IMPLEMENTATION OF FLEXIBLE OPERATION

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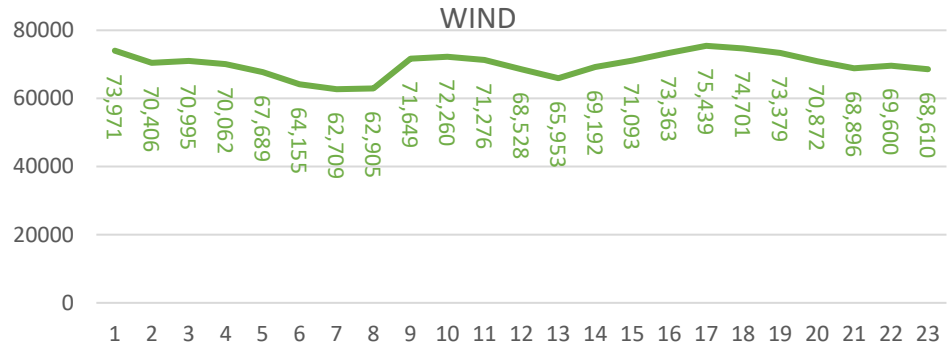
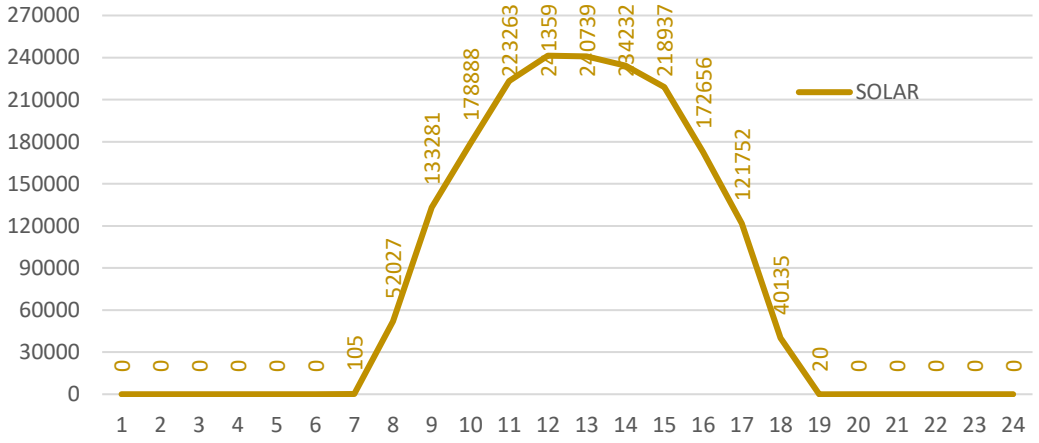
GENERATION PREDICTION YEAR, 2029-30

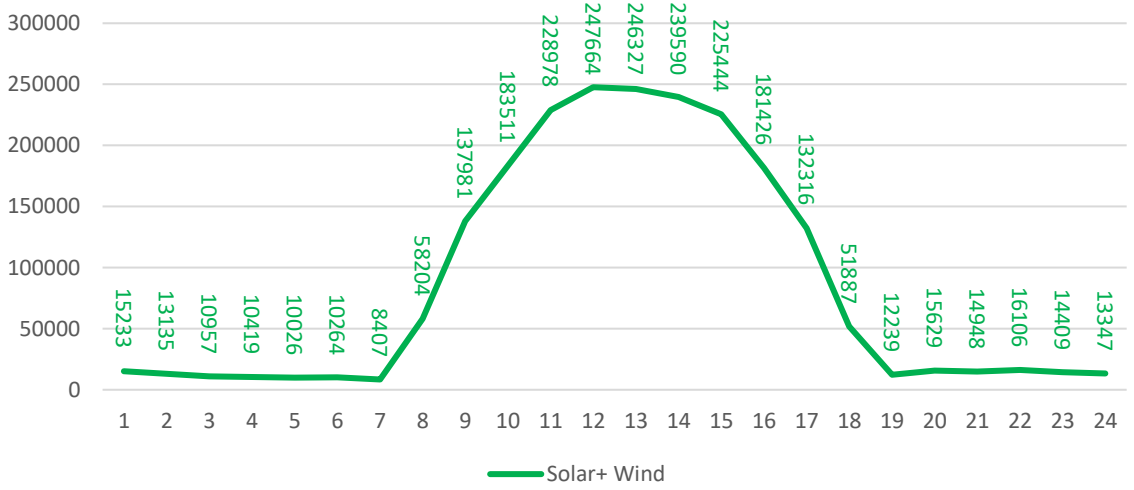
Peak Wind Power: The maximum wind generation of 75.44 GW is predicted in July, 2029 taking into account of 100 GW installed capacity



Peak Solar power: The maximum solar generation of 241 GW will be available at 12 pm in May, 2030 considering 292 GW installed capacity



Maximum RE Generation Day: It has been found that maximum RE (combined solar and wind) generation will be available in May, 2030. The Solar generation will fluctuate from 0 GW at 7 am to 241 GW at 12 pm and again 0 GW at 8 pm. The Wind generation will fluctuate from 16 GW to 4.6 GW. The maximum combined solar and wind generation will be 247.6 GW at 12 pm.



DEPTH OF FLEXIBILISATION Vs BESS CAPACITY

Three case studies show that requirement of BESS capacity are decreasing with increasing depth of flexibilization in coal-based power plants. Coal-fired power plants have to touch MTL once daily.

Most Critical Day (2029-30)			
	55% MTL	40% MTL	40% MTL + 2-shifting
Max. Coal Gen. (MW)	199322	208202	216449
Synchronished coal capacity (MW)	216664	226264	235180
Coal Capcity needed (MW)	254899	164696	276682
Ramp up rate (MW/Min.)	778	778	661
Ramp down rate (MW/Min.)	596	669	810
BSS Power (MW)	45800	32475	22876

COST OF RE INTEGRATION INTO GRID

Cost of Integration of renewable energy by 55% flexing = Rs. 0.82/-

Cost of Integration of renewable energy by 45% flexing = Rs. 0.78/-

Cost of Integration of renewable energy by BSES with 2 hrs. Storage = Rs. 1.54/-

Cost of Integration of renewable energy by BSES with 4 hrs. Storage = Rs. 3.61/-

CEA’s REGULATION AND PHASING PLAN

REGULATION ON TECHNICAL MINIMUM LOAD

CEA has notified a Regulation regarding Flexible operation of coal based Thermal Power Generating Units on 30.1.2023.

1. The 55% minimum load and 2% ramp rate (55% to 70%) operating requirement shall have to be implemented by all thermal generating units (Central/State/Pvt) within one year of the notification of the regulation.

2. Power plants shall implement measures, if required, as per the phasing plans by the respective power plants owners to operate thermal unit at 40% minimum load with following ramp rate:

   1% per minute - 40% to 55% and 55% to 40% load

   2% per minute - 55% to 70% and 70% to 55% load

   3% per minute - 70% to 100% and 100% to 70% load

PHASING PLAN

PHASE- PILOT

Duration: completed in March, 2024

Under this phase, **10 nos. of units of capacity 5850 MW** in aggregate of various thermal power plants have been planned and identified for which the study, field tests, retrofits etc. have already been initiated for flexible operation. The timeline for upgradation/retrofitting was 31st March, 2024.

