Council of Enviro Excellence

5th NATIONAL POWER-GEN ENERGY EFFICIENCY AWARDS-2026

5TH NATIONAL POWER-GEN ENERGY EFFICIENCY

SUMMIT AND AWARDS 2025

Enhancing Efficiency in Indian Thermal Power Plants

HEAT RATE IMPROVEMENT FOR THERMAL POWER PLANTS

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SUPERCRITICAL THERMAL POWER PLANT

Part Load Heat Rate Improvement & Auxiliary Power Optimisation

Flexible Operation Strategy for 660 MW & 800 MW Units

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Prepared for: 5th National Power-Gen Energy Efficiency Summit & Awards 2026

AGENDA

01 Understanding Flexible Operation

02 Heat Rate & Auxiliary Power Optimization at Part Load

UNDERSTANDING

Flexible Operation of Thermal Power Plants

Definition :

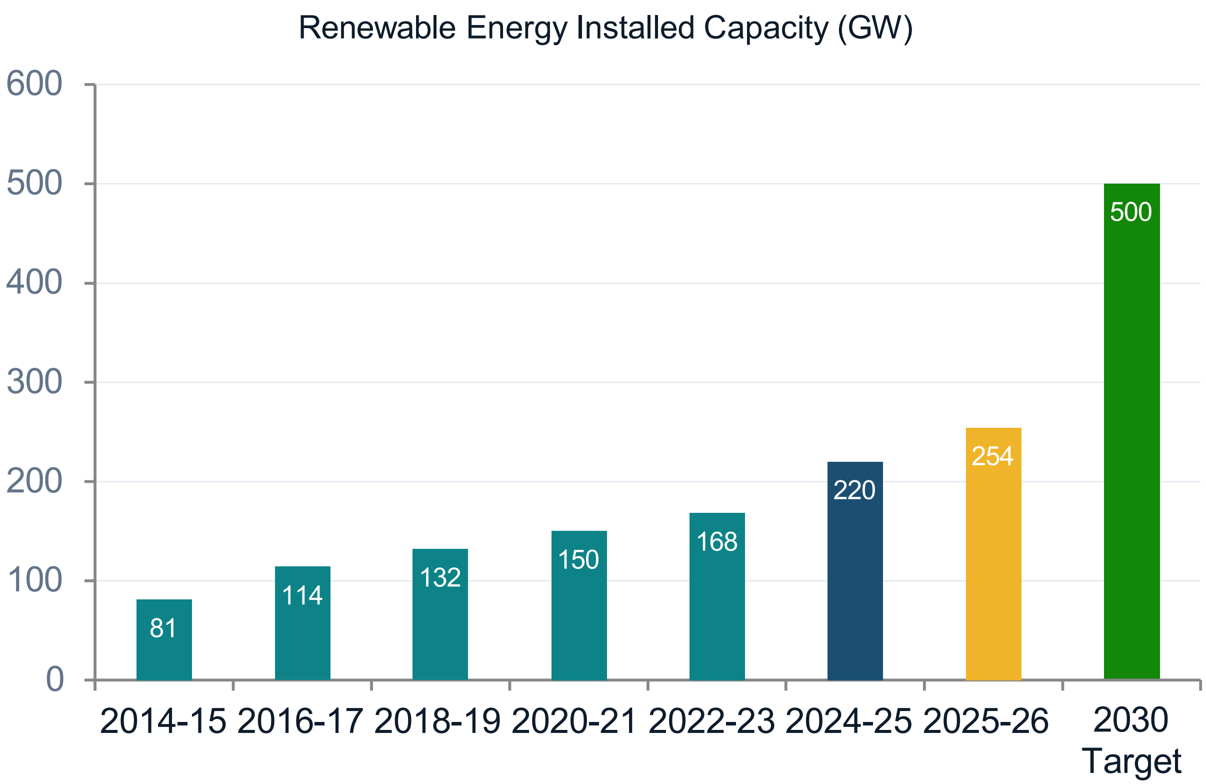
The capability of a thermal power plant to cope with the variability and uncertainty that solar and wind generation introduce — adjusting output rapidly across a wide load range to avoid renewable curtailment and maintain grid stability.

