Flexible Power for integration of renewable generation

Status, issues and challenges

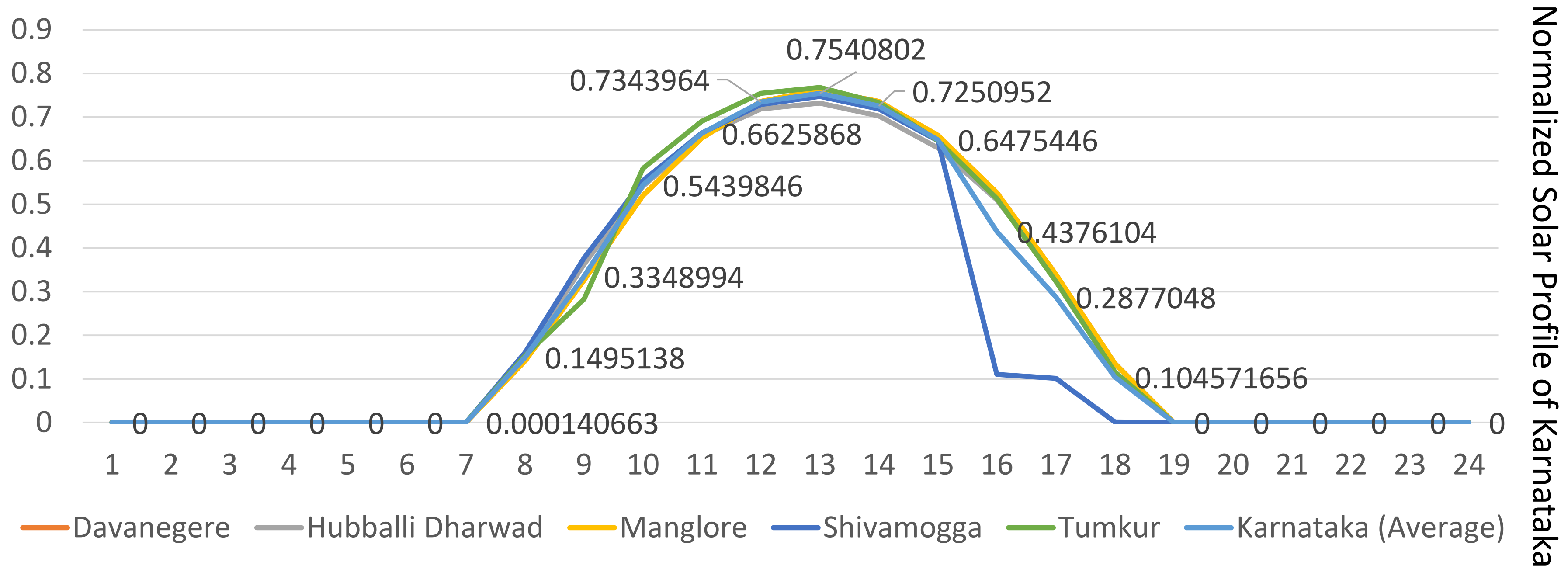
- B.C.Mallick, Chief Engineer, CEA

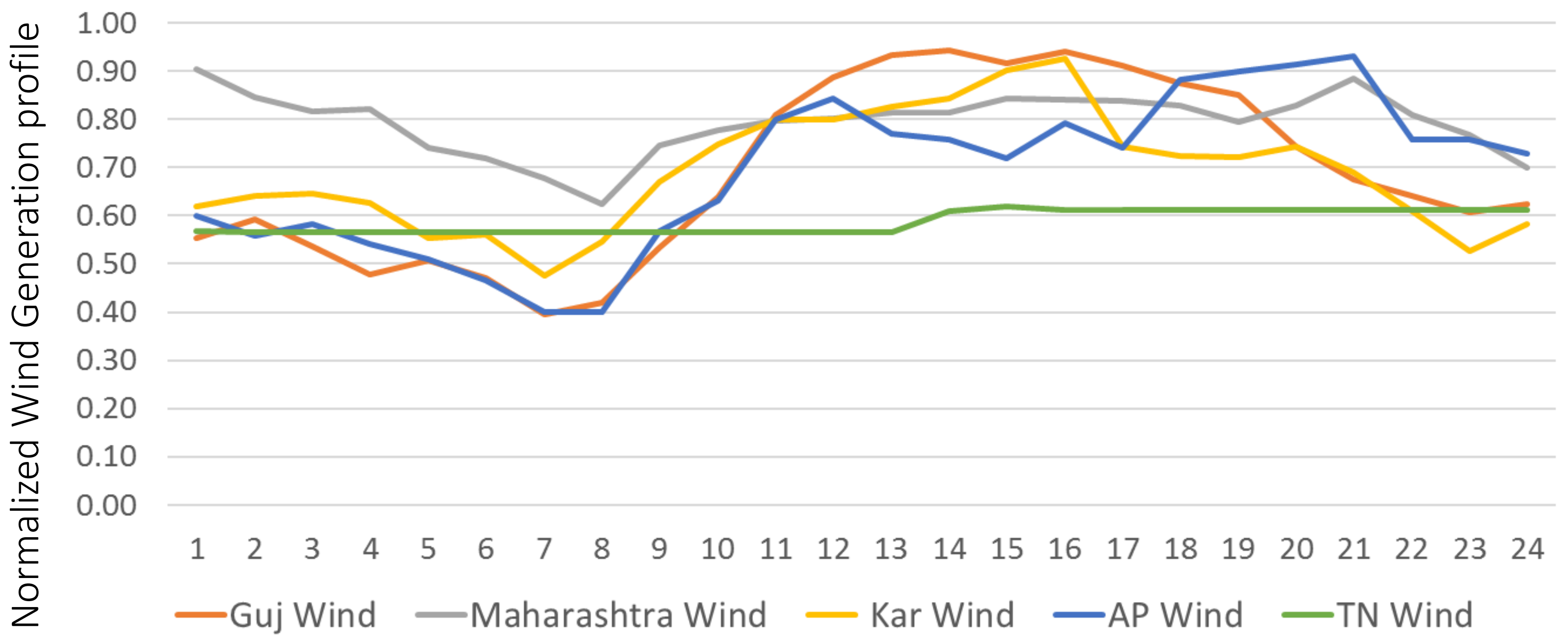
Solar & Wind capacity (GW)

