Flexible Power for Integration of Renewable Generation

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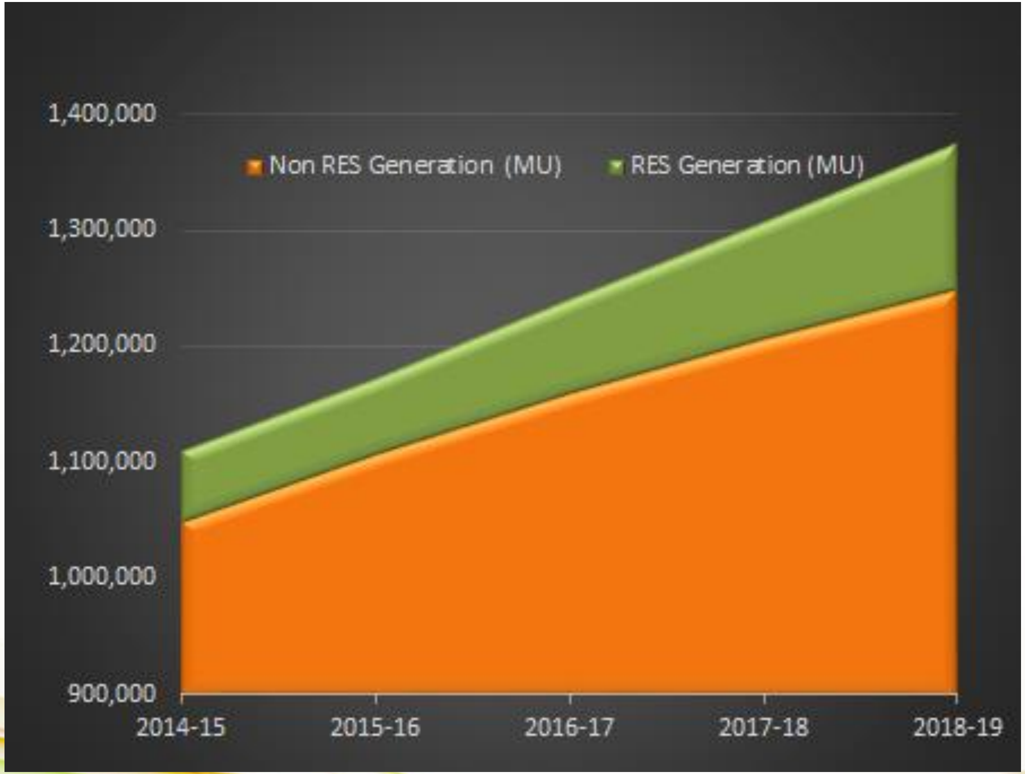
Installed Capacity (Actual/Planned)

	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

Renewable Capacity (GW)

	As on December, 2019	Expected in 2022
Solar	33.73	100.0
Wind	37.50	60.0
Biomass	10.00	10.0
Small hydro	4.67	5.0
Total	**85.90**	**175.0**

RE Generation



Year	RE Generation
2014-15	5.56%
2015-16	5.61%
2016-17	6.57%
2017-18	7.78%
2018-19	9.19%
2019-20*	9.85%

CAGR

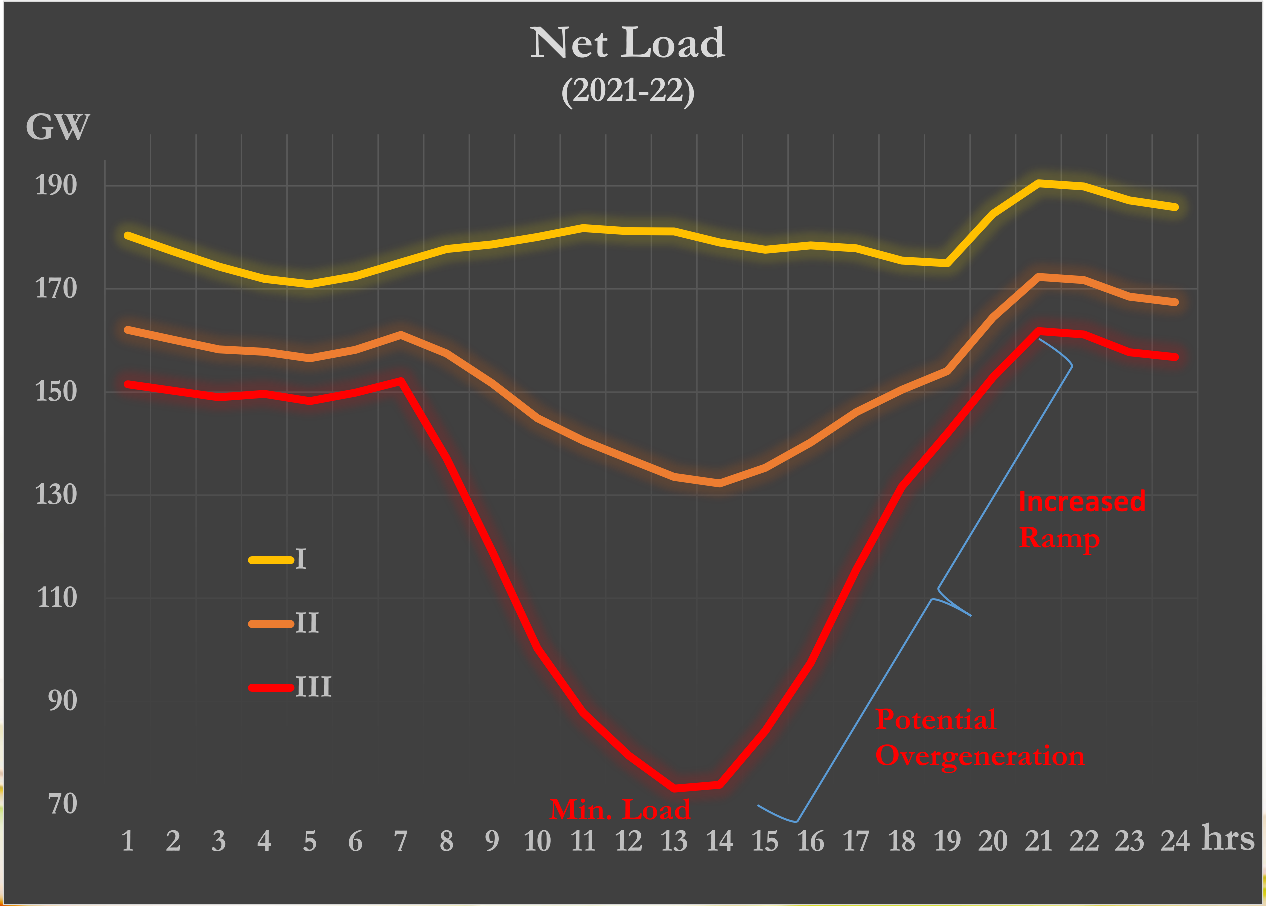
- RE Generation 19.62%
- Non-RE Generation 4.47%

