

Flexible operation of Thermal Power Plant: A Bridge to Decarbonized Energy System



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(DGM, System operation)

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Grid Controller of India Limited

Indian Grid...One of the World's Largest

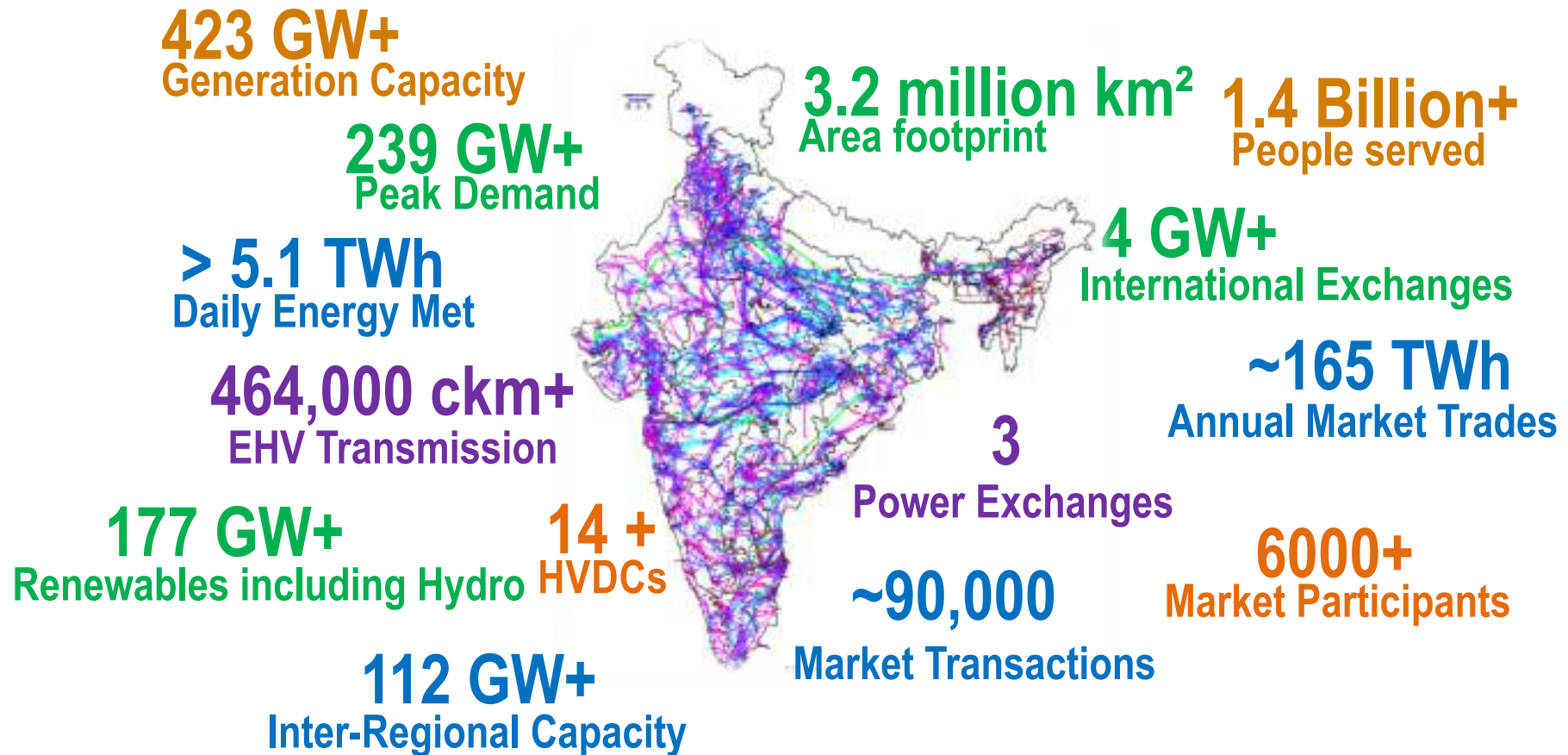


Source: GO15

- 1 national synchronous grid
- 2 electricity generation
- 3 electricity consumption
- 4 installed generation capacity
- 5 transmission system
- 6 wind generation
- 7 solar generation
- 8 hydro generation
- 9 pumped storage installed capacity

Source: IEA Key World Energy Statistics 2021 & IHA 2021 Hydro Status Report (2019 data, 2019 provisional data)

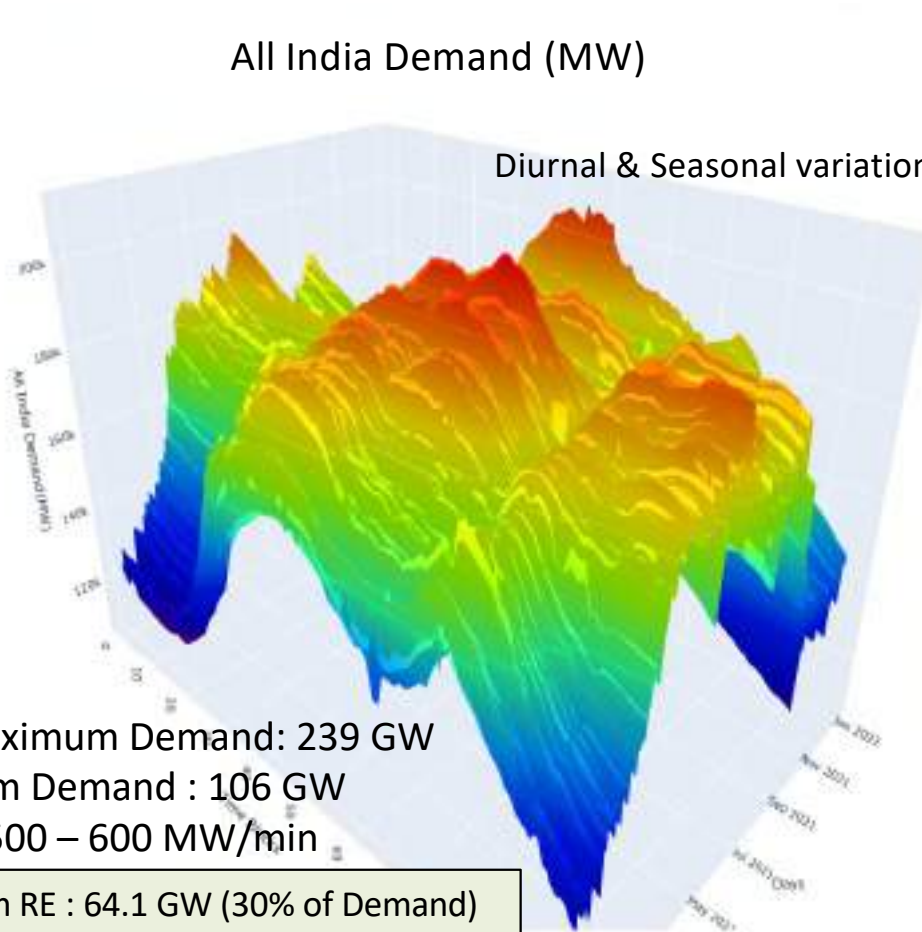
Dimensions



All India Demand & RE Generation Profile

All India Demand (MW)

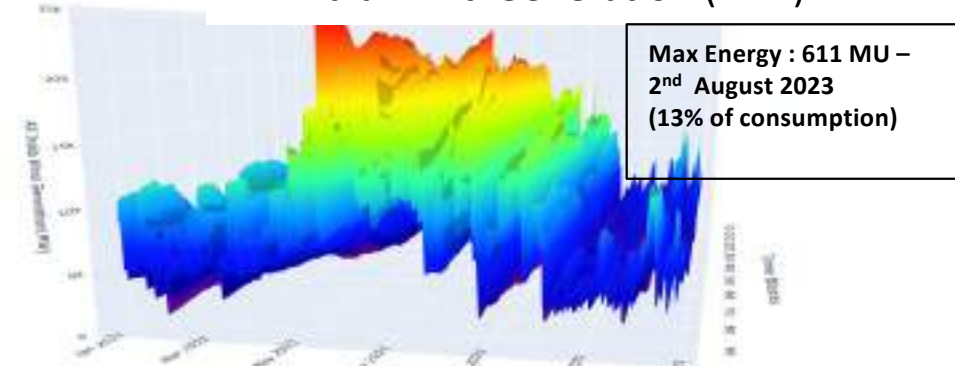
Diurnal & Seasonal variation



Peak Maximum Demand: 239 GW
Minimum Demand : 106 GW
Ramp : 500 – 600 MW/min

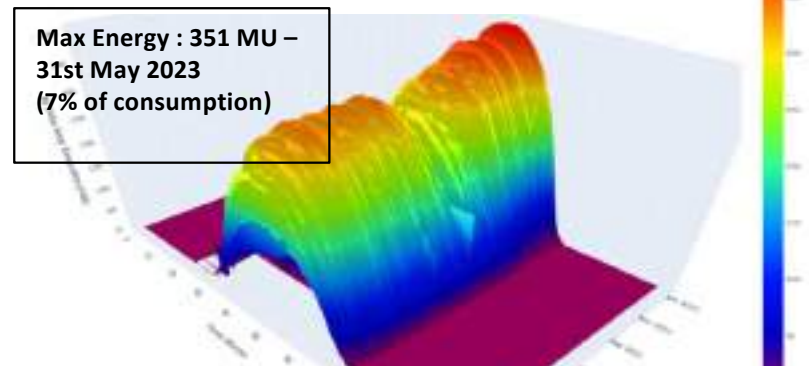
Maximum RE : 64.1 GW (30% of Demand)
@ 14-06-2023 12:00:00 PM

All India Wind Generation (MW)