	As on October, 2019	Expected in Year, 2021-22
Solar	32.52	100
Wind	37.28	60
Biomass	9.95	10
Small hydro	4.65	5
Total	**84.40**	**175**

Installed capacity

	As on 30.09.2019		As on 31.03.2022		As on 31.03.2030	
	(GW)	(%)	(GW)	(%)	(GW)	(%)
Thermal:	204.0	55.86	217.0	**45.30**	267.0	**32.1**
Hydro:	45.0	12.32	51.0	10.65	73.0	8.8
Gas:	25.0	6.85	26.0	5.43	25.0	3.0
Nuclear:	6.8	1.86	10.0	2.09	17.0	2.0
Renewable:	84.4	23.11	175.0	**36.53**	450.0	**54.1**
Total:	365.20	100.00	479.00	100.00	832.00	100.00


Normalized Solar Profile of Karnataka
0.7540802
0.7343964
0.7250952
0.6625868
0.6475446
0.5439846
0.4376104
0.3348994
0.2877048
0.1495138
0.104571656
0.000140663
Davanegere
Hubballi Dharwad
Manglore
Shivamogga
Tumkur
Karnataka (Average)


Normalized Wind Generation profile
Guj Wind
Maharashtra Wind
Kar Wind
AP Wind
TN Wind

Demand & Generation Analysis

Hourly Generation prediction, year, 2021-22

1. **Solar, Wind, Nuclear & Hydro:** The generation of Solar, Wind, Nuclear & Hydro are predicted on the basis of their past generation trend and the capacity considered in the year 2021-22.

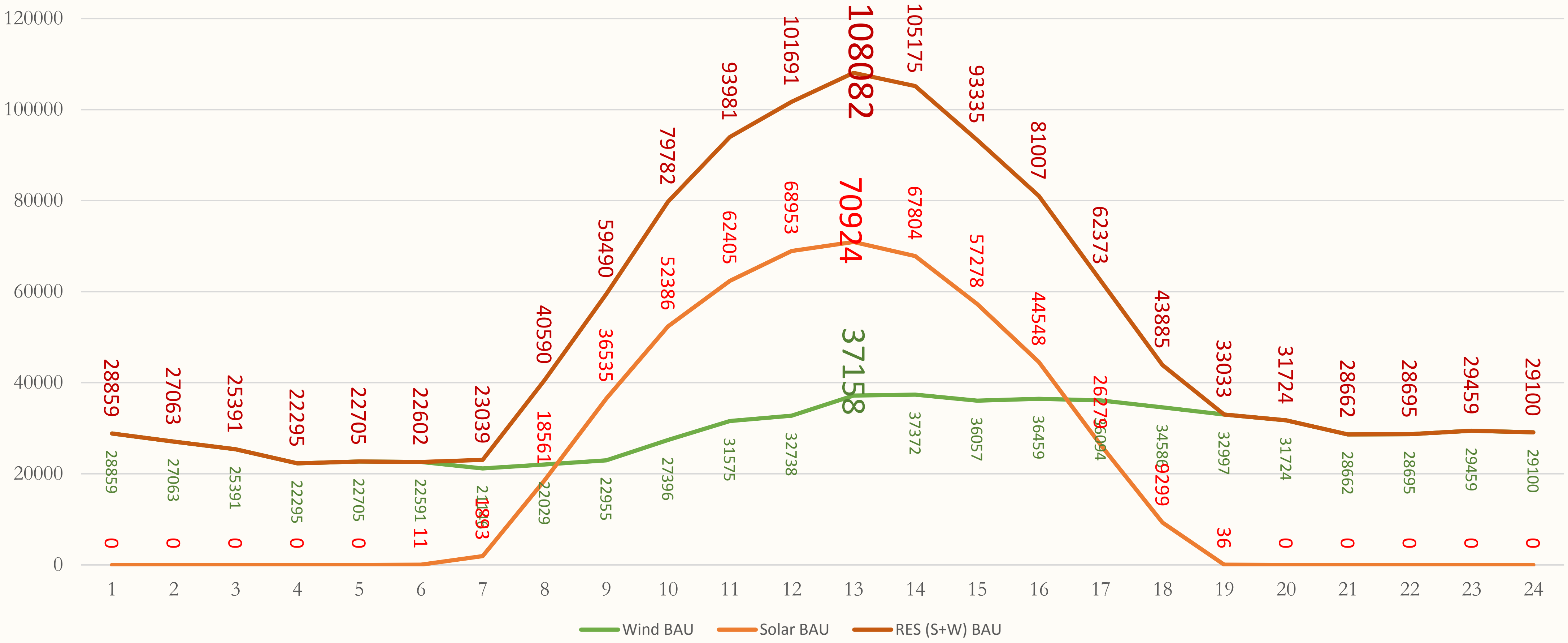
2. **Gas:** The gas generation data has been taken from CEA.

3. **Small Hydro, Biomass:** Since no reliable data is available for these small renewable sources, straight line assumptions has been used. Small Hydro is taken as 1000 MW and Biomass as 2000 MW as constant values.