Low Minimum Load

High Ramp Rates

Fast Start-Stop

India Renewables: Growth Trajectory & 2030 Vision



51.5%

Record Single-Day

Renewables met 51.5% of India's total electricity demand on 29 July 2025

403 BU

Generation Growth

RE generation in FY 2024-25, up from 191 BU in 2014-15 — a 2× increase

100 GW

Solar Milestone

Solar capacity crossed 100 GW in January 2025 — up from just 2.82 GW in 2014

500 GW

2030 Target

Non-fossil fuel capacity target. NDC goal of 50% non-fossil share already met 5 yrs early

RE share of electricity generation: 17.28% (2014-15) → 20.75% (2023-24) → 22.49% (FY 2024-25) | Target: 50% by 2030

Why Part Load / Flexible Operation is Unavoidable?

India's renewable surge is creating a fundamental mismatch between supply shape and demand shape

52% of India's installed capacity is now renewable (Nov 2025)

Solar alone crossed 132 GW. On 29 July 2025, renewables met 51.5% of India's electricity demand in a single day — a record. The grid is transforming at historic speed.

The Duck Curve is real and deepening

Midday solar surplus forces thermal backing-down. At sunset, demand spikes ~60 GW in hours. On 31 May 2025, thermal fleet backed to 58% + 10 GW solar curtailed — frequency still hit 50.48 Hz.

500 GW RE target by 2030 will intensify the challenge

CEA projects thermal plants must operate as low as 25–40% of capacity at midday in 2030. Without flexible operation, India would need to curtail massive volumes of renewable energy daily.

Thermal fleet cannot simply shut down

Coal supplies ~57% of India's electricity. Hydro and gas are insufficient for balancing. Thermal plants must evolve from base-load workhorses into flexible grid-balancing assets.

India Grid — Key Numbers

60 GW	Evening ramp requirement
39 days	Freq. band violations FY24–25
23 GW	RE curtailed in 2025
~₹3,500 Cr	Annual value of curtailed RE
75 GW	Diurnal demand swing

Source: GRID-India 2025 | CEA Draft Wear & Tear Report Feb 2026 | Power Line Sep 2025

Flexibility KPIs

40%

Minimum Stable Load

Deep turndown capability for grid support

3–5%

Ramp Rate per Minute

Fast response to grid frequency events

< 4 hr

Hot Start-up Time

Reduced start-up time vs. traditional cold start

1–2%

Heat Rate Improvement

Achievable gain through control modernization and other hardware changes

The Three Dimensions of Flexible Operation

Flexibility is not a single parameter — it is defined by three interlocking technical capabilities

01 Minimum Technical Load (MTL)

How LOW can the unit go?

55%	40%
Current MTL (India)	CEA 2030 Target

- Lowest stable output without flame failure or trip
- Enables solar/wind to supply more during midday
- Avoids plant shutdown — hot start takes 3–5 hrs
- High-ash Indian coal makes 40% MTL harder than global norms
- Global best practice: 25–30% on low-ash coal

02 Ramp Rate

How FAST can load change?

1–1.3% /min	3–5% /min
Actual achieved (India pilots)	CEA target / SC units

- Rate of load increase/decrease (% of rated capacity per minute)
- Higher ramp = faster grid frequency response
- CEA mandates 3% /min (70–100%), 2% /min (55–70%)
- Supercritical units: 5% /min capability
- Boiler thermal inertia is the primary limiting factor