PHASE-I

Duration: July, 2024 to June, 2026

Under this phase, the following **91 Nos. of units of capacity 51080 MW** in aggregate of various thermal power plants have been planned and identified for the upgradation/retrofitting for flexible operation including the study and field tests. This phase to be completed within 2 years i.e. from July, 2024 to June, 2026.

PHASE-II

Duration: July, 2026 to June, 2028

Under this phase, the following **100 Nos. of units of capacity 46825 MW** in aggregate of various thermal power plants have been planned and identified for the upgradation/retrofitting for flexible operation including the study and field tests. This phase to be completed within 2 years i.e. from July, 2026 to June, 2028.

PHASING PLAN

PHASE-III

Duration: July, 2028 to December, 2029

Under this phase, the following **101 Nos. of units of capacity 37215 MW** in aggregate of various thermal power plants have been planned and identified for the upgradation/retrofitting for flexible operation including the study and field tests. This phase to be completed within a period of 18 months i.e. from July, 2028 to December, 2029.

PHASE-IV

Duration: January, 2030 to December, 2030

Under this phase, the following **191 Nos. of units of capacity 55767 MW** in aggregate of various thermal power plants have been planned and identified for the upgradation/retrofitting for flexible operation including the study and field tests. This phase to be completed within a period of 12 months i.e. from January, 2030 to December, 2030.

In case the utilities comprehend that 40% operation of units having age more than 40 years under this phase is not viable/possible, the utilities may opt for 2-shift operation by suitable retrofits/study/tests. However the duration for the retrofits including the study/test of this phase shall be the same.

PHASING PLAN

PILOT PHASE (May, 2023 - March, 2024)

Phase	Sector	Organisation	Name of Project	Unit No.	Capacity (MW)	Region
Pilot	Central	NTPC	MAUDA TPS	1	500	WR
Pilot	Central	NTPC	SIMHADRI	3	500	SR
Pilot	Central	NTPC	DADRI	6	490	NR
Pilot	Central	DVC	MEJIA TPS	8	500	ER
Pilot	Central	NEYVELI LIGNITE	NEYVELI NEW TPP	2	500	SR
Pilot	State	KPCL	YERMARUS TPS	1	800	SR
Pilot	State	GSECL	WANAKBORI TPP	6	800	WR
Pilot	State	RRVUNL	SURATGARH SCTPP	8	660	NR
Pilot	State	WBPDC	SAGARDIGHI TPS	3	500	ER
Pilot	Private	CEPL	MUTHIARA	2	600	SR
Pilot Phase Total				**10**	**5850**	

PHASING PLAN

GIST OF PHASING PLAN

		PILOT PHASE May,2023-Mar,2024 (40%)	**PHASE I** July,2024-Jun,2026 (40%)	**PHASE II** July,2026-Jun,2028 (40%)	**PHASE III** July,2028-Dec,2029 (40%)	**PHASE IV** Jan,2030-Dec,2030 (40%)	**Total** **Units** (MW)
CENTRAL	UNITS CAPACITY(MW)	5 2490	28 17510	21 8860	17 7720	79 26760	150 63340
STATE	UNITS CAPACITY(MW)	4 2760	27 15910	17 7660	40 13410	94 21725	182 61465
PRIVATE	UNITS CAPACITY(MW)	1 600	36 17660	62 30305	44 16085	18 7282	161 71932
TOTAL	TOTAL (UNITS) TOTAL (Capacity)	**10** **5850**	**91** **51080**	**100** **46825**	**101** **37215**	**191** **55767**	**493** **196737**

COMPENSATION

INCREASE OPERATIONAL COST

Capital Expenditure for retrofit: One-time expenditure to be incurred in retrofitting of various measures to make the plant capable of low load operation.

O&M cost due to increased Life Consumption: Flexible operation also leads to a higher rate of deterioration of plant's components

Increased net Heat rate: Cost due to increase in Heat Rate and increased auxiliary consumption

Additional oil consumption: Cost of additional oil consumption for EFOR

ADDITIONAL FIXED COST DUE TO INCREASE CAPEX

a) **Capital Expenditure for retrofit:** One-time expenditure to be incurred in retrofitting of various measures to make the plant capable of low load operation.

i. In case of old units (commissioned before 01.01.2004) which have not upgraded their plant control and instrumentation system previously, capex requirement may be around Rs 30 crores for each unit.

ii. An estimated capital investment of around Rs 10 crores will be required for each unit commissioned on or after 01.01.2004 and except units covered under para (iii).

iii. As per the OEM few measures are required to be implemented for regular 40% load operation of subcritical units though the same (40%) was demonstrated during PG test. Considering above it is proposed a capital investment of Rs.6 crores may be allowed to the subcritical generating units where investment approval received on or after 01.01.2011

iv. Unit will be eligible for increased fixed tariff irrespective of actual operation once measures are implemented and exhibits desired low load operation. Considering five (5) years payback period the impact has been estimated.

v. Power plant may be penalized proportionally (Fixed cost) for not exhibiting low load operation at least 85% of time when asked for.

Unit Size (MW)	Recovery period (years)	Capital cost (Rs Cr)	Increased in fixed charge per annum (Rs. Cr.)	Capital cost (Rs Cr)	Increased in fixed charge per annum (Rs. Cr.)
200	5	30	7.65	10	2.55
500	5	30	7.65	10	2.55
660	5	30	7.65	10	2.55
800	5	30	7.65	10	2.55

Unit Size (MW)	Recovery period (years)	Capital cost (Rs Cr)	Increased in fixed charge per annum (Rs. Cr.)
200/250	5	6	1.53
500	5	6	1.53
600	5	6	1.53

ADDITIONAL FIXED COST DUE TO INCREASE IN O&M COST

b) O&M cost due to increased Life Consumption: Flexible operation also leads to a higher rate of deterioration of plant's components

i. As flexible operation is new in India no reliable data is available regarding actual life consumption or damaged. In other country also no such assessment has been done as cost of flexible power is being kept under ancillary services and price is market based which may be high or less compared to actual.

ii. USAID-Intertek Study: An estimate of the increase in O&M Cost due to reduction in life of components at Ramagundam, Jhajjar TPS of NTPC and Ukai of GSECL. The study was based on the five to ten-year historical cost data of the units (all the costs are at 2017 levels for NTPC & 2018 for GSECL Units). No two units have the same costs due to variation in factors affecting the costs like coal, age of plant, operating practices, operator's skill and design.

iii. Engie Lab estimates that on a yearly basis, the capital expenditures and additional maintenance result in a 0.3% to 4.3% cost impact versus the total costs of a unit, or expressed in rupees per kWh produced on such a unit: 0.01 to 0.15Rs/kWh. However, this estimate is based on the current level of flexibilization,(55% and above).