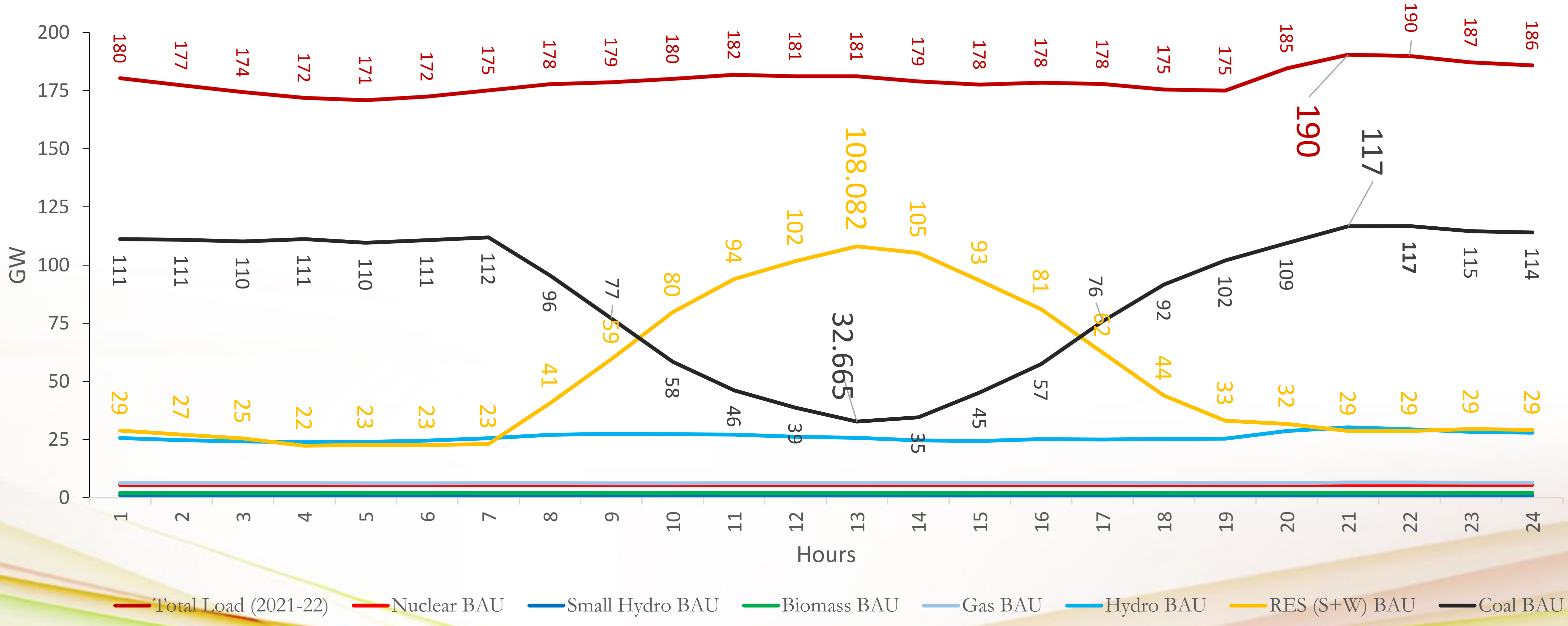
4. **Demand**: The national electricity demand for the year 2021-22 has been collected from 19th EPS, CEA

5. **Coal:** It is calculated figure. Added hourly generation of all generation sources except coal and subtracted from hourly demand and the result is the required hourly generation from coal.

Solar & Wind generation predicted on 27th July,2021



Demand & Generation on the day 27th July,2021



Demand & Generation on the day 27th July,2021

Date	Hours	Total Load (2021-22)	Solar BAU	Wind BAU	Nuclear BAU	Gas BAU	Biomass BAU	Small Hydro BAU	Hydro BAU	Coal BAU	Coal Ramp (MW/min)	Coal with reserve & APC	MTL (%)
27-Jul	00:00	180339	0	28859	5420	6241	2000	1000	25620	111199			
27-Jul	01:00	177283	0	27063	5421	6199	2000	1000	24714	110886	-5.21		
27-Jul	02:00	174349	0	25391	5427	6220	2000	1000	24191	110120	-12.77		
27-Jul	03:00	171930	0	22295	5443	6190	2000	1000	23845	111158	17.30		
27-Jul	04:00	170924	0	22705	5440	6180	2000	1000	24011	109588	-26.16		
27-Jul	05:00	172465	11	22591	5445	6178	2000	1000	24542	110699	18.50		
27-Jul	06:00	175127	1893	21146	5445	6203	2000	1000	25568	111872	19.56		
27-Jul	07:00	177762	18561	22029	5448	6193	2000	1000	26994	95537	-272.24		
27-Jul	08:00	178650	36535	22955	5453	6180	2000	1000	27488	77038	-308.32		
27-Jul	09:00	180073	52386	27396	5449	6142	2000	1000	27249	58450	-309.80		
27-Jul	10:00	181809	62405	31575	5440	6190	2000	1000	27104	46095	-205.93		
27-Jul	11:00	181212	68953	32738	5444	6251	2000	1000	26182	38645	-124.16		
27-Jul	12:00	181151	70924	37158	5442	6265	2000	1000	25697	32665	-99.66		
27-Jul	13:00	178995	67804	37372	5441	6296	2000	1000	24564	34519	30.89		
27-Jul	14:00	177595	57278	36057	5444	6283	2000	1000	24327	45205	178.11		
27-Jul	15:00	178441	44548	36459	5450	6368	2000	1000	25158	57458	204.22		
27-Jul	16:00	177872	26279	36094	5447	6339	2000	1000	24955	75757	304.98		
27-Jul	17:00	175491	9299	34586	5453	6272	2000	1000	25276	91606	264.15		
27-Jul	18:00	175006	36	32997	5457	6219	2000	1000	25316	101982	172.93		
27-Jul	19:00	184571	0	31724	5464	6276	2000	1000	28668	109439	124.29		
27-Jul	20:00	190480	0	28662	5462	6465	2000	1000	30191	116700	121.01		
27-Jul	21:00	189882	0	28695	5466	6535	2000	1000	29417	116769	1.15		
27-Jul	22:00	187171	0	29459	5466	6419	2000	1000	28300	114527	-37.37		
27-Jul	23:00	185868	0	29100	5463	6417	2000	1000	27904	113984	-9.05		
	Max	190480	70924	37372	5466	6535	2000	1000	30191	116769	305	139509	25.73
	Min	170924	0	21146	5420	6142	2000	1000	23845	32665	-310	35896	

