EVALUATION OF EXTENDED ONE-SHIFT THERMAL POWER PLANT OPERATIONS WITH BATTERY ENERGY STORAGE: IMPLICATIONS FOR COST OPTIMIZATION, EMISSIONS, AND GRID RELIABILITY IN INDIA

Abstract

In India, renewable energy is getting integrated into power generation rapidly which is incurring operational stress on coal-based thermal power plants. Power plant units designed for base-load operation are forced to provide flexibility, leading to frequent load ramps, inefficient part-loads and high maintenance costs. The present paper evaluates techno-economic and regulatory assessment of integrating a 75 MW/300 MWh BESS with a 500 MW thermal unit operating under an extended one-shift regime. The thermal unit maintains stable output during solar peak hours (11:00 AM–3:00 PM), with surplus energy stored and discharged during evening peak (7:00 PM–11:00 PM). The study evaluates the impact on operating costs, emissions intensity, and system reliability by taking CERC, CEA and NITI Aayog normative parameters into consideration. The result shows that despite high upfront costs, thermal-integrated BESS can generate value through arbitrage, reduced cycling losses, improved heat rate, and ancillary services.This Paper also discusses pathway for regulatory treatment within existing Indian market frameworks.

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1. Introduction

In India the power sector is getting transformed due to rise in demand, increase in VRE penetration and market-based dispatch. Coal plant's efficiency is getting degraded due to frequent flexible and below technical minimum operations instead of firm load operations.

2. Indian Power System Context

VRE penetration in India's power sector is reshaping its net-demand and operational variability. Coal units are now forced to operate flexibly incurring inefficiencies and O&M losses. In this context, the present study reframes BESS for stabilising, flexibility-enabling asset for thermal generation which was earlier framed for only renewables

3. Conceptual Framework: Extended One-Shift Operation with BESS

This model reframes load-following into an extended one-shift regime, maintaining the thermal unit at ≥55% load. The BESS acts as a stabilising buffer, absorbing surplus generation during the 11:00 AM–3:00 PM solar peak (instead of backing down to ~40%) by charging ~75 MW (500 MW unit), and discharging during the 7:00 PM–11:00 PM peak, reducing ramping, cycling, and mechanical stress.

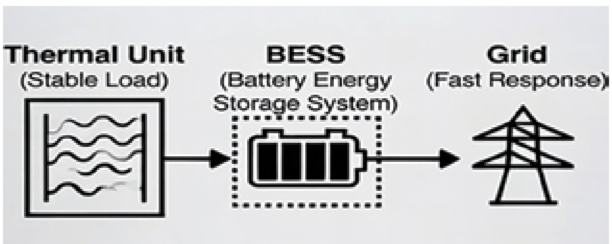

Figure 1. Conceptual schematic of the extended one-shift operating framework with BESS integration. The BESS acts as buffer for thermal unit during solar peak hours.

4. Technical Parameters and Assumptions

Table 1. Key technical and economic assumptions used in the analysis.

Category	Parameter	Value	Basis / Source Type
Plant	Installed capacity	500 MW	Representative unit assumption
Operation	Load during solar peak without BESS	40% of MCR	Scenario assumption
Operation	Stabilized load with BESS	55% of MCR	IEGC (Fourth Amendment), 2016
BESS sizing	Incremental power absorbed	75 MW	Derived (15% of 500 MW)
BESS sizing	Energy capacity	300 MWh	Derived (75 MW × 4 h)
BESS sizing	Power rating	75 MW	Project sizing
Utilization	Cycles per day	1.0	Extended one-shift logic
Efficiency	Round-trip efficiency	90%	Normative benchmark
Losses	Discharge loss	10%	Modeling assumption
Degrada-tion	Annual degradation	2% p.a.	International benchmarks
Life	Design life	15 years	Planning assumption
Cost	Benchmark CAPEX	₹1.5 Cr/ MWh	Derived from VGF Tranche -1 ceiling
Support	VGF	₹0.46 Cr/ MWh	VGF Tranche -1
Cost	Effective CAPEX after VGF	≈ ₹1.04 Cr/MWh	Derived

Note: VGF Tranche-1 is used to reflect early-stage thermal-integrated BESS deployment, which faces higher uncertainty and limited revenue monetization than mature solar BESS systems.

Parameters follow regulatory benchmarks and transparent assumptions; the BESS is sized to maintain ≥55% MCR during 11:00–3:00, absorbing ~75 MW for 4 hours (300 MWh), with losses explicitly modeled.