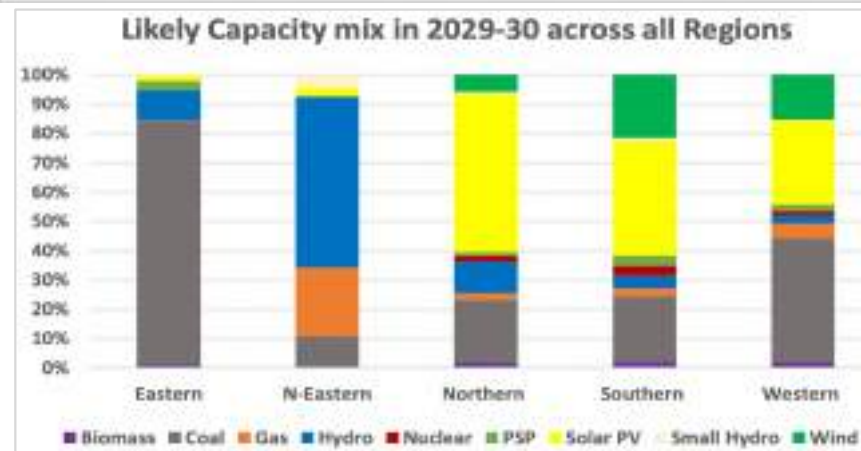
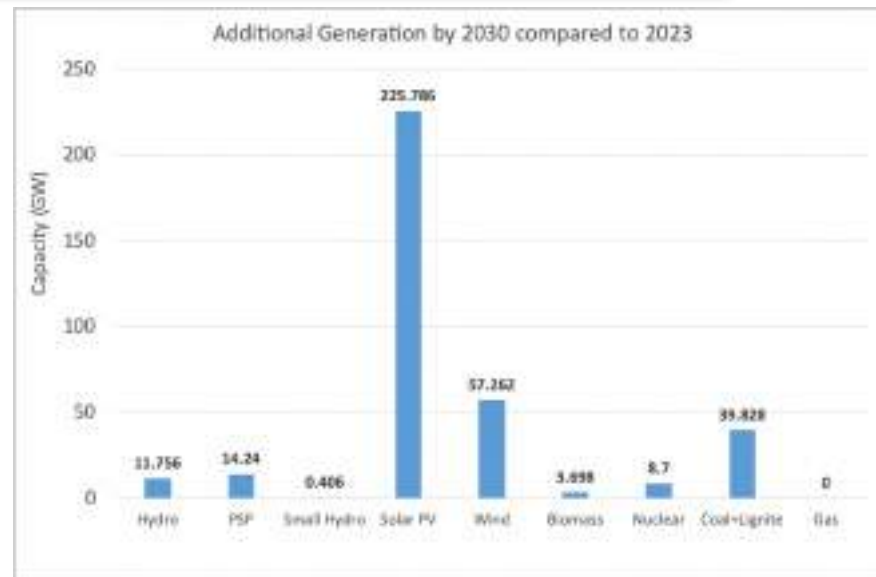
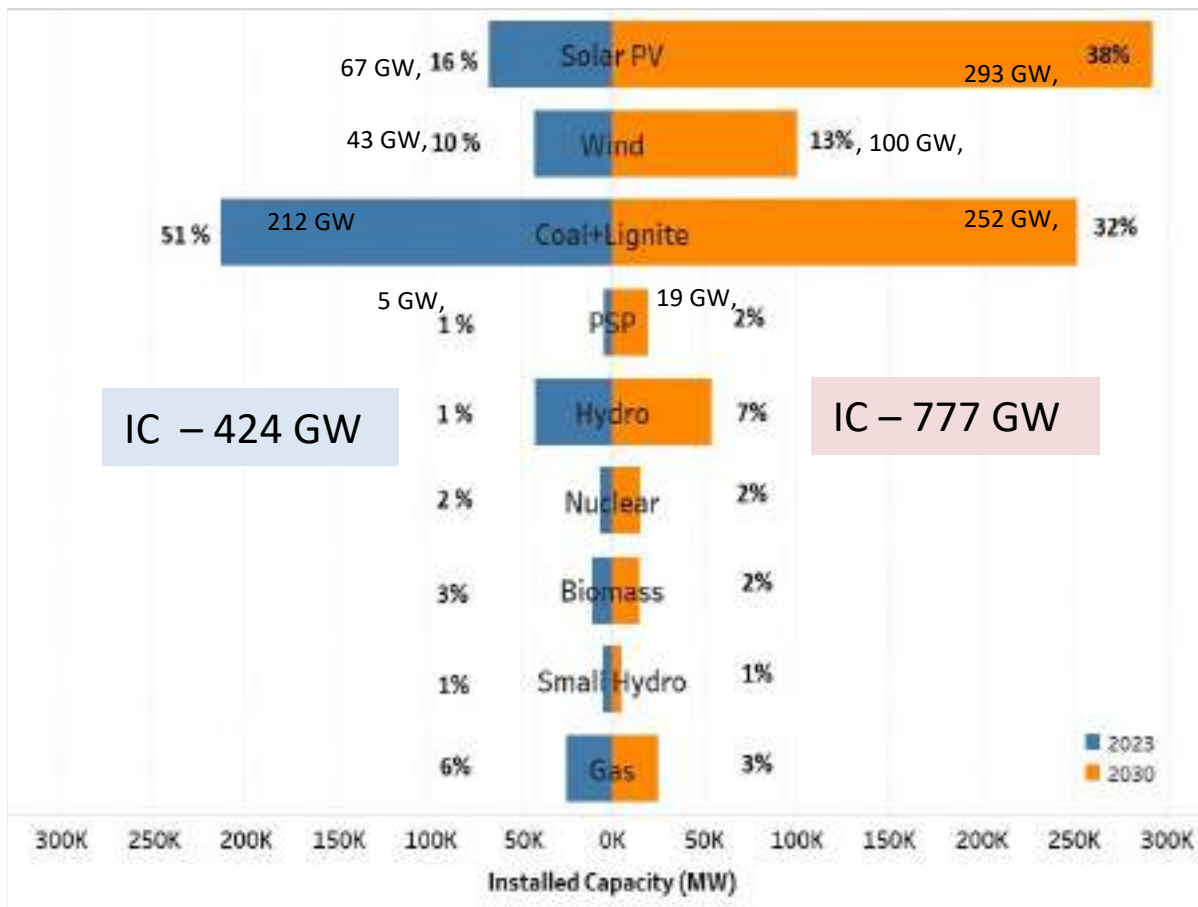
Maximum Wind : 27 GW @ 02-08-2023 15:30:00 PM (14% Penetration)

All India Solar Generation (MW)



Maximum Solar : 44.3 GW @ 13th Feb 2023 12:30 PM (22% Penetration)

All India Installed Capacity





Source : Report on Optimal Generation Capacity mix for 2029-30





Upcoming Pumped Storage : 5850 MW
 Upper Sileru : 9x150 MW
 Sharavathy : 2000 MW
 Kundah: 500 MW
 Sillahala Stage 1&2 : 2000 MW




 **Highest RE Installed Capacity in country**
 52.12 GW

Lift Irrigation – 9 GW
 TS – 7.5 GW (kaleswaram – 5.7 GW) ,
 KA – 1.3 GW , AP – 0.2 GW

Pumped Hydro Storage - 2000 MW
 Kadamparai (400 MW) in TN
 TS - N'Sgr (700 MW) & Srisaillam (900 MW) in TS

HVDC Pugalur-Thrissur
 320kV, 2000 MW, First VSC HVDC in India.

1000 MW Units
 2x1000 MW units in operation at Kudankulam

In 1902 - Shivanasamudra Generating plant
 42 MW Commissioned

SR Energy Particulars

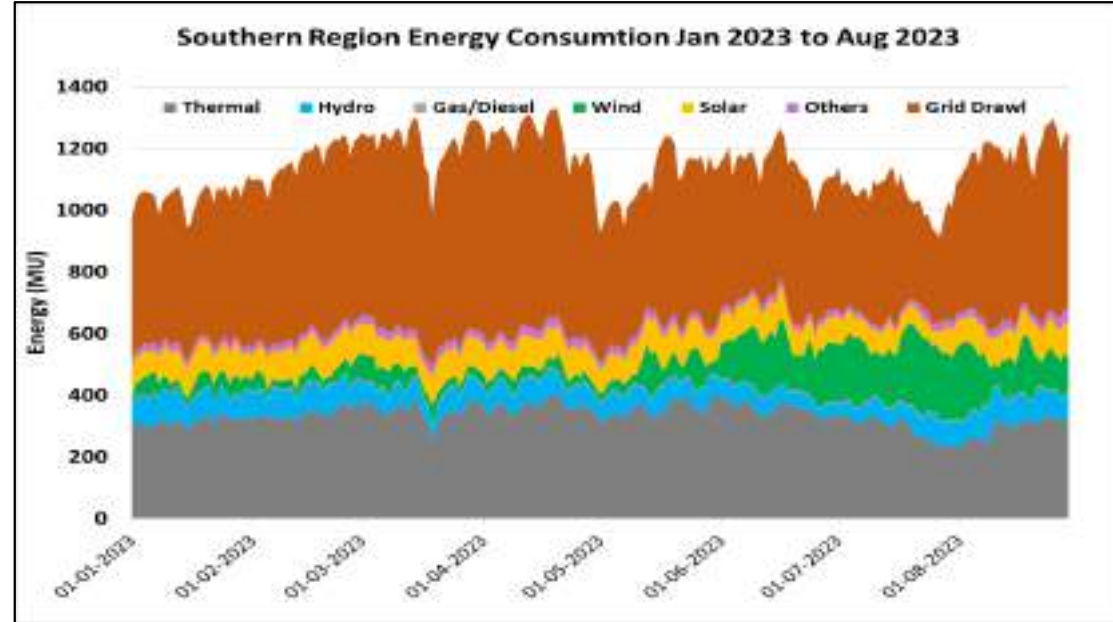
Southern Region	
IC	118 GW
PD	64337 MW
ME	1329 MU

Transmission

400 kV : 452 Nos ~ 45779 Ckm
765 kV : 22 Nos ~ 8315 Ckm

Transformation Capacity

400 kV : 330 Nos ~ 118442 MVA
765 kV : 20 Nos ~ 30000 MVA



KARNATAKA	
IC	24337 MW
PD	16950 MW
ME	309 MU
DA	190 MU

TELANGANA	
IC	12117 MW
PD	15497 MW
ME	303 MU
DA	185 MU

ANDHRA PRADESH	
IC	18389 MW
PD	12900 MW
ME	264 MU
DA	170 MU

IC – Installed Capacity
PD – Peak Demand
ME – Maximum Energy
DA – Daily Avg Consumption

2027-28 -SR PD:88 GW

PUDUCHERRY	
IC	32.5 MW
PD	512 MW
ME	11 MU
DA	7 MU

KERALA	
IC	3405 MW
PD	5024 MW
ME	103 MU
DA	69 MU

TAMIL NADU	
IC	23375 MW
PD	19387 MW
ME	415 MU
DA	282 MU

S.No	Scenario	Min Consumption (MU)	Max Consumption (MU)	Min RE Gen Day (MU)	Max RE Gen Day (MU)
1	Date	27-07-2023	19-04-2023	16-03-2023	01-08-2023
2	Thermal	225	399	356	229
3	Hydro	88	77	67	77
4	Gas/Diesel	5	6	6	6
5	Wind	228	29	22	251
6	Solar	59	97	77	83
7	Others	32	34	33	23
8	Grid Drawl	273	687	689	436
9	Consumption	911	1329	1250	1104

SR Highlights – Demand and Energy

SR statistics

2023

2022

Constituents	Max Demand Met (in MW)	Date & Time of Max Demand Met	Max Consumption (in MU)	Date of Max Consumption
Andhra Pradesh	12900	17-06-2023 13:42	264	16-06-2023
Telangana	15497	30-03-2023 11:01	303	03-03-2023
Karnataka	16950	25-08-2023 11:00	309	20-04-2023
Kerala	5024	18-04-2023 22:00	103	19-04-2023
Tamil Nadu	19387	20-04-2023 12:00	415	20-04-2023
Pondicherry	512	17-05-2023 22:45	12	18-05-2023
SR	64337	15-03-2023 12:20	1329	19-04-2023