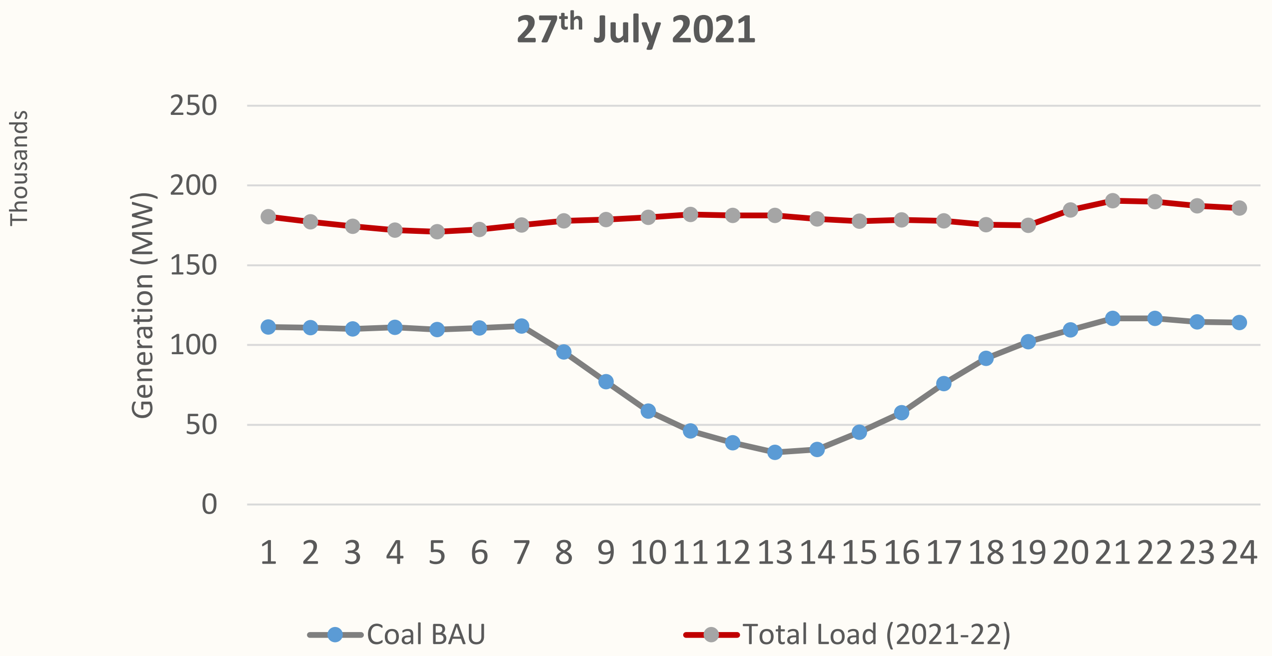
Month-wise lowest MTL

Day	Maximum Demand (MW)	Max RES (W+S) (MW)	Min. Thermal Generation (MW)	Max. Thermal Generation (MW)	MTL on critical day
19 April	194604	81274	65863	146917	41.23%
29 May	195640	90339	59368	138550	39.41%
25 June	197881	105715	40589	124800	29.91%
27 July	190480	108082	32665	116769	25.73%
15 August	189474	91355	37897	119009	29.29%
1 September	201308	72885	72037	139203	47.60%
18 October	205652	58364	98926	156765	58.04%
16 November	193583	68442	85361	151659	51.77%
29 December	197112	82185	82861	150421	50.67%
27 January	198222	75991	83623	150931	50.96%
4 February	201622	82015	81150	149265	50.01%
13 March	185585	74684	73474	140192	48.21%

MTL on significant days

S.No.	Day	Date	Max Total Demand	Max RES Generation	MTL	Max. Ramp Rate (MW/min)
1	Highest Demand Day	7th October 2021	225751	52421	62.65%	-216
2	Lowest Demand Day	13th March 2022	185585	74684.5	48.21%	-422
3	Highest RE Day	1st July 2021	201723	108926	33.39%	-332
4	Highest Ramp Down Day	13th March 2022	185585	74684	48.21%	-422
5	Highest Ramp Up Day	3rd Feb 2022	200364	74701	53.02%	379
6	Lowest MTL Day	27th July 2021	190480	108082	25.73%	-310

Ramp Rate - Requirement



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

Ex-bus generation of TPP: 117 GW
139 GW thermal capacity on Bar
Ramp capability: 1390 MW/min

The highest ramp down: - 422 MW/min. 13th Mar,2022
Ex-bus generation of TPP: 140 GW,
Thermal capacity to be synchronized: 167 GW.
Ramp capability: 1670 MW/min.

The highest ramp up: 379 MW/min. 3rd Feb,2022
Ex-bus generation of TPP: 154 GW,
Thermal capacity to be synchronized: 184 GW.
Ramp capability: 1840 MW/min.

Renewal generation integration into grid

Most critical day	:	27^{th} July,2021
Renewable gen.	:	108 GW
Peak thermal ex-bus/ gross gen.	:	116.7 GW / 139.5 GW
Min. thermal ex-bus/gross gen.	:	32.6 GW / 35.9 GW
Average MTL	:	25.7%
Flexible power required	:	84 GW

Balancing of Grid

- The installed capacity of renewables may vary from one state to another state.
- The State like Maharashtra, Tamil Nadu, Andhra Pradesh, Gujrat, Karnataka, Rajasthan, have huge potential of renewable and they need large amount of flexible power.
- On the other hand, many states have small capacity of renewables and practically they need small amount of flexible power.
- Thus, the requirement of additional flexible power of RE rich states can easily be met from flexible power available in other states.
- Thus, curtailment of renewable generation can be avoided in RE rich state if their system balancing is done with the support from other states.