RE Generation

RE output has three key limitations:

- ✔ ✔ **Variability:** varies from moment to moment, creating a need for balancing services on various time scales.
- ✔ ✔ **Uncertainty:** cannot be predicted with any certainty in advance.
- ✔ ✔ **Concentration:** is concentrated during a limited number of hours of the year.

Need for Flexible Power



Case I (0S+0W)
Net Load

Case II (34S+38W)
Net Load shape is relatively flat.

Case III (100S+60W)
Net Load drops by several thousand megawatts during Peak Solar production hours.

Combination of increased load in the evening hours and the reduction in solar output around sunset creates a very significant Upward Ramp.

Road Map for Flexible Power

A Committee was constituted in CEA under the Chairmanship of Chief Engineer, TPRM Div. in January 2018 to finalize:

- The amount of Flexible Power required for integration of 175GW renewable power in year 2021-22.
- A roadmap for Flexible Operation of Thermal, Gas and Hydro Power Stations to facilitate integration of RE.
- Methodology for selecting thermal units for optimum flexible operation.

The report was completed in January 2019. Some of the key findings of the report are discussed in the following presentation.

Net Demand Prediction, 2021-22

To forecast the hourly generation from all type of resources for each day of the year 2021-22, data was collected from CEA, POSOCO and MNRE.

- **Solar, Wind, Nuclear, Hydro & Gas**: The generation is predicted on the basis of their past generation trend and the capacity planned for the year 2021-22.
- **Small Hydro, Biomass**: Since no reliable generation data is available for these small renewable sources, Small Hydro is taken as 1000MW and Biomass as 2000 MW as constant values.
- **Demand**: The National Electricity Demand for the year 2021-22 has been taken from 19th Electrical Power Survey conducted by CEA.
- **Coal**: The hourly generation required from the coal is the hourly demand less by hourly generation from all other resources than coal.

Demand & Generation (MW) 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	

Minimum Thermal Load, MTL

Month wise MTL for the year 2021/22 is as follows:

Critical Day	Maximum Demand (MW)	Max RES (W+S) (MW)	Min. Thermal Generation (MW)	Max. Thermal Generation (MW)	MTL
19 April	1,94,604	81,274	65,863	1,46,917	41.23%
29 May	1,95,640	90,339	59,368	1,38,550	39.41%
25 June	1,97,881	1,05,715	40,589	1,24,800	29.91%
27 July	1,90,480	1,08,082	32,665	1,16,769	25.73%
15 August	1,89,474	91,355	37,897	1,19,009	29.29%
1 September	2,01,308	72,885	72,037	1,39,203	47.60%
18 October	2,05,652	58,364	98,926	1,56,765	58.04%
16 November	1,93,583	68,442	85,361	1,51,659	51.77%
29 December	1,97,112	82,185	82,861	1,50,421	50.67%
27 January	1,98,222	75,991	83,623	1,50,931	50.96%
4 February	2,01,622	82,015	81,150	1,49,265	50.01%
13 March	1,85,585	74,684	73,474	1,40,192	48.21%