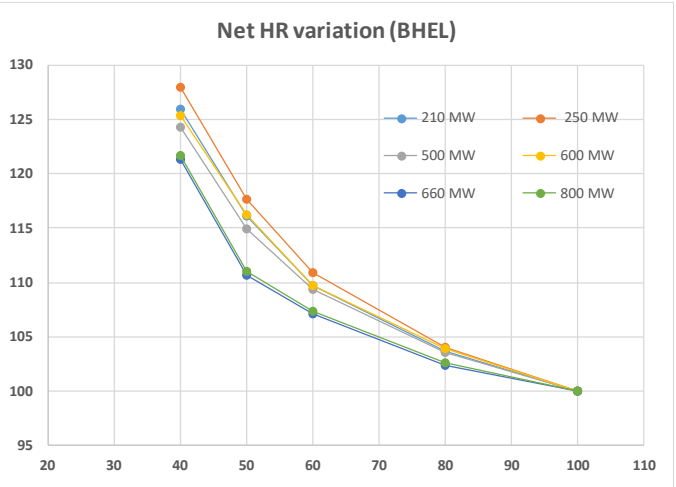
iv. Considering above the increase in annual O&M cost has been proposed as 9%, 14% and 20% at 50%, 45%, 40% loading respectively as increase in O&M costs shall depend on level of flexibilisation.

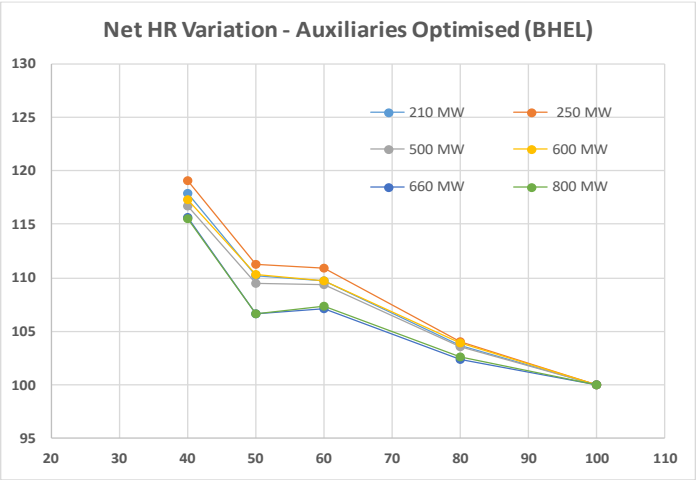
Capacity (MW)	Loading (%)	O&M cost Increase (%)
200	<55 to 50	9.00
	<50 to 45	14.00
	<45 to 40	20.00
500	<55 to 50	9.00
	<50 to 45	14.00
	<45 to 40	20.00
660	<55 to 50	9.00
	<50 to 45	14.00
	<45 to 40	20.00
800	<55 to 50	9.00
	<50 to 45	14.00
	<45 to 40	20.00

OPERATIONAL EXPENDITURE (OPEX)

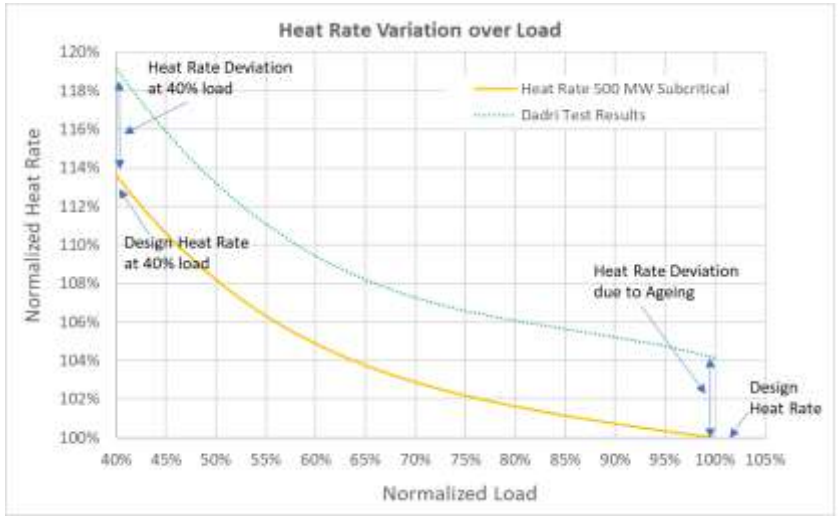
i. INCREASE HEAT RATE

Heat Balance study





Efficiency captured during flexibilisation test



After analyzing the HBD report of major OEMs (BHEL/GE/Siemens) and actual test report of low load operation unit size wise NHR degradation is given in table.

The study conducted by CEA indicates the impact of low load operation at 40% on variable part of tariff is around 16% for subcritical units (200/500MW) and around 15% for supercritical units(660/800MW).

Capacity (MW)	Loading (%)	Net Heat Rate Increase (%)
200	<55 to 50	10.00
	<50 to 45	13.00
	<45 to 40	16.00
500	<55 to 50	10.90
	<50 to 45	13.60
	<45 to 40	16.00
660	<55 to 50	8.70
	<50 to 45	11.90
	<45 to 40	14.60
800	<55 to 50	8.60
	<50 to 45	12.00
	<45 to 40	15.00

OPERATIONAL EXPENDITURE (OPEX)

iii. ADDITIONAL OIL CONSUMPTION

Based on the increased EFOR the norms for specific oil consumption and increased compensation may be allowed as per the Table.

S. No.	Specific Oil Consumption	Increased ECR (p/kWh)
1	CERC Norms (Present): 0.5 ml/kWh	2.5
2	At 0.7 ml/kWh (40-50% load)	3.5
3	At 0.8 ml/kWh (30-40% load)	4.0

In addition, due to flexible operation there would be loss of availability on account of increased maintenance requirements and increased EFOR which will make it difficult for the generator to recover full capacity charges. As per studies carried out by EPRI based on global data, there is a significant increase in EFOR due to varying operational modes and on units ageing.

Likely increase in tariff considering capital investment of Rs. 30 crores, increase of O&M cost, variable cost and EFOR cost

Unit Size (MW)	Loading (%)	Coal price Rs 2000.00 per ton	Coal price Rs 3300.00 per ton	Fixed Tariff increase (Paisa/kWh)		EFOR compensation (Paisa/kWh)	Total tariff (fixed & variable) increase (Paisa/kWh)	Total tariff (fixed & variable) increase (Paisa/kWh)	Proposed total tariff (fixed & variable) increase (Paisa/kWh)
		Variable Tariff increase (Paisa/kWh)	Variable Tariff increase (Paisa/kWh)	due to increased O&M cost	due to increased capital cost		Coal price Rs 2000.00 per ton	Coal price Rs 3300.00 per ton	
200	<55 to 50	20.4	27.4	7.3	7.68	1	36.38	43.38	39.88
	<50 to 45	26.7	35.6	11.4	7.68	1	46.78	55.68	51.23
	<45 to 40	32.9	43.8	16.4	7.68	1	57.98	68.88	63.43
500	<55 to 50	22	29.4	5	3.07	1	31.07	38.47	34.77
	<50 to 45	27.4	36.6	7.7	3.07	1	39.17	48.37	43.77
	<45 to 40	32.3	43.1	11	3.07	1	47.37	58.17	52.77
660	<55 to 50	16.7	22	5	2.56	1	25.26	30.56	27.91
	<50 to 45	23	30	7	2.56	1	33.56	40.56	37.06
	<45 to 40	28	37	10	2.56	1	41.56	50.56	46.06
800	<55 to 50	16	21	4	1.92	1	22.92	27.92	25.42
	<50 to 45	22	29	6	1.92	1	30.92	37.92	34.42
	<45 to 40	28	31	9	1.92	1	39.92	42.92	41.42

INCENTIVE

BACKGROUND

A Committee was constituted in CEA under the Chairmanship of Principal Chief Engineer-II, CEA, to deliberate upon the implementation of flexible operation of coal-based generating units at 40% Minimum Technical Load (MTL), in line with the CEA's notified phasing plan.