03 Start-up / Shut-down Time

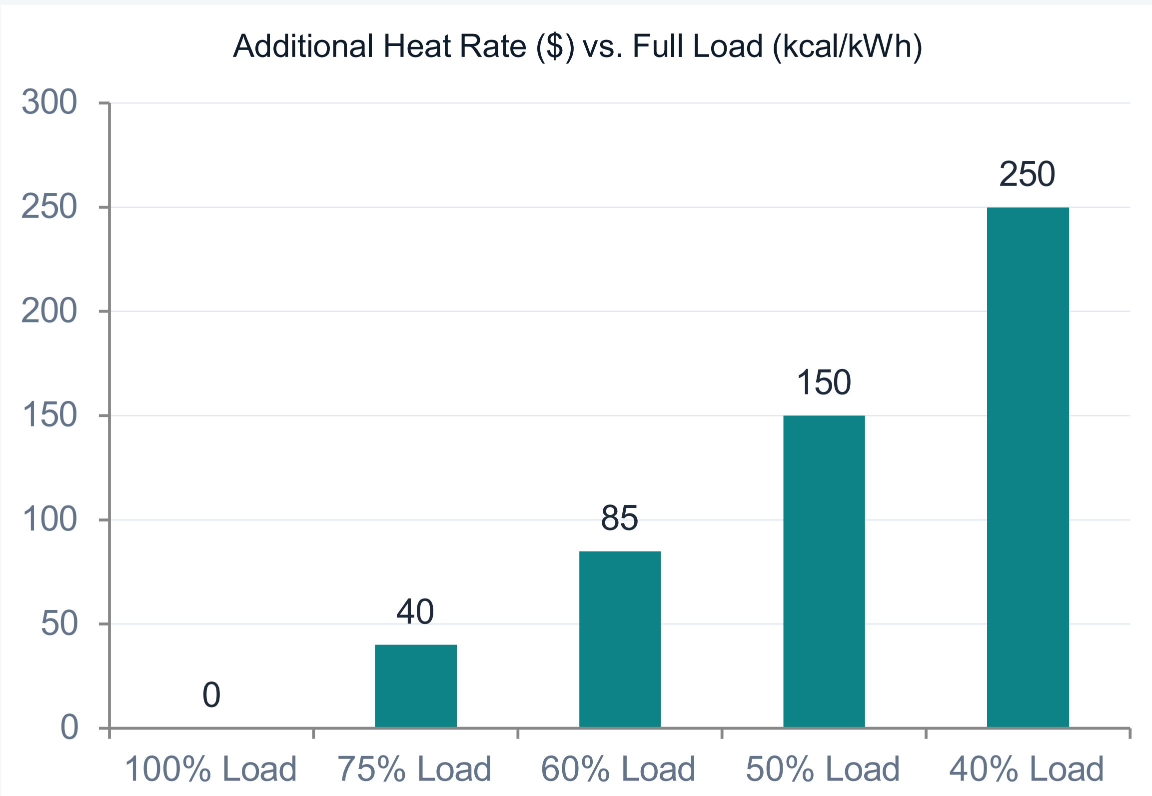
How QUICKLY can the unit restart?

8–10 hrs	2–4 hrs
Warm start (current India)	Target for 2-shift ops

- Cold start (>48 hrs shutdown): 11–14 hours
- Warm start (>8 hrs shutdown): 8–10 hours
- Hot start (<8 hr shutdown): 3–5 hours
- Two-shift operation needs reliable hot restart ≤4 hrs
- Off-load boiler circulation reduces restart time significantly

Source: CEA Flexible Operation Regulations Jan 2023 | Agora Energiewende (2017) Flexibility in TPPs | IEA CCC/242 | Mission Energy FLEX 2024

Fourth Dimension - Heat Rate Optimization at Part Load



O_2 Trimming

Maintain around 4% excess O_2. Prevents unburnt carbon loss

Mill Optimization

Select optimal mill combinations per load band

Soot Blowing

Intelligent scheduling based on flue gas temp

Spray Flow Control

Minimize attemperator spray at part load

($) Typical for 800 MW unit.

Heat Rate & Auxiliary Power Optimization at Part Load

Why at Part Load?

India's RE Integration Forces SC Units to operate away from Design. With flexible operation, coal based thermal power plant have to operate at lower load for most of the time to support the Grid. This will result in poor heat rate and higher operating cost at lower load. Therefore, considering flexible operation there is need to optimize the Heat rate and Auxiliary power for lower load operation.