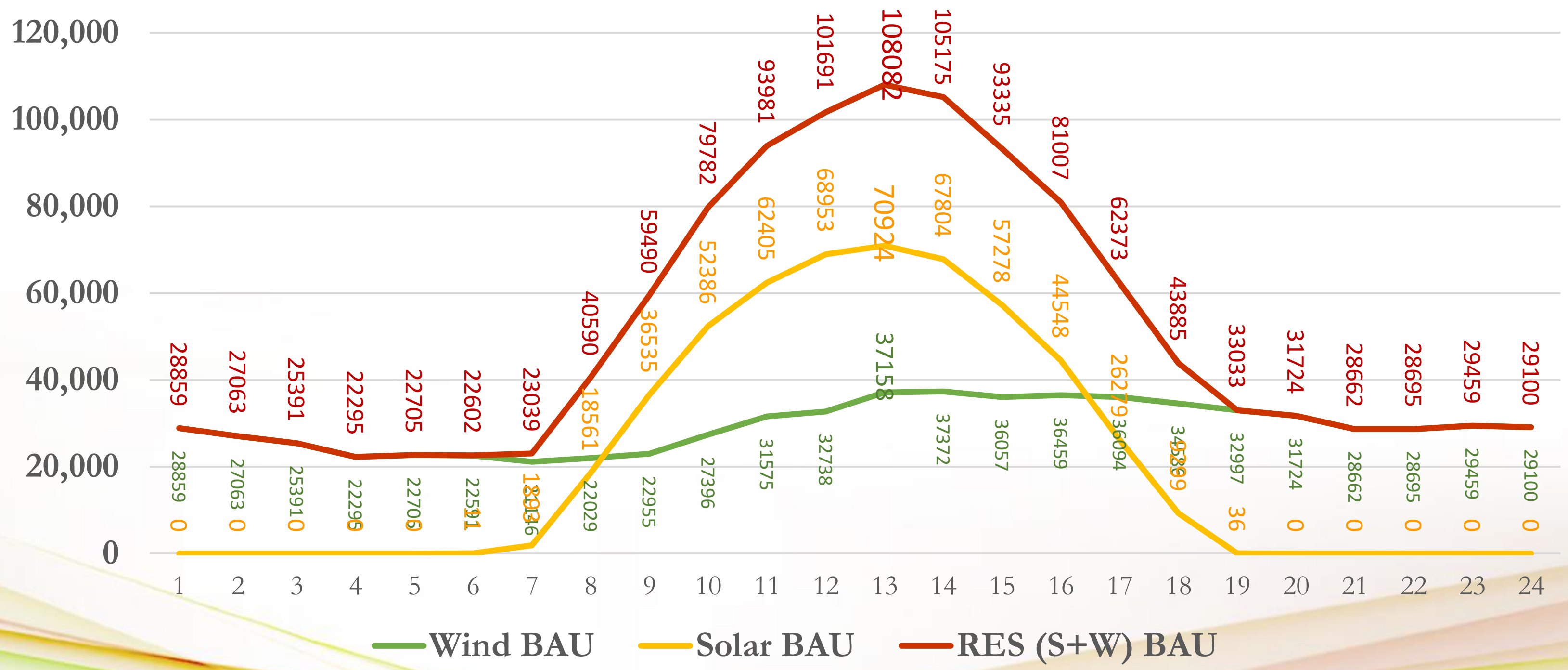
MTL on Significant Days

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

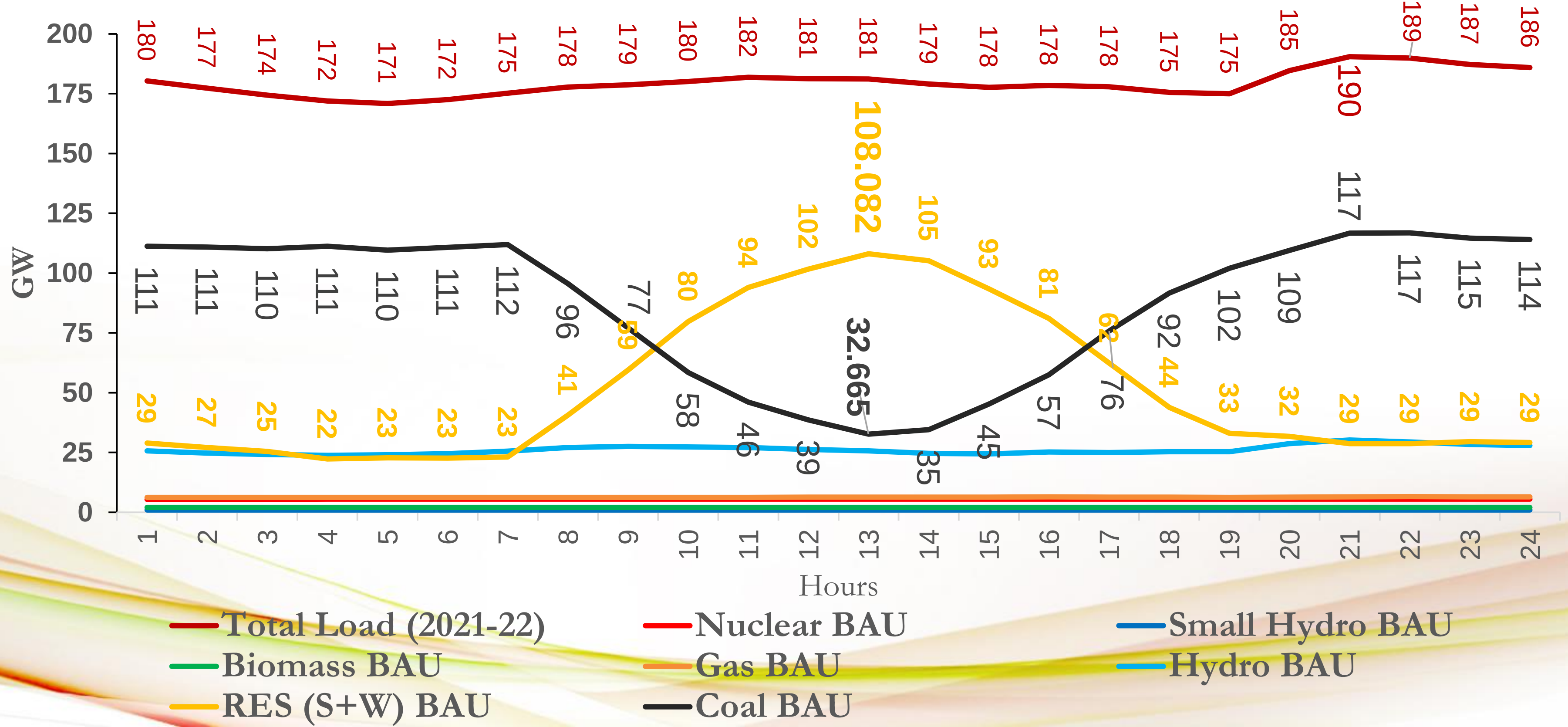
Most Critical Day for Renewable Integration