The Committee was mandated to:

- Examine technical, operational, and commercial challenges in flexible operation of coal-based power plants.
- Recommend a suitable framework for effective implementation of 40% MTL operation across the country.
- Develop an incentive mechanism and compensation methodology to encourage voluntary participation of thermal power plants in flexible operation.

ANALYSIS OF DATA FOR FLEXIBLE OPERATION

Farakka Unit 2 Outage(4.5 years data), Operational Data- 2 months August/September 2025. The committee asked data in the 1st meeting held on 02.07.2025 and data received on 07.10.2025 after 2nd meeting

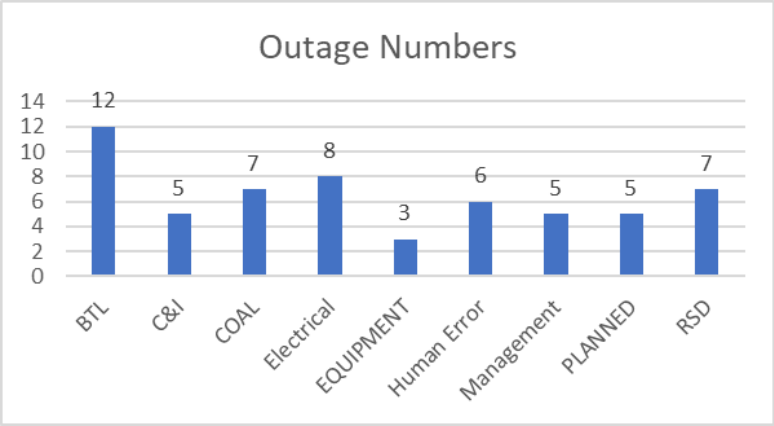


Figure 1: Outages Numbers &Duration

Cold	Warm	Hot
21	14	23

Table 1: Outages type

The unit has not operated below 55% during normal load reduction (except for start-ups/ Shutdown). A conservative ramp rate of <0.5% has been maintained throughout, except in a few blocks. There has been no parametric variation, apart from the existing liabilities.

The damages in the unit (as per the last 5 years of data provided) is because of the outages. The outages reflect the loss of reliability and a need to focus on capacity building/retraining (as visible from 6 human errors).

CONCLUSION: No significant damages is attributable to low load operation (during the existing flexible operation@55 % and conservative ramp rate of 0.5%. The unit has is part of NTPC's ageing fleet (39 years). It may be noted that as per the EPRI's bathtub curve(see Figure 2), the EFOR increases with significant ageing. And the life of equipment consumed due to ageing, can be reclaimed through R&M.

COMPENSATION AND COST RECOVERY FRAMEWORK

CEA has already circulated a compensation methodology for operating a generating unit below 55% and up to 40% MTL on the basis of few pilot studies conducted across the country. The compensation Methodology comprises followings.

1. Capital expenditure
2. Increased O&M cost
3. Heat rate degradation
4. Increased Auxiliary Power Consumption
5. Increased EFOR

CERC has already incorporated all recommendations except (2) of CEA's compensation methodology in its regulatory framework, including, capex for retrofitting, compensation for Station Heat Rate degradation, Auxiliary Consumption, and Specific Oil Consumption. For O&M cost actual operational data is required by CERC to assess sufficiency for increasing O&M cost below 55% operation of a coal based generating unit.

Capital expenditure incurred for flexible operation can be recovered under "beyond original scope" provisions in Regulations 25 and 26 of CERC (Terms and Conditions of Tariff) Regulations, 2024. However, increased O&M cost for flexible operation below 55% has not been provided by CERC.

The Compensation and cost recovery system shall be implemented by SERC/JERC

INCENTIVE SCHEME

The 40% load operation has not yet been introduced across the country, data required by CERC is not available. It may be noted that compensation methodology accounts for retrofits cost, efficiency loss, EFOR, higher O&M cost etc. are essential for low load operation of a unit. Further, it is important to incentivize generators for willingly participation in 40% load operation.

The incentive includes increased O&M cost which was not considered by CERC due to un-availability of operational data and incentive as percentage of annual O&M cost of the units as specified by CERC time to time. Thus, proposed incentive has two parts as stated below:

a) Increased O&M cost for operating at 40%-45% MTL is 20% of annual O&M cost as included in CEA's compensation methodology.
b) Incentive for operating at 40-45% load is 60% of increased O&M cost.

Proposed maximum incentive for operating at 40-45%MTL is 32% of annual O&M cost of the unit. The Incentive scheme shall be implemented by CERC/SERC/JRC

Unit Size (MW)	Loading (%)	Increased O&M cost (%)	Incentive (40%,50%,60% of increased O&M cost)	Net incentive as increased O&M cost (%)
1	2	3	4	5
200	<55 to 50	9.00	3.60	12.60
	<50 to 45	14.00	7.00	21.00
	<45 to 40	20.00	12.00	32.00
500	<55 to 50	9.00	3.60	12.60
	<50 to 45	14.00	7.00	21.00
	<45 to 40	20.00	12.00	32.00
660	<55 to 50	9.00	3.60	12.60
	<50 to 45	14.00	7.00	21.00
	<45 to 40	20.00	12.00	32.00
800	<55 to 50	9.00	3.60	12.60
	<50 to 45	14.00	7.00	21.00
	<45 to 40	20.00	12.00	32.00

INCENTIVE SCHEME

2. Admissibility:

i. Generating units shall be eligible for incentive if they declare their readiness for operating at 40% Minimum Technical Load (MTL).

ii. Generating units shall generate as per schedule provided by system operator during solar hours.

iii. Incentive shall be decided on actual MTL of units on the day i.e. <55-50%, <50-45% or <45-40%.

