Power Sector)
- Disaster Management Plant
- On-Site Emergency Plan
- Regular conducting Mock drill / Rehearsal

b. Emergency Response Plan

- Evacuation procedures
- First aid facilities
- Emergency control rooms
- Coordination with local authorities

13. Safety Training & Awareness in Thermal Power Plant in GSECL:

- Regular safety training programs
- Tool Box Safety Talk -Daily
- Mock drills and simulations
- Safety culture promotion
- Incident reporting and learning
- Safety Committee Meeting
- Safety Walk-down survey
- Safety demonstrations

14. Conclusion:

- Safety is essential for sustainable power generation
- Strict adherence to standards reduces risks
- Continuous monitoring and improvement required
- "Safety First" must be the core principle

Mr. SAMIR CHAUDHARI working as Safety Officer in Gujarat State Electricity Corporation Limited at Ukai Thermal Power Station. Worked in **Wanakbori TPS:** Total Capacity:2270 MW. **Ukai TPS:** Total Capacity:1110 MW. **Gandhinagar TPS:** Total Capacity:630 MW. **Sikka TPS:** Total Capacity:500MW. **Kutch Lignite TPS:** Total Capacity:75MW. **Bhavnagar Lignite TPS:** Total Capacity:500MW

Experienced as Safety Professional with more than **28 years of extensive experience** in the Power Sector covering **Transmission, Distribution, Thermal, Hydro and Gas-Based Power Plants** under erstwhile GEB and present power utilities of Gujarat. Specialized in Occupational Health & Safety, Industrial Safety, Fire & Chemical Safety, Environment Management, Behaviour Based Safety, Incident Investigation, and Safety Training.

Recognized for strong expertise in developing and implementing effective safety systems, conducting safety audits, improving workplace safety culture and ensuring compliance with national and international safety standards including ISO 45001:2018.

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Grounding Risks and Hidden Electrical Hazards in Generating Stations

By

Er. B. D. Gour, Certified Energy Auditor

Introduction

Modern generating stations, substations, and industrial electrical installations extensively depend upon sophisticated electronic systems for control, protection, communication, monitoring, automation, and data processing. These systems operate in electrically harsh environments where lightning surges, switching transients, electromagnetic interference, fault currents, harmonics, and improper grounding practices can adversely affect both safety and operational reliability. In such environments, a properly engineered earthing system is not merely a statutory requirement but a critical component for ensuring dependable operation of the complete electrical infrastructure.

The technical session highlights the various grounding-related risks encountered in generating stations and explains how improper earthing practices can lead to equipment malfunction, operational disturbances, unsafe conditions, and failures of critical systems. It emphasizes that modern power systems require earthing systems designed not only for safety but also for functional performance and electromagnetic compatibility.

1. Typical Problems Observed in Power Stations

Power stations frequently experience issues that are often symptoms of poor grounding or excessive electrical noise within the system. These include unexplained relay tripping, failure of electronic cards, fluctuating analog indications, communication failures, unstable RTD values, unwanted UPS bypass transfers, disturbances in vibration monitoring systems, and electric shock sensations on panel bodies. In many cases, these problems remain unresolved because the root cause lies hidden within the grounding and bonding network.

Such issues are usually associated with circulating grounding currents, poor shielding arrangements, high impedance grounding paths, inadequate bonding practices, and electromagnetic interference generated by high-energy electrical systems. Since modern plants increasingly rely on digital instrumentation and automation, even minor grounding deficiencies can significantly affect operational reliability.

2. Electrical Hazards Associated with Poor Earthing

A poor earthing system can create serious hazards for both personnel and equipment. Unsafe grounding conditions may result in electrocution, electric shock, arc flash incidents, fire hazards, equipment failures, explosions, and operational disturbances. In addition to immediate safety risks, inadequate grounding can also contribute to poor power quality, communication interruptions, malfunctioning of protective devices, and failure of automation systems.

An effective grounding system acts as the backbone of electrical safety and operational reliability. It provides a low impedance path for fault currents, limits dangerous touch and step voltages, controls transient over voltages, and minimizes electromagnetic interference affecting sensitive electronic equipment.

3. Objectives of Earthing

The primary objective of earthing in electrical installations is to ensure personnel safety by maintaining touch and step voltages within safe limits during fault conditions. During earth faults or lightning events, dangerous voltages can develop across metallic structures and equipment bodies. A properly designed grounding system safely dissipates these currents into the earth and minimizes the risk of electric shock.

Another important objective is equipment protection. The grounding system provides a low impedance path for fault current flow, enabling protective devices such as relays, circuit breakers, and fuses to operate rapidly and isolate faulty sections. Earthing also helps protect electrical equipment from lightning surges and transient over voltages.

In modern electronic systems, grounding also plays a functional role. Functional earthing provides a stable reference potential for electronic circuits and helps minimize electrical noise, electromagnetic interference, and unwanted voltage fluctuations. Proper grounding therefore improves reliability, communication quality, and system stability.

4. Protective Earthing and Functional Earthing

There is a difference between protective earthing and functional earthing, both of which are equally important in power stations. Protective earthing primarily focuses on personnel safety and equipment protection. Metallic enclosures, machine bodies, switchgear panels, transformer tanks, and exposed conductive parts are connected to earth so that fault currents can flow safely to ground and protective devices can disconnect the supply quickly.

Functional earthing, on the other hand, is associated with the reliable operation of electronic and control systems. Electronic circuits require a stable and noise-free reference point for proper operation. Functional grounding reduces electromagnetic interference, minimizes signal disturbances, controls static charges, and protects sensitive equipment from transient voltages. In modern digital substations and generating stations, functional grounding is as important as protective grounding.

5. Signal / Circuit Common

Electronic systems contain internal grounding networks commonly referred to as signal ground, logic ground, or circuit common. Signal voltages are measured with respect to these common reference points. Since these grounding paths form part of the normal operating circuitry, they must maintain very low impedance to ensure accurate operation of electronic components.

Improper grounding of signal circuits can lead to inaccurate measurements, unstable signals, communication errors, and malfunctioning of electronic devices. Therefore, grounding arrangements for instrumentation and control systems require careful engineering consideration.

6. Electrical Noise in Power Stations

Electrical noise refers to unwanted electrical signals that interfere with the operation of electronic equipment. Power stations are particularly vulnerable to electrical noise because of the presence of large transformers, switching operations, fault currents, lightning surges, variable frequency drives, RF equipment, and high current conductors.

Electrical noise can result in relay maloperation, communication failure, data corruption, equipment malfunction, and even permanent damage to sensitive electronics. Since many modern systems rely on digital communication and microprocessor-based control, controlling electrical noise has become increasingly important.

7. Noise Coupling Mechanisms

There are four major mechanisms through which electrical noise enters electronic systems. Conductive coupling occurs when noise travels through common conductors, power cables, or grounding paths. Shared grounding impedance and poor grounding arrangements often allow noise currents to circulate through electronic circuits. This type of interference can be minimized using single point grounding, isolation transformers, optical couplers, UPS systems, and fiber optic communication.

Capacitive coupling occurs because of stray capacitance between adjacent conductors or circuits. When voltage changes occur in one conductor, unwanted signals may be induced into nearby circuits. Closely spaced cables and improper cable routing increase this effect. Increasing separation distance, shielding sensitive circuits, and proper cable management help reduce capacitive coupling.

Inductive coupling is caused by magnetic field interaction between nearby conductors. Large loop areas behave like transformer windings and allow magnetic fields to induce unwanted currents into adjacent circuits. Twisted pair conductors, minimized loop areas, and proper shielding help reduce inductive coupling.

Electromagnetic or radiated coupling occurs when electromagnetic fields radiate through space and interfere with nearby equipment. At high frequencies, long grounding conductors themselves may behave like antennas. Proper shielding, short grounding conductors, and effective bonding are therefore essential to control electromagnetic interference.

8. Methods of Earthing

The manner in which electronic equipment is connected to the grounding system significantly affects functional performance. There are isolated earthing, single point earthing, and multiple point earthing systems.

Isolated earthing uses separate earth electrodes for electronic equipment in an attempt to isolate sensitive systems from electrical noise. However, such arrangements are generally unsafe and ineffective in power stations because voltage differences can develop during faults or lightning events. Isolated grounding may also delay fault detection and create hazardous conditions for both personnel and equipment.

Single point earthing is considered most suitable for low frequency systems. In this arrangement, all functional grounds are connected at one common point, thereby preventing circulating currents and ground loops. It is recommended to have separate functional earthing and protective earthing buses along with insulated functional grounding conductors. For installations where cabinets are widely separated, grouped single point grounding and fiber optic communication are recommended.

Multiple point earthing is more suitable for high frequency systems. In this method, equipment is connected to the nearest grounding point, thereby reducing high frequency impedance and minimizing standing wave effects. However, multiple grounding points may create ground loops and increase common mode noise if not properly designed.

9. Signal Reference Grid (SRG)

For high frequency electronic systems, concept of a Signal Reference Grid (SRG) can be used. An SRG consists of a closely meshed grounding network installed beneath equipment areas, usually below raised floors. This arrangement provides a low impedance reference plane and improves high frequency grounding performance. Typical grid spacing is approximately 0.6 meter by 0.6 meter, and such systems can provide effective performance up to frequencies of approximately 30 MHz.

10. Key Recommendations for Power Stations

Isolated earthing systems should be avoided. Single point grounding should generally be used for instrumentation and control systems, while multipoint grounding should be considered for high frequency digital systems.

Proper shielding, bonding, cable routing, and cable segregation are essential. Power and signal cables should be installed in separate trays wherever possible and crossing between them should occur at right angles to minimize coupling effects. Twisted pair shielded cables should be used for sensitive circuits.

The grounding grid should maintain low impedance throughout the station. All metallic structures and equipment should be properly bonded. Coordinated Surge Protection Devices should be installed at critical locations, and periodic testing should be conducted to verify grounding system performance.

11. Hidden Electrical Hazards in EHV Substations

Many substations develop hidden grounding defects over time. Corrosion, mechanical damage, loose joints, damaged risers, and deterioration of the grounding grid may remain undetected for years. These hidden defects can create dangerous touch and step voltages and compromise the effectiveness of the entire protection system.

It is hereby being stressed that grounding systems must not be assumed safe merely because they were properly installed initially. Regular inspection, testing, and condition assessment are necessary throughout the life of the installation.

12. Importance of Grounding System Testing

Grounding system testing is essential for verifying the actual performance of the installation under operating conditions. There are several important tests including **soil resistivity testing, gravel resistivity testing, step and touch potential testing, ground grid integrity testing, riser integrity testing, earth impedance measurement, earth fault loop impedance testing, and prospective fault current assessment.**

These tests help identify hidden defects, verify safety limits, evaluate fault current dissipation capability, and ensure compliance with modern electrical safety standards.

13. Benefits of Proper Earthing and Testing

A properly designed and maintained grounding system provides numerous benefits including improved personnel safety, reduced fire risk, enhanced equipment reliability, better electromagnetic compatibility, reduced downtime, and compliance with national and international standards.

Periodic testing also helps identify hidden defects before they become major safety or operational issues.