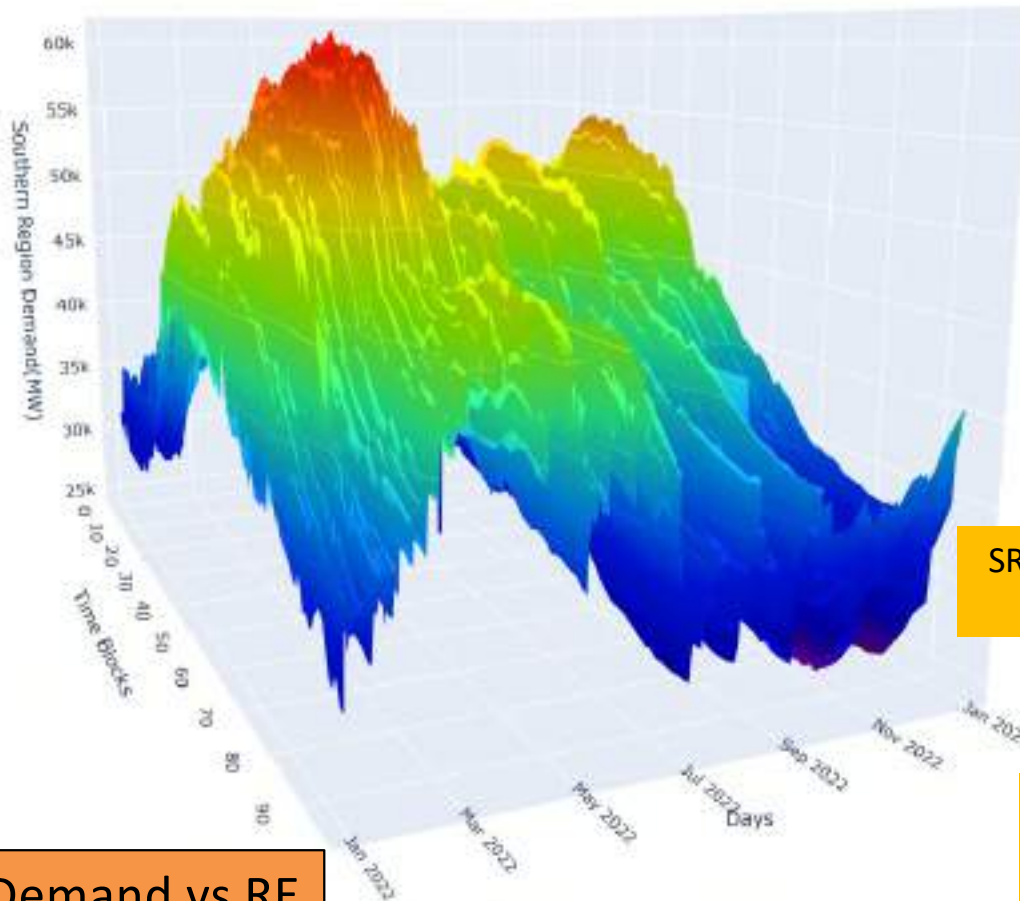
Constituents	Max Demand Met (in MW)	Date & Time of Max Demand Met	Max Consumption (in MU)	Date of Max Consumption
Andhra Pradesh	12293	08-04-2022 12:21	235	28-03-2022
Telangana	14160	29-03-2022 12:28	280	29-03-2022
Karnataka	14818	18-03-2022 11:00	241	03-05-2022
Kerala	4385	27-04-2022 21:00	93	28-04-2022
Tamil Nadu	17563	29-04-2022 14:30	388	29-04-2022
Pondicherry	482	06-05-2022 20:00	10	06-05-2022
SR	60876	01-04-2022 10:53	1252	01-04-2022

SR Peak Demand Increased by 3461 MW (5.6%)

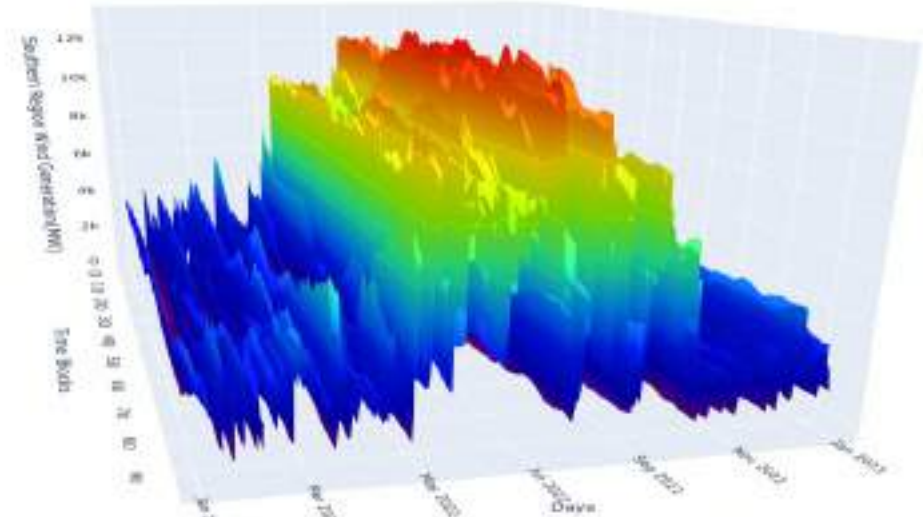
Southern Region Demand/Generation Characteristic

SR Max Demand – 64337 MW on 15th March 2023

SR Max Wind Generation – 13.85 GW MW on 1st Aug 2023

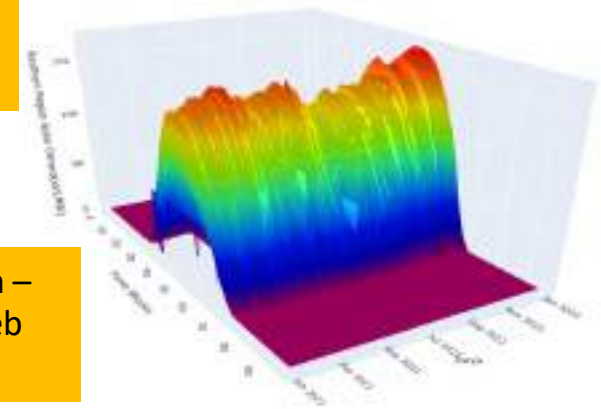


Demand vs RE

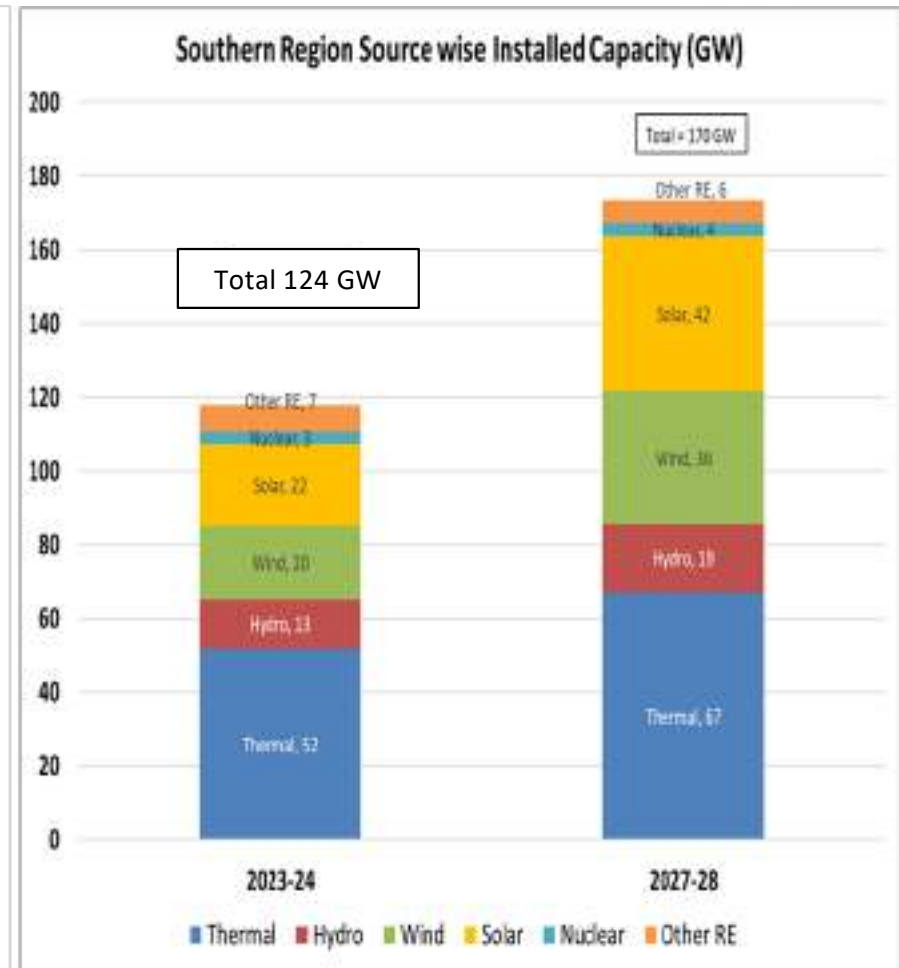
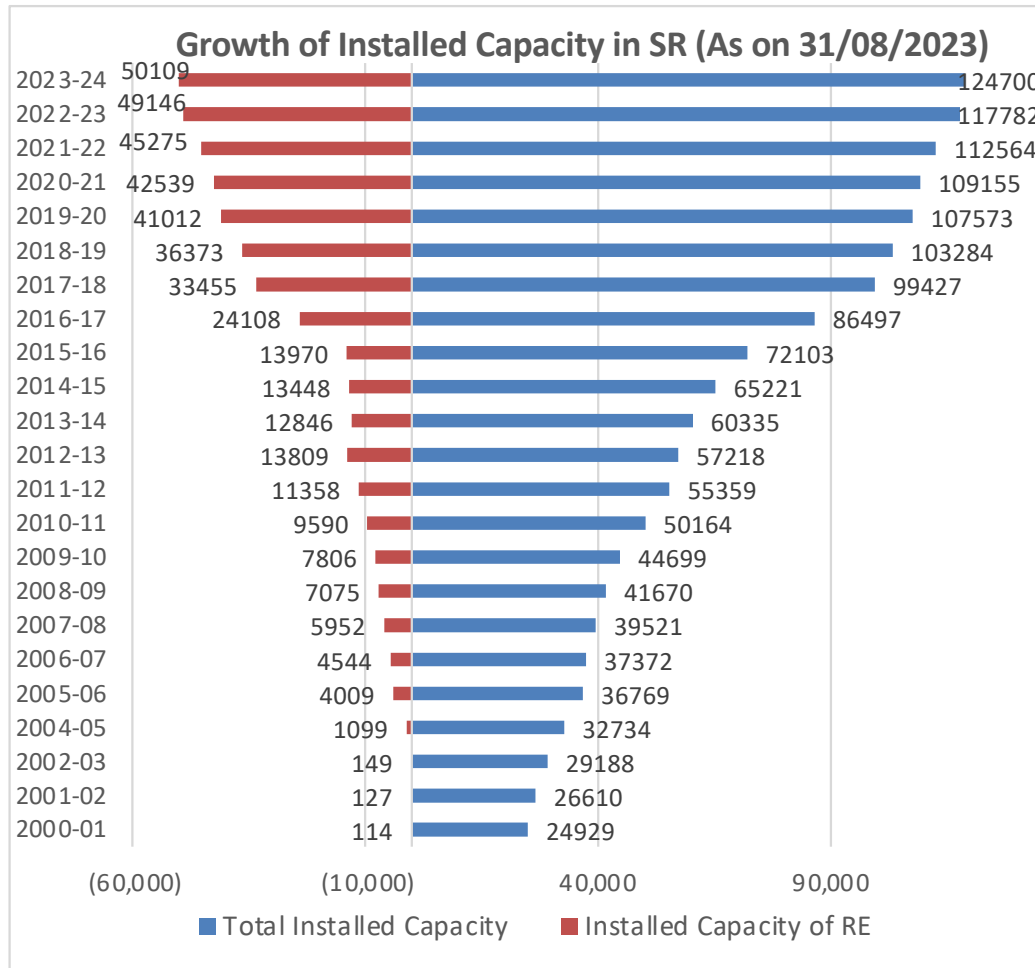


