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Workshop on

Renewable Energy Integration and Procurement

March 18 -19, 2024

South Asia Regional Energy Partnership (SAREP) and Sri Lanka Energy Program

Session 6A:Challenges of renewables penetration in the country

Challenges of renewables penetration in the country

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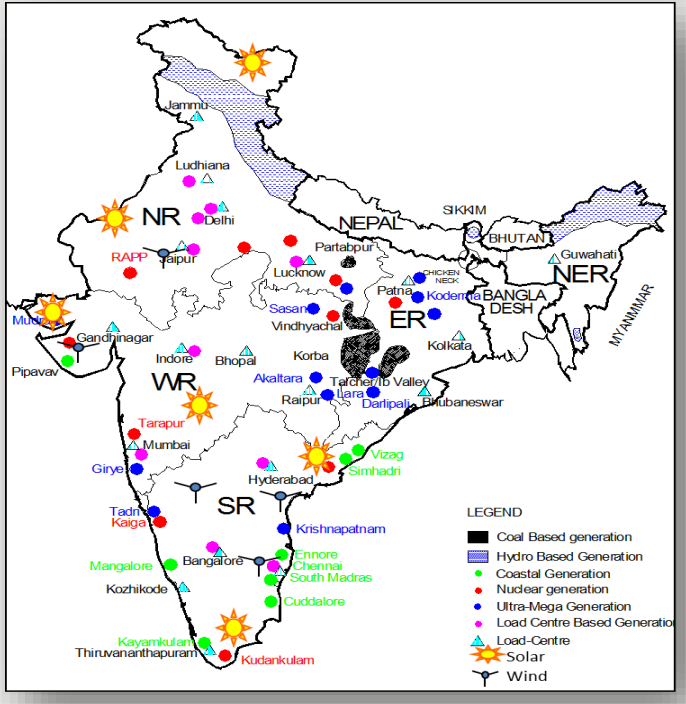
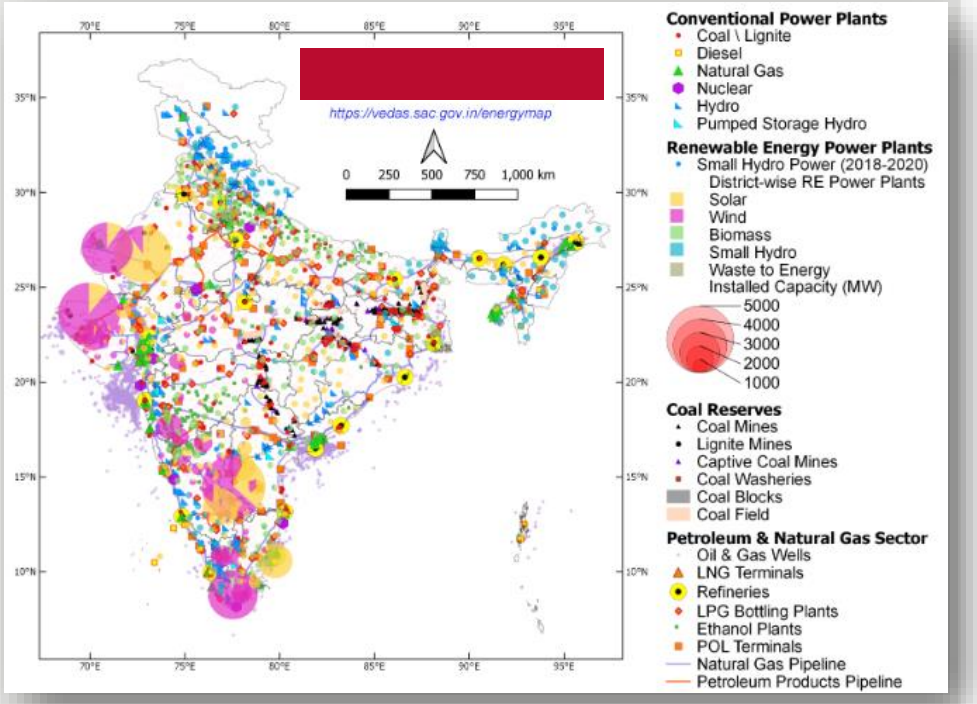
Founder, CEO, Grid-India (formerly POSOCO)

FIEEE, FINAE, LFIE(I) ,Member NAE US, Retired CPES GOI

Distinguished Member CIGRE, Distinguished Alumnus IIT KGP

Resource Spread across India





Hydro – North-Eastern & Northern India; Coal - Central India

Renewables – Northern, Western and Southern India

Changing Generation Resource Mix towards 2030

ALL INDIA INSTALLED CAPACITY (MW)			
Resource	**Mar 2023**	**Mar 2030**	**% Addition**
Hydro	42104	53860	28%
PSP	4746	5350	13%
Small Hydro	4944	18986	284%
Solar PV	66780	292566	338%
Wind	42633	99895	134%
Biomass	10802	14500	34%
Nuclear	6780	15480	128%
Coal+ Lignite	211855	251683	19%
Gas	24824	24824	0%
Total	**415469***	**777144****	87%
BESS	0	41650 (5-hr)	

*Excluding 2136 MW of Hydro imports from neighboring countries and 589 MW Diesel based capacity
**Excluding Hydro Imports of 5856 MW

Source: CEA Report On Optimal Generation Capacity Mix for 2030 (Ver 2.0)
https://cea.nic.in/wp-content/uploads/notification/2023/05/Optimal_mix_report__2029_30_Version_2.0__For_Uploading.pdf

	2024	2030
Maximum Demand Met (GW)	~240#	334^
Total Generation Installed Capacity (GW)	428*	777
Non-fossil Fuel Based Generation Installed Capacity (GW)	188*	500
Wind & Solar Installed Capacity (GW)	117*	393

As on 31st Dec 2023 as per Operational Data of Grid-India
* **As on 31st Nov'23** from CEA Installed Capacity Report
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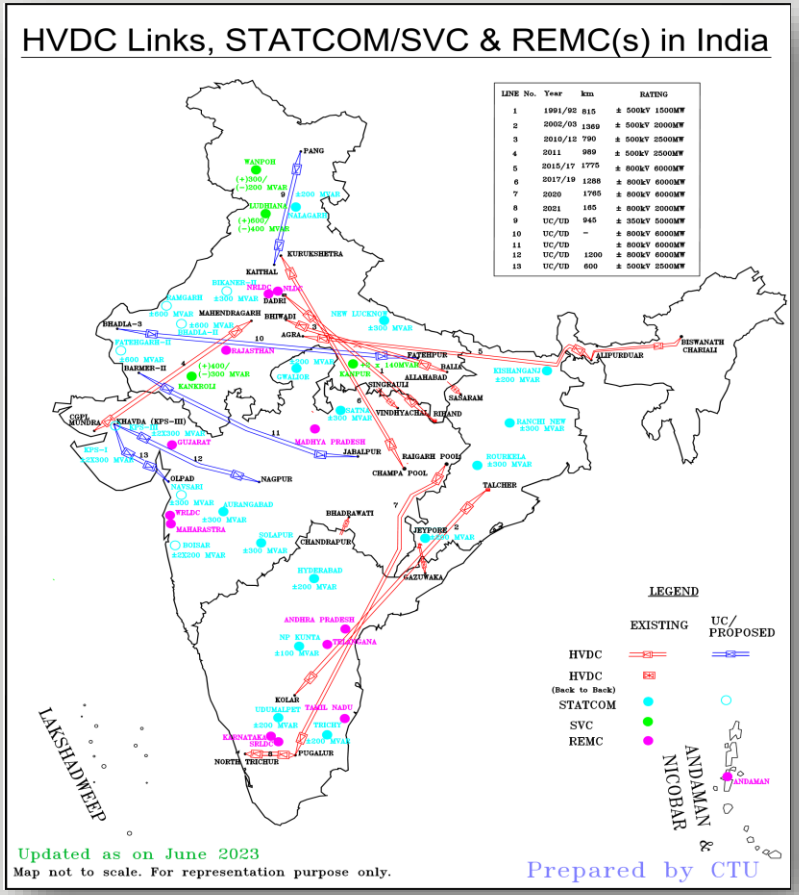
Transmission Infrastructure gearing up towards 2030



- **Transmission Lines (≥220kV) - 4,81,326 ckm**
  - 765 kV: 54,672 ckm
  - 400kV: 2,01,541 ckm
  - 220kV: 2,05,738 ckm
  - HVDC: 19,375 ckm
- **Transformation Capacity (≥220kV) : 12,25,260 MVA**
  - 765 kV: 284200 MVA
  - 400kV: 447433 MVA
  - 220kV: 460127 MVA
  - HVDC: 33500 MVA
- **3 nos. of ±800kV HVDC Bipole (18 GW)**
- **5 nos. of ±500kV HVDC Bipole (10.5 GW)**
- **1 no. of ±320kV VSC HVDC (2 GW)**
- **4 nos. of HVDC Back-to-Back (3 GW)**
- **20 no. of Hybrid STATCOMs (11,350 MVAr)**
- **4 nos. of SVC (2500 MVAr)**
- **48 nos. FSC/TCSC**