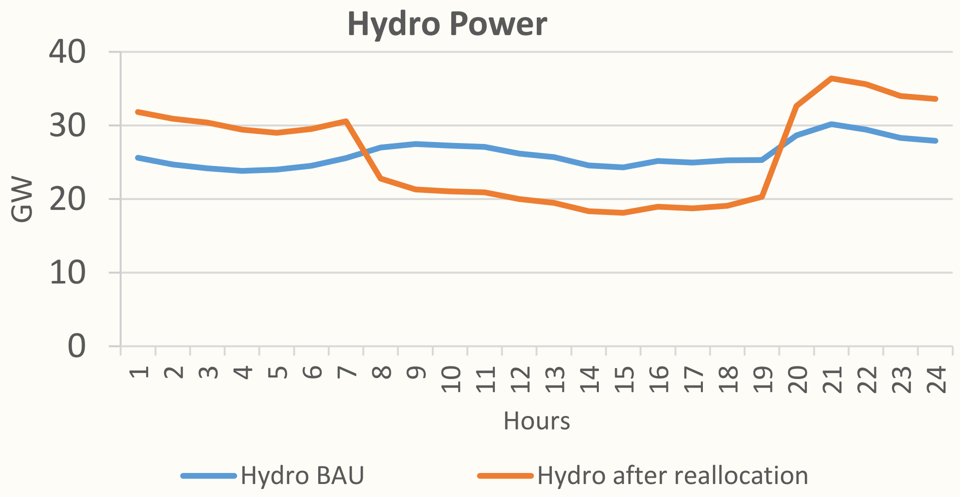
Coordinated Effort

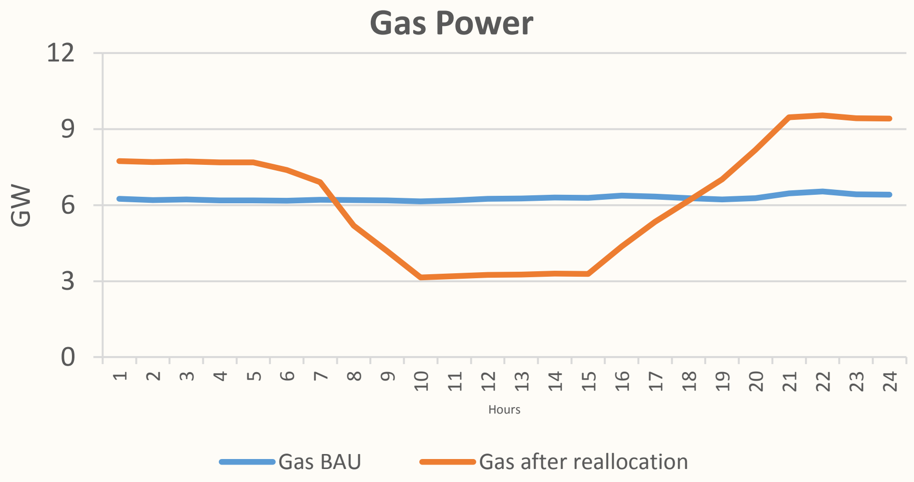
Step I: Hydro & Gas Reallocation

Step II: Two Shift Operation of Thermal units & Pump/ Battery Storage

Step - I: Hydro, PS Flexing & Gas Flexing

- Additional **6200 MW hydro gen. flexing including 4785 MW running & 1205 MW of under construction PS.**
- Regulatory intervention is proposed for:
  - **Lucrative tariff /incentives**
  - **Revision of grid code,**
  - **Implementation of 2-part tariff**





Gas plants do not flex much as of today, we need **3000 MW generation flexibility** from Gas plant by start/stop

MTL: 25.7% → 35.8%

Step - II: Two shift Operation of thermal units & Battery/PS

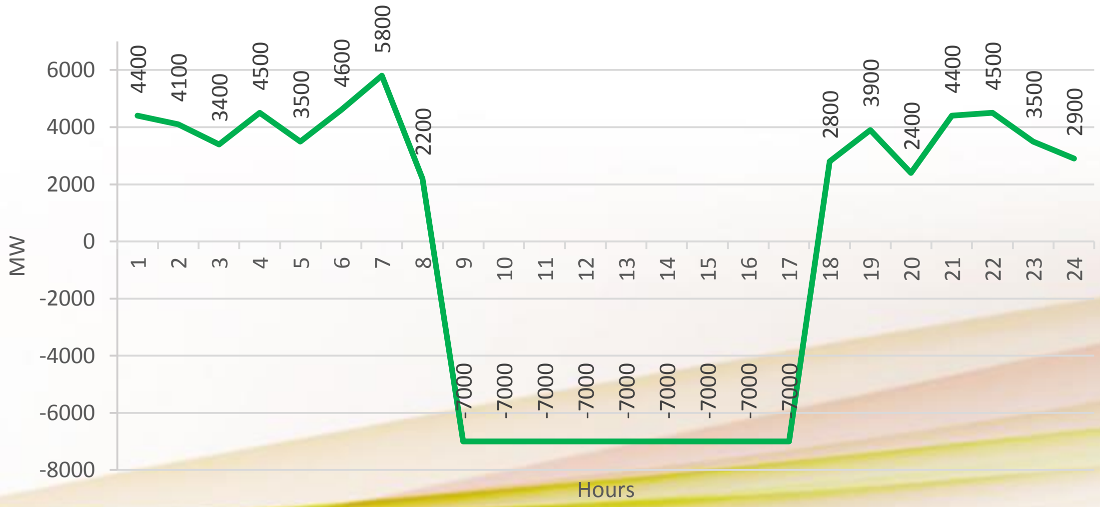
a) Two shift Operation of thermal units

MTL: 35.8% → 45.8%

Peak thermal: Ex-bus 98 GW

capacity on bar: 117 GW

b) Pump /Battery storage/both



Step – III: RE Curtailment

S.No.	Season	MU of RES produced	MU of RES curtailed	% of RES curtailed
1	Monsoon	100815	2555	2.53%
2	Non-Monsoon	173488	73	0.04%
3	Overall	274303	2628	0.96%
Overall % RES curtailed			**0.96%**	