Most Critical Day	:	27th July, 2021
Renewable Power	:	108 GW
Peak Thermal ex-bus/gross cap.	:	116.7 GW / 139.5 GW
Min. Thermal ex-bus/gross cap.	:	32.6 GW / 35.9 GW
Average MTL	:	25.7%
Flexible Power Required	:	**84 GW**

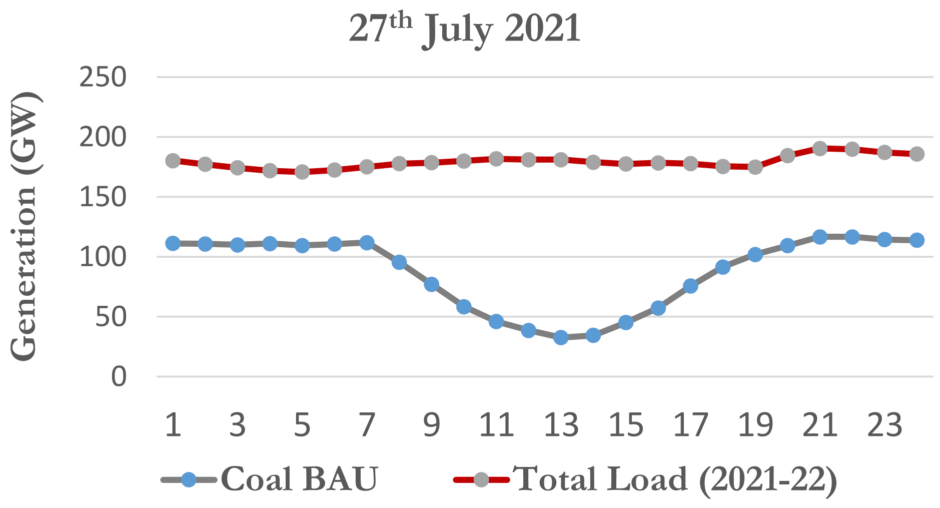
Solar & Wind Generation on 27th July, 2021



Demand & Generation on 27th July, 2021



Ramp Rate - Requirement



Ramp Rate on MTL day:

- 310 MW/min. at 0900 hrs.
+ 305 MW/min. at 1600 hrs.

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

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

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

Coordinated Effort

- It is clear that BAU generation from fuel sources other than coal will put undue pressure on Coal-Fired Units to flex as low as 26%, for which they are not designed.
- It is widely accepted that operation of Coal-Fired units at such low loads is not only financially unviable but also technically not feasible considering Indian coal.
- Hence, the Minimum Thermal Load on coal units should not go below 35% in worst-case scenario in Indian conditions.
- This calls for coordinated effort from all fuel sources to provide Flexible Power in the Grid.