5. Techno-Economic Analysis

5.1 Energy Arbitrage

Assumption:

- Analysis of IEX DAM shows consistent intra day price variation ,reflecting higher prices during evening peaks than solar-rich daytime hours,The assumed DAM price spread of ₹3.0/kWh is indicative and conservative, actual spreads vary across regions and seasons.
- A charging price of ₹3.0/kWh and a levelized BESS cost of ₹2.8/kWh are assumed , yielding an effective delivered cost of ₹5.8/kWh and a peak–off-peak spread of ₹3.0/kWh. With 300 MWh daily discharge and 10% losses, usable energy is 270 MWh/day.

Calculation:

Annual arbitrage revenue: 270 MWh × 365 × ₹3/

kWh = ₹29.57 crore/year

Implication: Under the assumed price spread a 300 MWh/day BESS can earn ~₹29.6 crore per year from energy arbitrage.

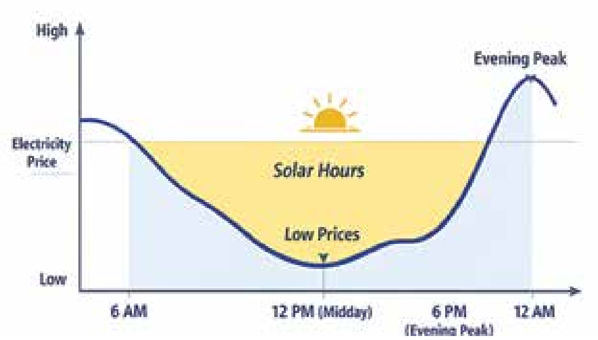

Figure 2. Conceptual intraday electricity price profile under high solar penetration. The figure infers a low prices during solar peak hours and high prices during evening hours.

5.2 Cycling and Wear-and-Tear Savings

Assumption:

- A conservative 5–10% incremental O&M burden is attributed to flexible operations.
- Thermal capacity is considered as 500 MW and BESS can avoid 30–40% of this incremental O&M burden.

Calculation:

- Base Annual O&M cost **:** 500 MW × ₹30 lakh/MW/year = **₹150 crore/year**
- Incremental O&M due to ramping (5–10%): **₹7.5–15 crore/year**
- O&M cost avoided through BESS (30–40%):₹**2.5–6 crore/year**

Implication: Reduced frequent ramps and cyclings through BESS offsets 2.5-6 crore/year in incremental O&M costs for 500 MW power plant (inline with CEA guidelines).

5.3 Heat Rate Improvement

Assumption: A conservative 5–7% heat-rate improvement is assumed ,representing a best-case for older subcritical units operating at deep part load when shifting from 40% to 55% load.

Calculation: For a 500 MW unit operating at 275 MW for 4 h/day

Annual energy= (275MW) x (4h) x 365) days = ~ 402 GWh/year ,

Fuel spend at ₹4/kWh is (402 GWh/year) x (₹4/kWh) = ₹160.8 crore/year,

Savings yield 5-7% of ₹160.8 crore/year = **₹8.0–11.3 crore/year**.

Implication: Avoiding deep part-load operation improves combustion stability, turbine efficiency, and auxiliary power and thereby yielding savings of **₹8.0–11.3 crore/year**.

6. Emission Intensity reduction:

Assumption: In Thermal power plant without BESS, the unit operates at ~40% load during solar peak hours. With BESS under the extended one-shift framework, output is stabilised at ~55% (≈275 MW) for 4 h/day.

Calculation: This assumption correspond to energy of ~402 GWh annually.Using coal emission factors of 0.9–1.0 tCO_2/MWh, associated emissions are 0.36–0.40 $MtCO_2$/year.

Implication: Operating thermal unit close to optimal load reduces emissions intensity and assumed to reduce emissions intensity by 3–5%, which corresponds to an avoided intensity-equivalent of ~11,000–20,000 tCO_2/year.

Interpretation.

This represents an **emissions-intensity improvement**, not an absolute emissions reduction

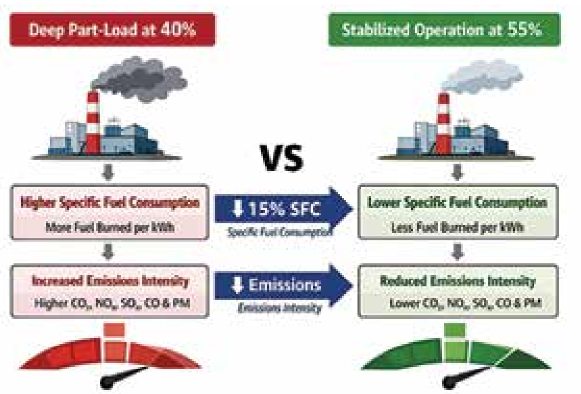

Figure 3. Emissions impact logic under extended one-shift stabilization. The Figure illustrates better emission control with BESS.