- Negligible amount of RE curtailment goes a long way in ensuring integration of clean power.
- The period June to August is period of high RE.
- **Value of curtailed energy is Rs 658 Cr.** considering rate of energy Rs.2.50 /kwh

Monsoon : June – August (3 Months)
Non Monsoon : Sept – May (9 Months)

Step – III: RE Curtailment

MTL Achieved (%) without support from other sources and without curtailment	Percentage RES Curtailed p.a. (%)	MTL Achieved (%) without support from other sources	MTL Achieved (%) with support from Hydro & Gas	Annual RES Curtailed in Million Units (MU)	Value of RES lost p.a. @ Rs2.5/kWh (Rs. Crore)
25.73 %	0.01 %	30 %	41.07 %	22	6
	0.09 %	35 %	46.38 %	252	63
	0.38 %	40 %	51.48 %	1035	259
	0.96 %	45 %	56.80 %	2630	658
	2.02 %	50 %	61.90 %	5541	1385
	3.99 %	55 %	67.21 %	10945	2736
	7.56 %	60 %	71.69 %	20736	5184

Capacity Utilization Factor	
CUF Solar	18.48 %
CUF Wind	21.40 %
CUF Solar (after 1% curtailment)	18.18 %

Step IV: Demand side Management

Demand-Side Management (DSM) refers to initiatives that help end-users to optimize their energy use. With DSM, consumers can reduce their electricity costs by adjusting their time and quantity of use. Following measures are expected to contribute in improving the flexible power scenario from the demand side.

1. Time of Day Tariff,
2. Open Electricity Market,
3. Demand response from High Voltage industrial consumers,
4. Supply of electricity to agriculture sector by dedicated feeders**,**
   - Agricultural consumption = 173185 MU
   - Agricultural consumption = 17.30 %
   - Connected load = 108834529 kW
   - Nos. of consumers = 20918824

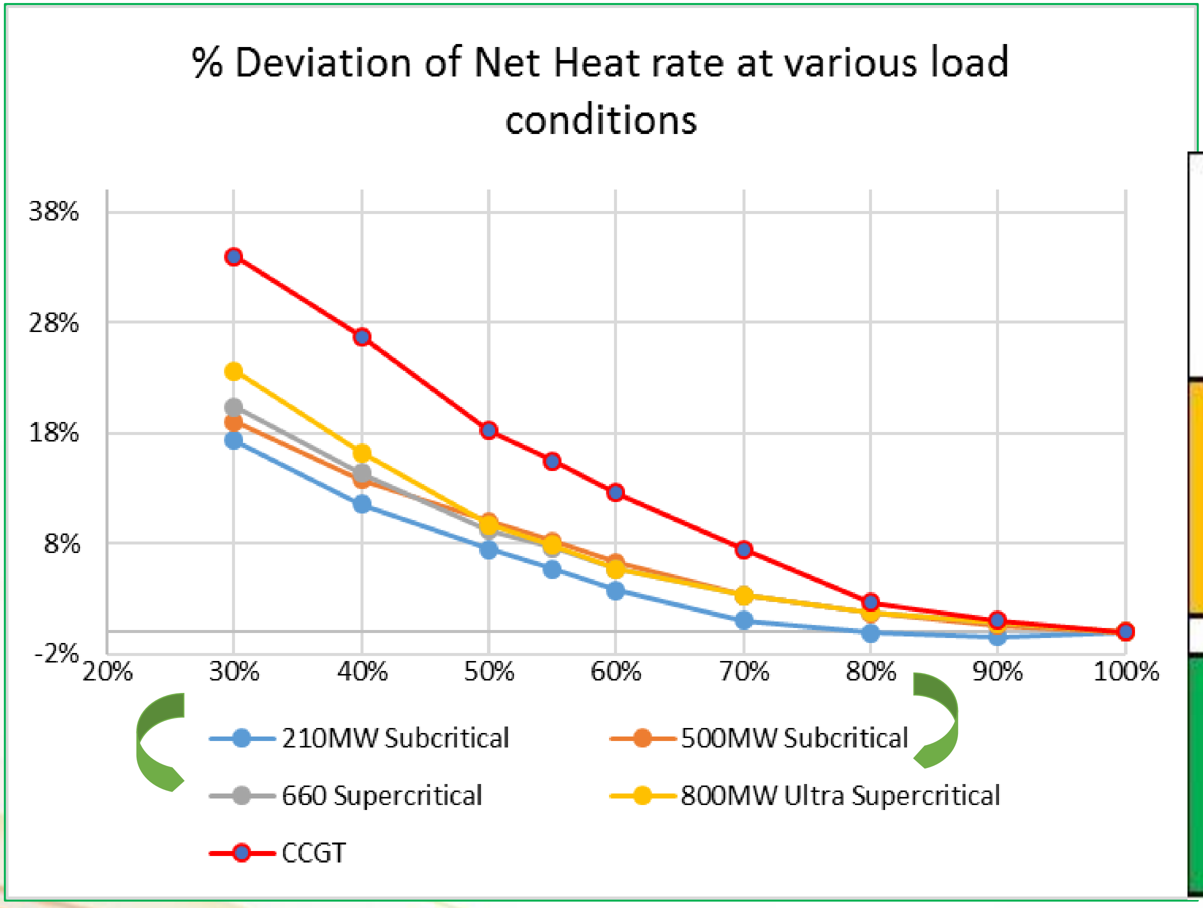
   2000 MW load is shifted from night hours to peak solar gen. hour it will improve 2% MTL.

