ROADMAP FOR FLEXIBILISATION OF THERMAL GENERATING UNITS

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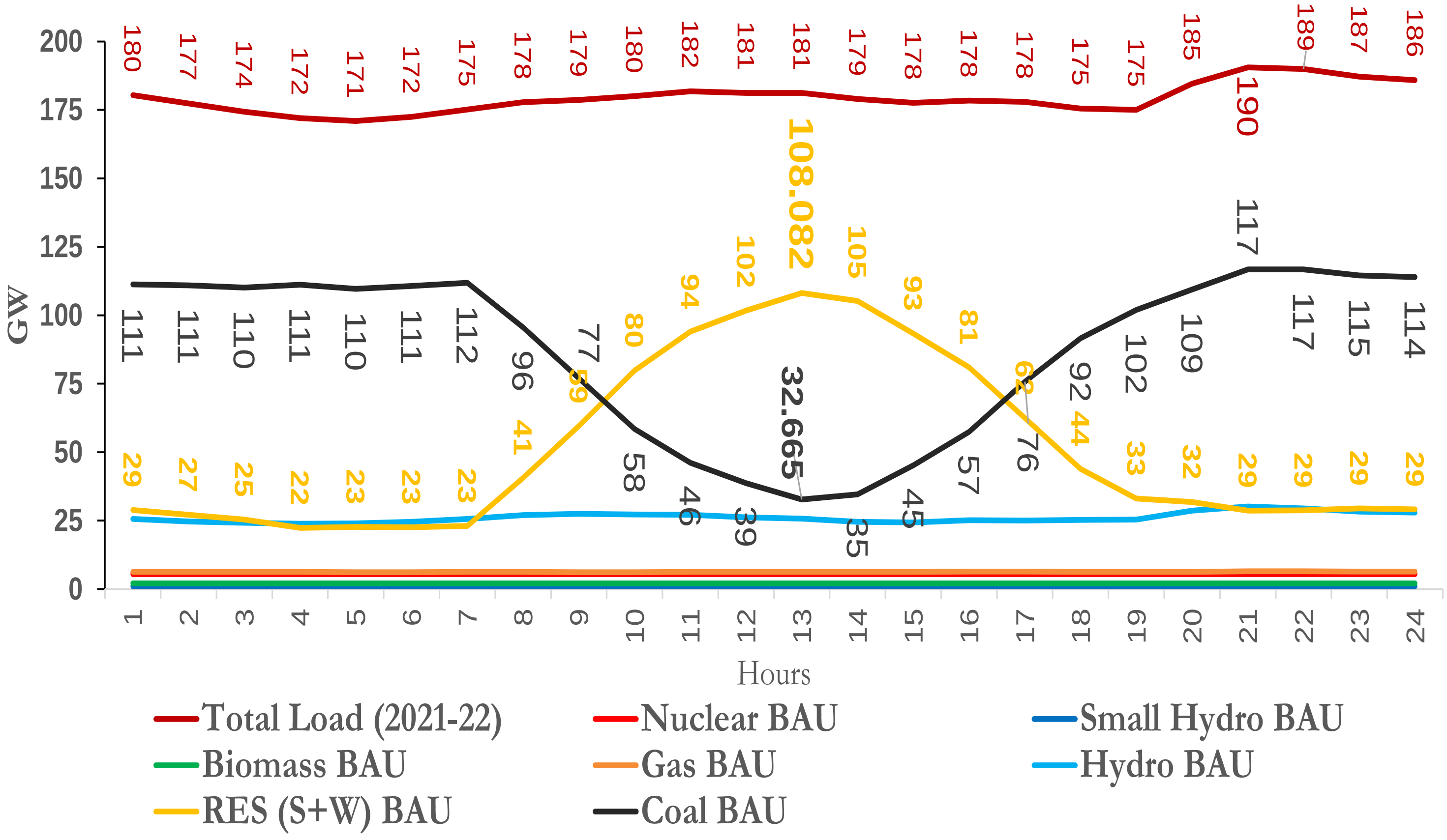
NEED FOR FLEXIBILISATION

Global Commitments : It aims is to achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030 as per its Intended Nationally Determined Contribution (INDC) submitted to UNFCCC in 2015.