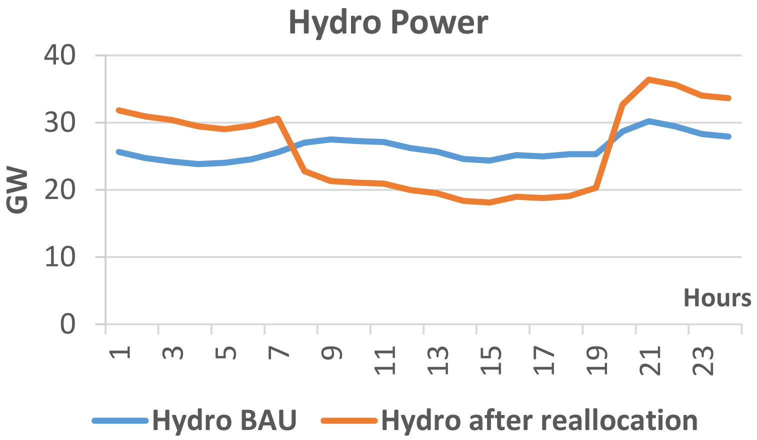
Coordinated Effort

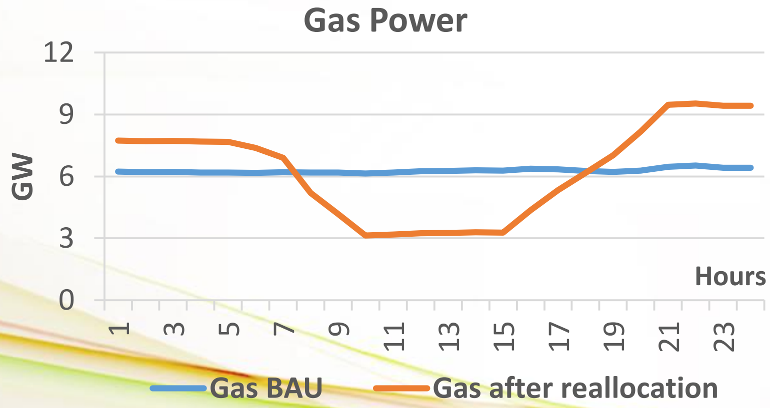
Step I: Hydro & Gas Reallocation

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

Step-I: Hydro, Pump Storage & Gas Flexing

- **Additional 6200MW Hydro Gen. flexing,** includes 4785MW existing & 1205MW under construction Pump Storage.





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

MTL: 25.7% → 35.8%

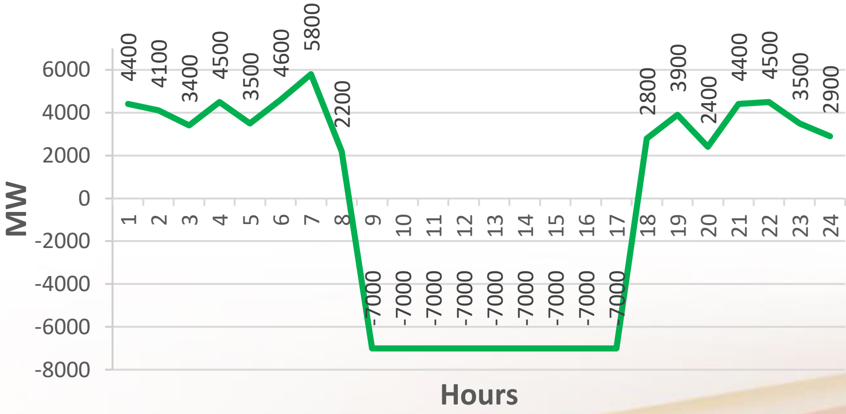
Step-II: Two shift Operation of Thermal Units & Battery/Pump Storage

a) Two shift Operation of Thermal Units

- 5GW capacity out of total available 10GW capacity of unit size less than 151MW and 25 year old are used for two shift operation.

b) Pump/Battery Storage/Both

- 7GW capacity of Pump/Battery storage is proposed to be used.



MTL: 35.8% → 45.8%

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

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 HV Industrial Consumers,
4. Supply of Electricity to Agriculture Sector by Dedicated Feeders,
   - Agricultural Consumption = 173,185 MU
   - Agricultural Consumption = 17.30%
   - Connected Load = 108,834,529 kW
   - No. of Consumers = 20,918,824

   Load shifted from Night hours to Peak Solar Gen. hour will improve 2% MTL.
5. Charging of Electric Vehicle when Solar Power is available will also improve MTL.

Flexible Operation of Thermal Units

Selection of Thermal Units

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. Supercritical/Sub-critical
8. Size of Unit

Categorization of Units

	Category	Capacity Range	Total Capacity	No. of Units
X	**Low Flexible**	660 to 800 MW	68,160	98
Y	**Flexible**	490 to 600 MW	70,770	133
Z	**Very Flexible**	195 to 360 MW	67,640	285
TSO	**Two Shift Operation**	< 151 MW	10,564	110
	Total		217,134	626

Thermal Scheduling for 27th July, 2021

- Peak Thermal Ex-Bus/Gross Capacity required **: 116.7GW/139.5GW**
- Considering Step 1 & 2
  Peak Thermal Ex-Bus/Gross Capacity required **: 98GW/117GW**

1	2	3	4	5	6
Category	Evening Load on each category (MW)	No. of Units	Average MTL of each category	ECR range of the category	MTL range of the category
Low Flexible (X)	52,380	75	50.00%	0.84 to 2.38	45% to 55%
Flexible (Y)	41,890	78	44.00%	1.20 to 2.36	40% to 50%
Very Flexible (Z)	23,280	90	40.00%	1.10 to 2.30	35% to 45%
Total	117,550	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 category.