iv. The incentive shall be granted on full day generation

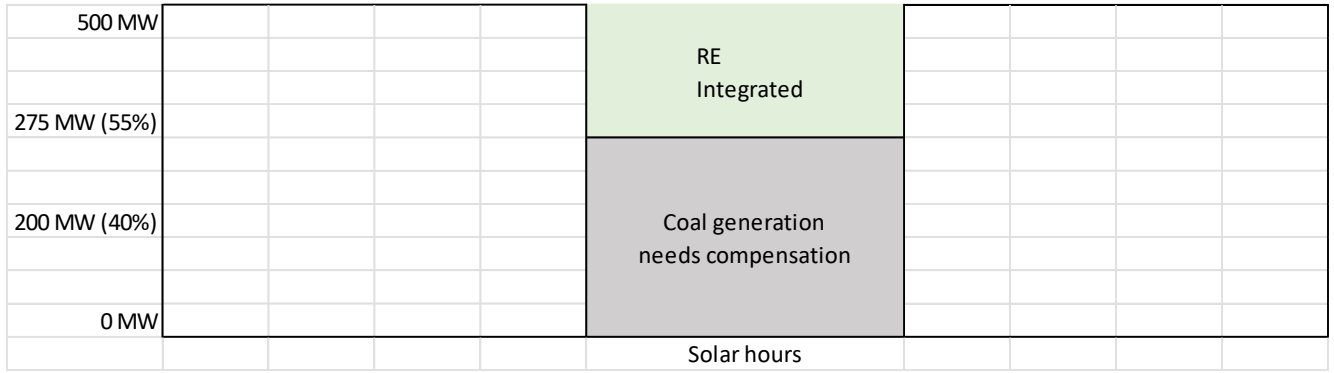
Unit Size (MW)	Loading (%)	Increased O&M cost (paisa/kWh)	Incentive (40%,50%,60 % of increased O&M cost) (paisa/kWh)	Incentive proposed (paisa/kWh)	Daily incentive (Crore Rupees)	Monthly incentive (Crore Rupees)	Annual incentive (Crore Rupees)
1	2	3	4	5	6	7	8
200	<55 to 50	7.9	3.2	11			
	<50 to 45	12.3	6.2	18			
	<45 to 40	17.5	10.5	28	0.09	2.82	34.34
500	<55 to 50	5.20	2.1	7			
	<50 to 45	8.10	4.1	12			
	<45 to 40	11.60	7.0	19	0.16	4.68	56.90
660	<55 to 50	5.00	2.0	7			
	<50 to 45	7.70	3.9	12			
	<45 to 40	11.00	6.6	18	0.20	5.85	71.23
800	<55 to 50	4.50	1.8	6			
	<50 to 45	7.00	3.5	11			
	<45 to 40	9.90	5.9	16	0.21	6.39	77.70

COST OF RE INTEGRATION

Cost of RE integration by flexible operation of 500 MW unit TPP

55% MTL Compensation Rate = Rs. 0.22 38per kWh
Energy generated at 55% MTL, 8hrs. = 2200000 kWh
Total compensation for 8 hrs. = Rs. 492360.00
Total RE integrated in 8 hrs. = 600000 kWh

Cost of RE integration = Rs.0. 82 per kWh



40% MTL Compensation Rate = Rs. 0.5817 per kWh
Energy generated at 40% MTL, 8hrs. = 1600000 kWh
Total compensation for 8 hrs. = Rs. 930720
Total RE integrated in 8 hrs. = 1200000 kWh

Cost of RE integration = Rs. 0.78 per kWh

40% MTL Compensation Rate = Rs. 0.4717 per kWh (without increased O&M cost)
Energy generated at 40% MTL, 8hrs. = 1600000 kWh
Total compensation for 8 hrs. = Rs. 754720

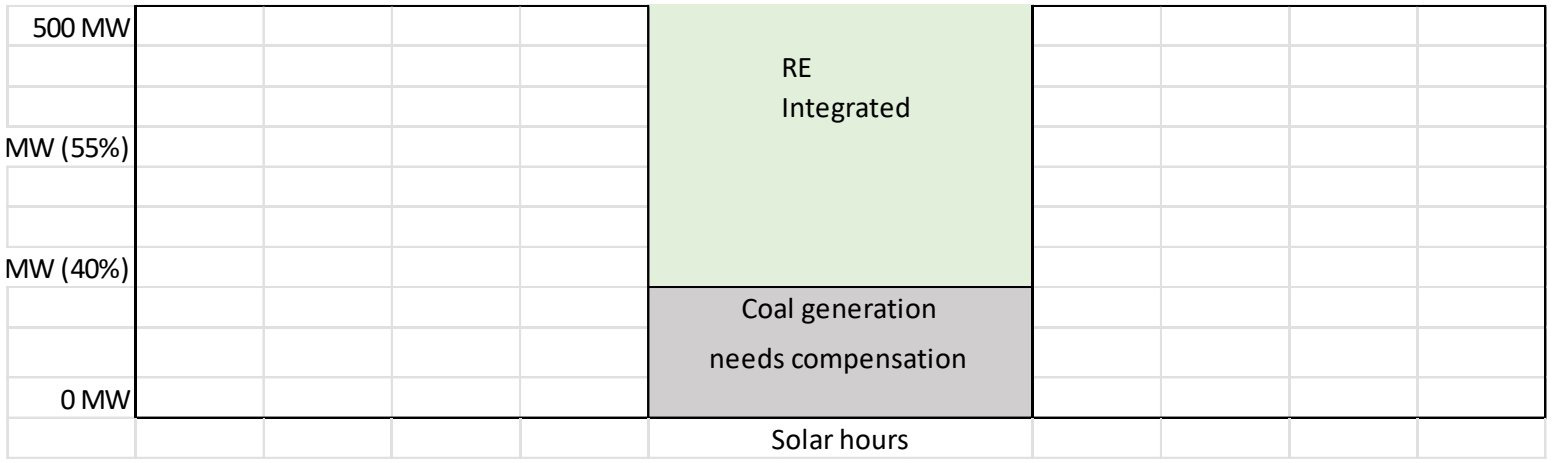
Incentive on total gen. (65% PLF) = Rs. 1482000
Total RE integrated in 8 hrs. = 1200000 kWh

Cost of RE integration = Rs 1.86 per kWh (with incentive)

COST COMPARISION: TPP FLEXIBILISATION Vs BESS

$$\text{Cost of RE integration} = \frac{\text{total compensation paid for 40\% MTL}}{\text{total RE integrated due to lowering generation}} = \text{Rs. 0.78/ kWh (as per CEA)}$$

$$\text{Cost of RE integration} = \frac{\text{total compensation paid for 40\% MTL}}{\text{total RE integrated due to lowering generation}} = \text{Rs. 0.63/ kWh (as per CERC)}$$



COST COMPARISION: TPP FLEXIBILISATION Vs BESS

$$\text{Cost of RE integration} = \frac{\text{total compensation paid for 55\% MTL}}{\text{total RE integrated due to lowering generation}} = \text{Rs. 0.82/ kWh}$$

$$\text{Cost of RE integration} = \frac{\text{total compensation paid for 40\% MTL}}{\text{total RE integrated due to lowering generation}} = \text{Rs. 1.86/ kWh (with incentive)}$$

After achieving 55% percent MTL, there are two options for RE integration viz. either (1) BESS or (2) further flexing up to 40% MTL.

An incremental cost of Rs. 1.04/- (One rupee and four paise) with incentive per unit of Renewable Energy over 55% MTL (total cost of integration= Rs.1.86).

Cost of BESS, 4 hrs. single cycle with VGF = Rs. 3.61 per kWh (total cost of integration =Rs. (3.61+0.82)= Rs. 4.43.00
BESS with 8 hrs. is not available, expected cost will more than Rs. 6.00/-

THANK YOU

CONCLUSION AND WAY FORWARD

- Flexible operation of coal-based power plants is critical for renewable energy integration and grid stability.
- It provides a low-cost, technically feasible, and immediately deployable solution compared to large-scale battery storage.
- Implementation of the incentive-cum-compensation scheme and regulatory coordination among CEA, CERC, SERCs, and Grid India are essential to scale down operations to 40% MTL successfully.