7. Regulatory Treatment in India

This section situates the proposed

thermal-integrated BESS within India's regulatory framework, distinguishing between explicit, draft, and case-specific pathways, while avoiding over-claiming.

7.1 Regulated tariff pathway (Section 62) — draft and evolving

CERC draft amendments propose recognizing integrated storage under cost-plus tariffs (Section 62), with provisions on capacity, auxiliary use, and efficiency accounting; if notified, this could enable recovery under Sections 62 and 79, but it currently has no legal force.

7.2 Treatment under existing PPAs — case-specific

Integration is not automatic; it requires beneficiary consent, regulatory approval, and rule compliance. Draft recognition does not amend contracts; adoption remains station specific.

7.3 Participation in system operations and markets

Storage may provide ancillary services (2022), support DSM compliance, and participate in DAM/RTM under 2021 rules; procedures remain evolving.

8. Cost–Benefit Assessment

This section presents a conservative cost–benefit assessment of integrating a 300 MWh BESS with a 500 MW thermal unit under the proposed extended one-shift operating framework. A 2% annual degradation rate is assumed, and cumulative benefits over *N* years are modeled using degradation-adjusted closed-form expression:

$$B_c = B_0 * \frac{1-(1-d)^N}{d}$$

where B_c is the cumulative benefit Over N years, B_o is initial annual benefit, d is the annual degradation rate (0.02), the term $\frac{1-(1-d)^N}{d}$ represents the degradation adjustment factor, calculated as **12.85**.

8.1 Capital Cost

By using VGF Tranche-1 ceiling (₹46 lakh/MWh) and a benchmark CAPEX of ₹1.5 crore/MWh: The gross CAPEX ≈ ₹450 crore, VGF ≈ ₹138 crore, and net CAPEX ≈ ₹312 crore.

This benchmark is indicative; actual costs will be discovered and may vary during competitive bidding.

8.2 Annual Monetized Benefits

Calculations already presented in Section 5 has been used , this subsection only consolidates key monetized benefit into a single summary table for life-cycle valuation and investment appraisal.

Table 2. Degradation-adjusted life-cycle monetized benefits from extended one-shift operation with BESS (15-year horizon, indicative)

Benefit stream	Basis of estimation	Annual value range (₹ crore/ year)	15-year degradation-adjusted value (₹ crore)
Energy arbitrage	Section 5.1	29.57	380
Avoided cycling-related O&M	Section 5.2	2.5–6	32–77
Fuel savings from heat-rate improvement	Section 5.3	8.0–11.3	103–145
Ancillary/ system support services	Conservative placeholder, subject to regulation	3–4	39–51
Total gross benefit	—	**42–51**	**554–653**

Note: Life-cycle values are obtained using a degradation-adjusted cumulative benefit factor of 12.85, corresponding to a 2% annual degradation rate over a 15-year project life.

When expressed as an average over the project life, the degradation-adjusted benefit corresponds to approximately ₹36 - ₹44 crore per annum.

8.4 Investment Appraisal and Financial Viability

Metric	Value
Net CAPEX	₹312 crore
Project life	15 years
Annual degradation	2%
Total Gross benefit (Avg)	₹607.83 crore

Average annual benefit (Degradation factored)	₹40.52 crore/year
Present value (PV) of benefits	₹332.8 crore
Net present value (NPV)	+₹20.8 crore
Benefit–cost ratio (BCR)	1.07
Internal rate of return (IRR)	10.41%
Simple payback period	~8 years
Discounted payback period	~13 years

Table 3: Summary of investment appraisal metrics for thermal-integrated BESS

Note: NPV, IRR, BCR, and payback are computed using standard DCF methods with a 9.226% discount rate, aligned with CERC guidelines (70:30 debt–equity, 14% RoE ceiling, SBI 1-year MCLR as debt proxy).

Note: Detailed sensitivity and threshold analyses assessing the robustness of these results to variations in key assumptions are presented in Appendix A.

8.5 Strategic (Non-priced) Benefits

- **Reduced outage risk and thermal stress:** Deep part-load operations and ramps will be reduced , resulting in reduced fatigue and extended equipment life.
- **Improved dispatch predictability:** Stable operation above technical minimum load simplifies operation schedules and reduces balancing complexies.
- **Lower emissions intensity:** Operating plant near optimal heat rates reduces coal use and further reduce emission rates per MWh.
- **Higher renewable absorption:** BESS buffers solar peaks without forcing inefficient thermal operation.
- **Enhanced grid resilience:** Fast-response storage improves local frequency and voltage support.