14. Standards and Regulatory Requirements

There are references of several important standards and regulations including IEEE 80, IEEE 81, IEEE 142, IEEE 837, IEE 1050, IEC 62305, IEC 62561, IS 3043:2018, NEC 2023, and CEA Technical Standards Regulations 2022.

These standards define requirements for grounding system design, step and touch voltage limits, earth fault loop impedance testing, grounding integrity assessment, and lightning protection systems. Modern regulations increasingly emphasize periodic testing and condition assessment rather than relying solely on initial installation practices.

15. Conclusion

- The technical session concludes that proper grounding is fundamental to electrical safety, operational reliability, and electromagnetic compatibility in modern power stations and substations. Functional grounding is now as important as protective grounding because of the widespread use of digital instrumentation and automation systems.
- Hidden grounding defects can create severe hazards if not identified through periodic testing and condition assessment. Therefore, grounding safety must never be assumed merely because earth pits or grounding conductors exist. Continuous monitoring, engineering analysis, periodic testing, preventive maintenance, and compliance with modern standards are essential to ensure long-term system safety and reliability.
- The overall message of this topic is clear: hidden grounding threats are real, testing is essential, and safety must always be verified rather than assumed.

About the Author

Mr. B. D. Gour, Chief Technical Officer at ETP Earthing & LPS Solution Pvt. Ltd., graduated from NIT Surat, is a seasoned electrical engineering professional with nearly four decades of rich and diverse industry experience. In his current role, he leads Engineering, Design, Innovation, Training, Testing & Audit Services, while also serving as a mentor, actively contributing to knowledge sharing and capacity building within the organization and other industry.

A Certified Energy Auditor, Mr. Gour is a distinguished member of the Institution of Engineers (India) and the Society of Power Engineers (India). Prior to his association with ETP, he served as Deputy General Manager (Electrical) at Larsen & Toubro, where he played a pivotal role in executing and managing complex electrical projects, Energy Management and Maintenance.

With 39 years of hands-on experience spanning design, maintenance, and project execution, Mr. Gour brings deep technical insight and practical expertise, particularly in the domain of energy management, earthing systems, electrical safety, and reliability engineering. His work reflects a strong commitment to enhancing safety standards and delivering sustainable engineering solutions.

IMECO

Upgradation of Electrostatic Precipitators (ESPs) to Meet CPCB SPM Norms

ENGINEERING A BETTER WORLD

IMECO is a prominent organization specializing in the upgradation, retrofit, and modernization of Electrostatic Precipitators (ESPs) for coal-fired thermal power plants, ensuring compliance with the revised Central Pollution Control Board (CPCB) emission norms.

With over three decades of domain expertise and an in-house R&D and manufacturing setup, IMECO provides comprehensive EPC solutions for performance improvement, emission reduction, and life extension of existing ESPs.

CPCB Emission Norms for Coal-Fired Thermal Power Plants.
(as per Notification dated December 7, 2015):

Plant Category	Year of Commissioning	SPM Limit (mg/Nm^3)
Units ≤ 2003	Before 31.12.2003	100
Units 2004–2016	01.01.2004 to 31.12.2016	50
Units ≥ 2017	After 01.01.2017	30

(All values at 6% O_2, dry basis)

Our Expertise

- Detailed condition assessment and emission study
- Redesign of collecting and emitting systems
- Supply of high-efficiency internals, rapping systems & TR sets
- Retrofit with advanced control systems
- Field erection, commissioning & performance guarantee

Benefits of IMECO Upgradation

- Achieve emission levels **<30 mg/Nm^3**
- Extend ESP life by 10–15 years
- Enhance reliability and minimize maintenance
- Reduce power consumption and operational cost
- Ensure compliance with CPCB and SPCB standards

Technology Edge

- Microprocessor-based control systems
- Optimized gas flow distribution
- High-efficiency electrodes and internals
- In-house design, engineering, and manufacturing

References

IMECO has successfully executed upgradation and retrofit projects both within India and abroad.

IMECO OVERSEAS (P) LIMITED
P-88/5, Helen Keller Sarani, Near Majerhat Station,
New Alipore, Kolkata - 700053, India
Web: www.imecoindia.com, E-mail : info@imecoindia.com
Linkedin Page : https://in.linkedin.com/company/imecoindia

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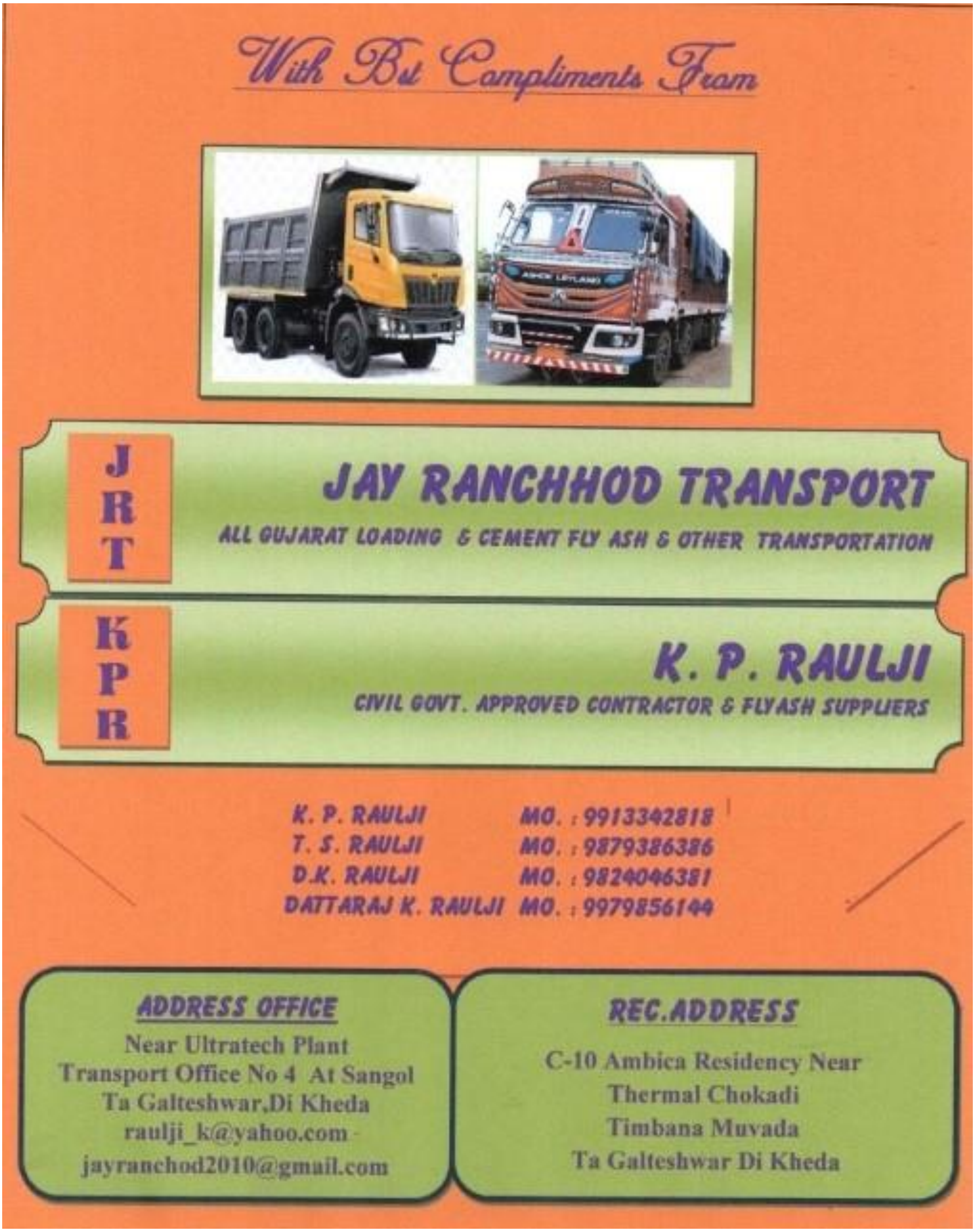
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T. S. RAULJI MO. : 9879386386
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DATTARAJ K. RAULJI MO. : 9979856144
ADDRESS OFFICE
Near Ultratech Plant
Transport Office No 4 At Sangol
Ta Galteshwar,Di Kheda
raulji_k@yahoo.com
jayranchod2010@gmail.com
REC.ADDRESS
C-10 Ambica Residency Near
Thermal Chokadi
Timbana Muvada
Ta Galteshwar Di Kheda

COAL SIZE AND ITS IMPORTANCE IN AFBC BOILER OPERATION

By

Er. Gohil Devpalsinh Indrajitsinh

INTRODUCTION:

In an AFBC Boiler - Atmospheric Fluidized Bed Combustions Boiler, the coal size is typically limited to below 10 mm (often 6-8 mm). Normally this size is require for stable fluidized in efficient & effective combustion and increase reliability of boiler.

1. **The benefits if coal size is below 10 mm:** Proper fluidization of the Bed – AFBC Boiler rely on fluidization of bed material i.e. sand and ash by air:
    a. Coal particles larger than 10 mm
    b. Do not fluidize uniformly.
    c. Tend to settle or segregate.
    d. Cause poor mixing with air and bed material
    e. Fine coal (<10 mm) behaves like bed particles and stays suspended in the fluidized bed.

2. Complete and efficient combustion – smaller coal size gives:
    a. Higher surface area
    b. Faster de-volatilization
    c. Better carbon burnout
    d. Oversized coal may leave the bed partially burnt
    e. Coal exit as high LOI – Loss of On Ignition in ash
    f. Reduce overall boiler efficiency.

3. Uniform bed temperature control – The AFBC Boiler operates at 800^{0}C to 900^{0}C. Large coal lumps burn slowly and locally causing:
    a. Hot spots
    b. Risk of bed agglomeration
    c. Unstable furnace temperature
    d. Fine coal ensures even heat release across the bed.

4. Prevention of bed agglomeration and de-fluidization – Large coal particles can:
    a. Partially melt ash
    b. Stick to sand particles
    c. Form clinkers
    d. Above leads to:
    e. Poor fluidization
    f. Sudden bed collapse or shutdown.

5. Reduced mechanical stress on equipment – Big coal lumps increase:
    a. Erosion of distributor nozzles.

b. Damage to air nozzles and refractory.
c. Smaller coal particles move smoothly with the bed, reducing wear.

6. Compatibility with fuel feeding system – The AFBC fuel feeders like screw/belt/pneumatic:

a. Are designed for crushed coal.
b. Can choke or jam with oversized coal
c. Consistent size (<10 mm) ensures stable fuel feed rate.

About the Author:

	**Er. Gohil Devpalsinh Indrajitsinh** BE (Mechanical & Electrical); M. Tech (TH); CE (M); CE (SL); PE (M); NDT Level – II; RT, UT, MT, VT, PT, LT, IR, MFL ECT, PAUT, TOFD,; Welding Inspector. More than 22 years' experience in Boiler Inspection, Operation and Maintenance. M - 9428108733 E-mail: boilerengineer99@gmail.com E-mail: princegroupofengineering@gmail.com

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Life Extension of Old Thermal Plants with Energy Efficient Clean Coal Technology Retrofits and Reduction of CO_2

By

Mr. Sarajit Sen, Dr. R.H. Kahar and Prabhat Verma

Abstract:

India's energy sector stands at a critical crossroads. With coal expected to remain the mainstay of power generation through 2030 and beyond—given the country's vast reserves of approximately 200 billion tones—there is an urgent need to address the efficiency and longevity of ageing thermal plants. This paper presents a comprehensive technical and policy framework for the life extension of old thermal plants through energy-efficient clean coal technology retrofits, with the dual objective of improving plant performance and reducing the CO_2 footprint.