Heat Rate Improvement: Sliding Pressure Operation (SPO)

Adjust turbine inlet pressure proportionally with load — eliminates throttling losses & reduces thermal stress

How It Works

1. **At full load**

   Turbine control valves fully open — no throttling

2. **At part load**

   Boiler firing rate reduces → steam pressure slides down proportionally

3. **Control action**

   Valves remain fully open; pressure follows load — no pressure drop losses

4. **Ramp-up**

   Boiler firing increases → pressure rises gradually — smooth thermal gradient

Performance Parameters

Load Range	**40–100% rated capacity**
HP Turbine Efficiency Gain	**4–5% at part load**
MDBFP Power Reduction at 50%	**~25%**
Thermal Stress Reduction	**Significant — smooth gradient**
CAPEX	**Low — control software upgrade only**
Payback Period	**< 1 year**
Ramp Smoothness	**Linear, no pressure transients**
Applicability	**All subcritical / supercritical / USC units**

✔ **Best ROI of all flexibility techniques — zero hardware cost**

Source: ScienceDirect – Sliding Pressure Overview | IEA CCC/242 | PowerMag Mitigating Flexible Ops Effects | CEA Flex Regs 2023

Heat Rate Improvement: Addition of new HP Heater

Increases Economizer inlet Feed Water Temperature, improved heat rate & reduces thermal stress

How It Works

1. **At full load**
   Heater remains inactive — no change
2. **At part load**
   HP Heater activates – Extraction from overload valve stage
3. **Control action**
   HP Heaters cut-in set point

Performance Parameters

Load Range	**30–50% rated capacity**
Heat Rate Gain	**0.6% at part load**
Thermal Stress Reduction	**Moderate**
CAPEX	**Medium — Hardware & software upgrade**
Payback Period	**< 4-6 year**
Applicability	**All supercritical / USC units**

Source: ScienceDirect – Sliding Pressure Overview | Siemens Flexible Operation

Waste Heat Recovery Using Low Temperature Economiser (LTE)

CONCEPT

A Low Temperature Economiser (LTE) is installed in the flue gas path downstream of the Air Preheater (APH) to recover low-grade waste heat from exhaust gases. The recovered heat is used for condensate heating, boiler feedwater preheating, or district heating.

WORKING PRINCIPLE

1. Flue gas leaving APH (~120–150°C) still contains significant recoverable heat
2. LTE transfers this heat to condensate/feedwater stream (~60–90°C)
3. Reduces extraction steam required in LP heaters, increasing turbine output

IMPACT

↓ Stack losses ↓ Plant heat rate ↑ Thermal efficiency +0.3–0.6%

TYPICAL PARAMETERS — 660 MW SUPERCRITICAL UNIT

Parameter	Typical Value
Flue gas inlet temperature	**120–150°C**
Flue gas outlet temperature	**90–100°C**
Condensate inlet temperature	**60–70°C**
Condensate outlet temperature	**85–95°C**
Heat recovered	**~20–30 MW**
Coal saving	**~0.8–1.2%**

SCHEMATIC ARRANGEMENT

LTE Benefits, Drawbacks & Payback Period

BENEFITS

- Improves plant efficiency by recovering low-grade waste heat
- Coal consumption reduction (~10,000–15,000 tonnes/year for 660 MW unit)
- Reduction in CO_2 emissions
- Increase in turbine power output due to reduced extraction steam
- Lower stack temperature, improving overall energy utilization
- Suitable for flexible operation and part-load efficiency improvement

DRAWBACKS & CHALLENGES

- Low temperature corrosion risk due to acid dew point (SO_3/H_2SO_4)
- Fouling and ash deposition on heat transfer surfaces
- Requires additional pumping power for condensate circulation
- Higher maintenance requirement vs. conventional economiser
- Material selection (ND steel/corrosion resistant alloys) increases cost

TYPICAL ECONOMICS

Capital Cost

₹18–25 Cr

Annual Coal Saving

₹6–8 Cr

Efficiency Gain

~0.4–0.6%

Payback Period

3–4 years

Low-Load Burner & Combustion Optimisation at Part Load

Hardware & Software upgrades to maintain stable flame with high-ash Indian coal at 40% MTL — the critical physical bottleneck

MTL: 40%

Wide-Turndown Burner Nozzles

Nozzle redesign for wider fuel-air ratio range. Swirl-stabilised flame at low coal feed rate. Essential for high-ash Indian coal (35–45% ash vs. 5–20% global).

Stable < 40%

Plasma / Oil Ignition Support

Plasma ignitors or oil guns provide continuous ignition support during low-load hold. Prevents flame-out without requiring full firing increase.

Ramp Response

Dynamic Mill Combination Control

Optimal mill combinations at each load band. At 40–55%: two-mill operation in coal pipe stability zone. Prevents coal pipe plugging.