5. Charging of Electric vehicle when solar generation is available – this will also improve MTL.

Road map for flexible operation

Identification of thermal units

1. Increase in tariff due to increase in Net Heat Rate



2. Life Consumption reflected in increased O&M cost

MW	Event	O&M Cost (INR-Lakh)			% Addl. / event
		Per Event	Per MW	Per MW (Current level) As allowed by CERC 2017	
200	Cold Start	91.3	0.46	28.70	1.59%
	Warm Start	51.4	0.26		0.90%
	Hot Start	38.0	0.19		0.66%
	Significant load following	0.5	0.01		0.01%
500	Cold Start	262.2	0.52	19.22	2.73%
	Warm Start	151.6	0.30		1.58%
	Hot Start	123.0	0.25		1.28%
	Significant load following	2.7	0.01		0.03%

A Scheduling Case Study

Scheduling in flexible regime with all India Merit Order Dispatch based on ECR

Factors considered for selection of a thermal unit:

1. Unit heat rate
2. Load centre unit
3. Pit head unit
4. Old units
5. New units
6. Merit Order/ ECR
7. Super critical/ Sub-critical
8. Size of unit

Categorization of units

Symbol	Category	Capacity Range	Capacity	No. of units
X	Low flexible	660 to 800 MW	68160	98
Y	Flexible	490 to 600 MW	70770	133
Z	Very Flexible	195 to 360 MW	67640	285
TSO	Two shift operation	< 151 MW	10564	110
	Total		217134	626

27th July with Step 1 & 2

1	2	3	4	5	6
Category	Evening Load on each category based on MOD (MW)	No. of units	Average MTL of each category as a whole	ECR range of the category	MTL range of the category
Low Flexible (X)	52380	75	50.00%	0.84 to 2.38	45% to 55%
Flexible (Y)	41890	78	44.00%	1.20 to 2.36	40% to 50%
Very Flexible (Z)	23280	90	40.00%	1.10 to 2.30	35% to 45%
Total	117550	243	45.88%	0.84 to 2.38	45.88%

Units having higher ECR are proposed to run at lower loads than units having lower ECR within the same category.

Flexibility test

Test/study conducted

1. Dadri, 500 MW unit# 6, NTPC
2. Mouda, 500 MW unit# 2, NTPC
3. Sagardighi, 500 MW unit# 3 , WBPDCL
4. Vindhyachal,500 MW unit# 11, NTPC
5. Anpara B, 500 MW unit# 4 & 5, UPRVNL

LIST OF TESTS

- Minimum Load Test at 40%
- Ramp Test (Up/Down) 1%
- Ramp Test (Up/Down) 3%

Dadri TPS

A flexibility test of 40% minimum load operation and 3% ramp up/ramp down (i.e. 15 MW/min) has been successfully conducted in Dadri TPS of NTPC.

Test Date	:	21-06-2018
Unit No.	:	2
Capacity	:	490 MW

Following tests were conducted:

Minimum Load Test at 40% achieved 200 MW

Ramp test: 250 MW to 200 MW and back to 250 MW with a ramp rate 2.5 MW/ min.

Again on June 22, 2018, the load was changed from 490 MW to 195 MW and back first with a ramp rate of 5 MW/min, and then with a ramp rate of 15 MW/min.

Time required for taking mills in from 250 to 350 MW generation

Time also required for taking mills out from 350 to 250 MW generation.

Mouda TPS

Mouda TPS, NTPC, Nagpur, Maharashtra:

Test Date: 29-09-2019

Unit No. : 2

Capacity : 500 MW

7 mills operation for full load and 5 mills operation for technical minimum load

Following tests were conducted with 3 mills in services

Test	Target	Achieved
Minimum Load Test at 40%	200 MW	200 MW
Ramp Test (3%)	3%/ mini	~1.1%/min
Ramp Test (1%)	1%/ mini	~0.55%/min

Sagardighi TPS

Sagardighi TPS, WBPDCL, Musheerabad, West Bengal:

Test Date : 27-06-2019

Unit No. : 3

Unit Capacity : 500 MW

7 mills operation for full load and 4-5 mills operation for technical minimum load

Following tests were conducted:

Test	Target	Achieved
Minimum Load Test at 40%	200 MW	200 MW
Ramp Up Test (3%)	3%/ mini	~1.6%/min
Ramp Down Test (3%)	3%/ mini	~2.6%/min
Ramp UpTest (3%)	1%/ mini	~1.1%/min
Ramp Down Test (3%)	1%/ mini	~0.67%/min

Study conducted

1. Vindhyachal,500 MW unit# 11, NTPC
2. Anpara B, 500 MW unit# 4 & 5, UPRVNL

Vindhyachal TPS

Vindhyachal STPS, NTPC, Singrauli, Madhya Pradesh

Test Date: 06-03-2019
Unit No. : 11
Capacity : 500 MW

- **Minimum load: 250 MW**
- Unit adopts variable pressure operation, so that when output of generator decreases, steam pressure also decreases. And when steam pressure decreases, it is easy for feed water to get into drum, and fluctuation of drum level becomes larger. It is recommend to make drum level control insensitive depends on the steam pressure.
- The unit is basically designed to be operated at rated output, therefore as the output becomes low, combustion situation becomes worse and control becomes unstable. Also the unit has very little experience at 275MW, at first, JCOAL recommend to achieve 250MW operation by combustion adjustment and tuning of control system.
- At 250MW operation, number of operating BFPs could be reduced to one, and this contributes to increase thermal efficiency.
- For further reduction of minimum load, detailed investigations should be done by the operational data of 250MW.

Anpara-B TPS

Anpara B, UPRVUNL, Uttar Pradesh

Unit # 4 & 5

-
- Optimal load demand distribution technology for multiple plants
- Monitoring and improving technology for plant performance
- Boiler combustion optimization technology utilizing AI
- Plant loading (startup/ramping/shutdown) optimization technology

- Expected　Time Shortening
- ■Cold-ColdStart:Approx.45%
- ■ColdStart:Approx.35-60%
- ■WarmStart:Approx.15%

- Sliding Pressure Mode
- Effect: Metal temperature difference improvement (reduced life consumption) and efficiency will be improved at part load.