Drawing on proven international experience, including completed Renovation, Modernization and Life Extension (R&M/EER&M) projects in India — such as the Sabarmati E&F and Bandel 210 MWe units — and advanced supercritical retrofit feasibility studies, this paper establishes that energy-efficient plant life extension is not only technically viable but economically and environmentally imperative. Key findings include heat rate improvements of up to 25%, capacity uprating, life extension of 15–20 years, and significant reductions in CO_2, NOx, SOx and particulate emissions.

1. Introduction and Context

India's power sector faces a complex challenge: rapidly growing energy demand, an ambitious renewables programme, and a large fleet of ageing coal-fired plants whose performance has deteriorated significantly over time. According to the Central Electricity Authority (CEA), India's installed generation capacity is projected to grow from approximately 520 GW in 2026 to over 771 GW by 2030, with coal-based thermal capacity remaining the single largest component at around 228 GW (2026) rising to 252 GW (2030).

The present situation is characterized by:

- Peak demand shortfall is marginally negative, with the risk of further strain due to grid-connected renewable load and seasonal hydro load variation — which could be in the region of 10%
- Load shedding for grid control and compromised quality of power
- Extreme cyclic demand on grid-connected thermal units, posing challenges to maintenance schedules and plant health, resulting in forced outages
- The future energy mix projection suggests the requirement of a balanced generation mix - a peak demand surplus of 15% spinning reserve is required for grid stability. Coal-based thermals will continue to provide the spinning reserve to back up renewable and seasonal hydro loads. This optimizes the carbon footprint while maintaining affordable tariffs, as coal represents the cheapest primary energy source available to India.
- Gas-based thermals will remain limited, as the spark spread is always significantly higher than the dark spread owing to limited domestic availability of natural gas and geopolitical risks associated with imported LNG prices. Consequently, the drive for energy efficiency of coal plants and

their life extension through clean coal technologies is not merely desirable — it is imperative for India's energy security.

2. Policy Implementation and Power Sector Performance

India's power sector performance data (CEA) reveals several concerning trends that underline the urgency of renovation and Modernization:

a. Supply and Demand Gap

- Capacity addition shortfalls have persisted over more than a decade
- Supply and peak demand are converging but still lack adequate reserve margin
- Grid-connected renewables add to generation complexities, requiring reliable thermal backup

b. Performance of Existing Fleet

- Poor performance of old plants adds to pressures on available generation capacity
- Low Plant Load Factor (PLF), availability and reliability issues are widespread
- State Government utilities are, in general, poor performers relative to central and private sector utilities

c. Why Replacement is Not the Answer

The option of replacing old inefficient capacity with entirely new plants is not viable in the present context for several reasons:

- It puts additional pressure on an already stretched new installation programme
- New project permitting, fuel linkage and grid connectivity face significant bureaucratic and logistical constraints
- Higher capital expenditure (CAPEX) and longer gestation periods are not compatible with urgent supply requirements

d. The R&M Option

Renovation & Modernization (R&M) offers a fast, efficient and cost-effective means to increase capacity and its reliability. Energy Efficient Plant Life Extension is a no-brainer in the present context because:

- No new plant permits are required; lower CAPEX and shorter gestation time
- Energy efficiency enhancement significantly improves merit order rating, generation economics and return on investment (ROI)
- It meets environmental trends and regulatory requirements
- Enhanced reliability and availability improve PLF and hence available power

3. Plant Cycle Efficiency Enhancement — The R&M Objective

The objective of Renovation, Modernization and Life Extension (R&M/EER&M) is to enhance plant cycle efficiency, expressed principally as the Unit Heat Rate (UHR), through comprehensive upgrade of both the Turbine-Generator and Boiler islands. The key goals are:

- Enhance efficiency through lower unit heat rate
- Improve merit order dispatch, which in turn improves the Plant Load Factor
- Possibility to increase unit capacity if required

- Improve plant reliability and availability
- Extend operational life

An old plant that undergoes a comprehensive R&M can obtain a lease of life of at least 15–20 years. The benefits compound across the extended operating period:

- Higher cycle efficiency results in lower generation costs
- Lower fuel consumption directly translates to a lower carbon footprint
- Reduced emissions of all pollutants (SPM, NOx, SOx, CO_2)

The turbine efficiency curve, over its service life, shows a characteristic pattern of gradual deterioration punctuated by partial recovery during overhauls. However, unrecovered degradation accumulates with each cycle. A comprehensive R&M at year ~25 of service can restore efficiency to above the original design baseline, through the application of state-of-the- art technologies that were not available when the plant was originally designed.

4. State-of-the-Art Technologies for Efficiency Improvement

a. Turbine Retrofit Technologies

The turbine steam path is the primary area for heat rate improvement. Modern retrofit technologies that are applied to existing turbine casings include:

- Advanced Blade Technology: Three-dimensional aerodynamic blading designed using computational fluid dynamics, achieving significantly higher isentropic efficiency than the original design
- Entropy/Velocity Distribution Optimization: Optimized stage loading and blade profiling to minimize irreversibility and improve stage efficiency
- Integral Covered Bucket Design: Shrouded blades that reduce tip leakage losses and improve damping characteristics
- Advanced Seals: Modern brush seals or advanced labyrinth seals to minimize inter- stage and gland leakage losses. These technologies together deliver approximately 5% improvement over the original OEM turbine design, comprising approximately 2.5% increase in electrical output and approximately 2.5% decrease in thermal input. From the pre-retrofit deteriorated condition, the improvement in heat rate can be almost 20%.

b. Generator Rehabilitation / Upgrade: Generator R&M employs advanced technologies to improve performance and extend life:

- F-Class Insulation: Higher temperature rating allows improved power factor capability and thermal performance
- Coil Design Optimization: Redesigned coils for reduced losses and better heat transfer
- Gas Cooling Optimization: Improved hydrogen cooling flow paths to reduce thermal gradients
- Advanced Brazing Materials: Higher reliability brazed connections for improved longevity.

Three principal rehabilitation approaches are available: Field Rewind (increases reactive capability — KVARs), Stator Rewind (increases active power capability — KW and improves power factor), and complete Generator Replacement for maximum performance uplift. Each approach shows a characteristic expansion of the generator capability curve.

c. Boiler R&M Technologies: Boiler R&M solutions are applicable to both wall-fired and corner-fired boilers, and encompass:

- Pressure Parts Replacement: Replacement of life-expired boiler tubes, headers to restore design integrity and extend operational life
- Low-NOx Firing System: Modern low-NOx burners with staged combustion to reduce
- NOx formation at source
- DCS Modernization: Full replacement of obsolete analogue controls with modern Distributed Control Systems for improved reliability, diagnostics and operating precision
- Environmental Equipment Retrofits: Installation of Electrostatic Precipitators (ESP), Selective Catalytic Reduction (SCR) for NOx control, and Flue Gas Desulphurization (FGD) for SOx control
- Air heater Refurbishment: Addition of heating surface to reduce flue gas exit temperature and recover additional heat
- Milling Plant Upgrade: Mill capacity upgrade, new/retrofitted Primary Air fans, Dynamic Classifiers for improved fineness, improved PF piping and gravimetric feeders for more accurate and reliable coal feeding

Boiler R&M ensures the restoration of design efficiency with enhanced reliability. Plants over 40 years old are still in service worldwide, meeting present-day environmental standards and enduring power market forces, following such retrofits.

5. Case Studies—Proven R&M Experience

5.1 Sabarmati E&F Units—2 x 110 MWe Sub-critical R&M (Ongoing Project). This project by Doosan Skoda demonstrates a comprehensive Energy Efficient R&M with capacity upgrade of 2 x 110 MWe sub-critical units. The objectives and achievements are tabulated below:

Parameter	Pre-R&M	Post R&M Target / Achieved
TBN Heat Rate	~2,175 Kcal/KW (design); significantly worse in present condition	1,999 Kcal/KW (8% below design baseline; 25% below present condition)
MW Output	110 MWe	121 MWe (+11 MWe, ~10% increase)
Lifetime Extension	Near end of life	120,000 hours additional life

Scope of Works — Turbine

- HP, IP, LP Steam Path Upgrade and Replacement with advanced blade technology
- Regenerative Equipment Upgrade including feed heaters and deaerator

Scope of Works — Boiler

- Re-Heater Modification to accommodate uprated steam conditions dictated by the retrofitted turbine
- Boiler modelling and performance verification for the new Heat Balance Diagram (HBD)
- New re-heater surface with inlet and outlet headers
- CDS tubing for re-heaters to reduce pressure drop and accommodate extended surface

5.2 Bandel 210 MWe EER&M — Objectives and Guarantees. The Bandel Energy Efficient R&M project represents one of the most comprehensive

R&M programmes undertaken in India, covering the full plant scope. The targets and guaranteed results achieved are presented in the following table:

Parameter	Target	Guarantee Achieved
Unit Capacity	Increase from 210 MWe to 215 MWe	215 MWe
PLF	80% from present ~60% average	PLF as per grid requirement
Gross Unit Heat Rate	2,456 Kcal/KW from ~3,000 Kcal/KW	2,345 Kcal/KW
Auxiliary Power Consumption	13.5 MW for key auxiliaries	13.0 MW for key auxiliaries
Fuel Diet	Worst coal with CV 3,300 Kcal/Kg	Worst coal with CV 3,300 Kcal/Kg
Particulate Emission	90 mg/Nm³	90 mg/Nm³
Life Extension	Minimum 15 years	Minimum 15 years

The EER&M project was delivered at approximately 50% of the cost of a new plant. The plant has continued to operate at full load even after 10–11 years of project completion, validating the life extension guarantee.