Thrust on Renewables : India has vast renewable potential of around 1050 GW which is largely untapped.

Target 2022: Setting up of 175GW installed capacity from renewables by December 2022.



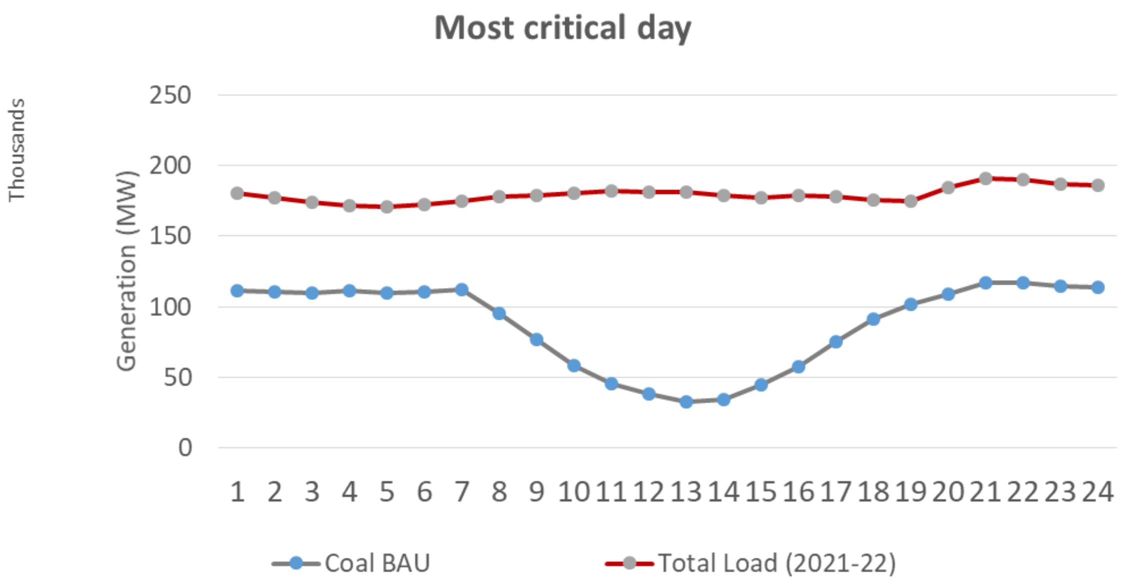
Present Status: The installed capacity of renewables has reached to 114 GW. Solar and Wind capacity are 62 GW and 42 GW respectively.

Target 2030: The likely installed capacity of renewables by the end of 2029-30 will be 450 GW.

Why stress on thermal generating unit? Flexible operation of existing coal-fired power plants is very much required to ensure security, reliability of power supply and stability of electricity grids.

KEY REQUIREMENT OF FLEXIBILISATION

- As per CEA report (2019), peak thermal flexible capacity (gross) required on the most critical day in year 2022 was found to be 140 GW considering 175GW renewable capacity and the coordinated efforts from hydro, gas capacity and PSS, the requirement of thermal capacity could be reduced to 117 GW.



Ramp Rate:
-310 MW/min. at 900 hrs.
+305 MW/min. at 1600 hrs.

Highest: - 422 MW/min

Highest: 379 MW/min.

With increase in grid ramping requirements over the years, most of the additional ramping is being met by thermal generation, thermal ramp touched 250 MW/min.

The day wise flexibility requirement of the grid is increasing at 8-9 GW/annum, and it reached a maximum of 72 GW during winter of 2021-22.

REGULATION ON TECHNICAL MINIMUM LOAD

CEA has already prepared a draft regulation to implement 55% and 40% minimum load as per the following timeline:

1. The 55% minimum load and 2% ramp rate 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, within five years from date of this notification by the respective power plants owners to operate thermal unit at 40% minimum load with desired ramp rate.