GENERATION CAPACITY IN 2029-30

1. **Solar & Wind:** The capacity of 292 GW Solar and 100 GW Wind has been assumed

2. **Gas, Hydro, Small Hydro, Nuclear and Biomass:** The considered capacity of Gas, Hydro, Small Hydro, Nuclear and Biomass are 24824 MW, 53860 MW, 5350 MW, 15480 and 14500 MW respectively.

3. **PSP (Generation):** The generation of PSP may vary from 15368 MW to 17985 MW.

4. **PSP (load):** The capacity of Pump Storage Plants has been considered as 18836 MW which is pumping load.

5. **Electricity Demand:** The grid demand data of various day have been taken from 20th Electric Power Survey of India, CEA.

GENERATION PREDICTION FOR THE YEAR 2029-30

Peak Wind Power: The maximum wind generation of 75.44 GW is predicted in July, 2029 taking into account of 100 GW installed capacity

Peak Solar power: The maximum solar generation of 241 GW will be available at 12 pm in May, 2030 considering 292 GW installed capacity. The Solar generation will fluctuate from 0 GW at 7 am to 241 GW at 12 pm and again 0 GW at 8 pm.

Maximum VRE day when ratio of RE (Solar & Wind) to others generation is more than one: As projected the max VRE day situation will be happened in the grid in July, 2029 when flexible power requirement will be maximum for balancing the grid.

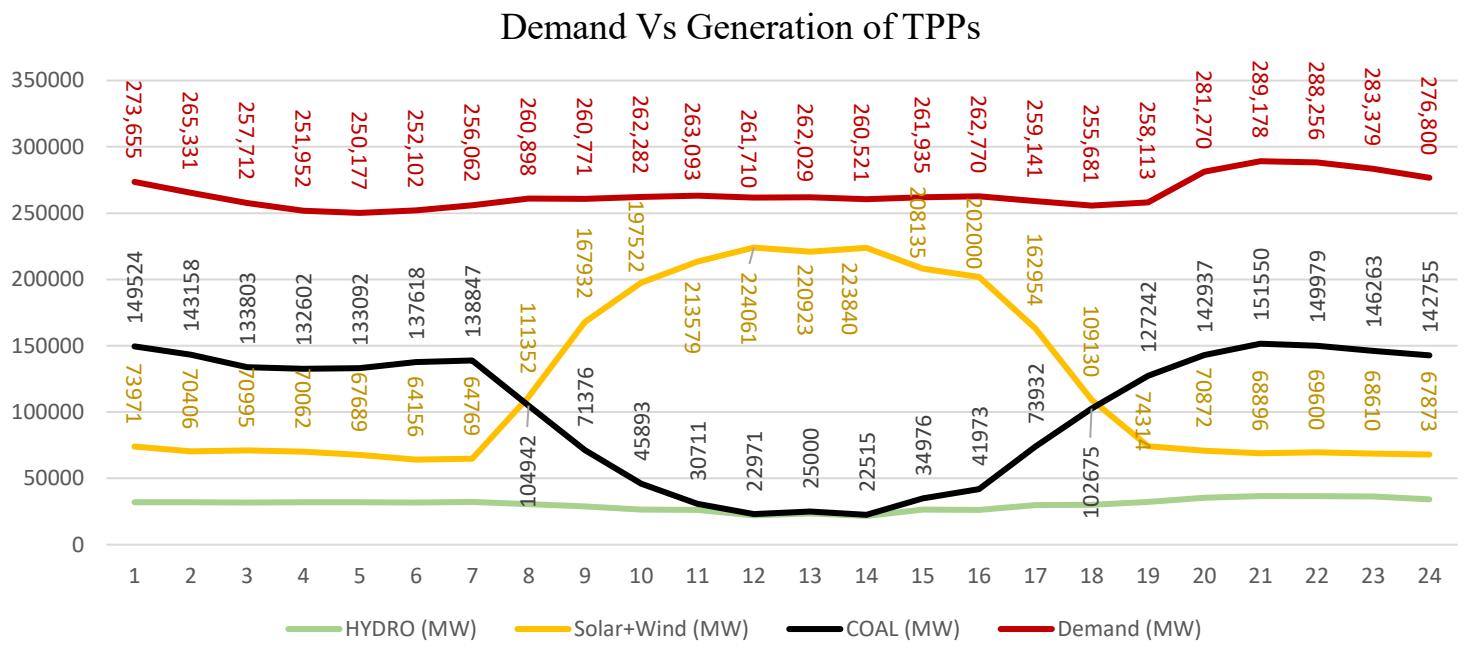
	Gas Gen. (MW)	Hydro Gen. (MW)	Nuclear (MW)	Solar and Wind Gen. (MW)	Biomass (MW)	PSP Gen. (MW)	PSP load (MW)
Max.	6519	49468	9474	247664	4002	17985	18836
Min.	487	7819	9474	8407	0	0	0

GENERATION OF COAL FIRED POWER PLANTS

This is a derived quantity and is calculated after subtracting hourly generation of all other types of sources in a day from hourly demand of that day. The Peak generation as well as minimum generation of the coal power plants are identified in this process.

If the minimum generation as identified in the grid available from coal power plants **by operating at MTL or more, the support of BESS will not be required**.