5.3 Bandel EER&M — Scope of Works

Boiler Island and C&I Scope

- Major Pressure Parts Replacement for life extension, reliability and performance improvement
- Milling Plant upgrade including new Primary Air fans, PF piping, Dynamic Classifiers and Gravimetric Feeders
- New ID Fans, Seal Air and Core Air fans; refurbishment of FD fans
- Low-NOx Firing System
- Air heater refurbishment and surface addition for reduced flue gas losses
- New soot blowers; replacement and refurbishment of valves and actuators
- DCS Modernization and renewal of field instruments
- Environmental Equipment Retrofit (ESP)

Turbine-Generator Island Scope

- HP, IP, LP Turbine Replacement with state-of-art blading technology
- Generator and Auxiliary Replacement
- TG Lubricating Oil System Upgrade
- Electro-hydraulic Governors
- New Emergency Stop Valves (ESVs), Intercept Valves (IVs) and Control Valves (CVs)
- Drains and Extraction System Refurbishment
- Condenser Retubing
- New Condensate Extraction Pumps (CEPs)
- Energy Efficient Boiler Feed Pump (BFP) Cartridges
- HP/LP Heater Tube Nest Replacement
- Deaerator Tower Replacement
- Renewal of HP/LP Bypass Valves; miscellaneous valves and actuators
- Renewal of Hangers and Supports of Critical Piping plus Insulation
- Turbo-visory System and Field Instruments

Balance of Plant (BOP) Scope

- Ash Handling Plant Upgrade

- Electrical Systems
- Fire System Augmentation
- Miscellaneous Civil Foundations and Control Room Interior Work

5.4 Key Project Milestones — Bandel EER&M. The project followed a structured milestone schedule over approximately 27–28 months from contract award to Performance Guarantee (PG) test, with the following key phases:

- Detailed Engineering: completed at approximately Month 12
- Completion of Material Orders: approximately Month 10
- Manufacturing: completed at approximately Month 17
- Delivery: Months 12–18
- Opening of Site Office and Pre-Shutdown Works: Months 13–18
- Shutdown Installation: Months 19–24
- Commissioning: Month 25 (Reliability Test)
- PG Test: Month 27
- Warranty Period: following PG test

6. Advanced Supercritical Retrofit — Concept and Feasibility

6.1 Overview and Motivation: Beyond conventional sub-critical R&M, the most ambitious option for life extension and efficiency improvement is the Advanced Supercritical Retrofit of existing sub-critical 500 MWe units. This concept, developed through a detailed feasibility study, represents a step-change in plant performance, converting an existing plant operating at subcritical steam conditions to operate at advanced supercritical steam parameters.

6.2 Efficiency Improvement

- Current subcritical boiler/turbine unit cycle efficiency: 34–35%
- Anticipated advanced supercritical retrofit cycle efficiency: 45% net (including Air Quality Control System — AQCS — penalty for FGD and SCR)
- Overall efficiency improvement: greater than 25%

This is a significant improvement even after accounting for the auxiliary power penalty imposed by the FGD and SCR systems required to meet modern environmental standards.

6.3 Conclusions of Feasibility Study: The advanced supercritical retrofit feasibility study confirmed:

- No technical showstoppers were identified
- Unit electrical output is maintained at 520 MWe Gross / 480 MWe Net (including SCR and FGD)
- Turbine inlet steam conditions: 280 bara, 600°C main steam, 610°C reheat steam
- Optimum turbine and thermal cycle retrofit for best techno-economic benefits
- Babcock UK's "Posiflow" vertical rifled bore tube low mass flux furnace walls are employed
- Plant is designed to be 'capture ready' for future CO_2 capture and sequestration by Oxyfuel combustion process 150,000 hour pressure part design life

6.4 **What a Supercritical Retrofit Involves:** The scope of a supercritical retrofit is extensive but carefully structured to maximize re-use of existing infrastructure and boiler structural steel framework. The key actions are:

Components Replaced:

- Replacement of boiler pressure parts within the boiler house envelope
- Replacement of HP and IP turbine modules; modification of the LP turbine
- Replacement of all main steam and feed water piping
- New feed pumps and feed heating system
- New DCS system (where not already installed)
- New SCR plant
- New FGD plant (where not already installed)

Components Re-Used (maximizing cost benefit):

- Boiler primary supporting steelwork (lighter supercritical boiler permits this)
- Draught plant, air heaters, PA fans, precipitators
- Milling plant, low-NOx burners, coal feeding system
- Flues and ducts, stack, coal and ash handling plant
- All civil foundations and boiler house structure
- Biomass co-firing system if installed

6.5 **Turbine Island — Supercritical Retrofit Specifics:** In the turbine island, the following components are replaced or renewed:

- HP Turbine Module and Bearing Pedestal
- IP Turbine Module and Bearing Pedestal
- LP Turbine Rotor and Inner Casing
- MS/RH Stop Valves, Control Valves, Interceptor Valves and Steam Admission Pipes
- Turbine Control and Protection systems, Turbo-visory system and ATRS
- Turbine Lubricating Oil Skid and Control Oil Skid
- Condenser tube bundle replacement
- Refurbishment of LP heaters with new tube bundles; 4 new HP heaters
- 3 x 50% Boiler Feed Pumps with turbine drives, electrics and associated valves
- Generator overhaul, excitation system and Unit Auxiliary Transformer
- Condensate polishing plant

6.6 **Emission Reductions from Supercritical Retrofit:** At a load factor of 70%, the emission reductions achieved by the advanced supercritical retrofit compared to the original sub-critical plant are as follows:

Emission Type	Annual Reduction	% Reduction
CO_2	483,500 tonnes per year	18%
NOx (with SCR)	5,100 tonnes per year	75%
SO_2 (with FGD)	44,600 tonnes per year	96%
Dust	270 tonnes per year	50%

6.7 **Economic Case — Supercritical vs Sub-critical Retrofit:** The capital costs of a supercritical retrofit are broadly comparable to an equivalent sub-critical R&M for the same MWe output. This is because, while the materials are of higher grade, flues, ducts and auxiliary equipment are smaller due to the improved cycle efficiency, and the installed boiler weight is similar to sub-critical. However, through-life costs are significantly reduced for the supercritical option across all categories:

- Coal consumption (primary saving)
- Clean-up consumables: limestone for FGD, ammonia for SCR
- Auxiliary power: feed pump addition, cooling water, ash removal, mills and fans

For reference 500 MWe UK plant, the estimated net saving over 25 years in favour of the supercritical option is £216,000,000, comprising approximately £185,000,000 from coal savings, £26,000,000 from auxiliary power savings, and £5,000,000 from clean-up consumable savings. These figures are indicative; the savings in an Indian context, expressed in INR per unit of generation, will depend on coal price and auxiliary power cost, but the proportional benefit is directly applicable.

7. Clean Coal Technologies — A Twin-Track Approach to CO_2 Abatement

7.1 The Two-Track Framework: The path towards CO_2 abatement from coal-fired generation is best understood as a two-track approach, with actions available over different time horizons:

Track 1 — Efficiency Improvement (Available Now)

Track 1 measures deliver immediate and significant CO_2 reductions through efficiency improvement and are commercially proven. These include:

- Conventional sub-critical R&M (as described in Sections 4–5 above)
- Advanced supercritical retrofit (Section 6)
- Biomass co-firing (reduces net CO_2 intensity)
- Feedwater heating upgrades (if NG is available)

Through Track 1 measures, a CO_2 reduction of approximately 55~60% from baseline is achievable in the near term (40% from baseline if Feedwater heating cannot be implemented).

Track 2 — Carbon Capture and Storage (Medium to Long Term)

Track 2 measures include Carbon Capture and Storage (CCS), These can potentially achieve CO_2 reductions of 60–95% but require medium to long-term development. The concept of a "capture-ready plant" is important here: plants retrofitted under Track 1 should be designed from the outset to be compatible with future Track 2 application, particularly Oxyfuel combustion-based CO_2 capture or post combustion capture like Amine Scrubbing.

7.2 Relative CO_2 Emission Rates by Technology

The relative CO_2 emission rates (indexed to old sub-critical plants at 100%) across the technology spectrum are broadly as follows:

Technology	Relative CO_2 Emission Rate
Old Sub-Critical (baseline)	~100%
Modern Sub-Critical	~85–90%
Modern Super-Critical	~75%
Enhanced Biomass Co-firing	~55–60%
Feedwater Heating Upgrades	~40%
Carbon Capture & Storage	~5–10%
IGCC	~75% (without CCS)
CCGT	~40% (gas-dependent)

This demonstrates that the window of Track 1 measures alone (highlighted in the original presentation) can reduce CO_2 emissions to approximately 40–60% of the old sub-critical baseline — a reduction that is achievable today with proven technology.

7.3 Continuous Technology Innovation — Boiler Design Evolution

Boiler technology has evolved significantly over decades, from natural circulation sub-critical designs through once-through supercritical to the advanced 'Posiflow' vertical rifled bore tube design used in the most recent supercritical applications. The Posiflow design offers:

- Vertical tube furnace walls eliminating the need for spiral wound furnace sections
- Positive flow characteristic: flow increases with heat flux, providing inherent stability
- Low mass flux design reducing auxiliary power for circulation
- Simplified mid-transition headers (not required)
- Common easier-to-form tube configuration
- Low pressure drop between tubes and lower design allowance
- Vertical tube design for supercritical conditions ideally suited for retrofitting subcritical boiler furnaces within the existing structural envelope.

8. Discussion

8.1 Economic Justification for EER&M

The economic case for EER&M is compelling in the Indian context. The key drivers are:

- EER&M projects are typically deliverable at approximately 50% of the capital cost of new plant construction
- Gestation times are significantly shorter than for new-build, typically 24–28 months for a major R&M versus 5–7 years for new plant
- No new land acquisition, fuel linkage or environmental clearance for a new plant is required
- The improvement in heat rate directly reduces variable generation cost (fuel cost), improving merit order and hence PLF
- The reduction in auxiliary power consumption further improves net generation economics
- Avoided penalties for non-compliance with emission norms represent a significant financial benefit

8.2 Environmental and Policy Alignment EER&M is well aligned with India's environmental policy objectives:

- Compliance with Ministry of Environment, Forest and Climate Change (MoEFCC) emission norms for existing thermal plants
- Reduction of CO_2 intensity of generation, supporting India's NDC commitments under the Paris Agreement
- Reduction of particulate matter, NOx and SOx emissions, directly improving public health outcomes in areas surrounding power stations
- The 'capture-ready' design concept provides an option for deeper decarbonization in the future without requiring further major investment

8.3 Grid Stability and Renewable Integration. Efficient, reliable coal plants are essential to the integration of large-scale variable renewable energy. As India adds substantial amounts of solar and wind capacity, the requirement for flexible, fast-responding thermal backup increases. Plants that have undergone EER&M exhibit improved operational flexibility, better ramp rates and enhanced reliability — precisely the characteristics required to manage the variability of solar and wind generation.

9. Conclusions

This paper has demonstrated, through technical analysis and reference to proven project experience, that:

- Energy Efficient Renovation, Modernization and Life Extension (EER&M) of India's ageing coal plant fleet is technically proven, economically justified and environmentally responsible
- Conventional sub-critical R&M can deliver heat rate improvements of 8% over design baseline and up to 25% from the pre-retrofit degraded condition, with capacity uprating and a minimum 15-year life extension
- The Turbine Retrofit using state-of-the-art blade, seal and bucket technologies is the key enabler of heat rate improvement, delivering approximately 5% improvement over the original OEM design
- Advanced Supercritical Retrofit of existing sub-critical units is technically feasible, with no showstoppers identified, delivering a cycle efficiency improvement from 34–35% to 45% net — a greater than 25% improvement
- Supercritical retrofit delivers 18% reduction in CO_2, 75% reduction in NOx (with SCR), 96% reduction in SOx (with FGD), and 50% reduction in dust emissions
- The cost advantage of EER&M over new build is significant, at approximately 50% of new plant cost
- The Clean Coal Technology twin-track approach provides a credible long-term roadmap from the current fleet to progressively lower-carbon generation, while ensuring energy security
- Coal will remain the mainstay of India's power generation given the country's vast reserves (approximately 200 billion tonnes) and the importance of affordable electricity tariffs to economic development
- Sustained good health of the coal plant fleet, through systematic EER&M programmes, is imperative for India's energy security and environmental commitments

About the Authors

Sarajit Sen: Sarajit Sen is the Managing Director of SMARTLuth Solution and Service Private Limited, Kolkata. He is a former Managing Director of DOOSAN Babcock India (Power Service Group) and former Head of Business Development at Babcock UK, where he led the boiler and environmental retrofit business for the European market. He also served as a Principal Engineer at Babcock UK in the areas of field engineering and commissioning. His extensive experience across project development, engineering and delivery in the thermal power sector forms the foundation of the technical case presented in this paper.