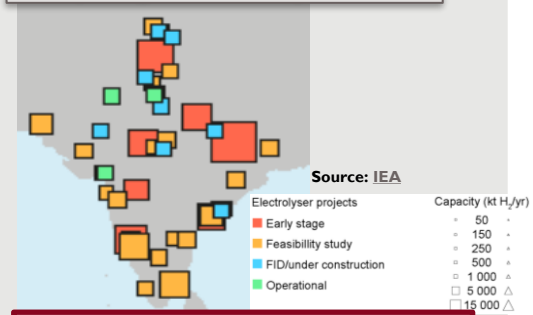
Transmission System Augmentation
Strengthening Integration of over 500 GW Renewables by 2030

- Additional requirement of Inter State Transmission System by 2030 for 66.5 GW Renewable Energy Zones (REZs)
  - Transmission Lines: 50,890 ckm
  - Transformation Capacity: 433,575 MVA
- 37 GW wind power auction trajectory announced till 2030
  - Evacuation system of off-shore wind power has been identified for 10 GW
- Green Hydrogen Mission
  - 5 MMT per annum by 2030
- Cross Border Interconnections
  - >5000 MW additional capacity planned

Gujarat – Khavda 30 GW REZ

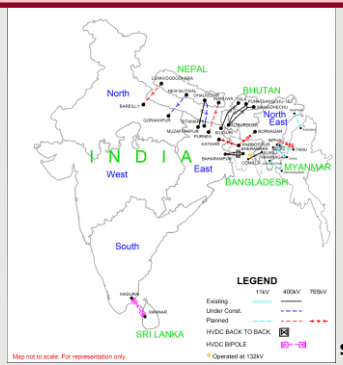
Source: CEA

Hydrogen Electrolyzers



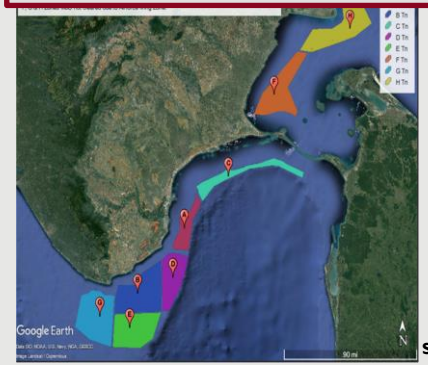
Source: IEA

Cross Border Interconnections



Source: CEA

Off-Shore Wind



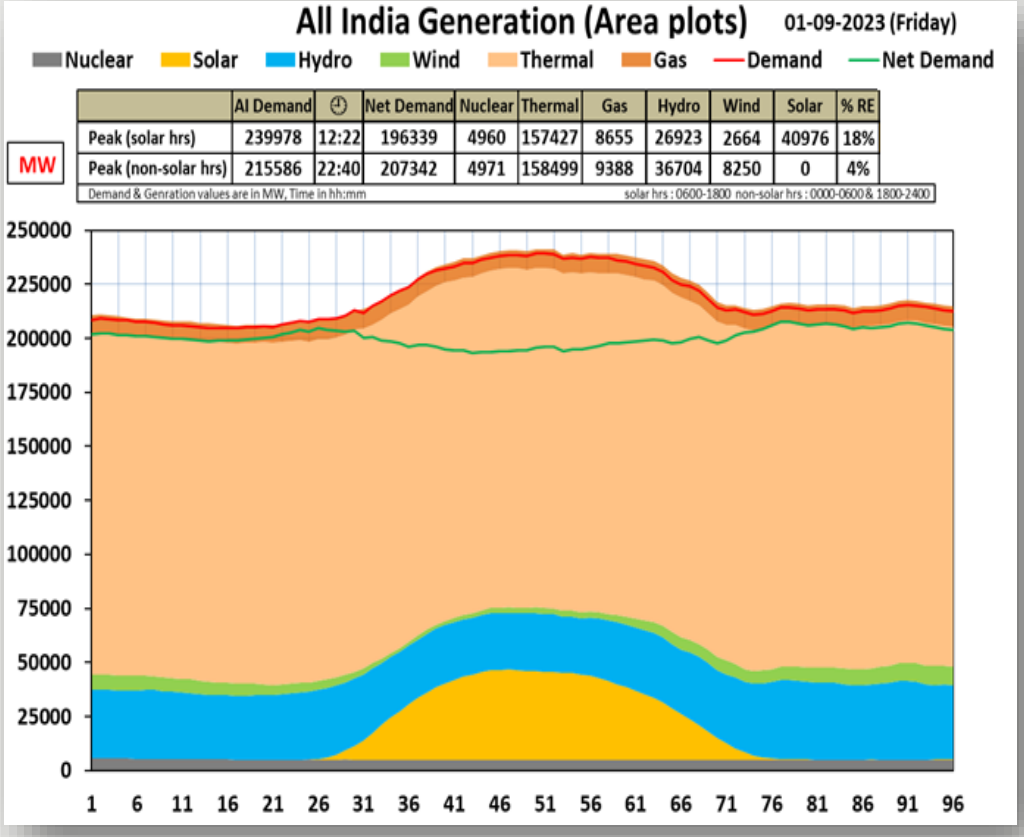
Source: CEA

2 nos. of ±800kV HVDC Bipole and 3 nos. of ±350kV VSC HVDC Hybrid STATCOMs, SVCs also planned

Distribution Reforms

- Promotion of Agricultural Solar Pumps
  - PM-KUSUM (Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan) Scheme
- Unnat Jyoti by Affordable LED for All (UJALA) Programme
  - LED bulbs, LED tube lights and energy efficient fans to replace conventional and inefficient variants
- Street Lighting National Programme (SLNP)
  - Smart and energy efficient LED street lights across India
- Shifting of agricultural power consumption to solar hours
  - Reliable power supply to farmers during daylight hours
- Revamped Distribution Sector Scheme (RDSS) nationwide Smart Meter program under implementation
  - 43 million smart meter contracts awarded since the start of 2023

Resource Adequacy



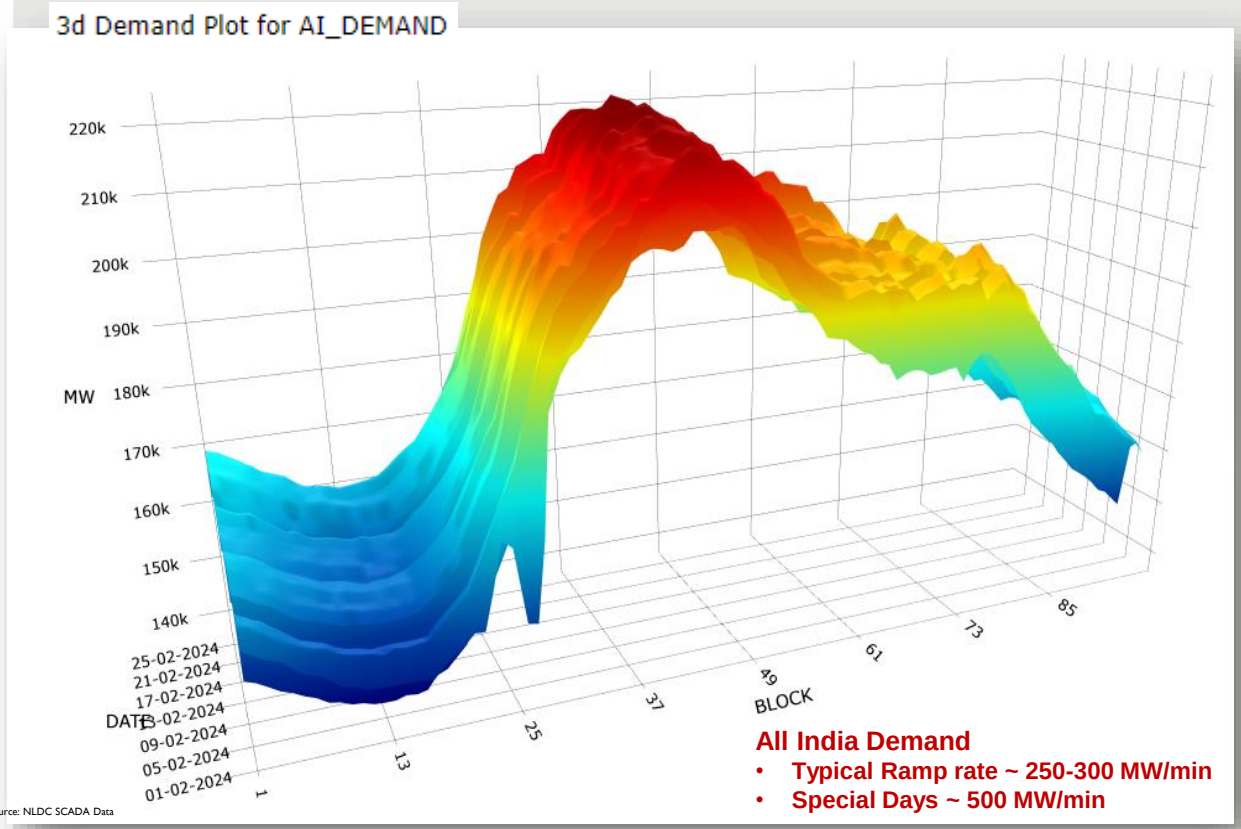
	AI Demand		Net Demand	Nuclear	Thermal	Gas	Hydro	Wind	Solar	% RE
Peak (solar hrs)	239978	12:22	196339	4960	157427	8655	26923	2664	40976	18%
Peak (non-solar hrs)	215586	22:40	207342	4971	158499	9388	36704	8250	0	4%