Flexibility Test

- As per CEA report (Jan 2019), around 67,640MW (31%) of thermal capacity is identified for operation in high degree of flexible mode while 70,770MW (32.59%) of the capacity is identified for operation in moderately flexible mode.
- At least one third capacity needs to be tested, measures implemented and made ready for high degree of flexible operation in the event of 175GW RE addition in the year 2021-22.
- The identified units shall have to undergo the tests runs to ascertain their capability, do gap analysis and carry modifications, if required any.
- So far, 5 thermal power units of State/Central utilities have undergone the pilot test/pretest studies to validate their flexing capabilities and many more are in the pipeline.

Intent of Tests

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 Thermal 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.

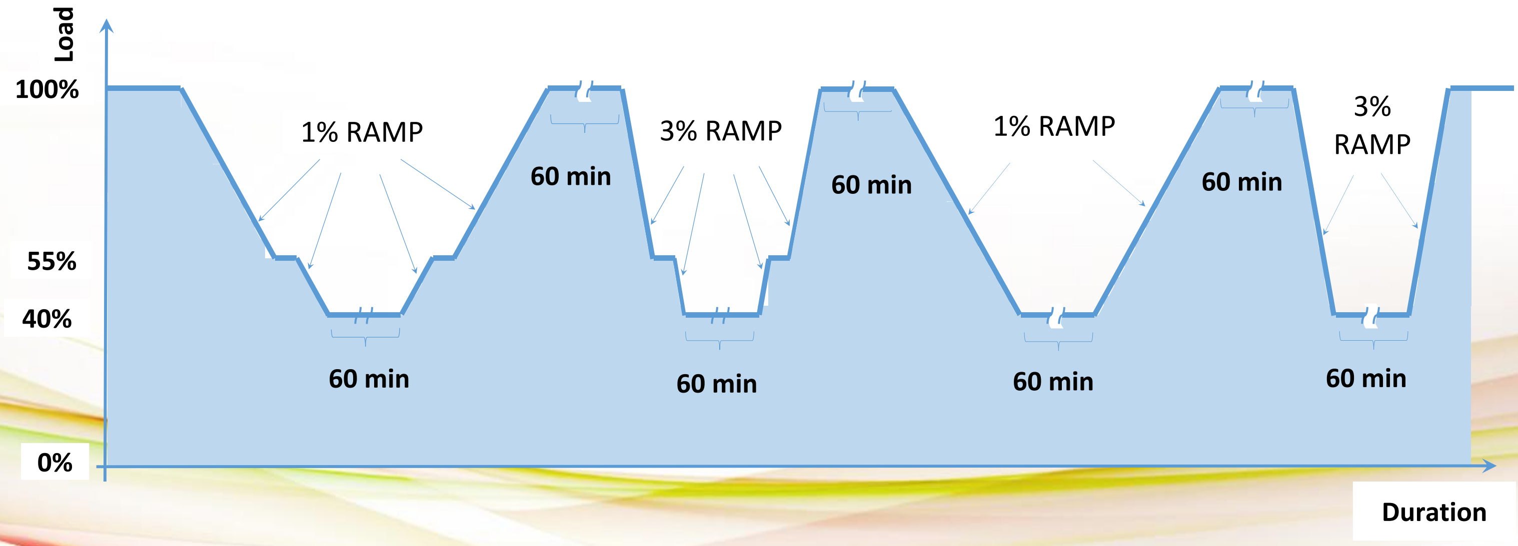
iii. **The final goal is to:**
- Check control system and evaluation of aging of equipment.
- Identifying the process limitations/restrictions (thermal, mechanical & operational) during the minimum load operation.
- Identification of retrofits required and possible for adoption in the plant.

List of Tests

i. Minimum Load Test at 55% Rated Capacity
ii. Minimum Load Test at 40% Rated Capacity
iii. Ramp Test (Up/Down) 1%/min
iv. Ramp Test (Up/Down) 3%/min

Test Sequence

The tests are conducted in the order shown below :



Pretest Requirements/Test Preparation

- Discussion with plant operational team for experience sharing regarding unit & equipment performance and operation at various load conditions.
- Coordination with RPC for scheduling.
- Modification of control logics for test runs, if required.
- Historian configuration of select operating parameters.
- Plant inspection and condition recording before and after tests.
- Healthiness and operational availability of all equipment & auxiliaries, mea suring instruments & devices.
- Selection of mill combination & other auxiliaries based on operational team feedback apart from mill availability and coal quality.

Test Preparation (contd.)

- Sequence of tests given is preferable but it may vary based on unit load, load schedules available and unit performance.
- Unit will be operated preferably in auto mode and can be taken in manual mode during ramping cycles & low load operation.
- Procedure given for each of the test may be required to be adjusted according to unit operation and response during the field trials.
- Tests may be stopped in between in view of unit safety and to avoid any instability in the unit operation.
- Coal and ash samples shall be collected during the tests.