SR Max RE – 28.1 GW MW on
13th June 2023

SR Max Solar Generation –
18.5 GW MW on 13th Feb
2023



Southern Region Generation



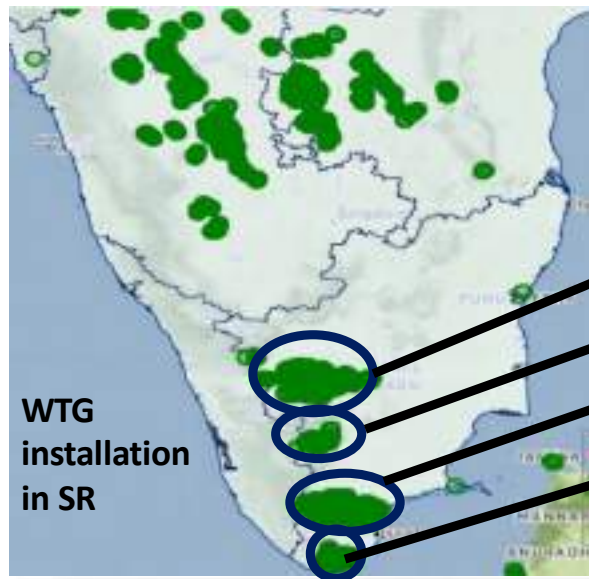
Renewable Energy in Southern Region

S.No	State	Date	Thermal	Hydro	Gas/Diesel	Wind	Solar	Net RE	Grid Drawl	Consumption	Penetration (%)
1	AP	12-07-2022	70	4	3	78	9	86	-6	159	59%
2	KA	22-05-2022	27	26	0	59	27	86	3	150	65%
3	TN	07-08-2022	21	23	5	110	23	133	81	269	49%
4	TS	23-05-2022	98	1	0	2	25	27	48	175	15%
5	SR	14-07-2022	168	117	8	263	61	323	236	874	37%



Plant	Total Capacity	COD	Control Area
NTPC Simhadri	25 MW	10 MW - 30.06.2021	SRLDC
		15 MW - 21.08.2021	
NTPC Ramagundam	100 MW	17.5 MW - 28.10.2021	SRLDC
		20 MW - 22.12.2021	
		42.5 MW - 24.03.2022	
NTPC Kayamkulam	92 MW	20 MW - 01.07.2022	Kerala SLDC
		22 MW - 31.03.2022	
		35 MW - 19.05.2022	
		35 MW - 24.06.2022	

Annual CUF	
1.	RE - 19.82 %
2.	Solar - 20.31
3.	Wind - 19.31

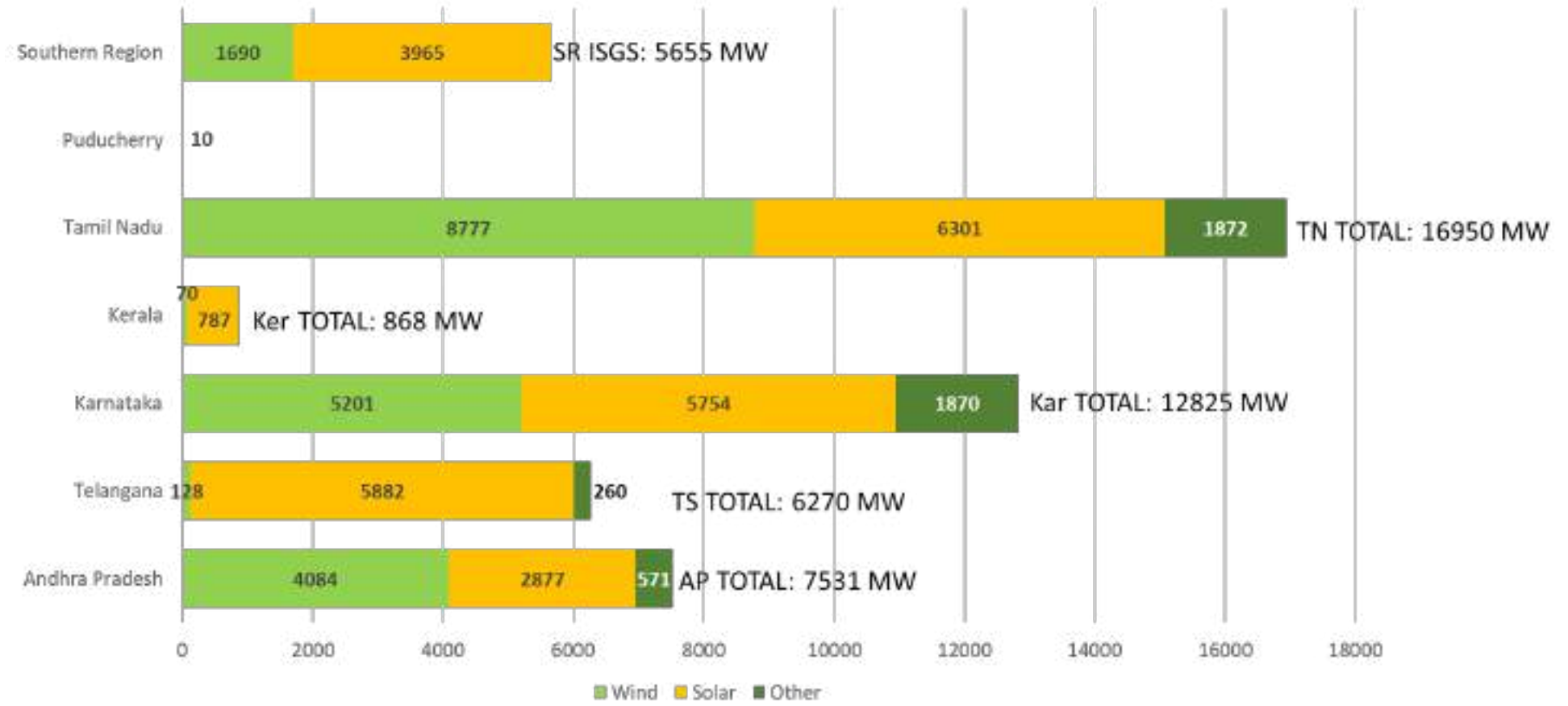


1986: 55kW, 90 kW - First RE Plant Commissioned at Muppandal, Iyanaruthu - TN

Name of the PASS	WEG installed capacity (MW)
Palakkad	3395.96
Cumbum	596.29
Sengottai	2843.96
Aralvaimozhi	1845.5
Total	8685.31

Renewable Energy in Southern Region

RE BREAK-UP IN SOUTHERN REGION AS ON 31/07/2023



Flexibility needed for RE integration

India's commitment at COP26 at Paris :

- ✓ Achieve the reduction in CO2 emission by 1 billion ton by 2030.
- ✓ Meet 50 per cent of the energy requirements from renewable energy by 2030
- ✓ 500 GW Non-fossil energy capacity by 2030.

- ✓ Integration of such massive amounts of RE which are intermittent and distributed in the power system pose serious challenges to grid operations.

- ✓ Requirement of high flexibility with high levels of renewable energy integration.
- ✓ Operation of coal based plants in a more flexible mode & RE with storage is the need of hour in the wake of huge intermittency and variability of renewable based generation

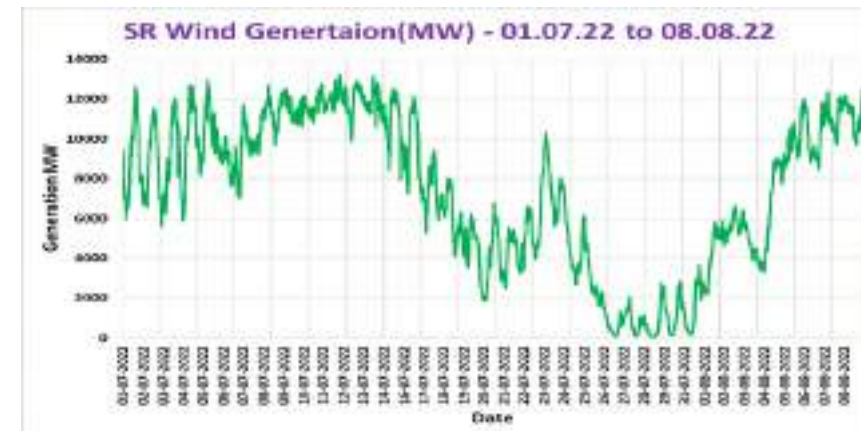
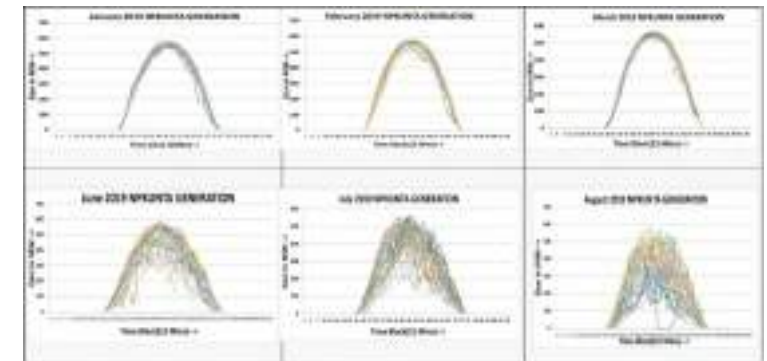
Flexibility depends on system-specific characteristics, including:

- ✓ Current and planned mix of generation technologies
- ✓ Flexibility in existing generation sources
- ✓ Interconnections with neighbouring power systems
- ✓ Hourly, daily, and seasonal profile of electricity demand and RE.

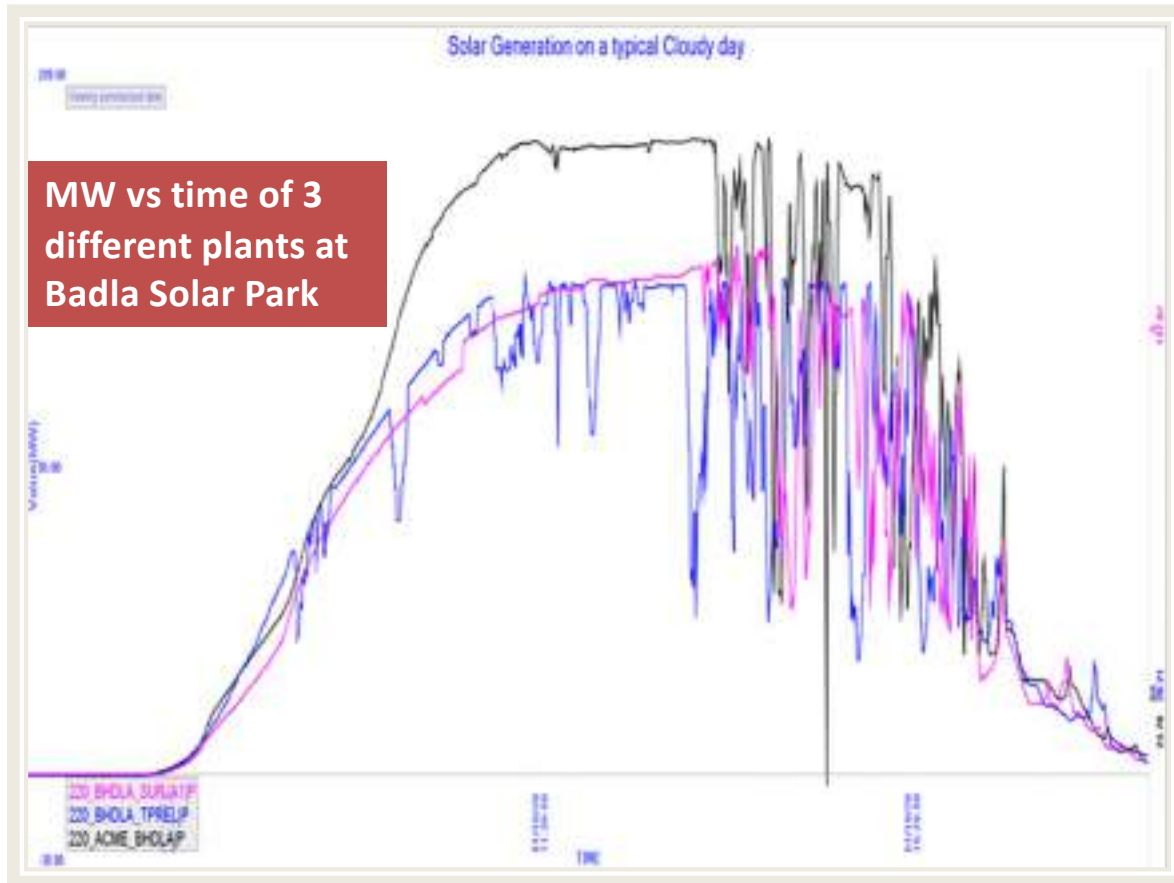
Grid Planning and Operation Considerations

RE is variable, uncertain and nonsynchronous, raising new considerations for grid planning and operations.