- Increasing non-solar peak
- Limited support from wind during non-solar hours
- Cloud cover, sandstorm
- RE generation loss due to fault ride through issues
- Resource droughts
  - Long duration storage, quick starting thermal
- Adequacy of reserves vital to handle contingencies

Assessment of Reserve Requirement

Type of reserve	Inter-state level MW	Intra state level MW	Total All India level MW
Secondary	3788	3211.6	7000
Tertiary	3788	8887.6	12676
Total	7576	12099.2	19676

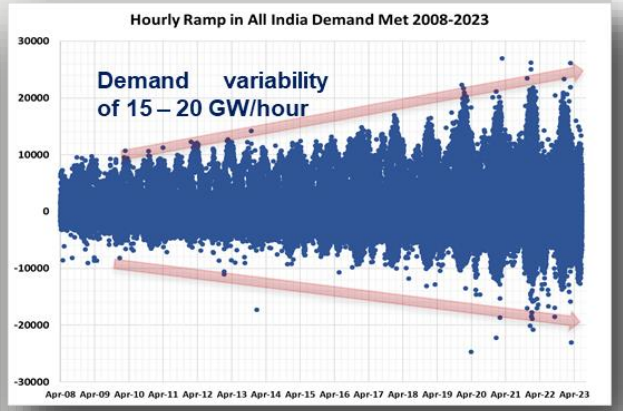
Growing Need for Flexibility – Increasing All India Demand Ramp

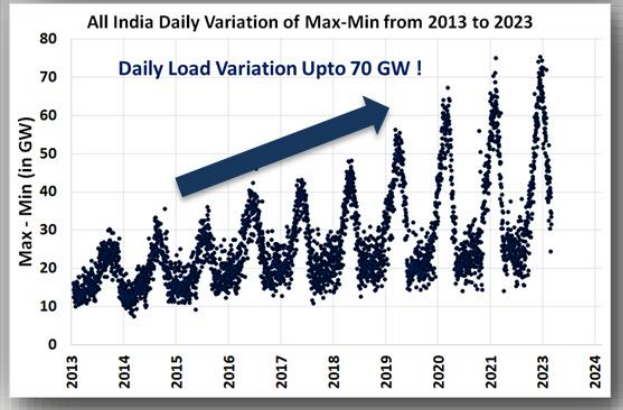


All India Demand

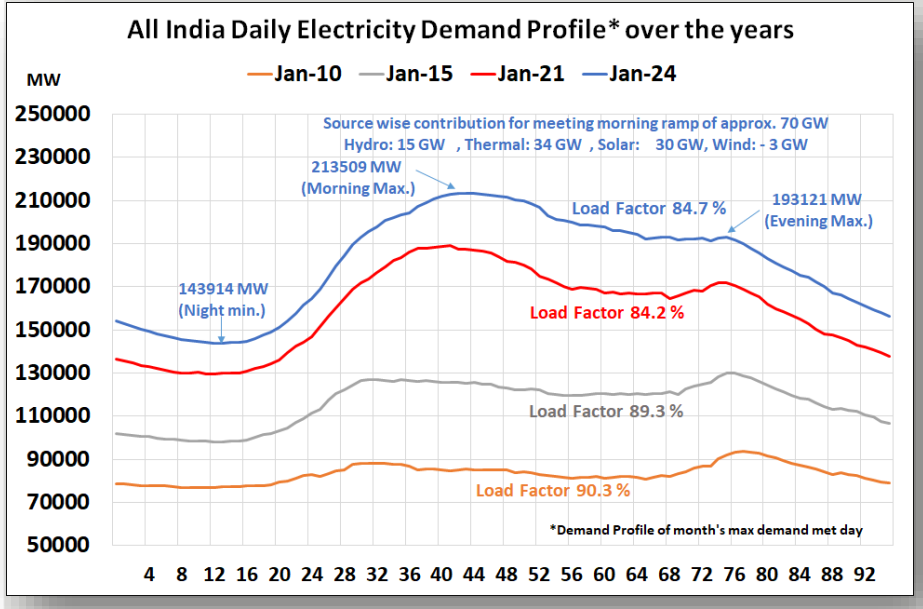
- **Typical Ramp rate ~ 250-300 MW/min**
- **Special Days ~ 500 MW/min**

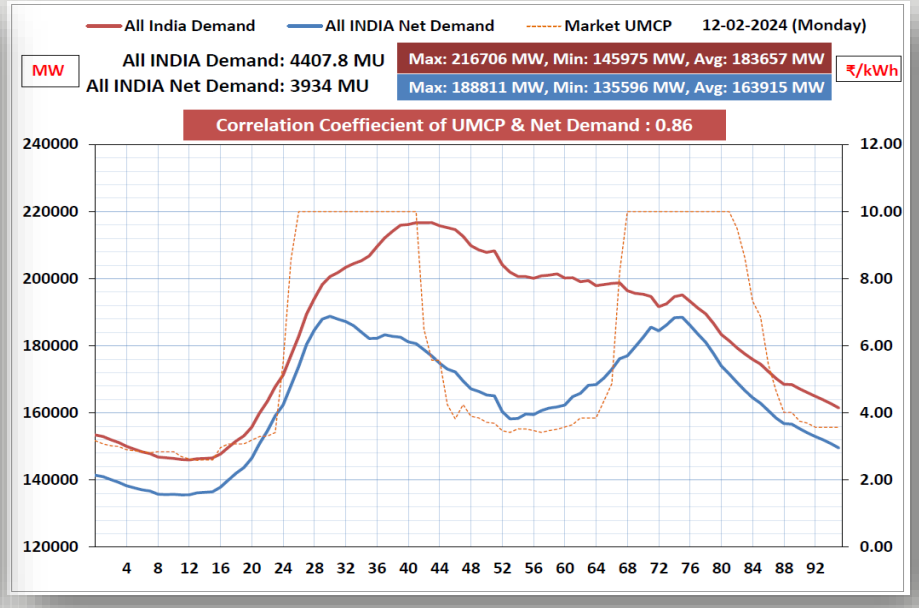
Source: NLDC SCADA Data





Flexibility Requirement



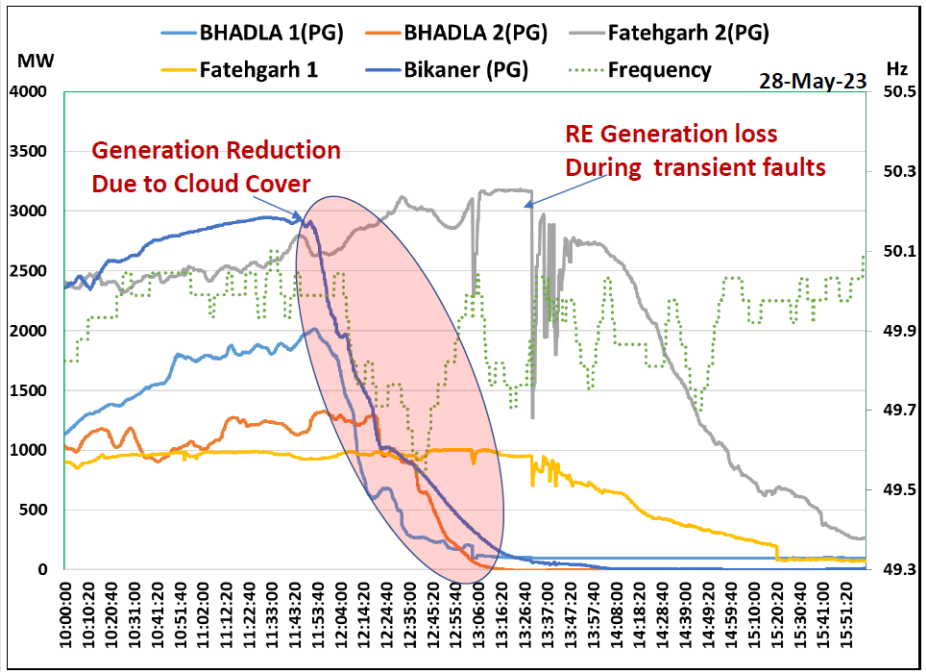


CEA: Flexibilization of Coal-Fired Power Plants (Tech. min upto 40 %)

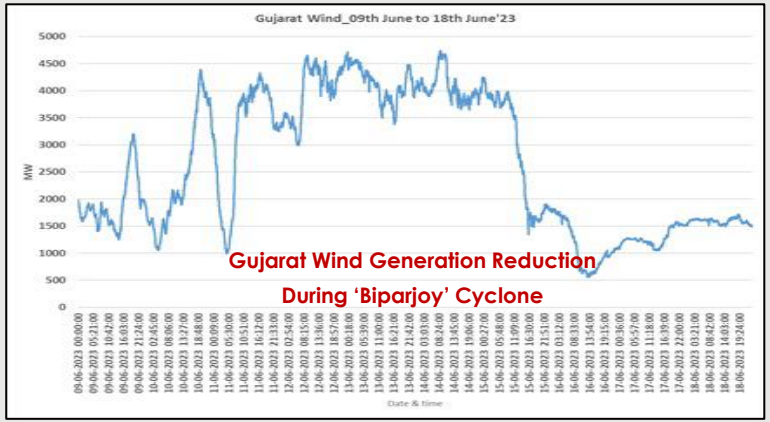
Phase 1: July,2024-Jun,2026 : 90 Units, Phase 2: July,2026-Jun,2028 : 160 Units