Dr. R.H. Kahar: Dr. R.H. Kahar is a co-author of this paper and an expert in the field of thermal power plant engineering and clean coal technologies, contributing to the technical analysis and policy framework presented herein.

Prabhat Verma: Prabhat Verma is a co-author of this paper and a Business Professional from the field of Conventional and Renewable Power Generation. Prabhat holds Electrical Engineering degree and Post Graduation in International Business. Prabhat have rich global experience of working with technology companies like ABB, Honeywell, Doosan & Cos-powers at senior positions. Currently he is actively working on implementing Desulphurization and Decarbonization solutions in coal based power plants both India and overseas.

SMARTLuth Solution and Service Private Limited
503, ECO CENTRE, SEC V, Salt Lake City, Kolkata – 700091
E-mail:Prabhat.verma@smartluth.com

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Operational Excellence & Performance Optimization in Thermal Power Plants

By

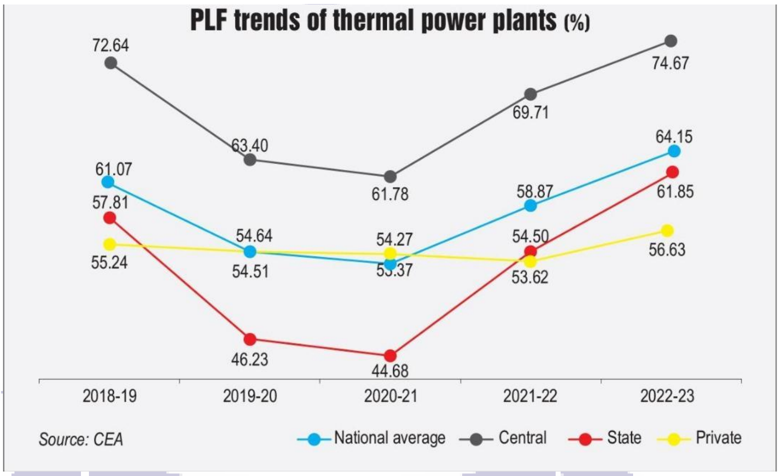
Er. Swaran Singh Sains, Addl. SE, PSPCL

Core Targets of Power Plant Optimization

Main objective: **Generate more MW at lowest cost with highest reliability.**

Key Plant Targets

- Availability > 90–95%
- PLF maximization
- Heat Rate reduction
- Aux Power consumption reduction
- Zero forced outages
- Flexible operation for grid demand



Biggest Loss Areas in Thermal Power Plants

Typical performance losses come from:

Area.	Typical Loss Impact
Boiler inefficiency.	3–8%
Turbine inefficiency.	2–5%
Condenser vacuum loss.	2–4%
Aux power consumption.	1–3%
Forced outages.	Huge revenue loss

- Therefore optimization must focus on Boiler + Turbine + Condenser + Aux systems + Maintenance.

Boiler Performance Optimization

The boiler contributes to the largest efficiency loss in the plant.

Key Optimization Areas

A. Combustion Optimization

Maintain perfect air–fuel ratio

Actions

- Burner tilt & secondary air damper tuning
- Coal fineness optimization (Pulverizer tuning)
- Excess O_2 control (3–4%)

- Reduce unburnt carbon in ash

Typical Gains

- 1–2% boiler efficiency improvement

B. Soot Blowing Optimization

Excess soot blowing wastes steam.

Modern Solution

- Smart soot blowing using furnace temperature monitoring
- Online fouling detection

Gain: 0.3–0.5% heat rate improvement

C. Boiler Tube Leak Reduction

Major cause of forced outages.

Modern Techniques

- Acoustic leak detection
- AI tube leak prediction
- Furnace camera monitoring

Steam Turbine Optimization

Turbine is the heart of power generation.

Key Performance Actions

A. Steam Path Efficiency

Loss due to deposits & erosion.

Actions

- Turbine blade cleaning (online/offline)
- Steam purity control
- Gland sealing optimization

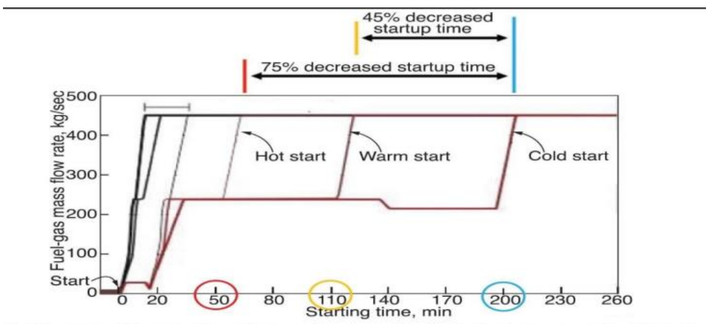
Gain: 1–2% output improvement

B. Turbine Vacuum Improvement

1 kPa vacuum loss → 1% power loss.

Actions

- Air ingress elimination
- Vacuum pump performance check
- Condenser cleanliness



1. Steam-turbine starting times differ dramatically for hot, warm, and cold starts

Condenser & Cooling System Optimization

Most ignored area but high impact.

Major Problems

- Fouling of condenser tubes
- Poor cooling tower performance
- Air leakage

Improvements

- Online condenser tube cleaning system
- Cooling tower fan optimization
- Regular air leak testing

Gain: 1–2% generation increase

Auxiliary Power Consumption Reduction

Aux power = Hidden generation loss
Typical: 8–10% of gross generation.

High Impact Equipment

Equipment.	Optimization
ID/FD/PA fans.	Install VFD
Boiler feed pumps.	Hydraulic efficiency testing
CW pumps.	Pump impeller trimming
Coal mills.	Load optimization

Typical Saving: 0.5–1.5% net generation increase

Reliability & Maintenance Excellence
Shift from Breakdown → Predictive Maintenance

Critical Monitoring Technologies

Equipment.	Monitoring Method
Turbine & Pumps.	Vibration analysis
Transformers.	Online DGA
Motors.	Partial discharge monitoring
Gearboxes.	Oil analysis
Boilers.	Thermography

Result

- Forced outages ↓ 30–50%
- Maintenance cost ↓ 10–20%

Digital Power Plant (Future Ready)

Modern plants use AI & Advanced Analytics.

Key Technologies

- Digital Twin of plant
- AI predictive maintenance
- Advanced Process Control (APC)
- Real-time performance dashboards

Example Benefits

- Early detection of turbine faults
- Boiler efficiency prediction
- Coal consumption optimization

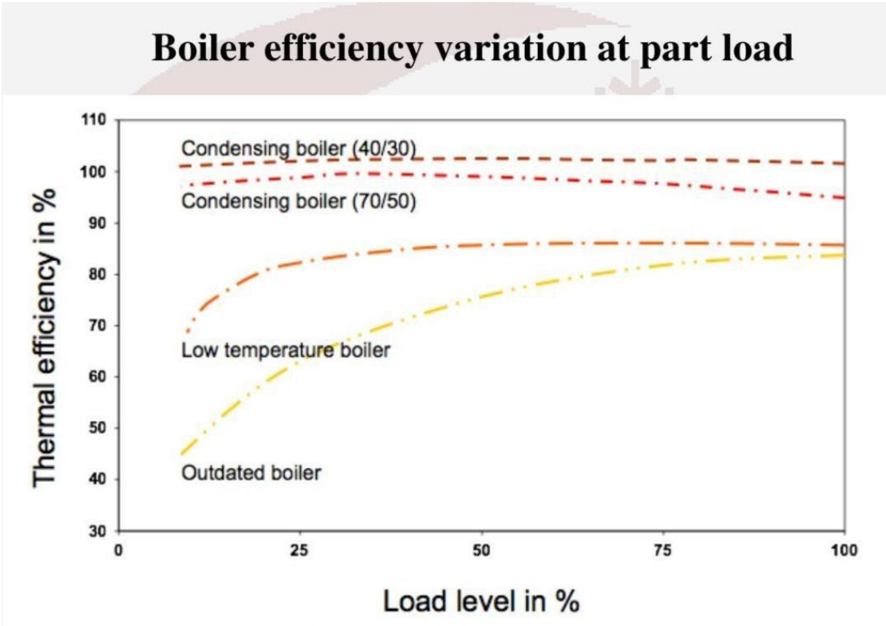
<u>Flexible Operation & Fast Load Changes</u>

Grid demand now requires plants to operate:

- At low load (40–50%)
- With frequent load changes

<u>Required Actions</u>

- Boiler sliding pressure operation
- Turbine thermal stress monitoring
- Advanced combustion control



<u>KPI Dashboard for Daily Monitoring</u>

<u>Reliability</u>

- Unit trips per month
- Forced outage rate
- Equipment availability

<u>Efficiency</u>

- Heat rate (kCal/kWh)
- Boiler efficiency
- Turbine cycle efficiency
- Aux power %

<u>Financial</u>

- Cost per kWh
- Coal consumption per unit

<u>Typical Improvement Potential</u>

<u>Area</u>.	<u>Improvement</u>
Heat rate.	2–4%
Aux power.	1–2%
Availability.	+3–5%
Maintenance cost.	−10–20%
Net generation.	+3–6%

*****

BEST OPERATING PRACTICE FOR:TURNING GEAR
(to prevent rotor bow and bearing damage)

By

Er. Swaran Singh Sains, Addl. SE, GGSSTP, Rupnagar

GOLDEN RULES IN CASE OF STOPPAGE OF TURBINE GEAR-
DO NOT PANIC or DO NOT FORCE TO ROTATE

INTRODUCTION

The 210 MW KWU design steam turbine supplied by BHEL at GGSSTP & GHTP (Power Stations in Punjab) is equipped with a shaft turning gear housed in bearing pedestal-3 and a hydraulic lift system. The hydraulic lift system consists of oil supply system such as:

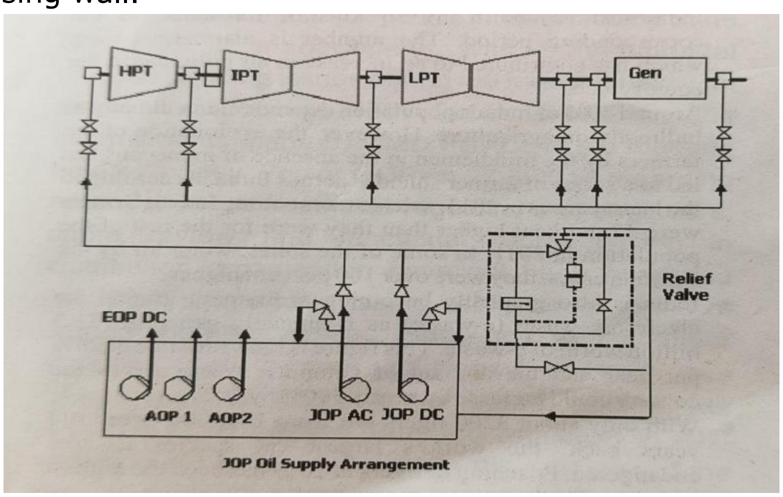
- Jacking Oil Pumps (JOP)
- Auxiliary Oil Pumps (AOP)
- Emergency Oil Pump (EOP)
- Gate valve gearing and turning gear etc.