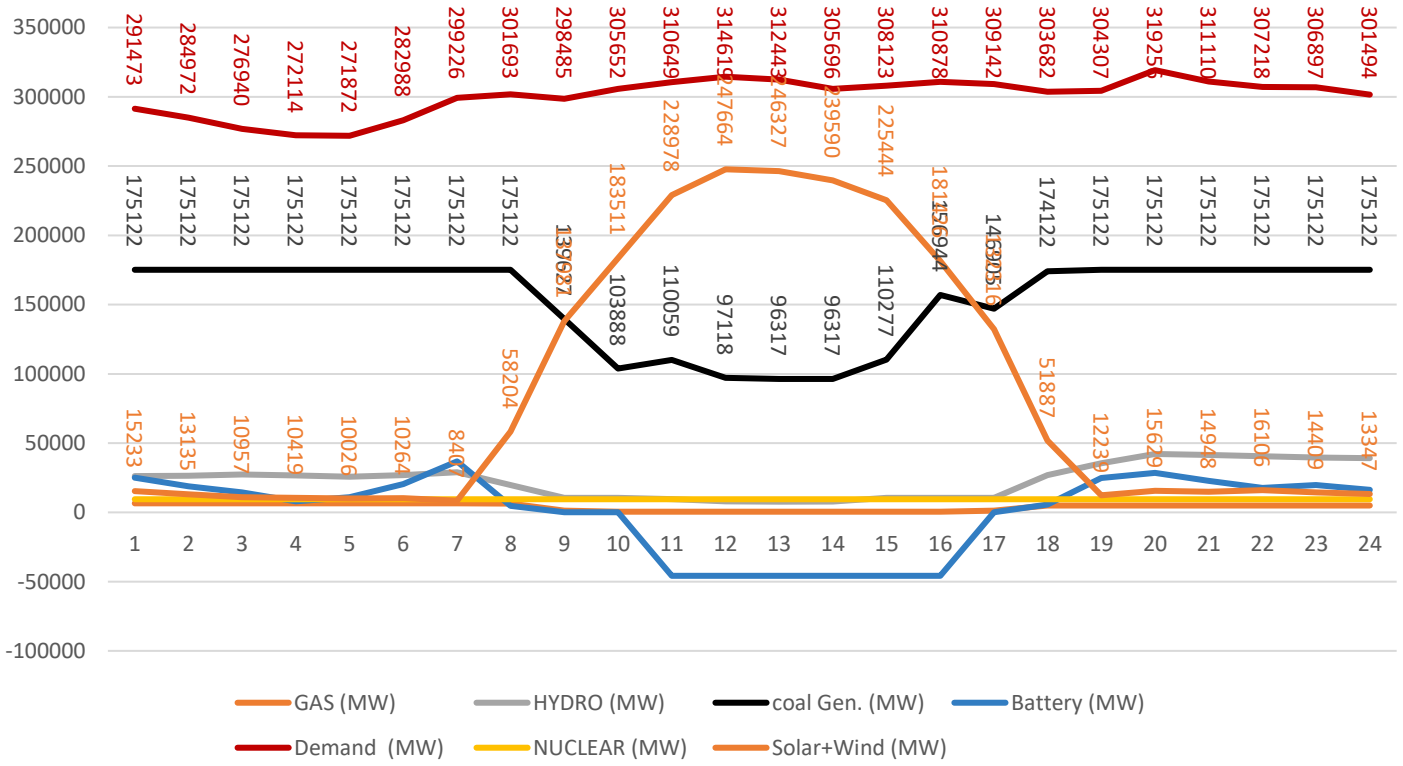
However, if minimum generation as identified available from coal power plants **by operating at less than MTL, the support of BESS is very much required**.



	GAS Gen.	HYDRO Gen.	NUCLEAR Gen.	Solar and Wind Gen.	Pump Load (MW)	Pump Gen.	Coal Gen.	Demand (MW)	Ramp rate (MW/Min.)
Max (MW)	4616	36657	9474	224061	0	17985	151550	289178	533
Min.(MW)	1847	21682	9474	64156	-18836	0	22515	250177	-565
MWh	85111	727264	227370	2943638	169740	134842	2406333	6354818	
Coal Power Plants PLF(%)							**66.16**		
Coal Power Plants MTL (%)							**14.86**		

CASE-I STUDY

Grid Balancing with flexible operation of coal-based power plants at 55% MTL along with Battery Energy Storage System (BESS) in 2029-30



CASE-I STUDY

Grid Balancing with flexible operation of coal-based power plants at 55% MTL along with Battery Energy Storage System (BESS)

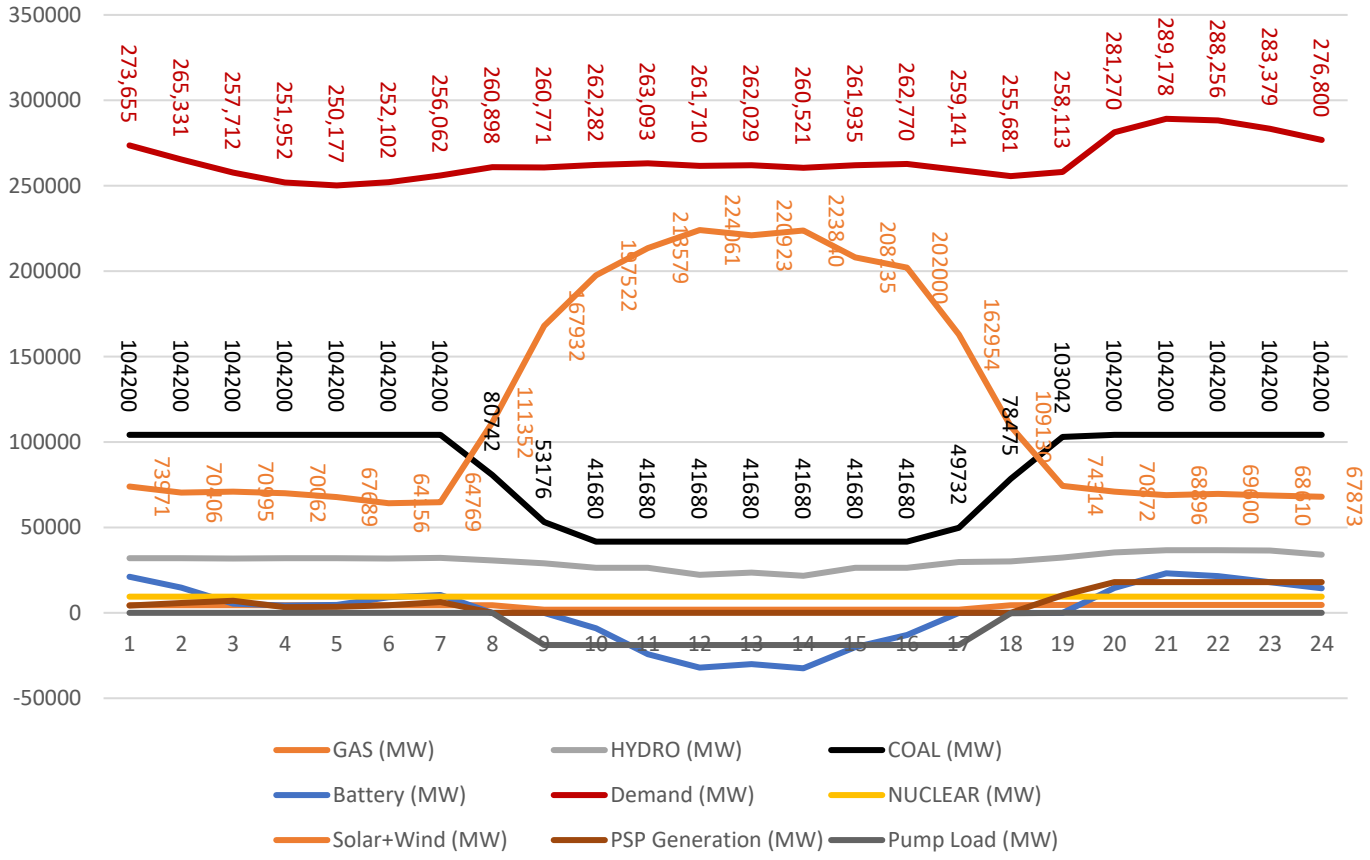
	Peak day	Max Solar day	Critical day
Ramp up rate (MW/min.)	458	778	329
Ramp down rate (MW/min.)	-565	-596	-459

Summary of Case-I (55% MTL)

		Peak demand day (MW)	Max Solar day (MW)	Most Critical day (MW)
Power Demand (MW)	Grid demand	334811	319256	289178
	PSP	18836	18836	18836
	Battery	28699	45800	43076
Generation (MW)	Gas	4862	6519	4616
	Hydro	49468	42150	36657
	Nuclear	9474	9474	9474
	Solar & Wind	230155	247664	224061
	Biomass	0	4002	0
	PSP	17985	15368	17985
	RE Loss (MWh)	0	24849	0
	55% MTL coal gen.	164850	175122	95055
	CFBC generation	4200	4200	4200
	Old plants gen.	20000	20000	20000
	Total coal gen.	189050	199322	119255