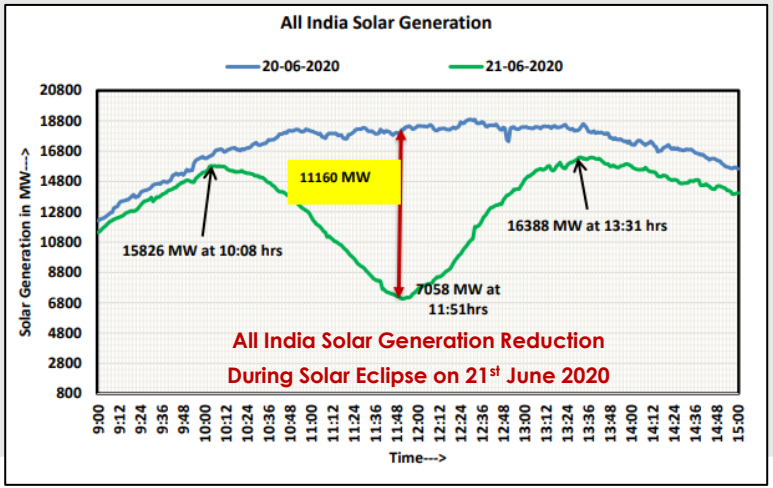
Phase 3: July,2028-Dec,2029 : 143 Units, Phase 4: Jan,2030-Dec,2030 : 196 Units

Growing Need for Flexibility – Cloud Covers and Increase in Extreme Weather Events

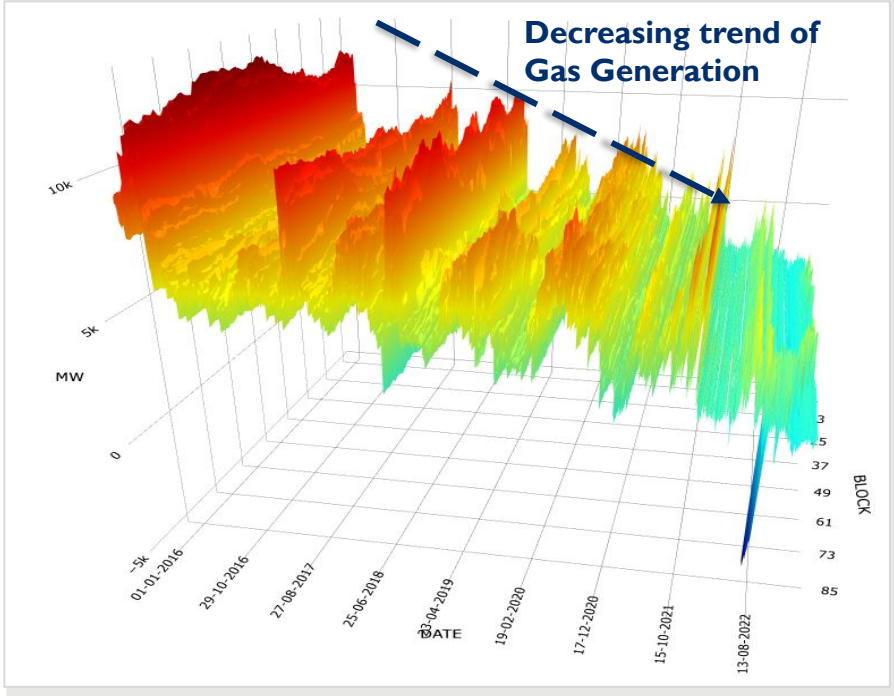


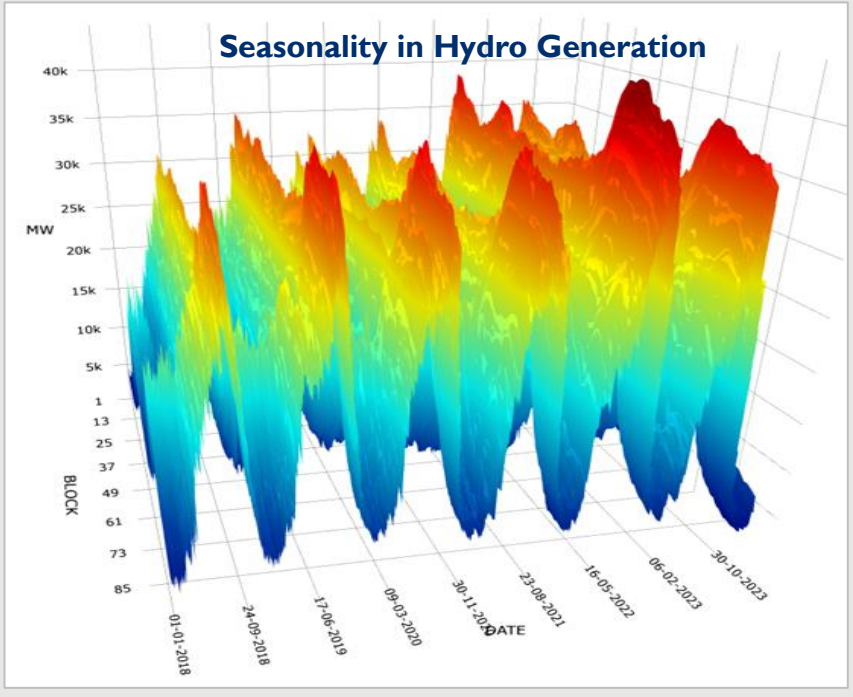
- Solar generation loss during peak solar hour due to cloud cover
- Approx. 8000 MW solar generation reduced within 1 hour.
- After 13:00 hrs, multiple transient faults occurred in RE complex





Flexibility Providers – Gas and Hydro Based Generation

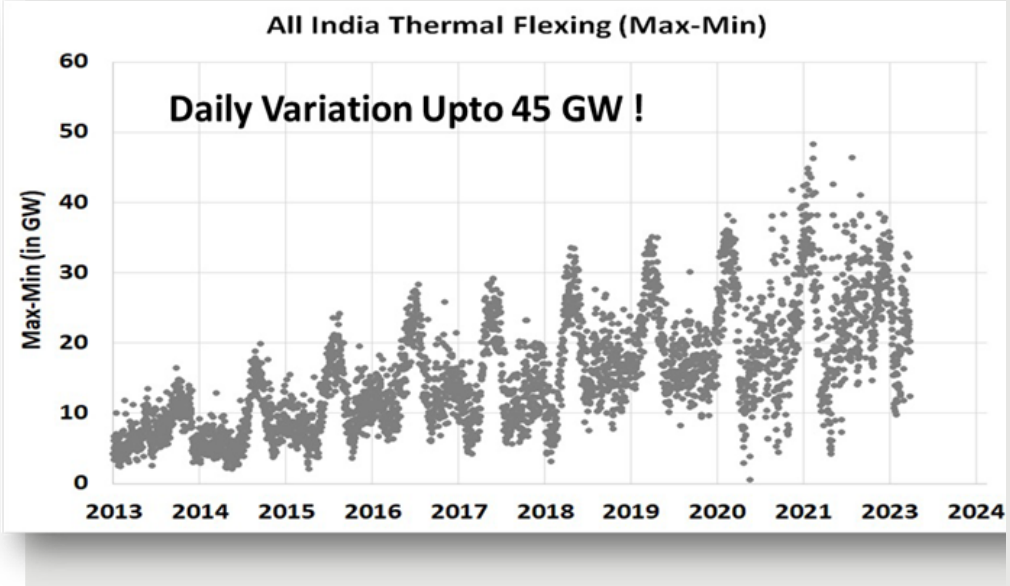


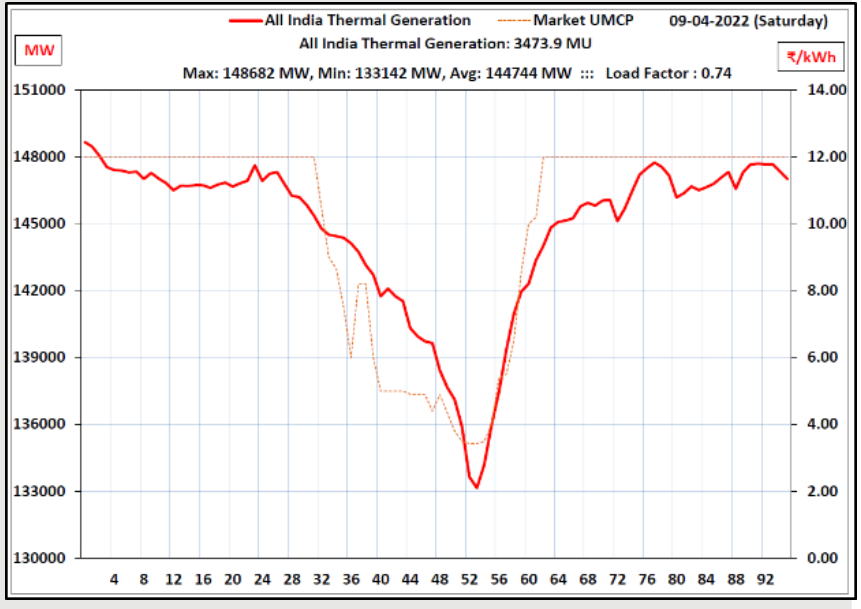


- **Flexibility from Gas Generation constrained by availability of Gas !!**
- **Limited flexibility in Off-grid Gas Stations; Limited flexibility in gas stations where open cycle operation is not possible**