The oil supply system gives following functions:

- Lubrication and cooling of TG bearings.
- On start up and shut down – driving the hydraulic turning gear.
- Jacking up the shaft at low speeds.
- For governing and LP bypass operation.
- Oil to seal oil system as stand-by arrangement (in Stage-I & II of GGSSTP Units).

1. FUNCTION

The function of turning gear is to prevent temperature differences between top & bottom halves of the rotor & casing when the machine (HP & IP turbine) is under shutdown. Excessive temperature differential > 30°C could cause distortion of turbine components. It rotates the shaft system at a speed of 90–120 rpm during start-up & shut-down, avoiding irregular heating or cooling. Blade ventilation during turning gear operation provides good heat transfer between upper & lower casing parts of turbine inner casing wall.



JOP Oil Supply Arrangement

2. OPERATION OF TURNING GEAR

- When the turbine is being shut down, the turning gear must be operated until HP casing temperature falls below 100°C.
- In case of cold start, turning gear operation must start before vacuum pulling and steam rolling.
- During shutdown/trip, turning gear operation begins while shafting is coasting to a halt. Jacking Oil Pump (JOP) is started at: Speed: 510 – 540 rpm JOP Pressure: 120 kg/cm^2 design pressure Gate valve gearing must be opened at 200 rpm or opened manually from UCB or locally (MOT).Shaft seal steam temperature must be continuously monitored during trip out and box-up (should be >180°C).
- Turbine speed during turning gear: 90 – 120 rpm.
- Alarm provided in UCB appears below 90 rpm(Modified at GGSSTP against design setting of 10 rpm).

3. CESSATION OF TURNING GEAR – CAUSES

If shafting stops rotating while turning gear is in operation due to contact between stationary and moving parts inside turbine: **NO EXTRA FORCE SHOULD BE APPLIED TO ROTATE.** Wait until temperature differentials are equalized. Major cause of seizure: sealing strips on casing and rotor.

- When the shafting is costing to a halt, it must pass through a period when full fluid film lubrication is not provided. The turbojet is provided with a shaft lifting pump jacking oil pump (JOP),which develops high-pressure oil between journal and bearings. The head pressure of JOP is 120kg/cm2 and distributes the oil pressure to all the six bearings of turbine and generator. This header pressure should not be less than 90kg/cm2 in any case. The jacking oil pressure required for each bearing is as follows:
- <u>JACKING OIL SYSTEM DETAILS</u>

a)JOP Header	120 kg/cm^2
b) Bearing-1	25 kg/cm^2
c) Bearing-2	45 kg/cm^2
d) Bearing-3 (Front & Rear)	75 kg/cm^2
e)Bearing-4 (Front & Rear)	50 kg/cm^2
f)Bearing-5 (Front & Rear)	50 kg/cm^2
g)Bearing-6.	65 kg/cm^2

- The jacking oil pressure quoted above are just guidelines. These oil pressures must be sufficient to rotate the turning gear manually. The oil pressures can be adjusted for each bearing through valves provided in pedestals. The correct adjustment of these pressures is ascertained by measuring the lift of the journal with a dial gauge. The lift should be 0.07 to 0.10 mm for each bearing.
- A spring loaded pressure relief valve prevents overloading of the JOP. The lifting pressure of the valve is adjusted to 170 kg/cm^2. If this pressure reduces due to malfunctioning of the relief valve, it can cause low pressure. This low pressure causes the stoppage of turning gear. **THE PRESSURE RELIEF VALVE MUST BE CHECKED DURING OVERHAUL FOR ANY RESTRICTION.**

- The provision of a bypass valve in the discharge line of JOP allows the JOP pressure in the header to be varied. Under some circumstances a sudden variation of jacking oil pressure can disturb the shafting system. **THE BYPASS VALVE SHOULD BE KEPT CLOSED.**
- The JOP takes its suction from MOT (main oil tank). The re-circulation of the oil from the discharge line into the MOT is prevented by a non-return valve provided in the discharge line of jacking oil pumps. Passing in NRV can cause low header oil pressure in the system. This low pressure causes the stoppage of turning gear. **THESE NRV'S MUST BE CHECKED DURING OVERHAULS FOR PASSING.**
- Each bearing is provided with a check valve in the JOP line in bearing pedestals. A leaky check valve in the supply line to a bearing, allowing a flow of oil from the bearing can cause the JOP to rotate counter to its normal direction. This is not important at low speed but at high speed – attention must be given. The passing in check valve can be checked from jacking oil pressure gauges provided inside the pedestal. Any alteration in the values could be indicative of a leaky check valve or joint or misalignment of turbine shaft system. **THE CHECK VALVES PROVIDED IN PEDESTALS MUST BE CHECKED DURING RUNNING OF TURBINE FOR ANY OIL LEAKAGE.**
- The Jacking Oil is fed to each Bearing through a Flexible Hose. These hoses should be replaced during each overhaul to avoid leakage from it.
- The jacking oil pockets of all TG bearings must be checked during every overhaul and should be corrected to the extent possible at site, otherwise replace the bearing. The values must be as given below –

Bearing No	Pressure
Bearing no 1	10–15 kg/cm^2
Bearing no 2	17–22 kg/cm^2
Bearing no 3	32–37 kg/cm^2
Bearing no 4	20–25 kg/cm^2
Bearing no 5	20–25 kg/cm^2
Bearing no 6	25–30 kg/cm^2

- Extra friction at sealing strips of pedestal oil guard rings. It is possible that extra friction may arise from sealing strips of pedestal oil guard rings when the machine is overhauled. The clearance between rotors and sealing strips becomes less at many points which causes cessation of turning gear. **EXTRA CARE MUST BE GIVEN DURING OVERHAUL OF HPT/IPT MODULES TO KEEP THE CLEARANCES WITHIN LIMITS.**
- Coasting down of the shafting system without the JOP, if due to some reasons such as failure of the power supply or any electrical failure of JOP, the turbine shafting system coasts to a halt. Failure of lifting pumps cause the cessation of turning gear.

WHEN COASTING DOWN WITH DC EMERGENCY OIL PUMP, TURNING GEAR VALVE OR BARRING GEAR VALVE MUST BE KEPT CLOSED IN ORDER TO KEEP THE BEARING OIL PRESSURE AS HIGH AS POSSIBLE AND SUFFICIENT LUBRICATING OIL TO BEARINGS.

- Failure of AC supply can interrupt the turning gear in stage – I, as both JOP's were AC driven, whereas in stage – II & III one JOP is AC driven & 2nd is DC driven. In case of AC supply failure in Stage – I (if DG sets failed to deliver AC supply) could cause the stoppage of turning gear. SO, ONE JOP IN UNIT- I & II HAS BEEN MODIFIED TO DC DRIVEN at GGSSTP.

- If at any time the main oil tank (MOT) becomes empty then due to no oil – turning gear will come to rest. THE DRAIN VALVES OF MAIN OIL TANK BE CHECKED IN EACH SHIFT AND ANY OIL PASSING/LEAKAGE ATTENDED PROMPTLY.
- The operation of “fire protection – ii” can also cause the stoppage of turning gear. In this case the aux. oil pump shall stop and only dc emergency oil pump & jacking oil pump shall come into service and gate valve gearing valve shall not open. **THE PROTECTION SYSTEM OF ATRS SCHEMES IS CHECKED REGULARLY.**
- Hot well level can also cause the stoppage of turning gear during trip out or after box up of unit. This happens because the condenser is spring loaded and very - very high level can cause the LP turbine to go downwards. The turbine shafting system remains at constant level. The LP turbine gland sealing strips touch the rotating rotor and cause to stop the turning gear hot well control should always be kept on auto mode.
- Low shaft seal steam temperature <d 200°C during trip out of machine can also cause the stoppage of turning gear due entry of wet steam into turbine glands. Due to entry of low temperature steam into high shaft seal temperature areas of HPT & IPT glands can cause disorder in sealing strips. KEEP THE DRAIN OPEN TO ATMOSPHERE TO HAVE A FLOW OF STEAM IN THE LINE.

4. **Warning –** If at any time turning gear comes to zero speed then immediately manual hand barring should be tried and keep the machine on hand barring, if possible. Kill the vacuum and isolate the gland sealing system. Call the maintenance agency immediately.

*****

2 – DAY CONFERENCE ON
"Design, Engineering, Erection, Testing, Commissioning, Operation & Maintenance of Thermal power plant"

The Society of Power Engineers (I) Vadodara Chapter &
Gujarat State Electricity Corporation Limited

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Renovation and Modernization of GSECL Thermal Units GSECL Experience and planning on R&M Efficiency and reliability Improvement

“Powering the Future, Revitalizing the Past: Empowering Thermal Energy for Tomorrow”

By

Er. J. K. Sandhi, GSECL

COAL BASE UNITS OF GSECL

Name of Station	Unit No.	Capacity of the Unit (MW)	Date of Commissioning
Ukai	3	200	21/01/1979
	4	200	11/09/1979
	5	210	30/01/1985
Gandhinagar	3	210	20/03/1990
	4	210	20/07/1991
	5	210	17/03/1998
Wanakbori	1	210	23/03/1982
	2	210	15/01/1983
	3	210	15/03/1984
	4	210	09/03/1986
	5	210	23/09/1986
	6	210	18/11/1987
	7	210	31/12/1998
	8	800	13/10/2019
KLTPS	3	75	31/03/1997
	4	75	20/12/2009
Sikka	3	250	14/09/2015
	4	250	28/12/2015
Ukai TPS	6	500	08/06/2013
BLTPS	1 2	250 250	16/05/2016 27/03/2017