STUDIES CONDUCTED

The studies/pilot tests conducted with the help of OEMs and under international cooperation

S.no	Plant	Size MW	Unit No.	COD	Utility	Agencies involved	Remarks
1	**Dadri**	500	2	25/01/2010	NTPC	IGEF, BHEL, EEC, CEA	Conducted in June 2018. Achieved 40% load (2.5 hrs) & 0.86% ramp up and 0.5% ramp down at 40% load
2	**Mouda**	500	2	29/03/2013	NTPC	BHEL, CEA	Conducted in May 2019. Achieved 40% load (1hr.) & 0.85% ramp up and 0.9% ramp down
3	**Sagardighi**	500	3	14/12/2015	WBPDCL	BHEL, CEA	Conducted in June 2019.Achieved 40% load (1hr.) & 1.1% ramp up and 0.67% ramp down.
4	**Ukai**	500	6	05/03/2013	GSECL	USAID, BHEL, CEA	Conducted in March 2020. Achieved 40% load (2.5 hrs) & 1 ramp up and 1.2 ramp down
5	**MRB TPS**	525	1	30/06/2011	MPL	IGEF, BHEL, EEC, CEA	Conducted in July,2021. Achieved 40% load & 0.95% ramp up and 0.38% ramp down. 40% load (1hr.)
6	**DSTPS**	500	1	29/07/2011	DVC	IGEF, BHEL, EEC, CEA	Conducted in March,22, 40 % achieved (1.5hrs), less than 1% ramp up and ramp down.

OBSERVATIONS FROM PILOT TESTS

- Excessive fluctuations in Steam temperatures. Steam temperature control becomes difficult as fuel flow rate and feed water flow rate decrease.
- High Drum level swings during ramping.
- Flame disturbance during ramping and at MTL.
- Fuel flow and air flow decrease, and balance of fuel and air sometimes collapses at some space in furnace of boiler, and combustion becomes unstable.
- Low boiler flue gas exit temperature, leading to corrosion.
- Actual ramp rate achieved about 1% or less in between 40 to 55% load

CHALLENGES OF FLEXIBILISATION

Fuel quality: Boilers are designed to burn coal of specified quality. Change in coal from the design coal to a lower quality coal affects boiler operation and performance and particularly during low load operation with poor coal quality, the combustion stability of the boiler is severely affected. Challenges with poor coal quality include:

1. Boiler slagging and fouling
2. Increased corrosion and erosion
3. Boiler tube metal temperatures excursion
4. Lower boiler efficiency
5. Overloading ash handling system
6. Overloading of dust removal system and increased emissions

Volatile Matter - Typical range of VM is 18% to 30%. Higher VM coals generally produce less NOx and are also easier to control in the combustion system, especially in low load operation. Some of the Indian coals have VM of around 15% and stable combustion becomes extremely difficult, even at higher loads. The problem gets aggravated further when coal fineness, A/F ratio and/or distribution of A/F is non-optimal, low volatile fuel results in furnace imbalances.

Gross calorific Value (GCV) - There is a large variation of GCV in Indian Coal, typically varying from 2500-6000Kcal/kg. The GCV of the fired coal is one of the key determinants of the technical minimum level.

CHALLENGES OF FLEXIBILISATION contd.

Moisture – Part load efficiency is an important consideration of flexible operation and moisture affects unit efficiency by impacting thermal performance. Moisture has a flame quenching tendency and absorbs latent heat. High coal moisture content will lower the coal's gross calorific value (GCV), which means that more fuel quantity will be required to be fired for the same heat input to the unit. Coal moisture affects the following:

1. Boiler efficiency
2. Mill drying/ Tempering air requirements
3. Gas velocities through the unit
4. Choking in coal pipes
5. Flame stability
6. Precipitator efficiency

Impact on Plant Life

Flexible operation increases the creep-fatigue damage caused by thermal stresses. These damages impact the thermal units by

- Increased life consumption leading to increased maintenance
- Increased number of start due to increased Equivalent Forced Outage Rate (EFOR).
- Efficiency loss due to increase of heat rate at lower load
- Increased auxiliary power consumption