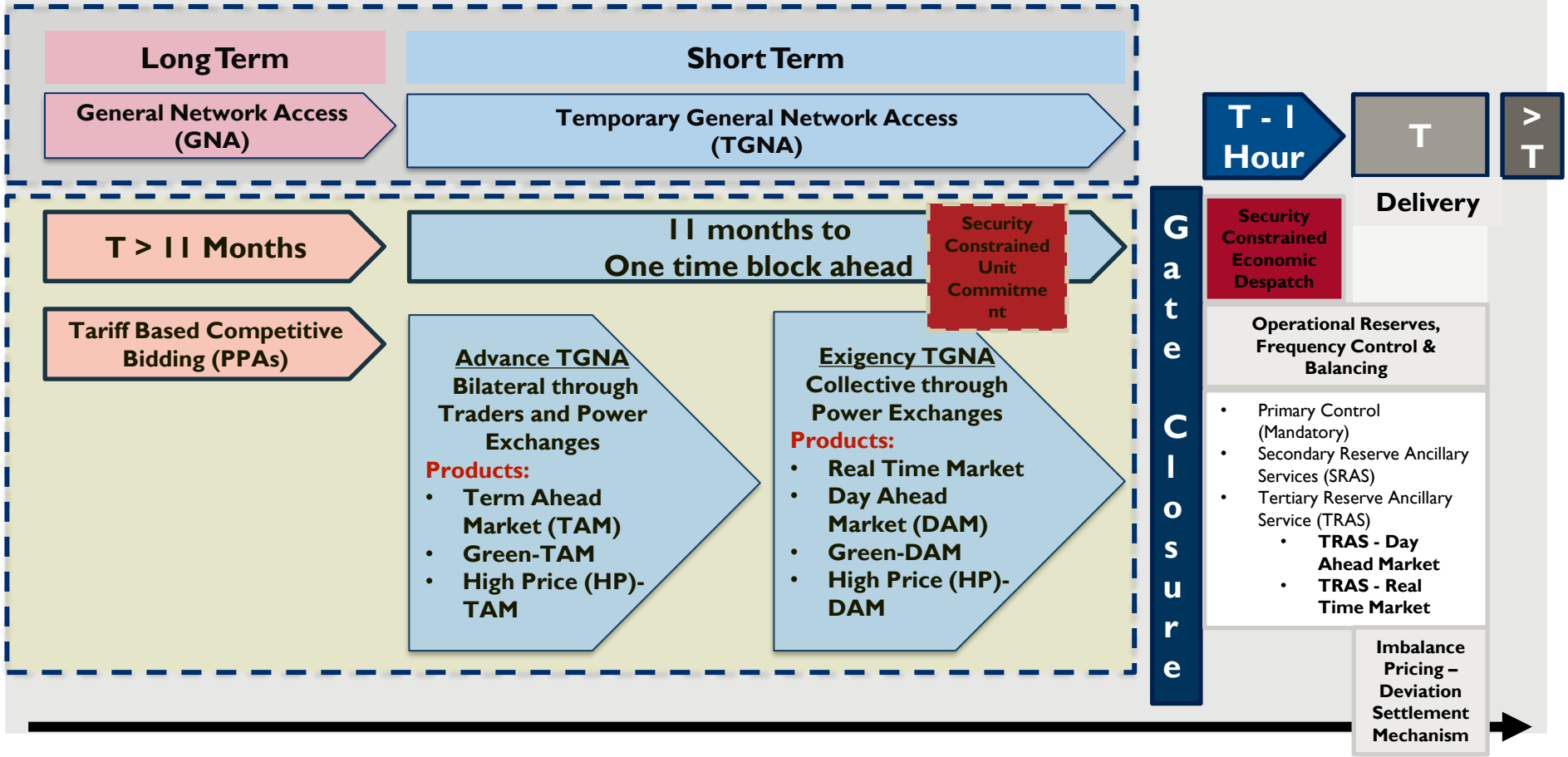
Flexibility from Hydro Generation is highly seasonal !!

Flexibility Providers – Coal/Lignite fired Generation



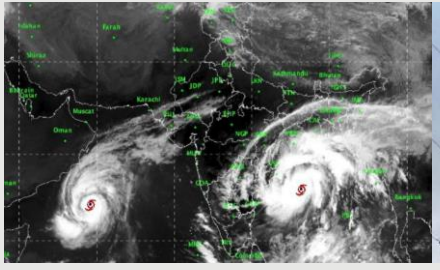


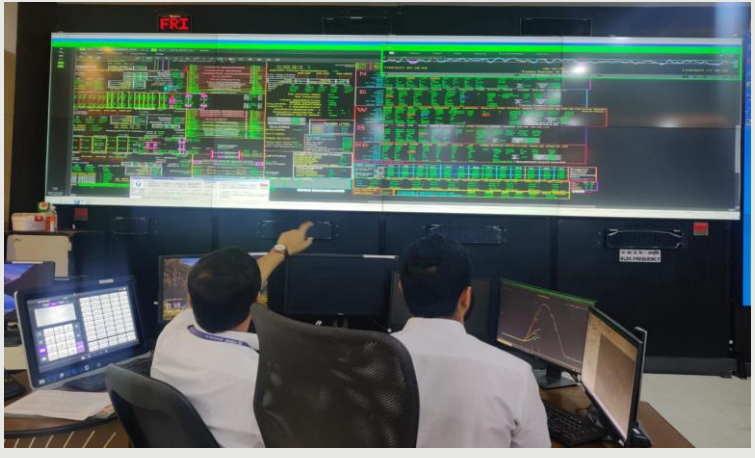
Market Structure – Access & Contracts delinked



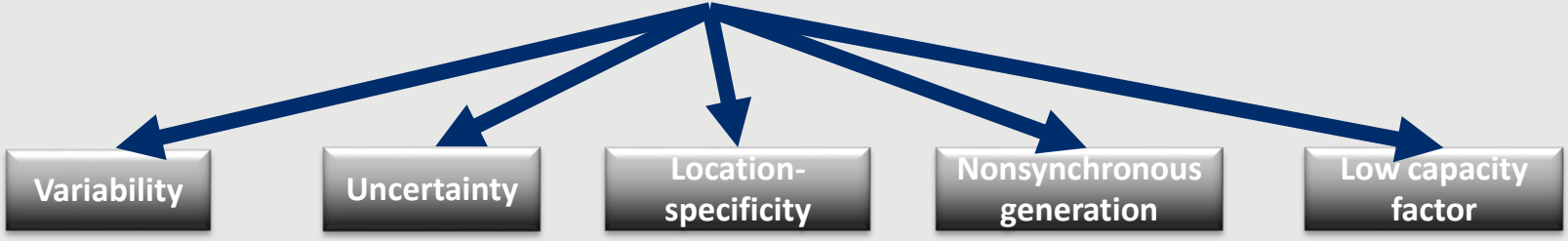
Power System Resilience – Climate Change Induced Events

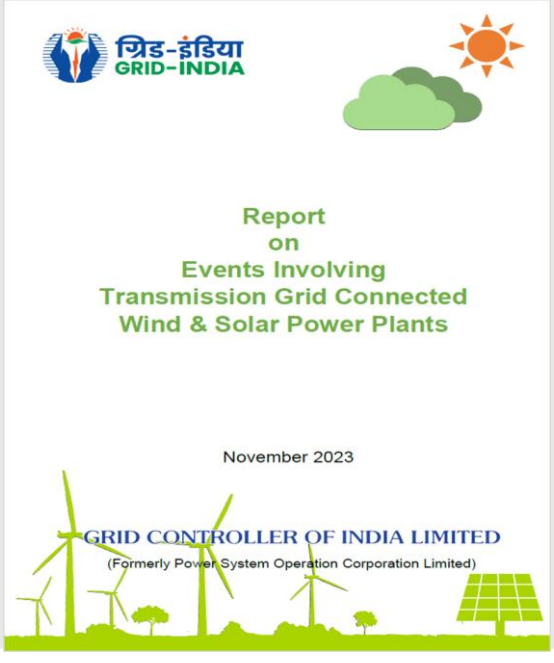
- Periodic mock drills for system restoration and operation of backup control centres
- Decongesting large RE pooling stations in cyclone prone areas at transmission planning stage
- Feedback for ensuring provision for start-up power from low voltage feeders at large generating station
- Reconfiguration of transmission system for flexibility under different operating conditions
- Creation of war-rooms during disaster
- Cyber security