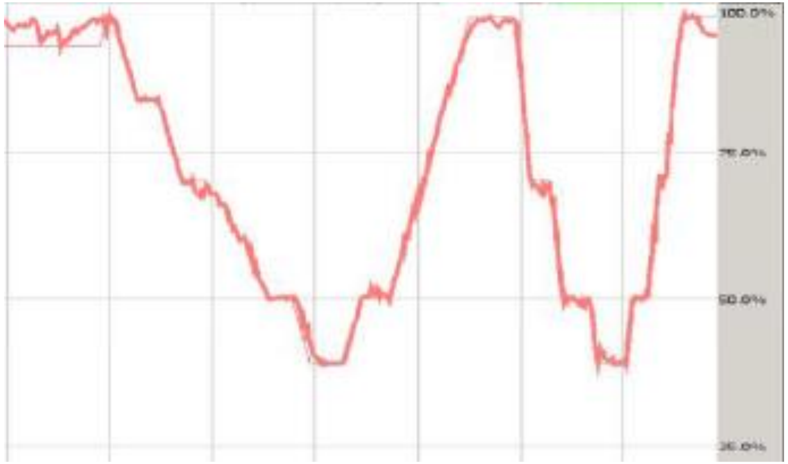
Tests/Studies Conducted

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

Dadri TPS

Owner/Location: NTPC Ltd./Dist. Gautambudh Nagar, UP

Test Date	:	21 to 22-06-2018
Unit	:	6
Capacity	:	500 MW



Following tests were conducted :

Test	Target	Achieved
Minimum Load Test at 40%	200 MW	200 MW
Ramp Up/Down Test	1%/ min	~0.86%/min/ ~0.50%/min
Ramp Up/Down Test	3%/ min	~1.50%/min

Agency : IGEF/Siemens

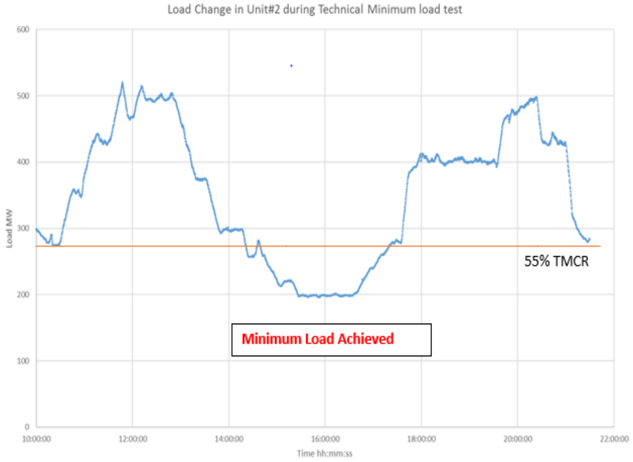
Mouda TPS

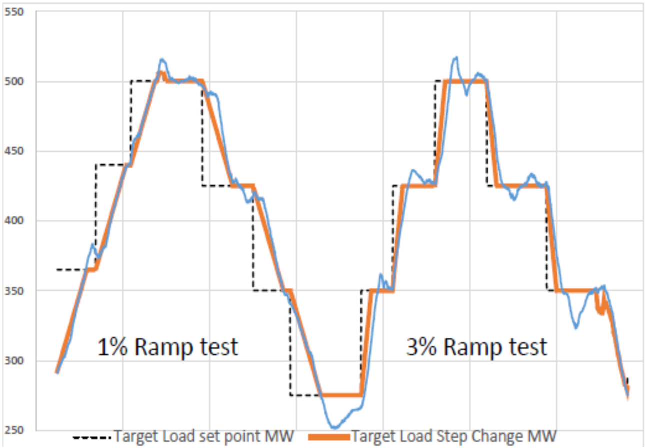
Owner/Location : NTPC Ltd., Dist. Nagpur, Maharashtra

Test Date : 29-09-2019

Unit No. : 2

Capacity : 500 MW





Following tests were conducted :

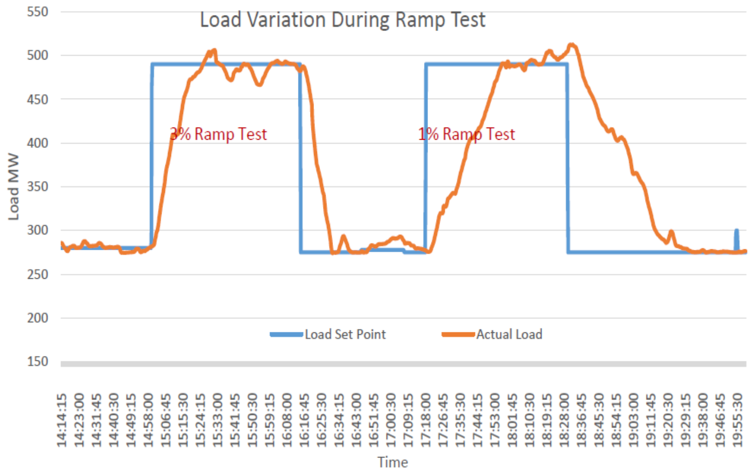
Test	Target	Achieved
Minimum Load Test at 40%	200 MW	200 MW
Ramp Test (3%)	3%/ min	~1.10%/min
Ramp Test (1%)	1%/ min	~0.55%/min

Agency : BHEL

Sagardighi TPS

Owner : WBPDCL, Musheerabad, West Bengal

Test Date	:	27-06-2019
Unit No.	:	3
Unit Capacity	:	500 MW



Following tests were conducted:

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

Agency : BHEL

Efficiency Test

Owner/Location : Mouda TPS, NTPC Ltd., Dist. Nagpur, Maharashtra

Test Date : 6th to 9th December, 2019

Unit No. : 4 & 5

Capacity : 660 MW

- Test Conducted at following loads:
  1. **100% Load**
  2. **75% Load**
  3. **55% Load**
  4. **48% Load**

Agency : TEPCO, Japan

Pretest Flexibilisation Study

- **Simulations** offer an effective tool for optimizing the plant performance and control structures as well as for assessing capabilities and limitations of plant with regard to process, materials, emissions or economics.