CASE-II STUDY

Grid Balancing with flexible operation of coal-based power plants at 40% MTL and 55% MTL of CFBC & old TPPs along with Battery Storage System (BSS)



CASE-II STUDY

Grid Balancing with flexible operation of coal-based power plants at 40% MTL and 55% MTL of CFBC & old TPPs along with Battery Storage System (BSS)

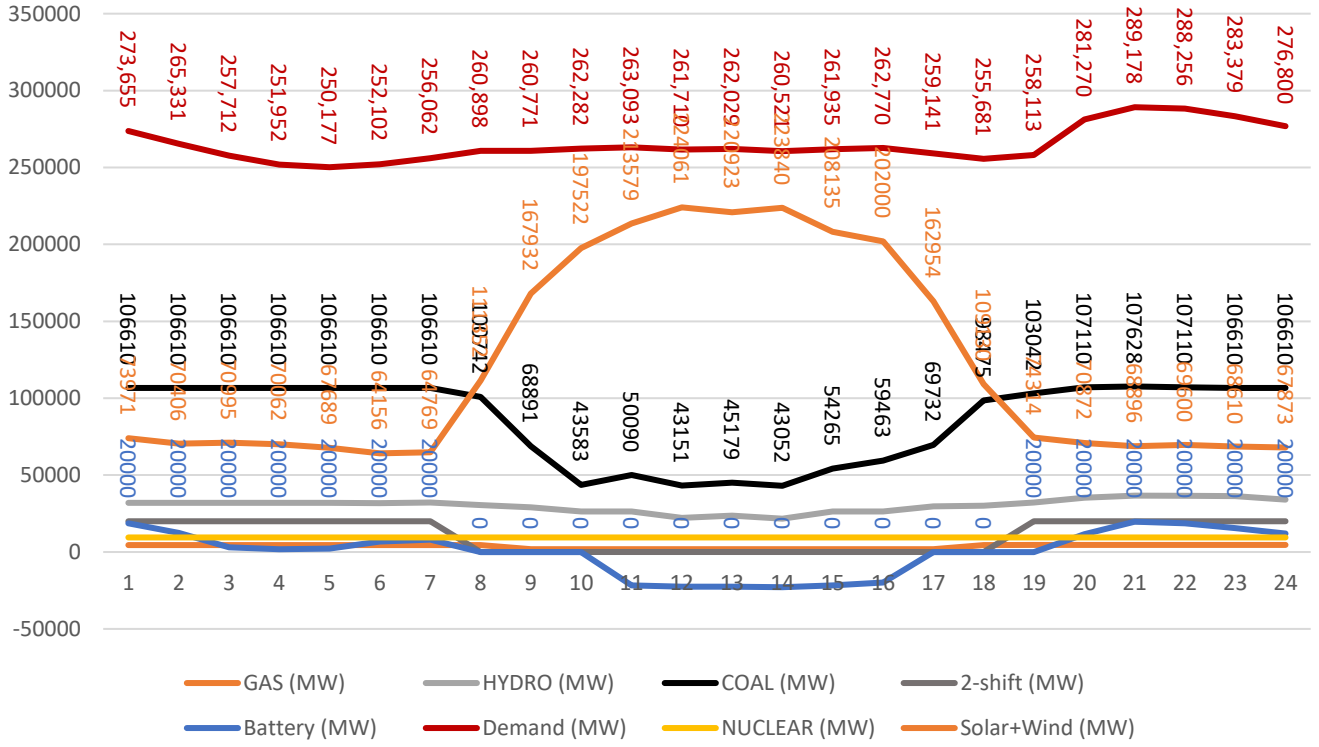
	Peak day	Max Solar day	Critical day
Ramp up rate (MW/min.)	437	778	479
Ramp down rate (MW/min.)	-565	-713	-459

Summary of Case-II (40% MTL)

		Peak demand day (MW)		Max Solar day (MW)		Most Critical day (MW)
Power Demand (MW)	Grid demand	334811		319256		289178
	PSP	18836		18836		18836
	Battery	10661	31796	25511	31796	31796
Generation (MW)	Gas	4862		6519		4616
	Hydro	49468		42150		36657
	Nuclear	9474		9474		9474
	Solar & Wind	230155		247664		224061
	Biomass	0		4002		0
	PSP	17985		15368		17985
	RE Loss (MWh)	698	0	0	0	0
	40% MTL coal gen.	180875	166560	190070	184577	102500
	CFBC generation	4200	4200	4200	4200	4200
	Old plants gen.	20000	20000	20000	20000	20000
	Total coal gen.	205075	190760	214270	208777	126700

CASE-III STUDY

Grid Balancing with flexible operation of coal-based power plants at 55%, 40% MTL and 2-shift operation of old TPPs along with Battery Storage System (BSS)



CASE-III STUDY

Grid Balancing with flexible operation of coal-based power plants at 55%, 40% MTL and 2-shift operation of old TPPs along with Battery Storage System (BSS)

	Peak day	Max Solar day	Critical day
Ramp up rate (MW/min.)	428	778	479
Ramp down rate (MW/min.)	-565	-810	-531

Summary of Case-III (40% MTL & 2-Shifting)

		Peak demand day (MW)		Max Solar day (MW)		Most Critical day (MW)
Power Demand (MW)	Grid demand	334811		319256		289178
	PSP	18836		18836		18836
	Battery	0	22876	17184	22876	22876
Generation (MW)	Gas	4862		6519		4616
	Hydro	49468		42150		36657
	Nuclear	9474		9474		9474
	Solar & Wind	230155		247664		224061
	Biomass	0		4002		0
	PSP	17985		15368		17985
	RE loss (MWh)	-3050	0	0	0	0
	40% Flex. Units Gen.	190044	170444	196458	192249	107700
	CFBC Gen.	4200	4200	4200	4200	4200
	2-shifting units Gen.	20000	20000	20000	20000	20000
	Total coal Gen. (MW)	214244	194644	220658	216449	131900

COAL FIRED POWER PLANTS

CATEGORISATION OF PQWER PLANTS:

1. Category-1 plants- most of the coal power plants are under this category which operate in the range of 40% power level to 100% level as per grid requirement.

2. Category-2 plants: these plants are in general very old or ball & tube mill plants which operate in the range of 55% power level to 100% power level and these plants are also identified for 2-shif operation.

3. Category-3 plants: CFBC plants are considered in this category and these plants operate in between 55% power level to 100% power level.

SCENARIOS:

1. A scenario has been considered with 55% MTL of all category coal-fired power plants. Balancing of load and generation in each and every hour of three deferent days in the year,2029-30 i.e. peak demand day, peak solar day and max. VRE day have been studied.

2. Another scenario with 40% MTL of category-1 power plants, 55% MTL for category-3 (CFBC) plants and 55% MTL for category-2 power plants have been considered.

3. Similarly, Another scenario with 40% MTL of category-1 power plants, 55% MTL for category-3 (CFBC) plants and 2-shift operation category-3 power plants have been considered.