1. System balancing requires more flexibility.
2. The need for operating reserves can increase.
3. More transmission and changes in planning are needed.
4. Existing Conventional generation need to be more flexible.
5. Voltage control and inertia response comes at an added cost.



Impact of Cloud Cover Bhadla Solar Park



- Largest solar park in the world
- Spread over a total area of 5,700 hectares (14,000 acres) in Bhadla, Rajasthan, India.
- Total capacity of 2245 MW.

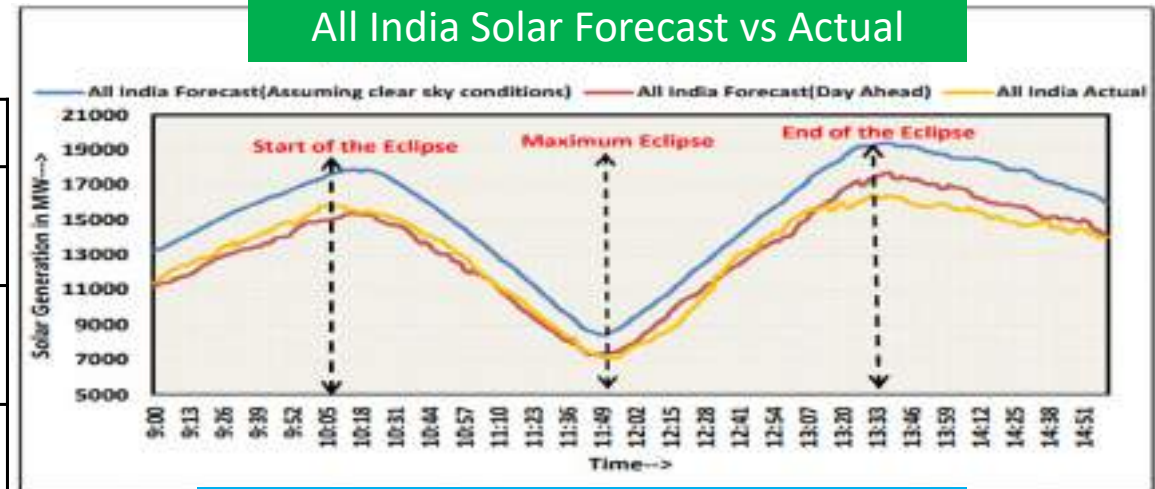
Solar Eclipse on 21st June 2020

- Solar eclipse - 0956 to 1429 hrs

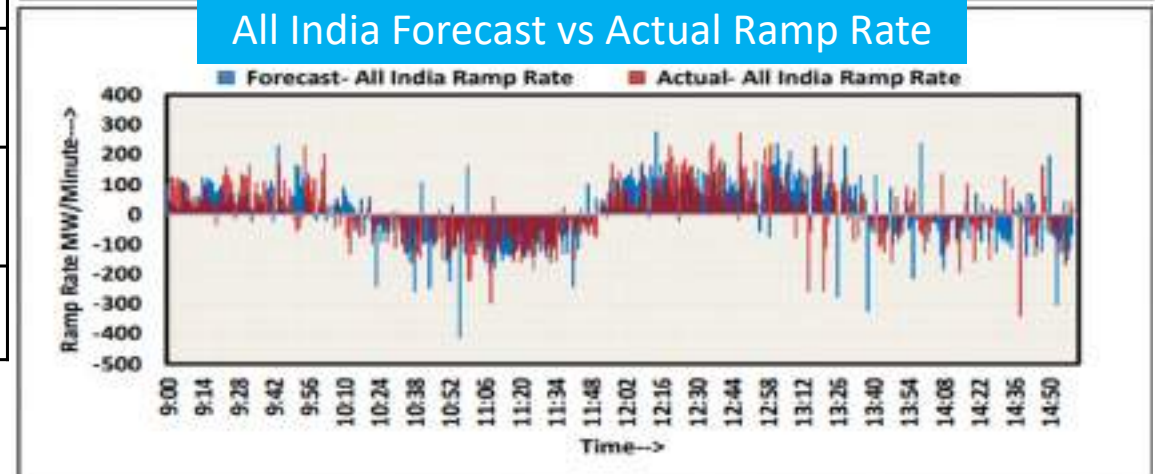
Description	Expected	Actual
Solar Generation Reduction	11.9GW	11.1GW
Avg Ramp Down rate/min	102 MW/Min	84 MW/Min
Avg Ramp Up rate/min	104 MW/Min	96 MW/Min
Thermal generation Variation	1600 MW	
Hydro generation Variation	7000 MW	
Gas generation variation	1050 MW	

- Other solar eclipse faced on 26.12.2019

All India Solar Forecast vs Actual

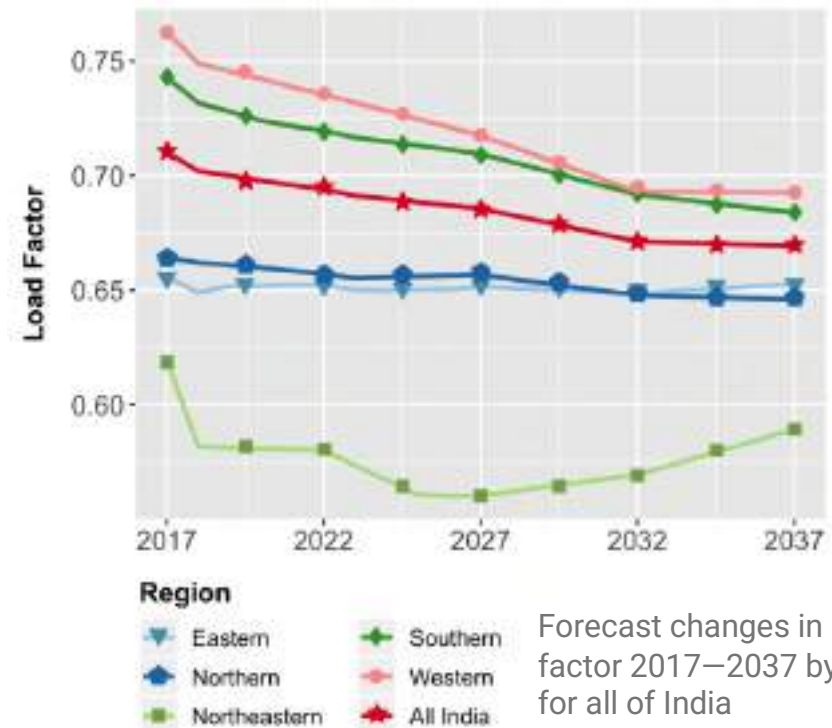
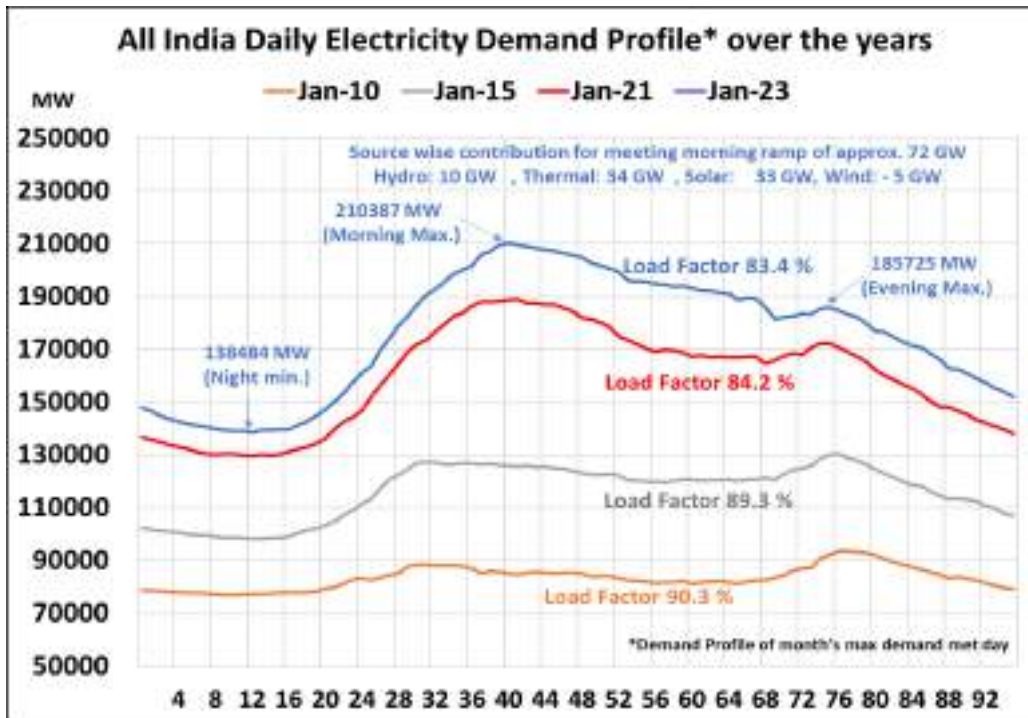


All India Forecast vs Actual Ramp Rate



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Changing load factor

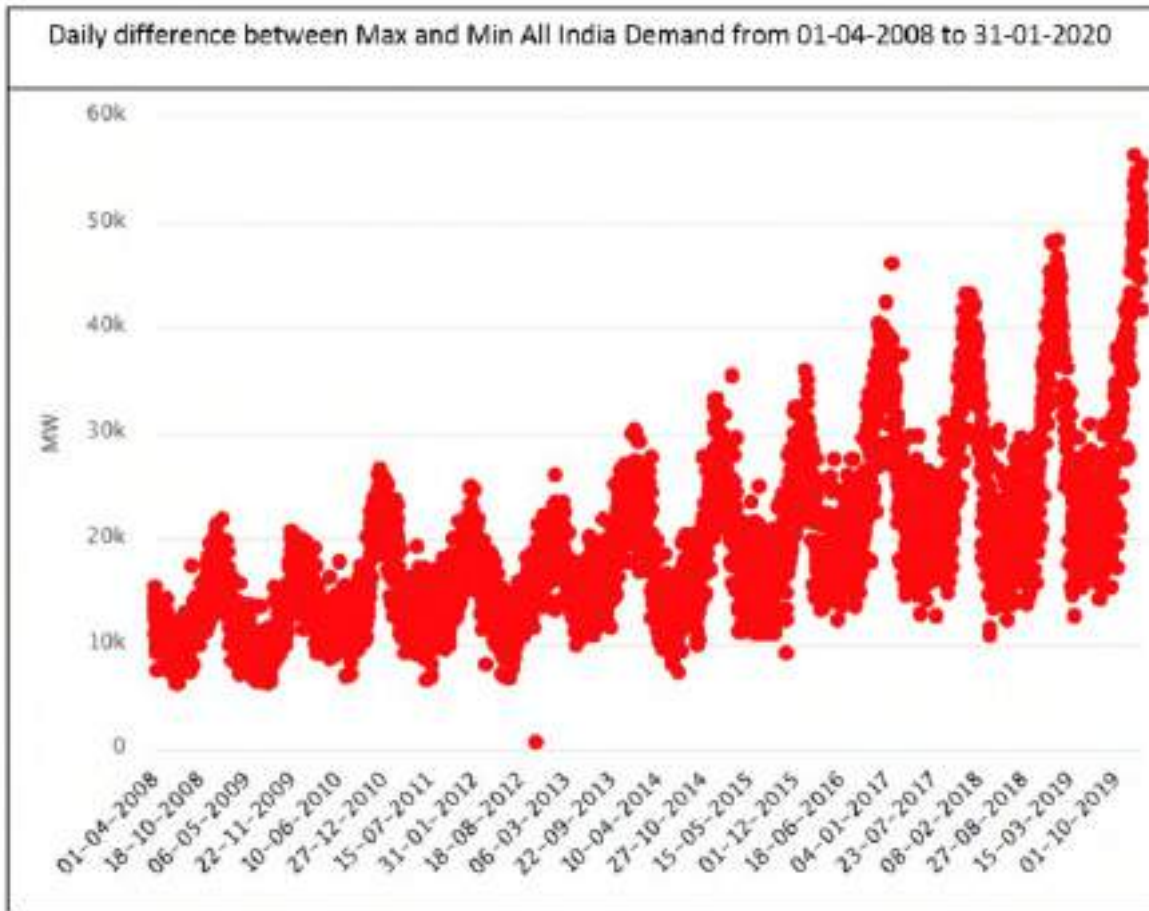


Forecast changes in load factor 2017–2037 by region & for all of India
Source: CEA 2018

