

Compensation methodology for operating a Thermal (Coal) Generating unit below 55% Minimum Power Level

1. Introduction

Penetration of large-scale renewable generation in the grid is bringing a new set of challenges in the power sector. The inconsistency and intermittency of solar & wind power has to be managed by other sources of generation in order to ensure the grid security, reliability and stability. Thus, huge flexible power is required for the balancing of grid from sources like pump storage system, thermal power plants, battery storage system etc. Thermal generation capacity constituting about 54% of total installed capacity is the dominant part of power generation in the country and more than 70% of country's energy demand is being met from thermal generation. Thus, lowering of minimum power load of existing coal-fired power plants along with ramp rate capability (ie flexible operation) is very much essential for handling the instability & intermittency of renewable generation and ensuring security, reliability of power supply. Further, the cost of flexible power from thermal fleet is very less compared to power from battery storage system.

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

2. Measures required for achieving lower Minimum Power Load

For achieving minimum power load (40%) and higher ramp rate, Coal based power plants may require few modifications by way of improved control systems etc and also required to be compensated for the loss of life and increased variable cost due to regular part load operation.

The primary focus of the utility shall have to be on the existing control system optimization and improvements in some of the areas like achieving automated control operation which includes proper tuning of operation so as to avoid temperature and pressure excursions. Control optimization shall also include main/reheat steam temperature control, boiler feed water recirculation control, flue gas temperature control. Better combustion control include, optimum fuel to air ratio, fuel to load coordination, furnace pressure control, burner tilt control and proper flame monitoring at low loads are essential. Condition monitoring of boiler and turbine, flame monitoring is crucial from the safety point of view. To reduce the running cost of the unit at low loads, the optimization of auxiliaries is also important. The above measures are essential for a unit and may require an estimated capital investment of Rs 10 crores. In case of very old units which have not upgraded their plant control and instrumentation system previously, the estimated capital investment will be Rs 30 crores depending on the retrofit.

3. Proposed Compensation

The compensation mechanism has been prepared based on the studies carried out by various agencies (CEA's report "Flexibilisation of coal fired power plants" published in Feb 2023). The power plant needs to be compensated for both fixed cost due to infusion of capital investment, increased O & M cost, variable charges due to efficiency loss at part load operation and additional oil consumption due to increased Equivalent Forced Outage Rate (EFOR).

A. FIXED COST

a) Capital Expenditure

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 around Rs 30 crores for each unit.
- ii. It is estimated that measures essential, to operate at 40% load may require an estimated capital investment of around Rs 10 crores for each unit commissioned on or after 01.01.2004 and except units covered under para 3(a)(iv).
- iii. 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 as under **Table-I**.

Table-I

Unit Size (MW)	Recovery period (years)	For units in Para 3(a)(ii)		For units in Para 3(a)(i)	
		Total Capital cost (Rs Cr)	Increase in fixed charge per annum (Rs. Cr.)	Total Capital cost (Rs Cr)	Increase in fixed charge per annum (Rs. Cr.)
200	5	10	2.55	30	7.65
500	5	10	2.55	30	7.65
660	5	10	2.55	30	7.65
800	5	10	2.55	30	7.65

- iv. As per the Regulation 8 (11) of Central Electricity Authority (Technical Standards for Construction of Electrical Plants and Electric Lines) notified on 20.08.2010, pulverised fuel combustion-based steam generator shall not require oil support above 40% unit load.
Therefore, measures/ retrofits are not required in these units for operation upto 40% load. However, 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 maximum capital investment of Rs.6 crores may be allowed to the **subcritical generating units** where investment approval received on or after 01.01.2011 and the impact is calculated as under Table-II:

Table-II

		For units in Para 3(a)(iv)	
Unit Size (MW)	Recovery period (years)	Capital cost (Rs Cr)	Increase in fixed charge per annum (Rs. Cr.)
200/250	5	6	1.53
500	5	6	1.53
600	5	6	1.53

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

b) O&M cost due to increased Life Consumption (damage costs):

Flexible operation also leads to a higher rate of deterioration of plant's components. This is observed in increased failure rate and more frequent replacement of components. The impact on life of components increases with increase in number of flexible operation instances and also with number of start stops the unit undergoes in a year. As a result, the operation and maintenance cost are significantly higher in units operated on a daily or weekly start-stop basis. Based on CEA Report "Flexibilization of coal fired power plants" the increase in annual O&M cost has been considered as 9%, 14% and 20% of O&M Cost at 50%, 45%, 40% loading respectively (**Table-III**).

The increase in O&M cost shall be allowed on the basis of plant actual low load operation. Unit will be eligible for full compensation if the unit participated in flexible operation minimum 310 days (85% days) in a year. For less than 310 days low load operation compensation may be calculated proportionately.