Renewable Integration Challenges





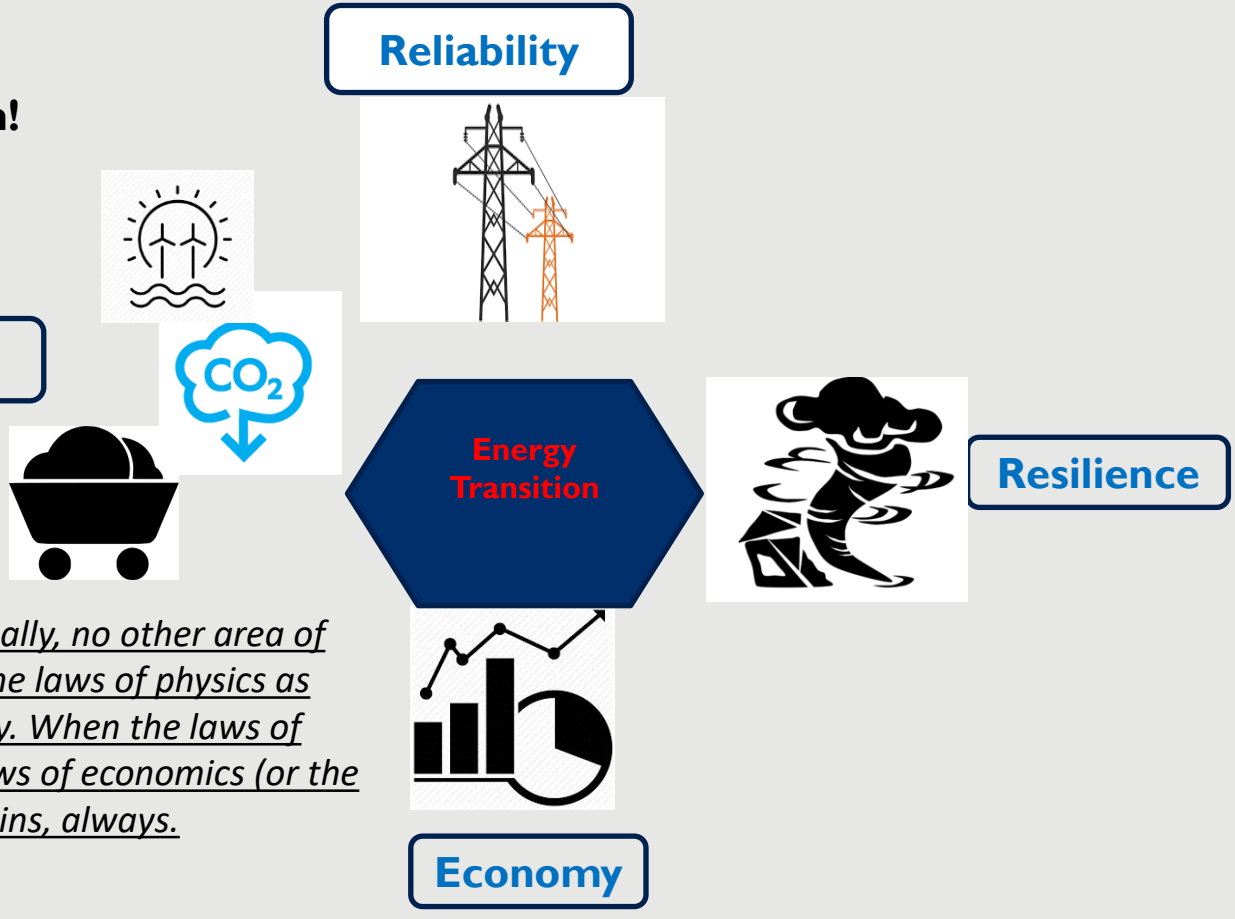
> **31 events** involving **generation loss of above 1000 MW** from renewable power plants - **January'22 to May'2023**

https://posoco.in/wp-content/uploads/2023/12/Report-on-Events-Involving-Transmission-Grid-Connected-Wind-Solar-Plants.pdf

Challenges

- **Non-compliance of Plants in real-time during fault ride through**
- **Sanctity of simulation models:** Compliances shown in simulation models not visible in real-time
- **Equipment Design:** Derating of PV inverters with ambient temp> 40 deg cel & WTG with ambient temp> 30 deg cel
- **Post-event Analysis:** Inadequate recording & data retention facilities at IBR/PPC level

The Conundrum!



George C. Loehr noted *Finally, no other area of human activity relies on the laws of physics as intimately as power supply. When the laws of physics collide with the laws of economics (or the laws of society), physics wins, always.*

Dimensions of Indian Power System

~ 430 GW
generation capacity

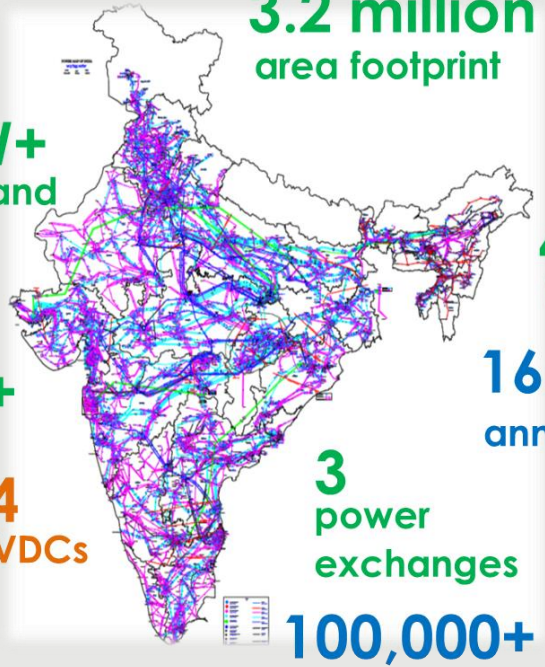
3.2 million km²
area footprint

1.4 Billion+
people served

239 GW+
peak demand

> 4.5 TWh
daily energy met

4 GW+
international exchanges



481326 ckm+
EHV transmission

165 TWh+
annual market trades

~182 GW
renewables
(including large Hydro)

14
HVDCs

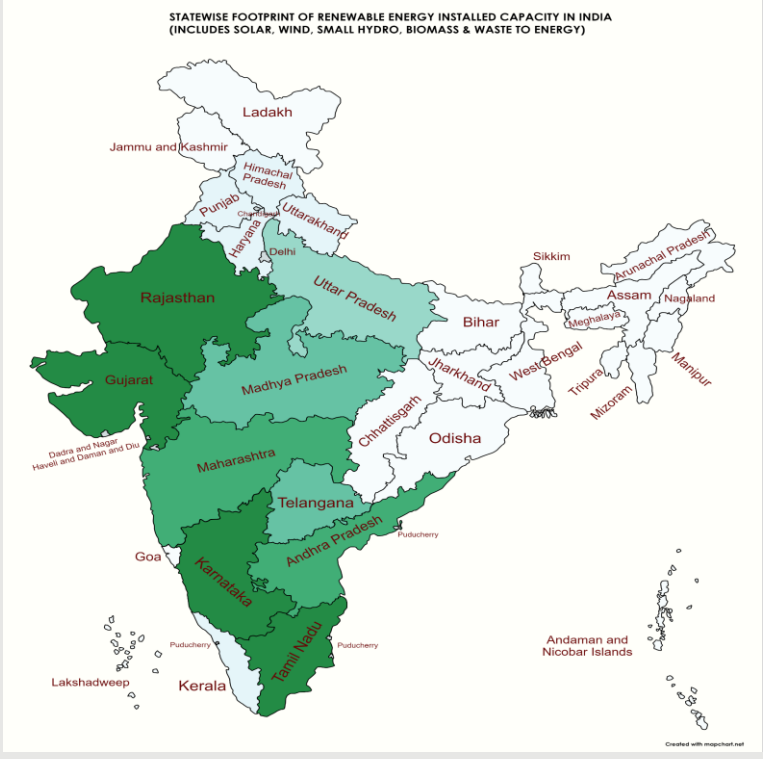
3
power exchanges

6000+
market participants

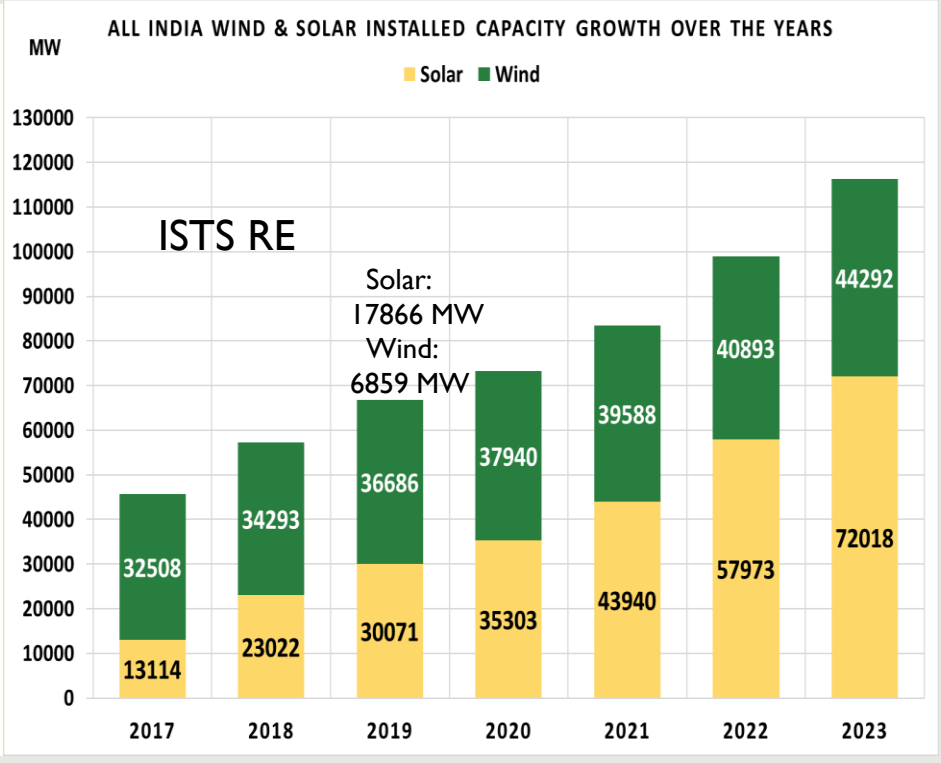
100,000+
market transactions

~ 117 GW
inter-regional capacity

Renewable Energy Footprint in India



Source: CEA Installed Capacity Report
https://cea.nic.in/installed-capacity-report/?lang=en