9. Comparative Assessment

Parameter	Conventional	Extended One-Shift
Ramp Frequency	High	Low
Heat Rate	Sub-optimal	Near optimal
O&M Cost	High	Lower
Emissions	Higher	Lower
Grid Support	Limited	High

10. Policy Implications

This evaluation offers policy-relevant insights for India's thermal power sector, which reflects the emerging regulatory framework rather than existing guidelines.

i. **Thermal flexibility role:** BESS should be recognised as a buffer for thermal power generation, rather than renewable energy storage buffer.

ii. **Support mechanisms:** VGF schemes are to be enhanced for thermal-integrated BESS where benefits are high.

iii. **Tariff clarity:** CERC provisions on cost recovery, adjustments to efficiency, and charges is essential for certainty in investments.

iv. **System planning:** Including thermal–storage hybrids in adequacy and capacity expansion studies could improve power reliability and lower costs.

11. Conclusion

Due to rapid integration of renewables , Thermal power plants in India are facing stress due to cycling inefficiencies ,higher O&M costs and higher emission intensity. The extended one shift operation (75 MW/300 MWh BESS with 500 MW) stabilises operations during solar peak by delivering ₹29.6 crore/year from arbitrage,₹2.5–6 crore from avoided cycling, ₹8.0–11.3 crore from fuel savings, 11,000–20,000 tCO_2 reductions, and positive 15-year NPV (₹20.8 crore), with IRR > WACC. MA

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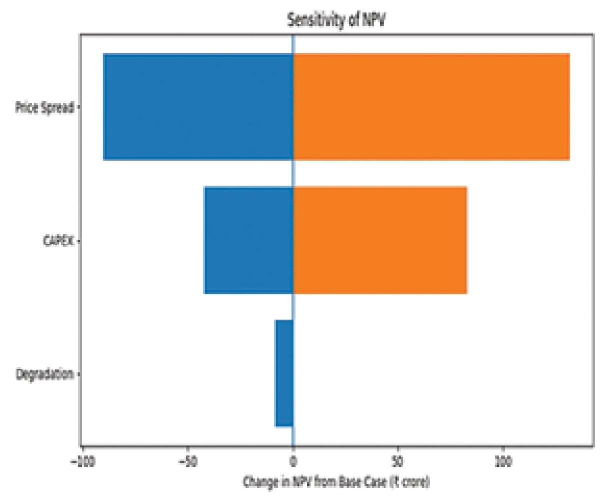
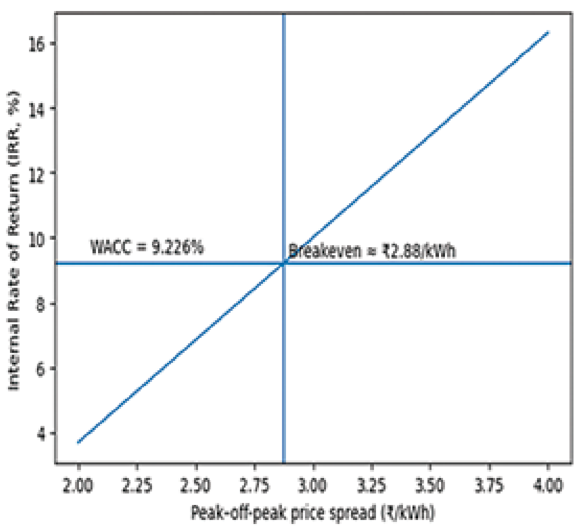
Appendix A. Sensitivity and Threshold Analysis



a) Tornado chart showing sensitivity of NPV to key parameters.



b) IRR Threshold

Figure 4. Sensitivity and threshold analysis of project viability.

Note: Figure (a) shows deviations from the base-case NPV (₹20.8 crore) due to changes in price spread), capital cost, and degradation. Figure (b) marks WACC (9.226%) and the IRR breakeven spread (≈₹2.88/kWh).

c) Sensitivity of project payback periods to key parameters

Parameter	Case	Simple Payback (years)	Discounted Payback @9.226% (years)
CAPEX	₹250 crore	6.0	9
CAPEX	₹312 crore (base)	8.0	13
CAPEX	₹375 crore	9.0	>15
Price spread	₹2/kWh	12	>15
Price spread	₹3/kWh (base)	8.0	13
Price spread	₹4/kWh	6.0	8
Degradation	1% p.a.	7.0	12
Degradation	2% p.a. (base)	8.0	13
Degradation	3% p.a.	8.0	15

Note: Simple payback is computed on an undiscounted basis, while discounted payback incorporates a 9.226% discount rate and a 2% annual degradation in usable BESS capacity in the base case.