Measures Identified

1. Thermo-Mechanical Assessment
2. Condition Monitoring
3. Fine tuning of Existing CMC Logic
4. Steam temperature Controls
5. Flue Gas Temperature Controls
6. Fuel firing system optimization
7. Automatic startup & shutdown of Mills
8. BFP Operation at Low Load
9. Axial Fans Operation for Low Load
10. Primary Frequency Control
11. Turbine Blade Vibration Monitoring
12. APC Reduction for Low Load Operation
13. Automatic Plant Startup

Regulatory intervention

- Capex: Implementation of measures for flexible operation

Actual basis after examination

- Opex:
  - Increase in Net Heat Rate at low load
  - Life Consumption reflected in increased O&M cost

Benchmarked costs (compensation) + markup (incentivisation)

Thank You

Measures Identified

1. Thermo-Mechanical Assessment:
   it is strongly recommended for carrying out a detailed thermo-mechanical assessment of the entire unit for capturing the current state of the equipment, their response and capability for flexible operation

2. Condition Monitoring:
   condition monitoring package is strongly advised for units subjected to flexible operation which will help in monitoring and quantifying the stress levels generated in any of the operation activity by means of additional instrumentations and computational logics
3. Fine tuning of Existing CMC Logic:
   The current CMC logic is performing well for steady state operation in load range of 55%–100% TMCR, control is required to be made capable for 40% TMCR to 100% TMCR

4. Steam temperature Controls:
   Specialized steam temperature control package is required for limiting steam temperature excursions within safe operating limits during flexible operation regime.
5. Flue Gas Temperature Controls:
   Specific control package is required for controlling these flue gas temperatures so as to avoid any acid corrosion damages in APH and downstream equipment

6. Fuel firing system optimization:
   Distribution of coal-air mixture in the furnace at all load conditions and fuel firing system assessment is required in this regard.

7. Automatic startup & shutdown of Mills:
   Auto mill cut-in and cut-out logic is thus recommended to improve boiler response as well as reliability of the flame

Measures Identified

8. BFP Operation at Low Load:

   For ensuring smooth operation of both BFP at low load, modifications of BFP recirculation valve from on/off type to regulating type along with changes in operating logic is required.

9. Axial Fans Operation for Low Load:

   For ensuring smooth operation of both set of axial fans at low load, incorporation of protection logic is required .

10. Primary Frequency Control:

    Primary frequency control by means of Condensate Throttling is suggested which will allow the unit to respond to load demand immediately and then stabilize further by load ramping.

11. Turbine Blade Vibration Monitoring:

    Steam flow pattern through turbine during load ramping condition and at low load conditions is significantly different from the flow pattern at rated conditions. These varying flow pattern result in vibrations in LP turbine blades during flexible operation. Thus monitoring throughout such operations is required.

12. APC Reduction for Low Load Operation:

    Various auxiliaries in water and steam cycle of the unit have been designed with 2 X 50% configuration required at 100% TMCR for ensuring reliability the low load operations at 40% TMCR, running both set of auxiliaries may not be required and thus single stream operation may be adopted which will allow for reduction in auxiliary power consumption.

13. Automatic Plant Startup:

    Automatic Plant Startup sequence is suggested for flexible operation as it will help in executing startup and shutdown cycles smoothly

Conclusion

1. Balancing shall be done at national level which will minimize the requirement of balancing power.

2. Hydro plants are especially suitable for quick supply of power. Coordination with state owned hydro plants would play an important role in re-allocation of hydro generation. Pumped storage, existing and under construction, shall be used exclusively for meeting the peak load or balancing the system. Provision of two-part tariff and revision of grid code are suggested. **Regulatory intervention is required**.

3. Gas power plants have better start stop capability and need to contribute to flexible generation as much as possible.

4. Establishment of new pump or battery storage or combination of both at strategic locations may be explored for energy storage during high solar generation period and utilizing the same during peak demand hours or at the time of need. Encourage pump storage in combination of solar and wind plant wherever such geographical advantages are available.

5. 210 MW & 500 MW units shall be operated at lower MTL than bigger size unit.

6. Among the fleet of 200 MW, 500/600 MW or 660/800 MW thermal units, which are efficient and have low ECR, should be given preference over other units in terms of generation schedule.

7. Test run/ study of thermal units for operation at low load shall be conducted before implementation of measures for flexible operation as the measures are plant specific.

8. Several measures need to be undertaken to make the plants capable of low load operation, (i) Capex to be reimbursed on actual basis after examination, (ii) Opex -based on a benchmarked costs (compensation) + markup (incentivisation). **Regulatory intervention is required**.

9. Capacity building of coal fired power plant operators becomes an important measure in the changing operational regime.

10. Demand side management including measure targeted at domestic, agricultural, industrial and e-mobility sector would enable more rational consumption pattern of electricity.

Efficiency Test

- Mouda TPS U#4, 660 MW and U#5, 660 MW

- Test Conducted on 6th to 8th December,2019
  100% load during evening hours
  70% load during day time
  55% load at night lean hours
  48% load at night lean hours (12:00 hrs to 03:00 hrs)

- Agency: TEPCO, Japan

Test procedure

1. INTENT:

i. The test is to evaluate thermal unit's response during:

- Ramp up/Ramp down between minimum load and base load.
- Current minimum technical load (55%) operation.
- Minimum load (40%) operation.

ii. The data collected at the end of tests is to verify the following

- Ability of boiler to sustain minimum load within design limits.
- Temperature and pressure excursions along with control loop parameters for compliance within design range.
- Constraints in main plant system including auxiliaries for improving ramp rates within the design limits.

iii. The goal of the proposed tests is to identify:

- Check of control system and evaluation of aging of equipment.
- Identifying of the process limitations/restrictions (thermal, mechanical, operation) during the new/old minimum load operation.
- Identification of retrofits required and possible for adoption in the plant.