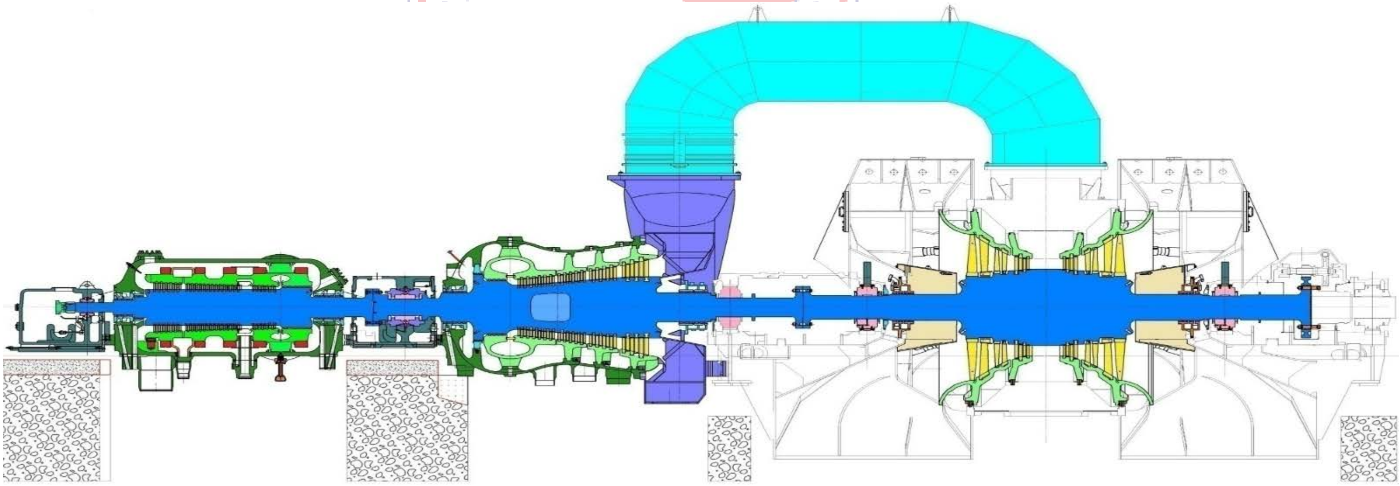
Main objective of R&M

- Even though all LMZ turbines units are older than 40 years, they are capable of running at full load but with higher heat rate due to aging effect. Ukai #3,4,5 & WTPS # 1,2 &3 are LMZ Turbines.
- The main objective of R&M is to make the operating units well equipped with modified latest technology with a view to improve their performance in terms of output i.e. Heat Rate &Efficiencyand also reduction in maintenance requirements and increase operating life.

- Looking to the above facts, it was decided to go for R&M of steam turbine & boiler with superior improved design/technology in phase manner.
- In first phase 210 MW WTPS Unit # 3 & 210 MW Ukai Unit # 4 Turbine & boiler R&M work has been completed in 2017.
- Looking to GSECL successful first phase R&M of old units, MoP/CEA published notifications and mandate 200 MW and above turbine R&M in India instead of retiring of the units before 2030.
- In second phase 200 MW Ukai Unit # 3 & 210 MW Ukai Unit # 5 Turbine & boiler R&M work is planned. At present Ukai Unit # 3 R&M work is in progress by BHEL and will be completed in Jun-26.
- Similarly in phase –III, WTPS 210 MW Unit # 1 & 2 Turbine and Boiler R&M work contracts hasbeen awarded. Boiler R&M work awarded to BHEL and Turbine R&M work awarded to M/s. NGSL. Work will be carried out as per shutdown planning.

Turbine Retrofitting (Methodology)

- Replacement of Complete HP & IP Module with efficient design module.
- Replacement of LP Rotor with efficient design rotor blades.
- Installation of HP-LP Bypass System
- Installation of new Jacking oil system.
- Modification in lube / control oil system & related auxiliaries.
- Replacement of Mech governing system to EHC governing system.
- The inlet steam parameters & Vacuum - fixed as boundary parameters.



NEW GOVERNING SYSTEM KEY BENEFITS-

Features	Old GoverningSystem (Low Pressure)	New Governing System (High Pressure)
Operating Pressure	20 bar	160 bar
No. of SV & CV	12	8
Governing Signal	Hydro-Mechanical	Electro-Hydraulic
Actuator Type	Large & bulky	Light & Compact
Turbine protection system	Mechanical	Electronic
Control & Operation	Complicated	Easy
Response time	Sluggish	Faster

Control Fluid Piping Layout	Complicated	Simplified

MODIFICATION OF BOILER 2[ND] PASS & APH FOR EFFICIENCY IMPROVEMENT

PARTICULARS	UKAI # 4 (200 MW)		WANAKBORI # 3 (210 MW)	
	BEFORE R&M	AFTER R&M	BEFORE R&M	AFTER R&M
Unit wise order value	Rs.54 Cr.		Rs.54 Cr.	
Total contract price	Rs.108 Cr.			
Completion of R&M	24/05/2017		05/12/2017	
Total shut down period	169 days		134 days	
• Major Works carried Out (Boiler Modification) : • Replacement of Single Bank stagger designed economizer with double bank inline design economizer to increase heating surface. • Replacement of LT SH coils and LTSH headers. • Replacement of Ecco hopper, ECO to APH flue gas duct, and Hot air & cold air ducts of APH. • Replacement of APH with modular design and increase the PA angle from 50 to 72 Deg C.				
Boiler Efficiency (%)	**85.22%**	**87.14%**	**85.83%**	**87.10%**

IMPROVEMENT HIGHLIGHTS AFTER 1[ST] PHASE R&M

PARTICULARS	UKAI UNIT – 4 (200 MW)		WANAKBORI UNIT – 3 (210 MW)	
	BEFORE R&M	AFTER R&M	BEFORE R&M	AFTER R&M
Unit wise order value	Rs.112.64 Crores including taxes		Rs.94.11 Crores including taxes	
Total contract price	Rs.206.80 Crores including taxes			
Boiler Efficiency (%)	85.22%	87.14%	85.83%	87.10%
Turbine Heat Rate (kcal/kwh)	2265	1939.2	2260	1944.14
Reduction in Variable Cost (Rs/unit)	0.43		0.43	
Per year saving in Coal Consumption (MT)	1,39,741.4 MT		1,36,674.20 MT	
Landed Cost of Coal	Rs 4350/MT		Rs 4865/MT	
Per month Saving in Fuel Cost	Rs.5.07 Crores		Rs.5.54 Crores	
Total Saving in Fuel Cost (From May-17/Nov-17 to March-26)	Rs 578 Crores		Rs. 479.92 Crores	
Annual reduction in CO_2 emissions	0.21 million MT		0.2 million MT	
Total reduction in CO_2 emissions (From May-17/Nov-17 to March-26)	1.855 million MT		1.666 million MT	

KEY BENEFITS OF 1[ST] PHASE R&M

Achievements :

- Turbine heat rate improved by 14.38%.
- Up to 5.3% improvement in thermal efficiency of the Units.
- Saving in fuel cost up to March'26 Post R &M :
  - (a) UTPS # 4: @ Rs.578 Crores (2,271,000,000 kwh X 0.5 =113.5)
  - (b) WTPS # 3: @ Rs.479.92 Crores(1508499000 kWH X 0.5 =75.42 cr)
- Saving in Variable cost by @ Rs.0.46 to 0.50 per unit.
- Breakeven achieved within 2.5 years
- Life extension envisaged by 12 to 15 years

- ➢ Estimated CO_2 emission reduction – 2,33,700 T per unit per year at 75% PLF
- ➢ Reduction in power consumption of coalplant, boiler and ash plant auxiliaries.
- ➢ Less maintenance and improve availability of unit.
- ➢ Safe & Reliable Operation
- ➢ Increase in schedule being cheaper generation, the merit position of these units is improved by 08-10 placesin State Merit Order.

Retrofitted Turbine Capabilities:

- ➢ Fast Start up / loading
- ➢ Safe & Reliable Operation
- ➢ Flexible Operation
- ➢ Improved Ramp Rate -Hot Start (10 MW/Min), Warm Start (7.0 MW/Min) & Cold Start (3.0 MW/Min)5% Instantaneous overload capacity

2nd phase R&MUKAI UNIT 3 & 5Turbine retrofitting

Project details for 2nd stage Turbine retrofitting work

- **Tender No.** GSECL/PP/SE(P-II)/TURBINE R&M/PHASE-II/UTPS#&5/10 dated 08.04.2022 (estimated cost Rs.323,75,01,435=00)
- **Tender was opened on** 22.07.2022 and M/s.BHEL& M/s.GE Power has participate in this tender.
- **Price bid opened on 05.09.2022** and received offer as
  GE: 271,08,49,169 (#5) + 255,71,34,581 (# 3) = Rs.526,79,83,750

BHEL: 372,65,21,503 (inc tax) for both unit (L1)

- **Offered Heat rate was GE:** Unit #5: 1910.37 Kcal/Kwh& Unit # 3: 1909.1 Kcal/Kwh
  BHEL : Unit #5: 1927.54 Kcal/Kwh& Unit # 3: 1927.56 Kcal/Kwh
- After e-RA M/s. BHEL came as L1 at an end cost of Rs. **299,77,77,503.00**
- **LOI issued** to M/s.BHEL on GSECL/PP/SE(P-II)/TURBINE R&M/ UTPS# 3&5/LOI/81/16.01.2023

PROJECTED PARAMETERS BEFORE AND AFTER SECOND PHASE R&M

Ukai unit No.3

Description	Unit	Design	Operating	After R&M	Difference
TURBINE H.R	Kcal/Kwh	2044	2216.3	1927.56	288.74
GROSS H.R	Kcal/Kwh	2376.4	2673	2158.86	514.14
COAL FLOW	t/h(4750kcal/kg)	100	140		
M.S FLOW	t/h	638		577.33	60.67

Ukai unit No.5

Description	Unit	Design	Operating	After R&M	Difference
TURBINE H.R	Kcal/Kwh	2062	2180.18	1927.54	252.64
GROSS H.R	Kcal/Kwh	2397	2539.43	2158.84	380.59
COAL FLOW	t/h(4440kcal/kg)	121	138		
M.S FLOW	t/h	670	649	610	60

KEY BENEFITS FROM 2nd PHASE TURBINE R&M

- ➢ Turbine heat rate will be improved by **13.02 %**
- ➢ **5.3 %** Improvement in turbine cycle efficiency.
- ➢ Reduction in fuel cost **54.63 cr/year**
- ➢ Reduction in CO_2 emission **1.57 Lacs MT /year**.
- ➢ Life extension envisaged by more that**15 years**.
- ➢ Reduction in power consumption of coalplant, boiler and ash plant auxiliaries.
- ➢ Less maintenance and improve availability of unit.
- ➢ Safe & Reliable Operation
- ➢ Fast Start up / loading

- Flexible Operation
- Improved Ramp Rate -
- Increase in schedule being cheaper generation, the merit position of these units will improve in State Merit Order.
- Breakeven achieved within **2.8 years**

3rd phase R&MWTPS UNIT 1 & 2Turbine retrofitting andBoiler second pass modification

Turbine retrofitting project details

- **Tender No.** GSECL/PP/SE (P-II)/TURBINE R&M/WTPS-1&2/175 DTD 17.06.2022 (estimated cost Rs. **239,93,13,728=00 without taxes)**
  Tender was opened on 10.11.2023 and M/s.BHEL, M/s.GE Power & M/S.Seimens has participate in this tender.
- **Price bid opened on 05.01.2024** and received offer as
  GE: = 408,25,67,910 - HR **1911.41**
  BHEL: 260,00,55,748 – HR 1935 (L1)

Seimens: Rs.417,80,72,000- HR 1925

- After e-RA M/s. NGSL came as L1 at an end cost of Rs. **327,59,11,748.00**
- **LOI issued** to GSECL on GSECL/PP/SE (P-II)/Turbine R&M/WTPS 1&2/467 DTD 11.06.2024