Table-III

Capacity (MW)	Loading (%)	Increase in O&M (%)	Proposed increase in O&M cost (Rs Cr.)
200	<55 to 50	9.00	6.58
	<50 to 45	14.00	10.23
	<45 to 40	20.00	14.62
500	<55 to 50	9.00	11.23
	<50 to 45	14.00	17.47
	<45 to 40	20.00	24.97
660	<55 to 50	9.00	13.34
	<50 to 45	14.00	20.76
	<45 to 40	20.00	29.66
800	<55 to 50	9.00	14.55
	<50 to 45	14.00	22.64
	<45 to 40	20.00	32.35

B) VARIABLE COST

- a) **Cost due to increase in Net Heat Rate:** It has been observed that the extent of deterioration in Net Heat Rate depends on the percentage unit loading. Units running minimum power load below 55% shall be additionally compensated in Electricity Charge Rate (ECR) to the extent of Net Heat Rate (NHR) deterioration. Based on the actual study/test conducted at few coal based power plants and Heat Balance Diagram (HBD) reports of major OEMs (BHEL/GE/Siemens) on unit size Net Heat Rate degradation, compensation has been proposed in variable part of tariff considering coal price Rs 2000.00 per ton (estimated average cost of coal at pithead plants), Rs. 3300.00 per ton (estimated average cost of coal at non-pithead plants) and is as in **Table-IV**

Table-IV

Capacity (MW)	Loading (%)	Net Heat Rate increase (%)	Variable Tariff increase (%) at coal price Rs 2000/ton	Variable Tariff increase (%) at coal price Rs 3300/ton	Proposed variable Tariff increase (%)
200	<55-50	10.00	9.88	9.94	9.91
	<50-45	13.00	12.84	12.92	12.88
	<45-40	16.00	15.81	15.90	15.86
500	<55-50	10.90	10.76	10.83	10.80
	<50-45	13.60	13.44	13.51	13.48
	<45-40	16.00	15.81	15.90	15.86
660	<55-50	8.70	8.59	8.64	8.62
	<50-45	11.90	11.75	11.82	11.79
	<45-40	14.60	14.42	14.50	14.46
800	<55-50	8.60	8.49	8.54	8.52
	<50-45	12.00	11.84	11.92	11.88
	<45-40	15.00	14.81	14.90	14.86

The variable cost of any plant has been estimated using the formula given below:

$$\text{Variable Expense (Rs/kwh)} = \text{Coal Cost (Rs/kwh)} + \text{Oil Cost (Rs/kwh)}$$

$$\text{Coal Cost (Rs/kwh)} =$$

$$\text{Coal Cost (Rs/MT)} \times \left[\frac{\text{Station Heat Rate (kcal / kwh)} - \frac{\text{Oil CV (kcal / l)} \times \text{Specific Oil Consumption (ml / kwh)}}{1000}}{\text{Fuel Calorific Value (kcal / kg)}} \right]$$

$$\text{Oil Cost (Rs/kwh)} = \frac{\text{Oil Cost (Rs / kL)} \times \text{Specific Oil Consumption (ml / kwh)}}{10^6}$$

$$\text{Variable Charge at bus bar (Rs/kwh)} = \frac{\text{Variable Expense (Rs / kwh)}}{\left(1 - \frac{\% \text{ Aux Consumption}}{100}\right)}$$

- b) **Cost due to additional oil consumption for additional EFOR (Equivalent Forced Outage Rate):**Based on Electric Power Research Institute study report the additional EFOR due to regular low load operation of thermal generating units may increase specific oil consumption from 0.5 ml/kWh to 0.7 ml/kWh. Therefore, it is proposed to compensate 1.0 paisa/ kWh on account of EFOR.

Note : EFOR – Equivalent Forced Outage Rate is defined the percentage of scheduled operating time that a unit is out of service due to unexpected problems or failures and can no reach full load capacity due to component/equipment failures.

4. Likely increase in paisa/ kWh on account of proposed compensation

Sample calculation on basis of the compensation mechanism proposed above and various assumptions are given in Annexure-I.:

- i. Total likely increase in tariff considering capital investment of Rs. 30 crores, increase of O&M cost, variable cost and EFOR cost is given in Table-A.
- ii. Total likely increase in tariff considering capital investment of Rs.10 crores,increase of O&M cost,variable cost and EFOR cost is given in Table-B.
- iii. Total likely increase in tariff considering capital investment of Rs. 6 crores, increase of O&M cost, variable cost and EFOR cost is given in Table-C,This is only applicable for subcritical unit's where investment approval received on or after 01.01.2011.