~ 4% O_2

O_2 Trim & Combustion Optimisation

Maintain excess O_2 around 4% threshold at part load. Prevents CO formation and LOI (Loss on Ignition). Optimised soot blowing based on furnace exit gas temperature.

Heat Rate ↓0.2%

Intelligent Soot Blowing System (ISBS)

Traditional time-based soot blowing replaced with condition-based system using furnace exit temperature differential. Reduces auxiliary steam and maintains heat transfer.

Advance Process Control (APC)

Integrated approach

APC limits SH/RH temperature excursions, reduce thermal stress & improve reliability by incorporating feed forward signal based on plant operating data. It optimize the combustion process resulting in improved efficiency on low load.

Source: IEA CCC/242 Flexible Operation of Coal-Fired Plants | CEA R&M Guidelines 2023 | PowerMag Mitigating Flexible Ops | NTPC/BHEL Technical

2-Boiler + 1-Turbine Configuration

Innovative Plant Architecture for Optimised Part Load Operation Without Unit Shutdown

Configuration Concept & Architecture

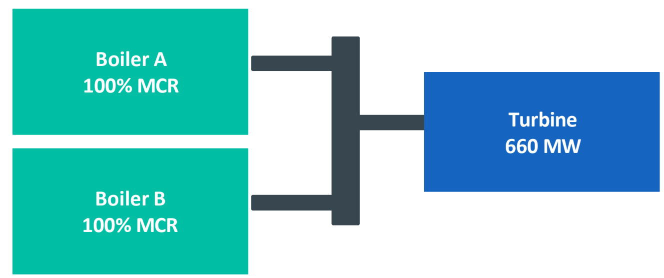
- Two supercritical boilers (each ~50–55% of turbine MCR rating) feed a single turbine
- Example: 2 × 300-350 MW boilers → 1 × 660 MW turbine
- At full load: both boilers operate simultaneously at 100% MCR each — turbine at full rated load
- At part load: ONE boiler is shut down completely. Remaining boiler operates at 80–100% MCR
- Result: the remaining boiler operates near its design point — near-design-point heat rate maintained even at 50% overall plant output
- Operational capability with any one or both boilers

KEY ADVANTAGES:

Parameter	1B–1T	2B–1T
Minimum Load	~40%	~25%
Part-load Heat Rate	Base	2–4% Lower
Boiler Trip Impact	100% outage	40–60% load loss
Maintenance Flexibility	Low	High
Grid Flexibility	Moderate	High

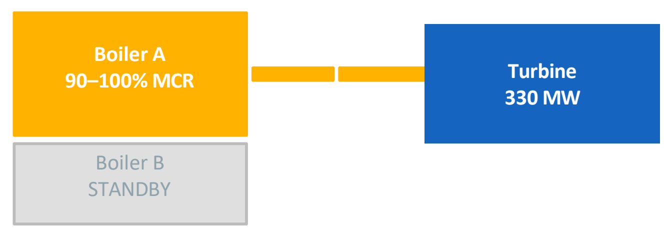
Configuration Schematic (Full Load vs Part Load)

FULL LOAD



Both boilers ON → Turbine at 100%

PART LOAD (50%)



Boiler A at full load → Turbine at 50%

Low-Rating Supercritical Units (~350 MW)

Purpose-Built for Flexible Operation | Inherently Better Part-Load Heat Rate

Concept & Technical Rationale

- A LRSC unit (~350MW) is thermodynamically equivalent to a 660 MW unit at 100% MCR in cycle efficiency terms
- Steam parameters remain supercritical— full thermodynamic advantage is retained at smaller ratings
- Auxiliary systems (fans, pumps, mills) are sized for the smaller unit — no oversizing penalty at part load
- Continuous part load operation of higher rating set results in poor operational efficiency and high operating cost. Best solution is lower rating high efficient machine.
- Precedent: In Europe 250–350 MW supercritical units specifically for flexible grid role
- Minimum Technical Load (MTL) becomes lower ~140 MW instead of 264 MW for 660 MW unit — far better grid flexibility