PROJECTED PARAMETERS BEFORE AND AFTER R&M

Description	Unit	Design	Operating	After R&M	Difference
TURBINE H.R	Kcal/Kwh	**2062**	**2245**	**1911.41**	**333.6**
GROSS H.R	Kcal/Kwh	2376	2673	**2216.41**	**456.6**
COAL FLOW	t/h(4440 kcal/kg)	121	148		
M.S FLOW	t/h	**670**	**685**	**591.14**	**93.9**
Load	MW	**210**	**210**	**210**	**210**

KEY BENEFITS FROM TURBINE RETROFITTING OF UNIT #1 & 2

- Turbine heat rate will be improved by **13.12 %**
- **5.4 %** Improvement in turbine cycle efficiency.
- reduction in fuel cost **66.34 cr per year**.
- Reduction in CO_2 emission due to less fuel firing **1.90 Lacs MT/ year.**
- Life extension envisaged by more that 15 years.
- Reduction in power consumption of coalplant, boiler and ash plant auxiliaries.
- Less maintenance and improve availability of unit.
- Safe & Reliable Operation
- Fast Start up / loading
- Flexible Operation
- Improved Ramp Rate -
- Increase in schedule being cheaper generation, the merit position of these units will improve in State Merit Order.
- Breakeven achieved within **2.4** years

Modification of Boiler 2nd Pass & APH for efficiency improvement and flexible operation at 40% TMCR in UKAI unit #3 & #5 & WTPS unit #1 & #2 By GSECL

- **Tender No.** GSECL/PP/SE (P-II)/Boiler R&M/ WTPS#1&#2 and UTPS#3& #5 /1560 (ID NO. 9023) (estimated cost Rs. **466,52,00,000 without taxes)**
- **Tender was opened on** 10.11.2023 and M/s.BHEL, M/s.GE Power & M/S.Seimens has participate in this tender.
- **Price bid opened on 14.05.2024**
- After e-RA M/s. BHEL came as L1 at an end cost of Rs. **444,63,07,280**
- **LOA issued** to M/s. BHEL
  GSECL/CE (P&P)/SE (P-II)/R&M/Boiler/UTPS/LOI/ 496 UKAI (₹ 221,78,94,550)
  GSECL/CE (P&P)/SE (P-II)/R&M/Boiler/WTPS/LOI/ 497 WTPS (₹ 222,84,12,730)

BENEFITS FROM 2ND PASS MODIFICATIONS IN BOILER

- Boiler efficiency will improved by **1** %
- saving in fuel cost **7-8 cr /year**.
- Reduction in CO2 emission **14,442 MT**
- Run the Boiler at 40% TMCR without oil support to avoid frequent start/stop due to RE penetration.
- Life extension envisaged by more that 15 years.
- Reduction in power consumption of coalplant, boiler and ash plant auxiliaries.
- Less maintenance and improve availability of unit.
- Increase in schedule being cheaper generation, the merit position of these units will improve in State Merit Order.
- Breakeven achieved within **8-10** years

OTHER AREAS R&M INITIATIVE BY GSECL

- ESP R&M of various GSECL thermal Power station.
- Ukai Unit # 3,4 &5 ESP R&M completed in 2016-17.
- WTPS Unit #1,2 &3 ESP R&M completed in 2017-18.
- WTPS Unit # 4, 5 & 6 In June-23, Jul-25 & Jan-22 respectively

Improvement in SPM level after ESP R&M:

Sr No	**Name of TPS**	**Unit No**	**Unit Capacity in MW**	SPM	
				Before R&M	After R&M
01	Ukai TPS	3,4&5	2x200 MW, 1X210 MW	190 to 230 mg/Nm3	30 to 50 mg/Nm2
02	Wanakbori TPS	1,2 &3	3 x 210 MW	190 to 230 mg/Nm3	30 to 50 mg/Nm2
03	Wanakbori TPS	4,5&6	3 x 210 MW	190 to 230 mg/Nm3	30 to 50 mg/Nm2

Coal handling plant R&M initiative.

- GSECL 200/210 MW units have already complete their useful service life.
- The CHP of Ukai, Wanakbori& Gandhinagar TPS required R&M due to aging effect.
- Technical study for the same is under progress.
- Already for Ukai unit # 3,4&5, complete revamping of CHP system contract has been finalized and very soon new system erection work will start in parallel to running system. This will increase availability of system and also enhance feed flow rate.
- Also at Ukai TPS re-Modelling of existing railway track work is awarded to M/s.G-ride and work is already under progress. This will enable faster and easy movement of locomotives which results in reduction of demurrage charges.
- GSECL keen to complete other stations CHP R&M, as soon as possible.
- This may results in improvement of plant availability.

C&I Upgradation

- has successful completed C&I R&M for Wanakbori Unit # 1 to 6 & Ukai Unit # 3 & 4.
- **Key Benefits:**
- Plant availability and reliability increased.
- Unit can be compatible & support grid flexibility looking to RE integration.
- Optimization in the process by fine turning and precise utilization of resources.
- In next phase C&I R&M work contract for Gandhinagr Unit # 5 has been awarded to M/s. SIEMENS &Ukai Unit # 5 C&I R&M contract awarded to M/s. ABB. Both units work will be executed in next available shutdown.

#######

50 YEARS OF SERVICE

EXPERIENCE THE EXCELLENCE

Residual Life Assessment and Non Destructive Technique

Remaining Life Assessment (RLA) and Non-Destructive Technique (NDT) of these equipment like boilers, turbines, process piping, tank vessels, heaters & reactors of process power plants become necessary due to structural & microstructural damage through thermomechanical, electrical & chemical interaction. ERDA, recognised by the Central Boiler Board (CBB) as a well-known Remaining Life Assessment organisation under the Indian Boiler Regulation (IBR), 1950 provides various offline and online RLA and NDT services for mechanical equipments.

Facilities Available

- Visual Inspection
- Liquid Penetration Test
- Magnetic Particle Inspection -Yoke and Coil Method
- Ultrasonic Flaw Detection, TOFD, PAUT or Phased Array UT
- Ultrasonic Thickness Measurement
- Videoscopy Inspection
- Eddy Current Testing
- In-situ Metallography (IMG) Replica Test
- In-situ Hardness Measurement
- In-situ Chemical Analysis
- In-situ Vibration Analysis
- Infrared Thermography

Facilities Available

- Full-fledged Metallurgical Test facilities analysis of Microstructure/ Scanning Electron Microscope (SEM)/Energy Dispersive X-RayAnalysis (EDS or EDAX) /Spectrograph
- Mechanical Laboratory for UTS/YS/EL/Bending/ Flaring/Flatting/Impact
- Full-fledged Root Cause Analysis Facilities
- Stress Analysis and Analytical Residual Life Prediction Service of Power Plant Components using Finite Element Analysis (FEA) by FiniteElement Method (FEM) and Computational Fluid Dynamic (CFD)
- Vibration Analysis of Rotating Components

Equipment Covered

- Boiler
- Process Piping
- Turbine
- Tank/Vessel
- Heater
- Reactor

Experience Base

- 350 Boilers - RLA & NDT
- 220 Turbines - RLA & NDT
- 700 HT Motor Vibration Analysis

Magnetic Particle Inspection of Boiler Drum

Ultrasonic Testing of De SuperHeater Pipe

Visual Inspection of LP Casing

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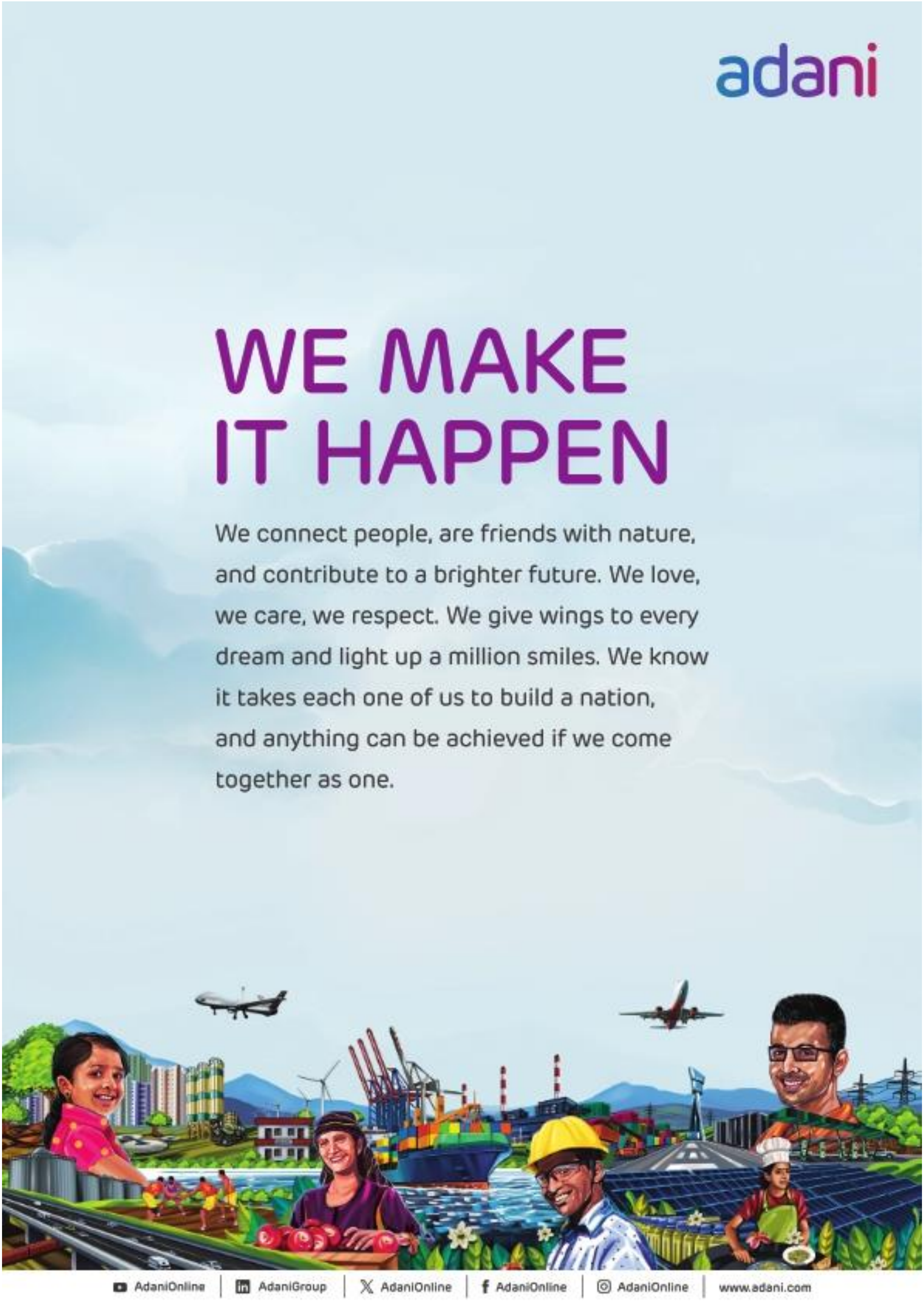
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