- ✓ Decline in Load factor in India over the years
- ✓ Indicate growing need for flexible resources

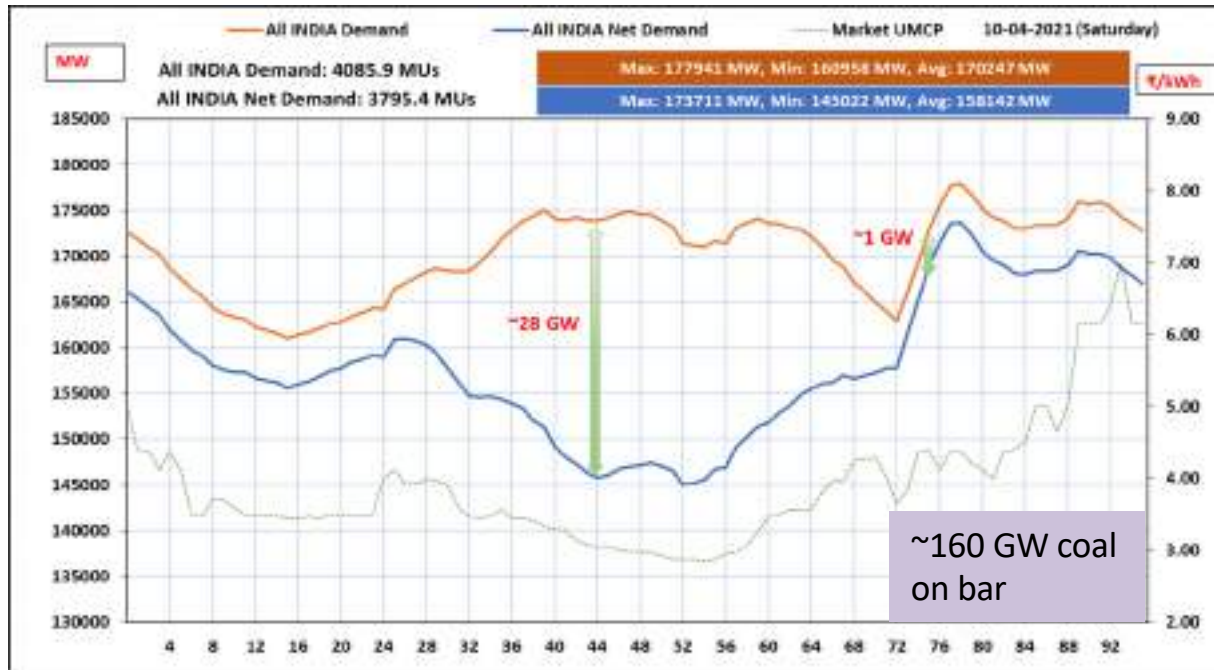
- ✓ Total load factor will decline by 4% by 2037
- ✓ WR & SR will see decline of 7% & 6% from 2020 to 20237

Increasing variation in demand



- ✓ Daily load profile becoming more variable
- ✓ Large variation between peak & off-peak demand
- ✓ Requirement of load following or peak demand management services

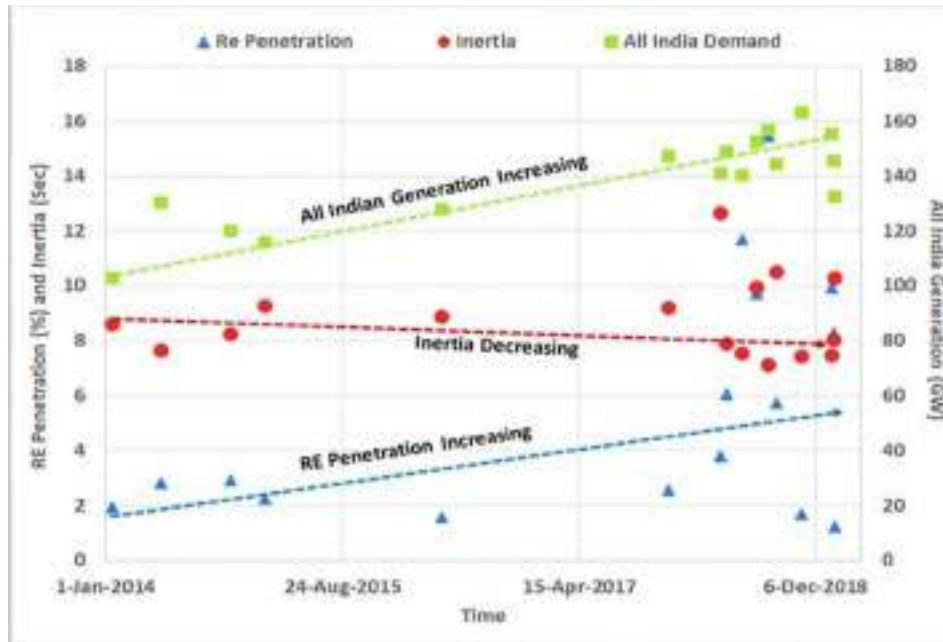
The Duck belly is increasing !



✓ Reduction in Pmin thermal units along could facilitate integration of higher Solar capacity

✓ Increase in flexibility needs & ramping requirement of the rest of the generation fleet.

System Inertia



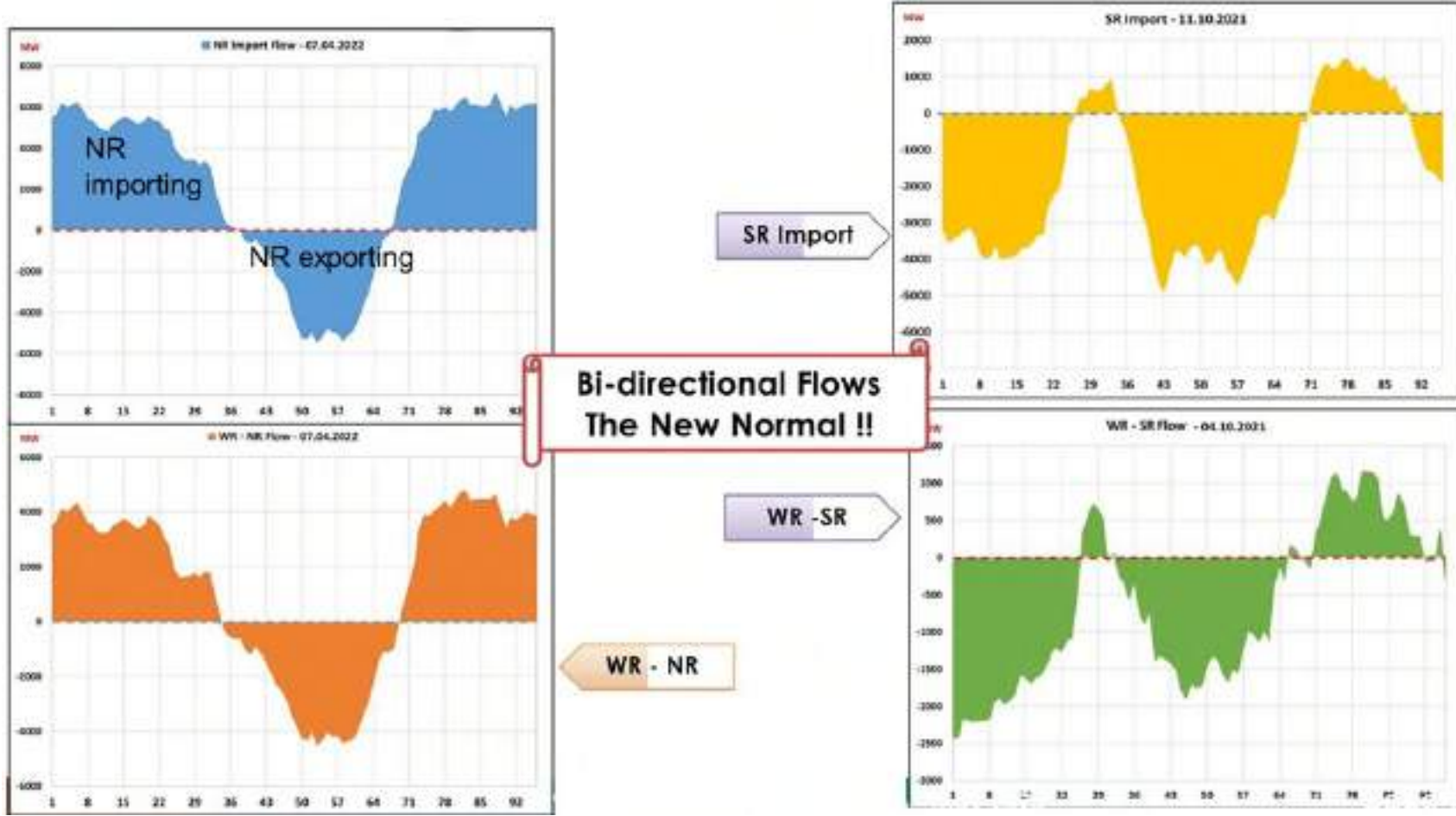
- Inertia
Conventional units are the main sources of inertia as they rotate at the same frequency as the electricity grid.
- Decreasing Inertia
 - Renewables: Increase in non-synchronous machines
 - Reducing trend of inertia
 - **Low System Strength** in the vicinity of RE complexes and **reduction in System Inertia** leading to
 - Lower Frequency Nadirs
 - Unit trip, UFR operation
 - Higher RoCoF
 - Protection maloperation
 - Instability