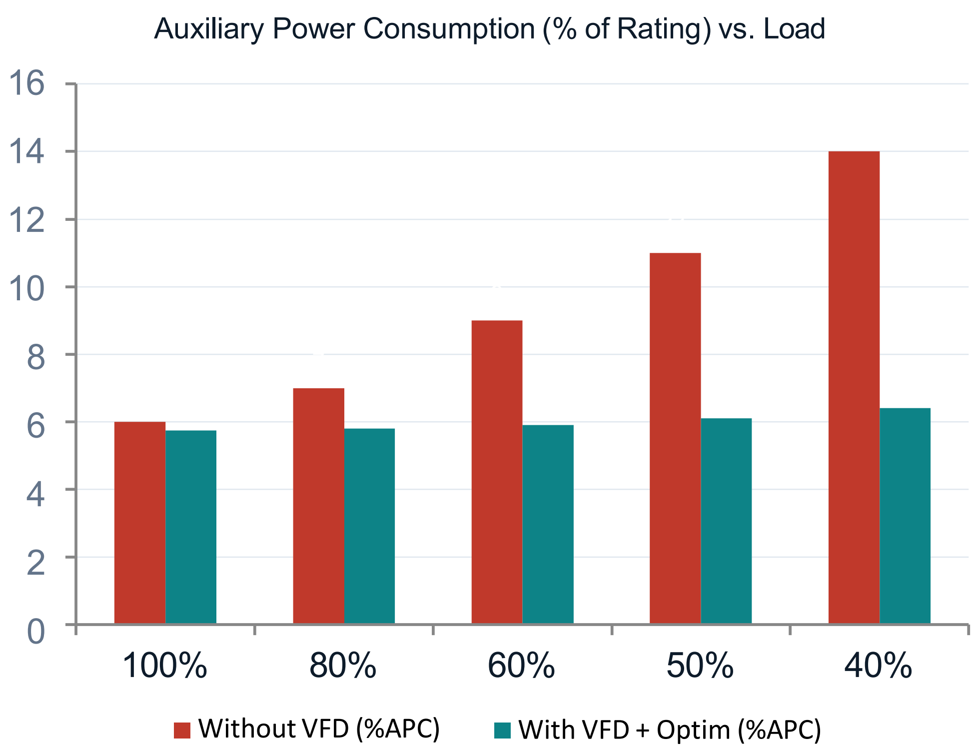
KEY ADVANTAGES OF 2X350MW VS 1X660MW

PARAMETER	2x350 MW	1x660 MW	Remarks
Plant Availability	Higher	Lower	Availability of 2x350 MW configuration shall be higher because of 2 units.
Operational Flexibility	Higher	Lower	Low load operation, Ramp-up and Ramp-down of 2x350 MW configuration shall be better and it is more suitable for flexible operation.
Part load Efficiency	Higher	Lower	For plant loads 350 MW and below with 1 unit in operation, part load station efficiency of 2x350 MW configuration shall be higher
Efficiency at TMCR	Higher	Higher	Comparable Efficiency at full load operation.

DESCRIPTION		350 MW UNIT AT BASE LOAD	660 MW UNIT OPERATING AT 350 MW LOAD
Load	%	100	53.03
Efficiency	%	Base	Base - ~2.5

Auxiliary System Optimisation

VFDs on fans & pumps, BFP sequencing and condenser management — cuts parasitic load at part-load conditions



Optimisation Measures

VFDs on ID/FD/PA Fans

Variable Frequency Drives replace damper control. Precise air-flow at any load. ~2–3% auxiliary power saving at 50% load. Essential for tight O_2 control.

BFP Load Sequencing

Switch from turbine-driven BFP to motor-driven BFP at part load. Reduces standby BFP losses. Variable speed motor drive on BFP adds further control precision.

Cooling Water Pump Optimisation

At 50% load, CW flow can be reduced 30–40% with VFD without vacuum degradation. Online condenser cleaning maintains backpressure at reduced CW flow.

Coal Feeder & Classifier Upgrade

Variable speed coal feeders and dynamic classifiers maintain coal fineness across load range. Reduces mill power at part load and prevents pipe plugging.

Source: IEA CCC/242 | CEA Flexible Operation Regulations 2023 | ScienceDirect – Auxiliary Power Reduction Studies | NTPC O&M Reports


Thank You!
for your attention
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BHEL