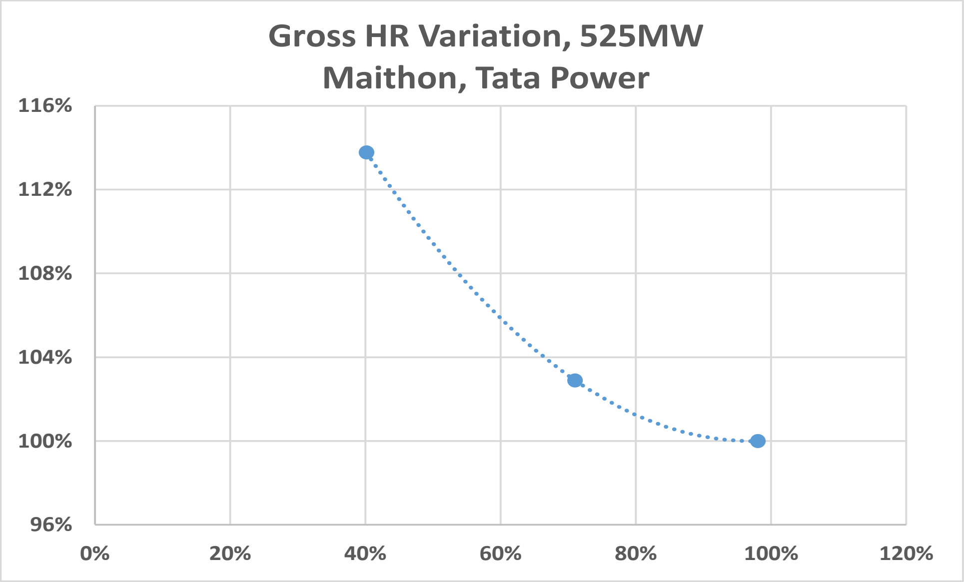
Impact on Environment

- At low loads, there can be instances when the temperature in the ESP falls below the dew point and there is a built up of ash due the moisture, which becomes difficult to remove.
- With high Sulphur coal there can be severe acid corrosion due to maintaining lower flue gas outlet temperature.
- During frequent start-ups, the ESPs are kept out of service during oil firing. Difficult to maintain SPM emissions norms .

CHALLENGES OF FLEXIBILISATION contd.

Impact on Efficiency

The loss on account of deterioration in efficiency of the unit at part loads is another major category of flexing costs. A typical deterioration of efficiency (net heat rate) for different categories is shown in figure.



Impact on Maintenance and Operators

As flexible operation leads to increased life consumption of plant components, increased outages and failures, it calls for revisiting the maintenance practices, increased inspection schedules and ensuring sufficient spares.

Some of the components will have accelerated wear and failures during flexing operation (like mills, boiler pressure parts, valves) and would require increased maintenance.

The maintenance strategy has to be devised, based on the extent of flexibilization.

MODIFICATIONS REQUIRED

I. Measures for Minimum Load Operation

- Control Optimization
- Drum Level Control
- Flue Gas Temperature Control
- Automated Start/Stop of Mills

II. Measures for Ramp Rate Improvement

- Control Optimization
- Burner Tilt Controls
- Furnace/Differential Pressure (Δp) Control
- Furnace Pressure Control Upgrade
- Unit CMC

III. Measures for Efficiency (Heat Rate) Improvement

- Sliding Pressure Control
- Top Heater implementation
- Optimization of Auxiliaries