Inertia calculated using Curve Fitting Method

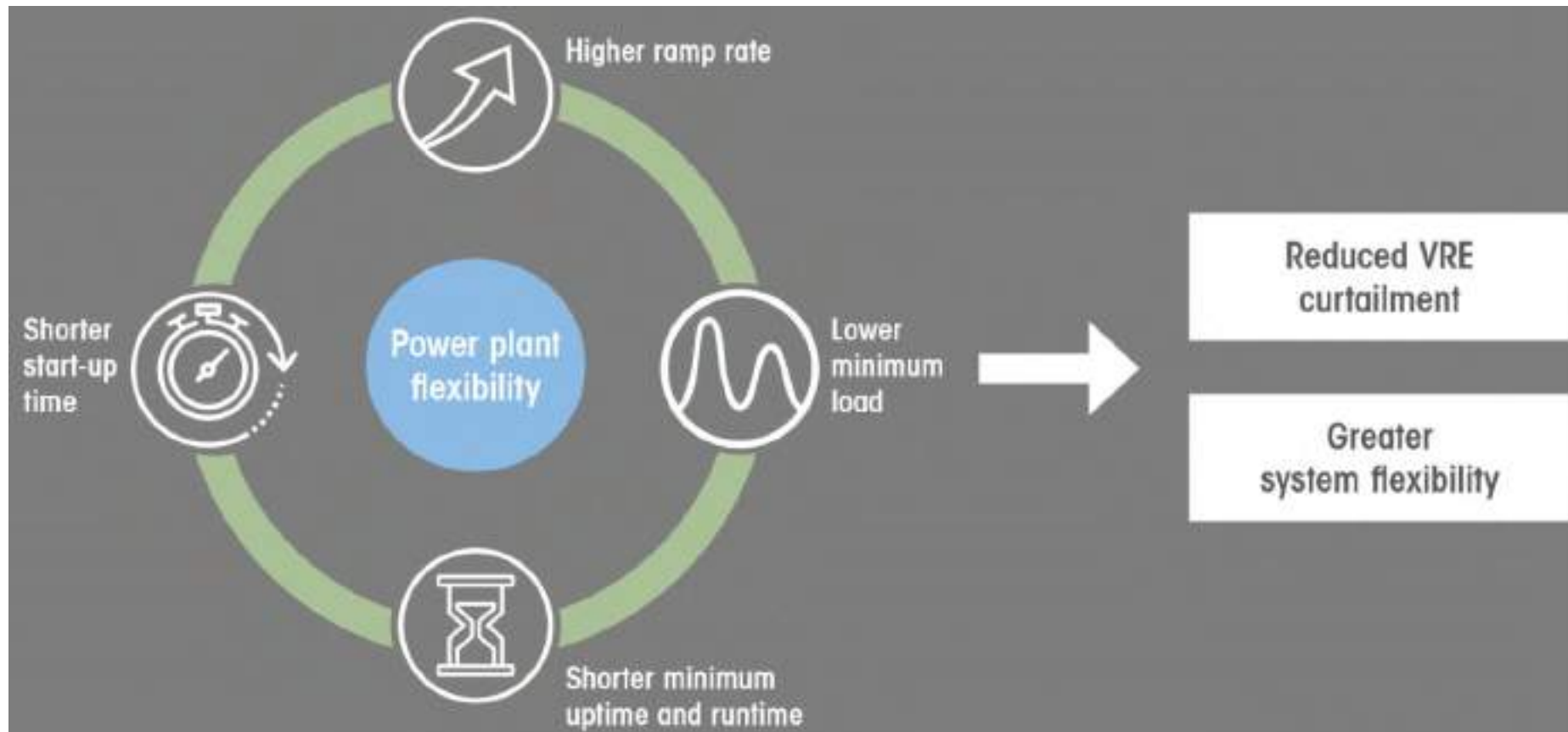
<https://posoco.in/wp-content/uploads/2022/01/Assessment-of-Inertia-in-Indian-Power-System.pdf>

Planning of synchronous condenser facility, Grid forming inverters need to be prioritized as part of transmission planning for RE

Large diurnal and seasonal variation in Inter-regional power flow



Conventional power plant flexibility



Source: IRENA (2019)

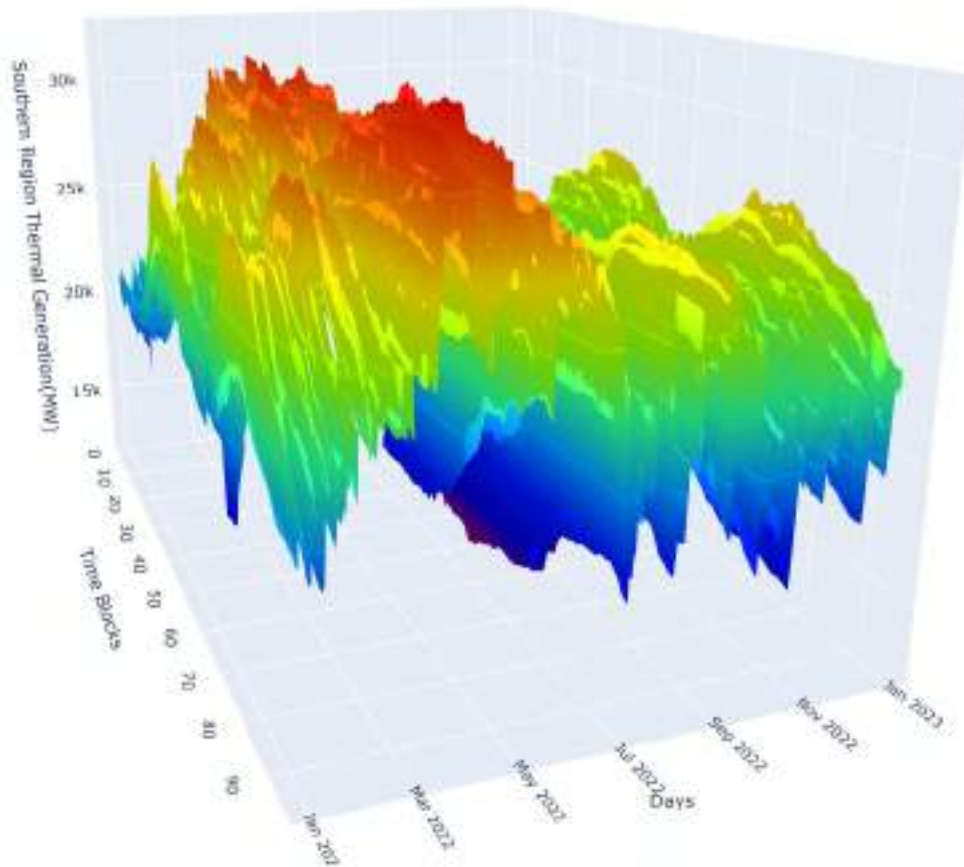
Operational Initiatives

• Conventional Plants

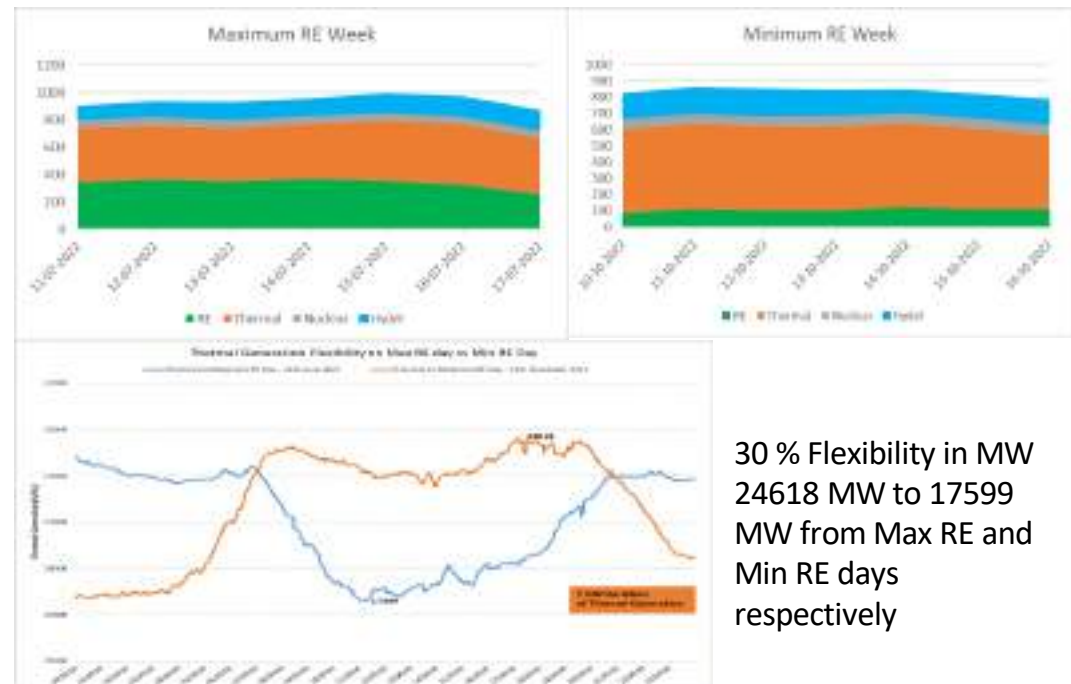
- ✓ Conventional generator annual maintenance planned in high RE
 - ✓ Coal units are typically backed down midday to accommodate RE
 - ✓ Coal plants experiencing more starts and spend more of their operating time at minimum generation
-
- Shift in operating timings of Pump Hydro plant from night time to midday to coincide with greater solar generation.
-
- Use of Real Time markets by states for sale of power during high RE generation period.
-
- Frequency Control
 - ✓ Use of Ancillary services, Hydro and thermal flexing for managing ramp requirement and frequency management
 - ✓ AGC implementation in 69 power plants with 67.3 GW capacity
-
- Efforts in improvement of forecasting of Demand and RE

Thermal generation in Southern Region

SR Thermal Generation Flexibility from 32 GW(Peak) to 14 GW(off-peak)