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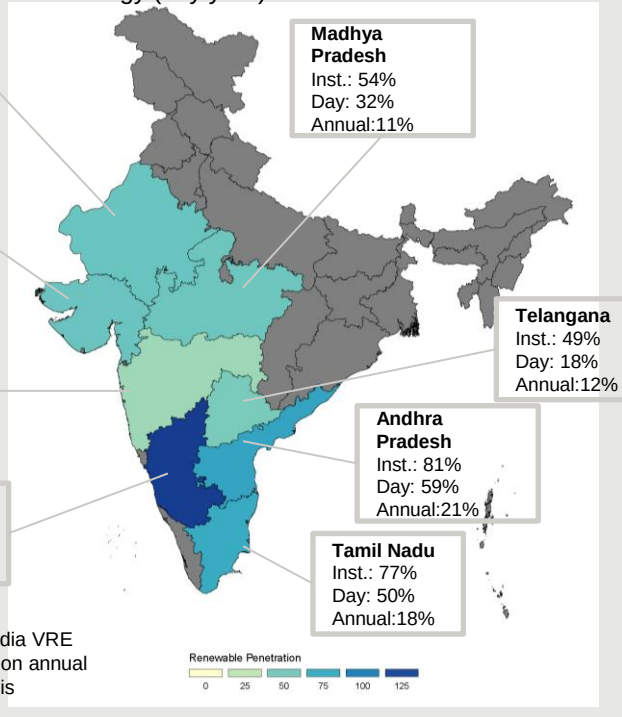
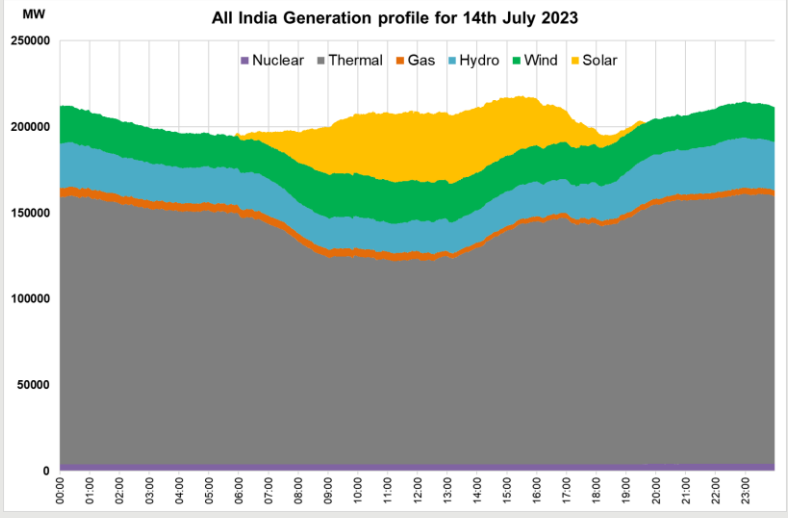
Growing penetration of Renewables in the grid

Maximum Wind+Solar penetration in instantaneous MW and energy (day/year) terms



11% All India VRE penetration on annual basis



Highest Instantaneous RE penetration of ~32.4 % was recorded on 14th July 2023

Renewable Energy in India: Vision 2030

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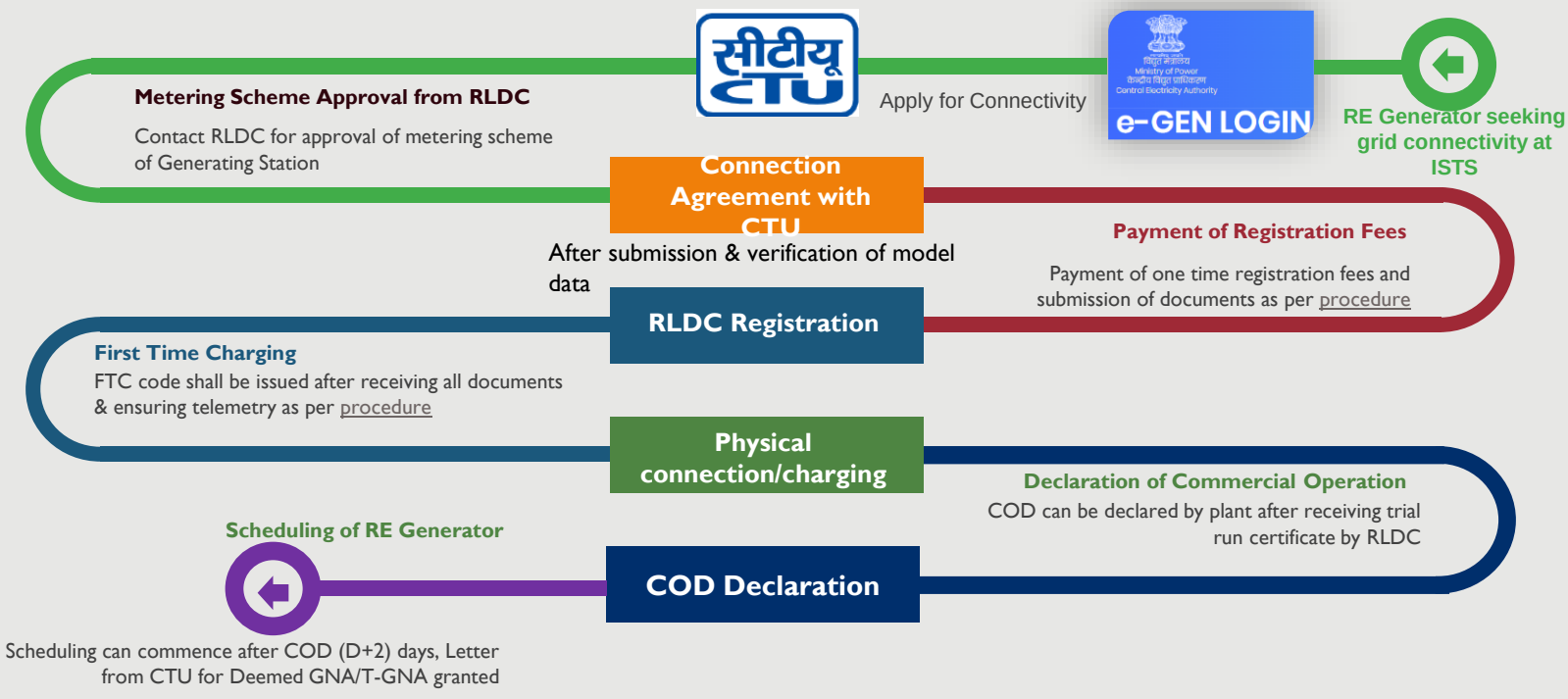
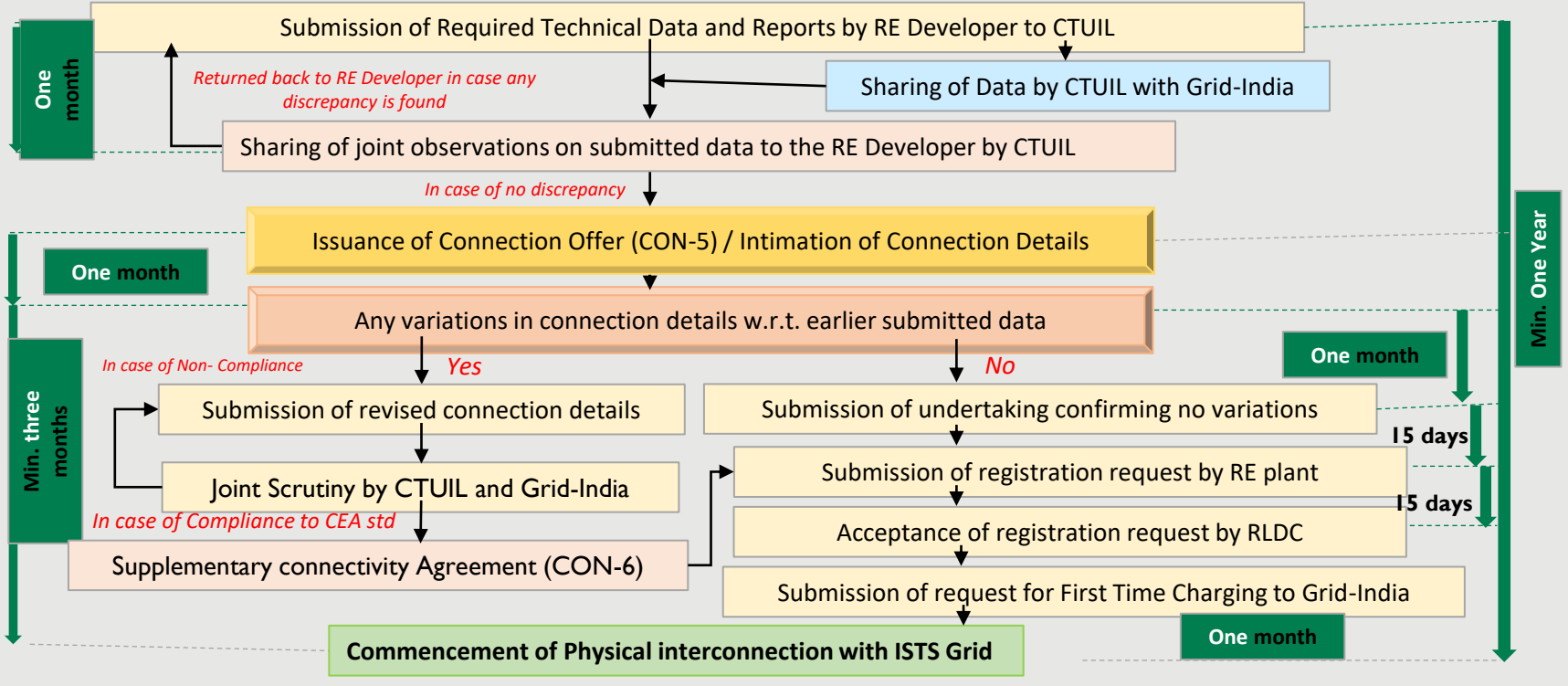
RE Generator - Grid Integration Process