IV. Other Measures

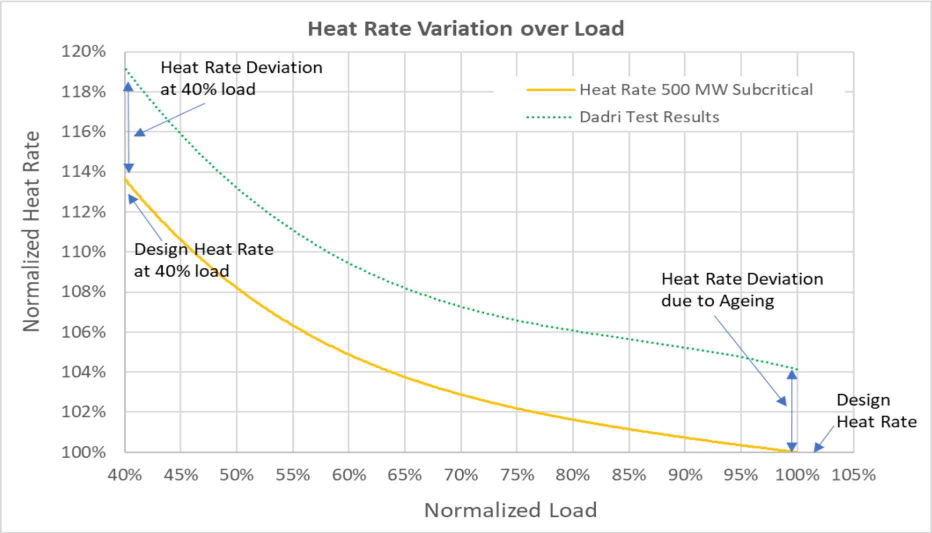
- Boiler Combustion System
- Minimum Mill Operation
- Firing System
- Combustion/Flame monitoring
- Condensate Throttling – *it is a proven measure for primary control to enable fast increase of turbine power in case of grid frequency deviations and able to provide 3-4% power at 100% load within 30 to 120 secs.*
- Heat Conservation System – *Worm/ hot startup by keeping the unit in warm condition*
- HP Turbine Deactivation - *Few advanced supercritical turbines have feature of HP deactivation*

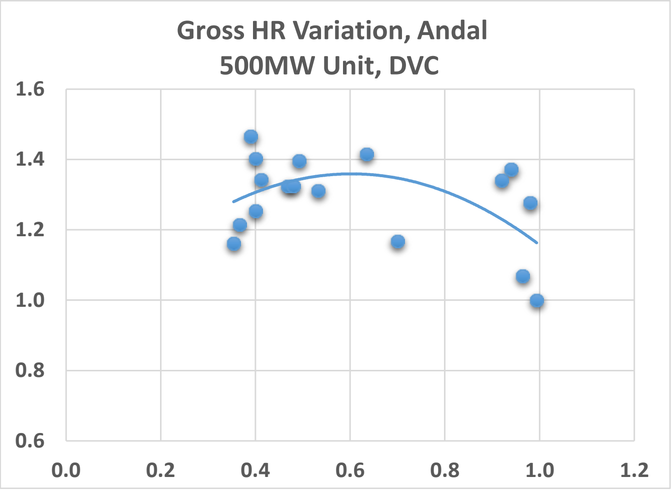
VI. Measures for Condition Monitoring

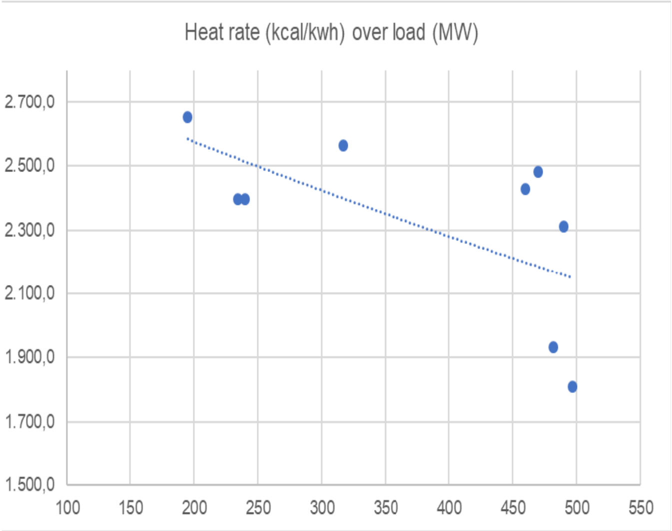
- Boiler Fatigue Monitoring System
- Vibration Monitoring System -*Operational risks for turbine blade failure could be monitored through non-contact type blade vibration monitoring system*
- Generator Monitoring - *like partial discharge (PD), rotor flux, rotor shaft voltage, end winding vibrations, stator temperature etc. are important*.