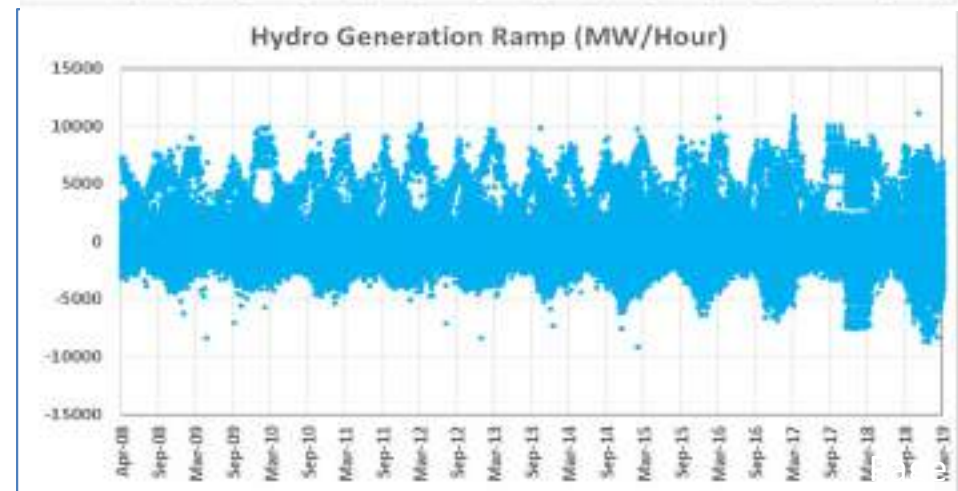
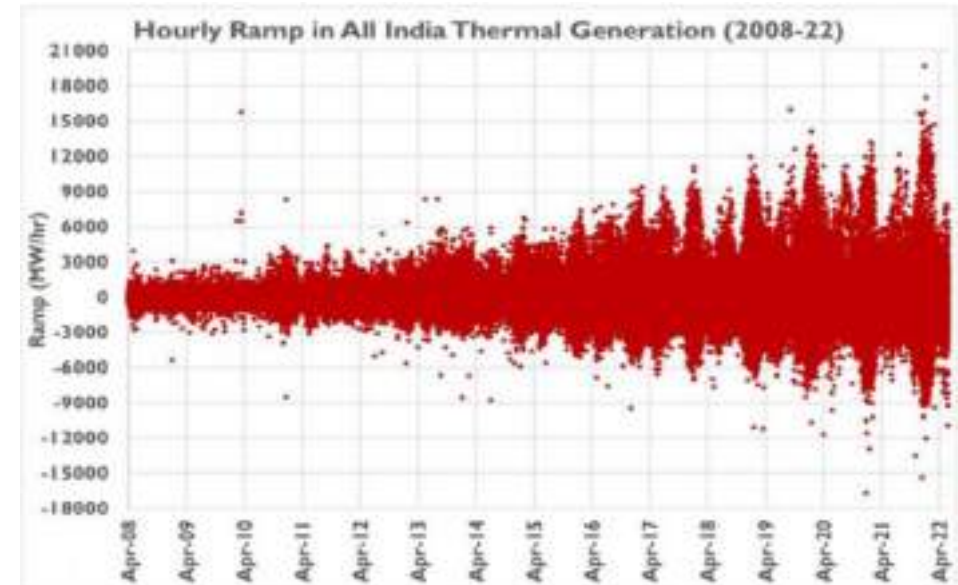
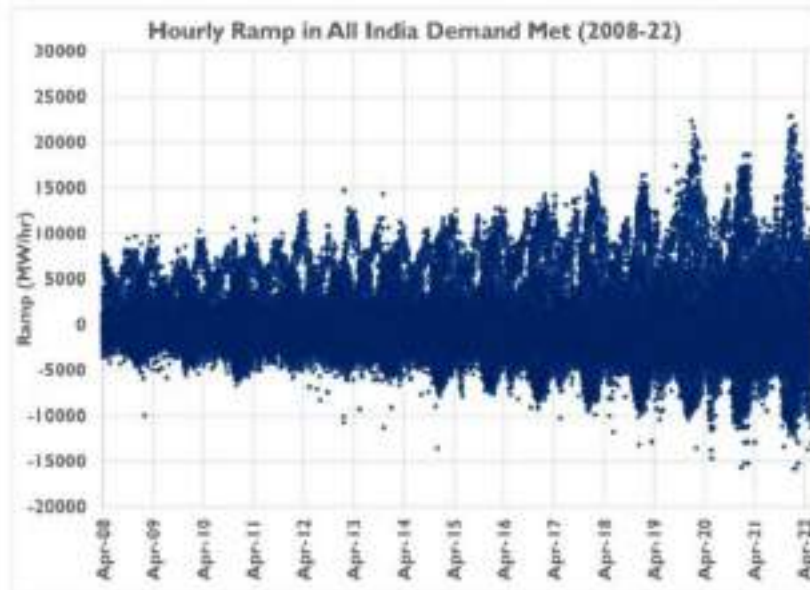


- Present Installed Capacity: 47.1 GW
- Upcoming Installation : 10.64 GW
 - Central : 0.8 GW
 - State : 9 GW (TS : 4 GW, AP : 0.8 GW, TN: 3.4 GW)
- Thermal Flexibility – During Min RE Energy Week – 60 % and Max RE Energy Week – 44 %



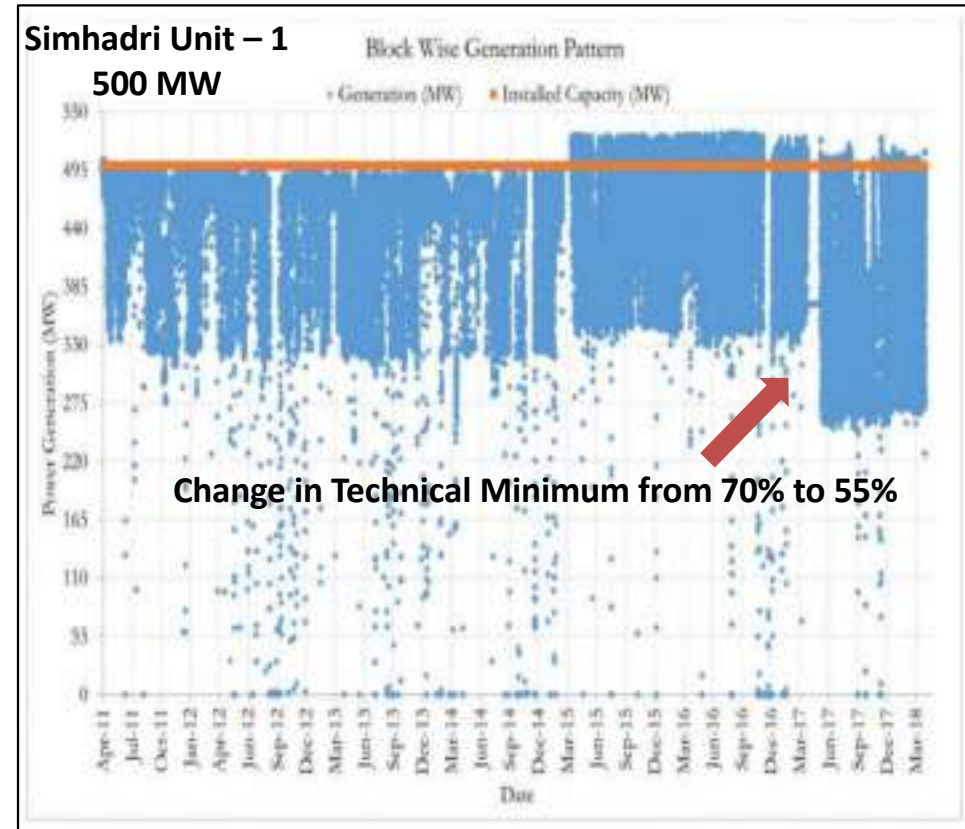
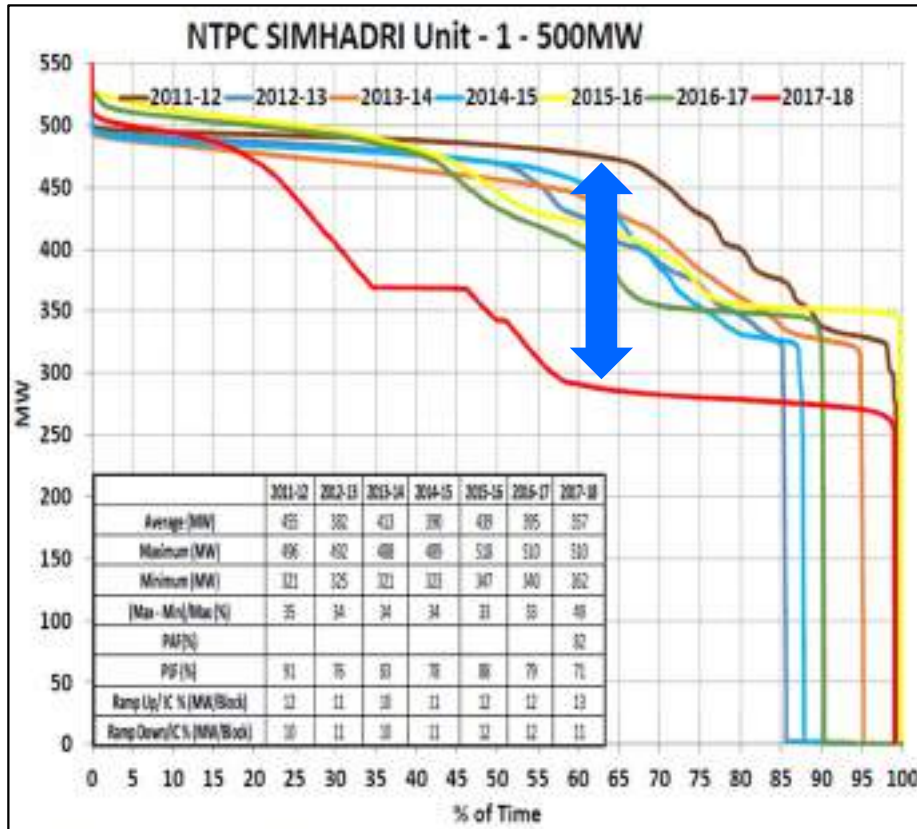
30 % Flexibility in MW
24618 MW to 17599
MW from Max RE and
Min RE days
respectively

Flexibility Need and Provision



- **Indian Electricity Grid Code (IEGC)**
 - Generators declare rate of ramping up / down in 15 minute block
 - **Minimum ramp rate** – 1% of MCR per min (IEGC-2023 & Tariff regulation)
 - Reduction of conventional thermal generation to the 55 % levels
 - Compensation for flexible operations - May 2017
- **Central Electricity Authority (CEA) regulation on flexible operation of Coal based Thermal power generating units**
 - Ramp rate: + 3 % per min (operation between 70 to 100% of MCR)
+2% per min (operation between 55 to 70% of MCR)
+1% per min (operation between 40 to 55% of MCR)
 - Technical minimum load – minimum power level of 40%

Thermal Flexibilization

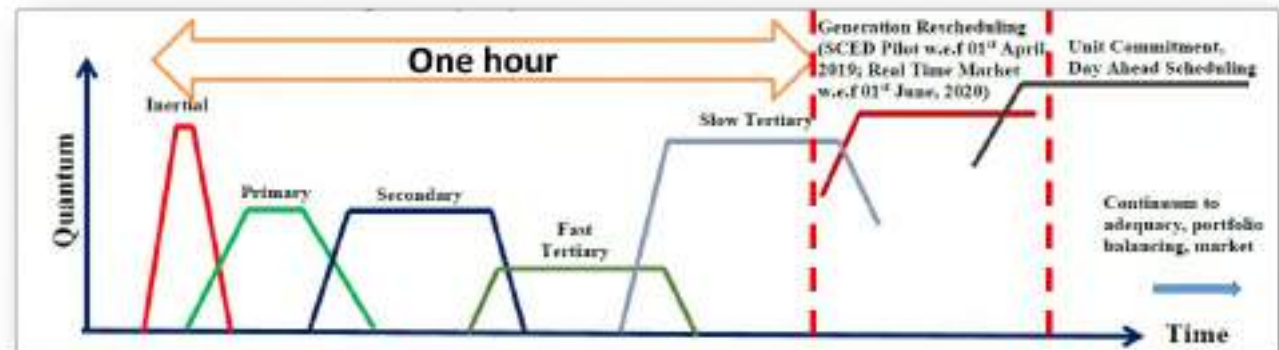


IEGC 4th Amendment - 55% Technical Minimum for Central Generating Stations; effective from 15.05.17

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System Balancing and Frequency Control Continuum

- ✓ Generation must exactly match electricity demand at all times to maintain reliability.
- ✓ Various categories of operating reserves and ancillary services function on different timescales, from sub-seconds to several hours.
- ✓ Central Electricity Authority (Flexible Operation of Coal based Thermal Power Generating Units) Regulations, 2023
 - ✓ Minimum power level of 40 %
 - ✓ Achieve minimum power level of 55%, shall achieve the same within one year
 - ✓ Ramp rate capability of minimum 3% per minute for their operation between 70 to 100%
 - ✓ Ramp rate capability of minimum 2 % per minute for their operation between 55 to 70%



Reserve	Start	Full Availability	Duration of Response	Mode of Activation
Primary Control	Instantaneous	Within 30 sec.	Up to 5 min.	Automatic
Secondary Control	Within 30 sec.	Within 15 min.	Up to 30 min./till replaced by Tertiary Reserves	Automatic
Tertiary Control	Within 15 minutes	15 minutes – 60 minutes	Till replaced by rescheduling of generation	Manual

Way Forward

- Flexible Thermal Generation – Must for ensuring Resource Adequacy, flexibility & grid balancing services with increase of RE in generation mix.
- Implementation of Central Electricity Authority (Flexible Operation of Coal based Thermal Power Generating Units) Regulations, 2023