Table-A. Likely Incremental Tariff (Rs 30 crores capital investment)

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	13.68	22.57	6.70	7.68	1	29.06	37.95	33.51
	<50 to 45	17.78	29.34	10.42	7.68	1	36.88	48.44	42.66
	<45 to 40	21.89	36.11	14.88	7.68	1	45.45	59.67	52.56
500	<55 to 50	14.66	24.20	4.57	3.07	1	23.30	32.84	28.07
	<50 to 45	18.30	30.19	7.11	3.07	1	29.48	41.37	35.43
	<45 to 40	21.53	35.52	10.16	3.07	1	35.76	49.75	42.76
660	<55 to 50	11.17	18.42	4.12	2.56	1	18.85	26.10	22.48
	<50 to 45	15.27	25.20	6.40	2.56	1	25.23	35.16	30.20
	<45 to 40	18.74	30.92	9.14	2.56	1	31.44	43.62	37.53
800	<55 to 50	10.65	17.57	3.70	1.92	1	17.27	24.19	20.73
	<50 to 45	14.86	24.52	5.76	1.92	1	23.54	33.20	28.37
	<45 to 40	18.58	30.65	8.23	1.92	1	29.73	41.80	35.77

Table-B. Likely Incremental Tariff (Rs 10 crores capital investment)

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	13.68	22.57	6.70	2.56	1.00	23.94	32.83	28.39
	<50 to 45	17.78	29.34	10.42	2.56	1.00	31.76	43.32	37.54
	<45 to 40	21.89	36.11	14.88	2.56	1.00	40.33	54.55	47.44
500	<55 to 50	14.66	24.20	4.57	1.02	1.00	21.25	30.79	26.02
	<50 to 45	18.30	30.19	7.11	1.02	1.00	27.43	39.32	33.38
	<45 to 40	21.53	35.52	10.16	1.02	1.00	33.71	47.70	40.71
660	<55 to 50	11.17	18.42	4.12	0.85	1.00	17.14	24.39	20.77
	<50 to 45	15.27	25.20	6.40	0.85	1.00	23.52	33.45	28.49
	<45 to 40	18.74	30.92	9.14	0.85	1.00	29.73	41.91	35.82
800	<55 to 50	10.65	17.57	3.70	0.64	1.00	15.99	22.91	19.45
	<50 to 45	14.86	24.52	5.76	0.64	1.00	22.26	31.92	27.09
	<45 to 40	18.58	30.65	8.23	0.64	1.00	28.45	40.52	34.49

Table-C. Likely Incremental Tariff for units where investment approval received on or after 01.01.2011 (Rs 6 crores capital investment)

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	13.68	22.57	6.70	1.54	1	22.92	31.81	27.37
	<50 to 45	17.78	29.34	10.42	1.54	1	30.74	42.30	36.52
	<45 to 40	21.89	36.11	14.88	1.54	1	39.31	53.53	46.42
500	<55 to 50	14.66	24.20	4.57	0.61	1	20.84	30.38	25.61
	<50 to 45	18.30	30.19	7.11	0.61	1	27.02	38.91	32.97
	<45 to 40	21.53	35.52	10.16	0.61	1	33.30	47.29	40.30
660	<55 to 50	11.17	18.42	4.12	0	1	16.29	23.54	19.92
	<50 to 45	15.27	25.20	6.40	0	1	22.67	32.60	27.64
	<45 to 40	18.74	30.92	9.14	0	1	28.88	41.06	34.97
800	<55 to 50	10.65	17.57	3.70	0	1	15.35	22.27	18.81
	<50 to 45	14.86	24.52	5.76	0	1	21.62	31.28	26.45
	<45 to 40	18.58	30.65	8.23	0	1	27.81	39.88	33.85

- No additional capital investment is required in the unit size of 660MW and 800 MW units for operating them at 40% load.

Assumptions

1. General:

- i. Auxiliary power consumption (APC): 6.5%,
- ii. Average PLF: 60%,
- iii. PAF: 100%,
- iv. Debt to equity ratio: 70:30,
- v. Return on equity: 15.5%,
- vi. Interest on loan: 10%,
- vii. Depreciation rate: 5.28%,
- viii. Specific oil consumption: 0.5 ml/kWh,
- ix. Price of oil: Rs 35/lt,
- x. GCV of oil: 10000 kcal/lt,
- xi. GCV of Coal: 3800 kcal/kg.
- xii. Landing cost of coal
 - a) Rs. 2000.00 per ton (estimated average cost of coal at pithead plants)
 - b) Rs. 3300.00 per ton (estimated average cost of coal at non-pithead plants)
- ii. Weighted average cost of capital for annuity calculations : 10%

2. Unit size 200 MW

O&M Cost Rs 36.56 lakh/MW, Heat rate 2430 kcal/kWh.

3. Unit size 500 MW

O&M Cost Rs 24.97 lakh/MW, Heat rate 2390 kcal/kWh

4. Unit size 660 MW

O&M Cost Rs 22.47 lakh/MW, Heat rate 2280 kcal/kWh.

5. Unit size 800 MW

O&M Cost Rs 20.22 lakh/MW, Heat rate 2200 kcal/kWh.