Efficiency Tests

Efficiency test were conducted at Low Load at following stations: Dadri, Mauda, Maithon and Andal. The details are plotted as below







It is seen in the case of Dadri, the overall plant HR behavior was found to follow the same pattern as of original HBD calculations. The deviation from design heat rate at 100% and at 40% is found to be same (around 4%) and this deviation can be attributed to ageing of the plant.

Therefore, HBD calculations with applied ageing can predict the performance at part load with reasonable accuracy. However, to confirm the HR degradation, efficiency tests needs to be conducted as per the prescribed standard procedures on sufficient number of units of different unit sizes to arrive at HR deterioration figures.

COST OF FLEXIBLE POWER

Cost Components:

1. ***Capital Expenditure (CAPEX)*** **-** one-time expenditure incurred in the retrofitting of various systems to make the plant capable of low load operation.

2. ***Operational Expenditure (OPEX)*****:**

    i. Cost due to increase in Net Heat Rate
    ii. Cost due to Increased Life Consumption (Damage costs)
    iii. Cost due to additional oil consumption for additional EFOR

1. CAPITAL EXPENDITURE (CAPEX)

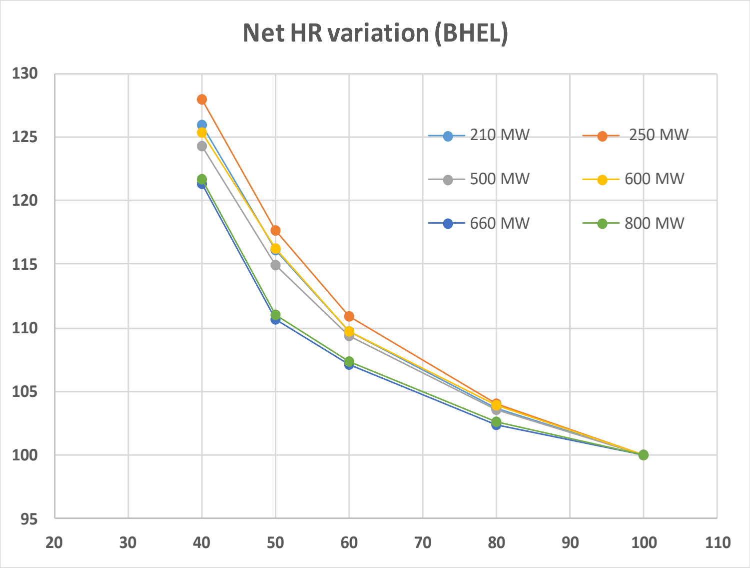
The measures as discussed previously are essential for a unit to operate at 40% load and may require a capital investment of around six to ten crores.

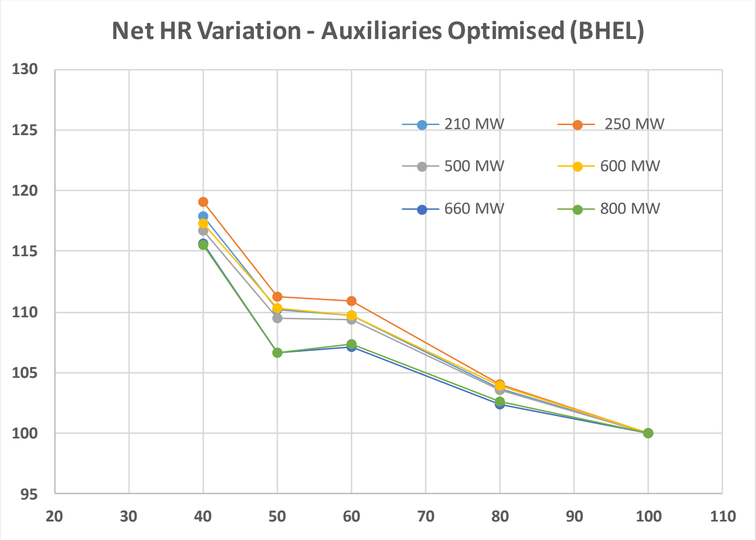
In case of very old units which have not upgraded their plant control and instrumentation system previously, such capex requirement may increase up to 30 crores or more.