- Specific end application could be the optimization of controls, stress assessment in critical components and plant safety analysis in transient operation such as fast load changes.

- These studies are precursor for conducting tests runs on thermal unit to ascertain their flexibility capability.

- Such studies have been conducted by **JCOAL** for **Anpara** and **Vindhyachal**.

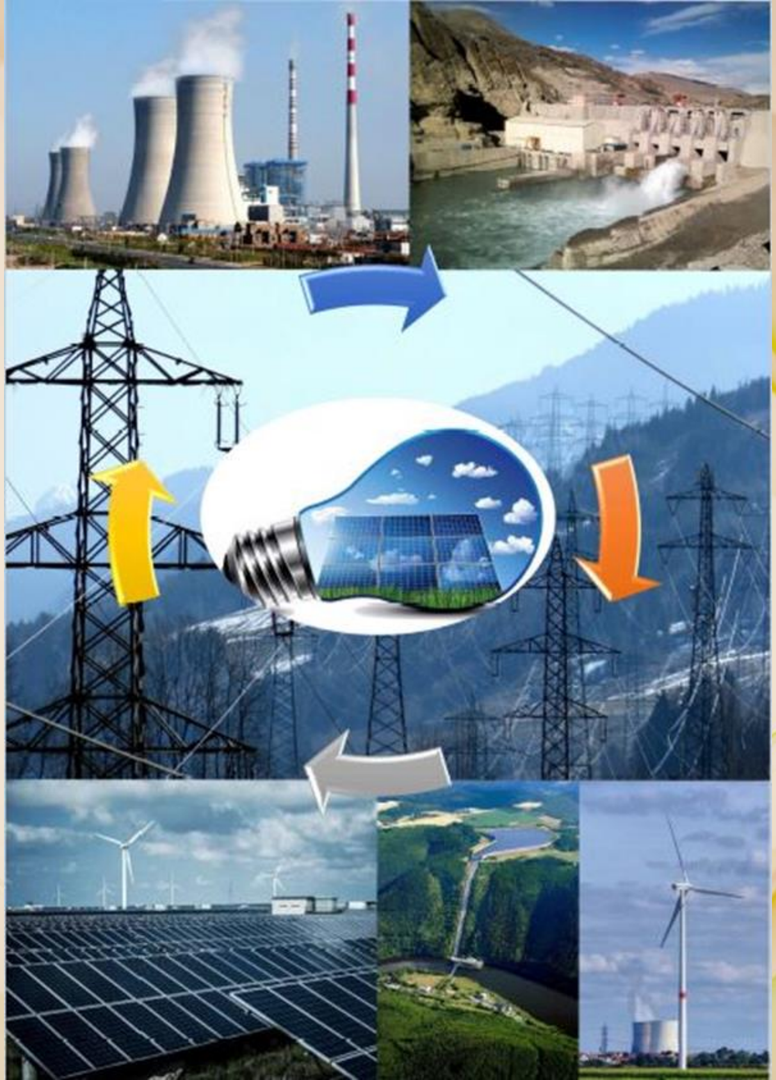
Conclusion

- Balancing shall be done at national level which will minimize the requirement of balancing power.
- 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 & under construction, shall be exclusively used for meeting the peak load or balancing the system.
- Gas power plants have better start/stop capability and need to contribute to flexible power as much as possible.
- Establishment of new pump or battery storage or combination of both at strategic locations for energy storage during high solar generation period and utilizing the same during peak demand hours or at the time of need.
- 210 MW & 500 MW units shall be operated at lower MTL than bigger size unit.

Conclusion contd.

- Among the fleet of 200MW, 500/600MW or 660/800MW thermal units, which are efficient and have low ECR, should be given preference over other units in terms of generation schedule.
- 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.
- 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 bench marked costs(compensation)+markup(incentivisation). Regulatory intervention is required.
- Capacity building of coal fired power plant operators becomes an important measure in the changing operational regime.
- Demand Side Management including measure targeted at domestic, agricultural, industrial and e-mobility sector would enable more rational consumption pattern of electricity.

Thank You



Balancing of Grid at National Level

- The potential and installed capacity of renewables vary from state to state.
- The states like Maharashtra, Tamil Nadu, Andhra Pradesh, Gujrat, Karnataka, Rajasthan have huge potential of renewables and would need large amount of flexible power.
- On the other hand, many states have small capacity of renewables and would need small amount of flexible power.
- Thus, the requirement of additional flexible power of RE rich states can easily be met from surplus 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.