2. OPERATIONAL EXPENDITURE (OPEX)

i. INCREASE HEAT RATE

Heat Balance study





- The heat rate degradation studies were performed by OEMs (*BHEL/GE/Siemens*) for various unit sizes at different loading conditions based on heat balance. The heat balance calculations done by *BHEL* indicates the heat rate (net) degradation from full load to 40% load is in the range of 13.5% to 16.5% with optimized auxiliary and without optimization it is in the range of 21.3% to 27.9%.
- Hence, it is obvious that the scheme of auxiliaries control needs to be modified for low load operation at 50% and below to get the significant performance benefits.
- GE, India has also conducted study for the heat rate deterioration at different loads levels for different unit sizes of thermal units. The heat rate (net) degradation is found to be in the order of 12% to 16% for different unit sizes at a load of 40%.
- Similarly, Siemens, India conducted the heat balance study and the heat rate (net) degradation is found to be in the order of 7% to 10% for different unit sizes at a load of 40%.

2. OPERATIONAL EXPENDITURE (OPEX)

ii. INCREASED O&M COST

The increase in O&M cost has been considered based on the loading levels of the units and at 40% loading it has been assumed as 20%.

Impact of low load on Tariff

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 increase in O&M cost has been considered based on the loading levels of the units and at 40% loading it has been assumed as 20%.

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) whereas the impact on fixed part of tariff is around 2.7%-4.7% depending on the unit size.

Loading	Net HR Degradation including aux.	Fixed Cost Increase (%)	Variable Cost Increase (%)	Tariff Increase (%)
200 MW				
50%	10%	2.34	9.82	4.66
45%	13%	3.43	12.76	6.31
40%	16%	4.74	15.70	8.12
500 MW				
50%	10.9%	1.57	10.60	4.53
45%	13.6%	2.38	13.29	5.93
40%	16%	3.33	15.61	7.33
660 MW				
50%	8.7%	1.42	8.44	3.66
45%	11.9%	2.14	11.63	5.22
40%	14.6%	3.02	14.22	6.56
800 MW				
50%	8.6%	1.27	8.39	3.51
45%	12%	1.92	11.70	5.00
40%	15%	2.70	14.63	6.45

2. OPERATIONAL EXPENDITURE (OPEX)

iii. ADDITIONAL OIL CONSUMPTION

Based on the increased EFOR (considering EPRI report) the norms for specific oil consumption may be allowed as per the Table.

S. No.	Operation Mode	EFOR	Increase in EFOR	Sp. Oil Consumption
1	Base Load	5	-	0.5
2	Load Following (Loading Factor <60%)	7.06	2.06	0.70
3	Minimum Load (Loading Factor 40 % to 50%)	7.19	2.19	0.72
4	Minimum Load (Loading Factor 30-40%)	>7.19	>2.19	0.8
5	Minimum Load (Loading Factor 30-40%) with provisions for varying coal			1.0

Proposed compensation on account of EFOR

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	3.5
3	At 0.8 ml/kWh	4.0
4	At 1.0 ml/kWh	5.0

Assuming the cost of oil at Rs. 45,000/kL

COMPARISON OF FLEXIBLE POWER

Source of flexible Power:

1. Reallocation of Hydro Generation,
2. Pump Storage,
3. Gas Flexing,
4. Demand Side Management
5. Low Load Operation of Thermal Power Plants,
6. 2-Shift operation
7. Battery Storage System,

Low Load Operation of Thermal Power Plants:

It is the cheapest source of flexible power available in the grid. The details are as under:

Max. Gross Coal Capacity Required (as per Optimal gen. report)	=	232 GW,
Max. gen. (75% units)	=	174 GW
Spinning reserves (7%)	=	12.18 GW
Auxiliary consumption (7%)	=	11.32 GW
Ex-bus gen.	=	150.49 GW
55% min. load (aux. 7.5%)	=	76.56 GW
40% min. Load (aux. 8%)	=	55.38 GW

21.18 GW (76.56-55.38) more Renewable integration is possible by lowering the min load from 55% to 40%.

Capex = 10 Crore per unit (average)

Total no. of Units = 600

Total investment = 600X10 = 6000 Crore

Battery Storage System:

If we consider 27 GW BSS with an average cost of 4.5 Crore/MW, total cost will be more than one lakh twenty one thousand crore.

Thus BSS will be costly, imported, having less life about 9-10 years and disposal issues.

CONCLUSION

- **Best option**: Flexibilisation of coal fired power plants is primarily required to fulfil the needs of integration of renewables in the grid. There may be many options for integrating renewables, flexible coal fired plants is the best option considering its availability, proportion and low cost.
- **Easily available:** It is of importance that the existing resources available for flexibilisation in the system should be utilized first in a safe and secure manner before adopting newer options such as battery storage, etc. Indian power sector has got large fleet of subcritical coal fired units of capacity less than 500MW, which are considered most suitable for flexibilisation. The implementation of the policy replacing small units with large ones, the retirement of small capacity coal-fired power units should be avoided considering large requirement of flexible power expected in future.

- **Unit specific**: To explore the flexible power capability, the thermal units need to be tested from safety and security point of view and quantification. These pilot tests are also essential for accessing the need for retrofits which are plant specific. Enhancing the flexibility results in a higher profitability of a plant and reduces the number of units required to meet the demand of flexible power.
- **Precaution:** To ensure the security of the grid and safety of plants, the low load operation of coal-fired power plants should not be less than 35–40% of rated power due to coal quality.

CONCLUSION contd.

- **Retrofit:** Flexible operations for coal power plants are technically feasible by upgradation of controls, etc. The pilot tests conducted at various plants is the proof that Indian plants are capable to flex. Converting the baseload coal fired power plants into flexible plants would most likely incur costs, which would require compensation. To improve the availability of flexible power in the grid by conversion of baseload coal fired power plant into flexible power plants, it should be economically feasible for the generating companies.
- **Optimize retrofit:** For getting more flexibility, it does not require to retrofit the entire plant but retrofit only certain subsystem of power plant that are most effective in tackling plant flexibility. The technical measures shall depend on the levels of minimum load operation to be adopted. Lower load operation (40%) shall require measures like reassessment O&M practices, automation/optimization of controls, proper flame detection systems, efficient measures to optimize combustion process, stable minimum mill operation, use of steam coil air preheater.
- **Operator Training:** Due to operation of thermal plants as base load plants there is low operator confidence for flexibilisation. Flexibilization of units calls for added precautions. Catastrophic equipment failure can take place due to negligence and poor operation and maintenance practices. Hence, operator training is essential for the implementation of flexibilisation.

WAY FORWARD

1. Immediate action needs to be taken for preparing thermal generating units flexible.
2. Regulation shall be introduced for 40% minimum technical load operation of thermal generating units.
3. Suitable compensation mechanism, shall be introduced in central and state level, wherever applicable, for the compensation of the costs incurred as discussed.
4. Suitable guidelines shall be prepared.
5. Availability of training simulators needs to be ensured for the training of operators at 40% low load operation.
6. Keeping in mind the requirement of flexible power in future, design of new thermal generating units shall be modified so that it can be possible to operate these with optimized auxiliaries, at loads lower than 40% (say 30%) without oil support and, at higher ramp rates of 2% in lower load range.

7. Study shall be initiated for finding the possibility of two shift operation of existing thermal generating units as per the grid requirement. Design of new thermal generating units shall be modified so that it can be possible to operate in 2 shift mode on regular basis.

Thank you