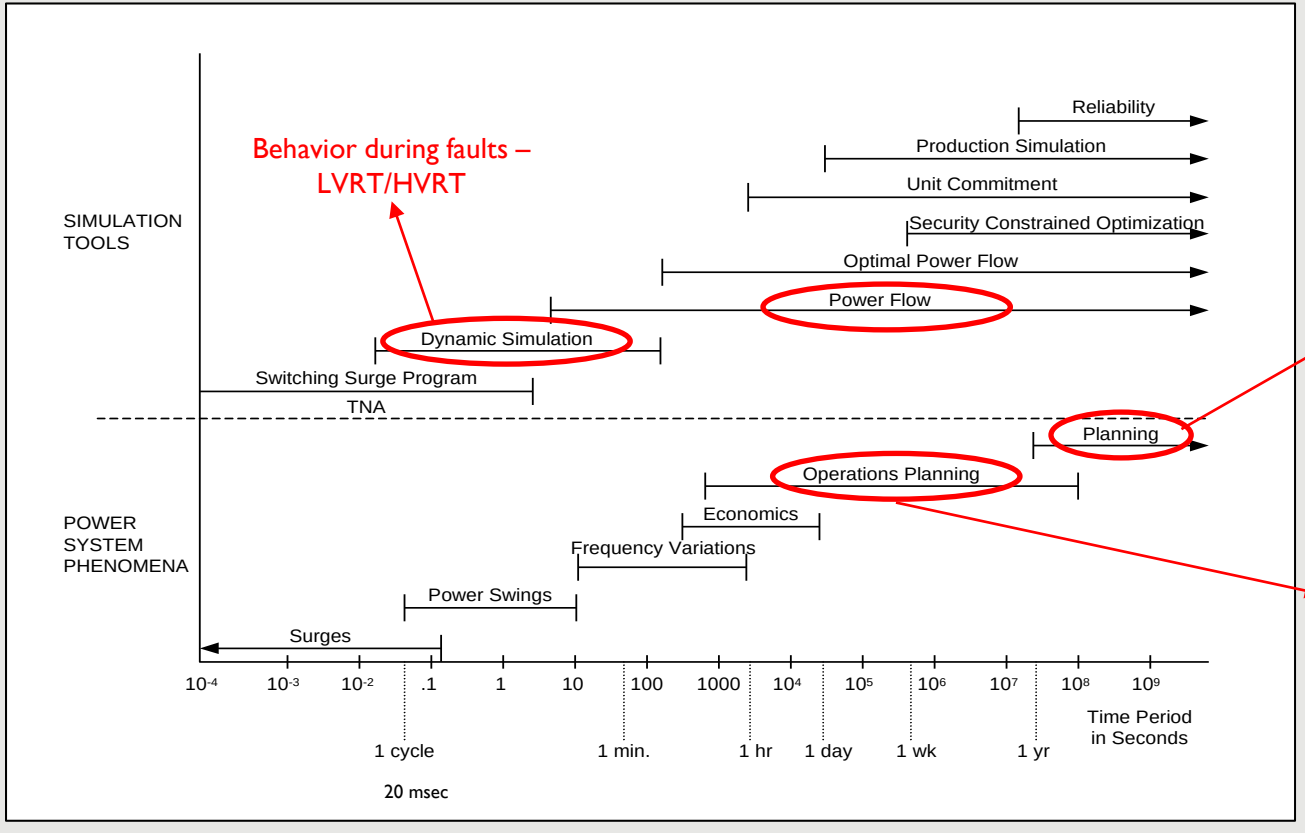


Technical Data Submission– Time Line



Power System Simulation – Timelines

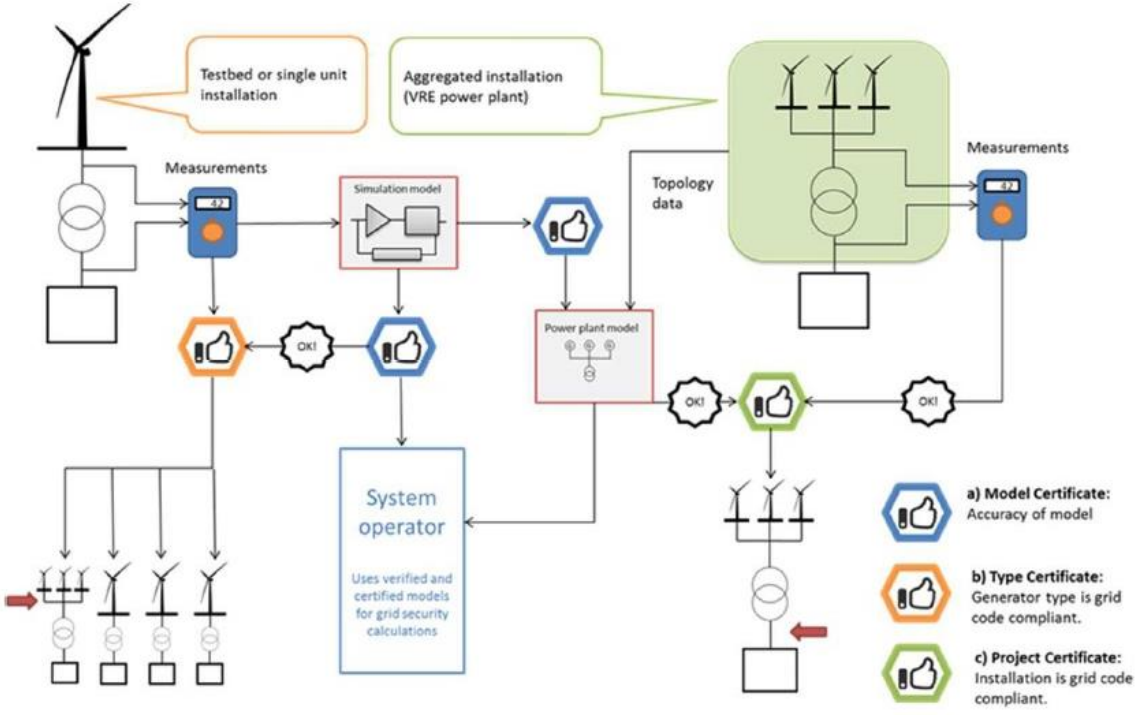
Validity of simulation models must for deriving accurate insights from simulation results



Transmission System Adequacy for Power Evacuation

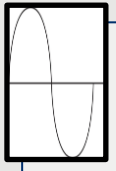
- Parameters (Line loading, Voltages etc.) within limits or not
- Reactive Power Support etc.

Model validation is needed to deal with 10.000s of generation units



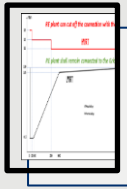
Credit: Thomas Ackermann, Energynautics

Test/Study reports for submission to Nodal Agency



Power Quality

- Harmonic Current Injection at POI
- DC Current Injection at POI
- Flicker injection at POI



Voltage ride through

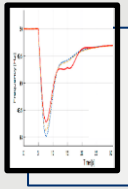
- To demonstrate ride through capability for balance and unbalanced faults (LVRT & HVRT)

Control Capability

- To show capability to control active power injection in accordance with a set point

Reactive Capability

- Reactive power capability (0.95 lag - unity - 0.95 leading) at rated output



Frequency Response

- Rated output for voltage (0.95pu -1.0 pu – 1.05 pu) and Freq. (49.5 Hz – 50.5 Hz)

Ramping Capability

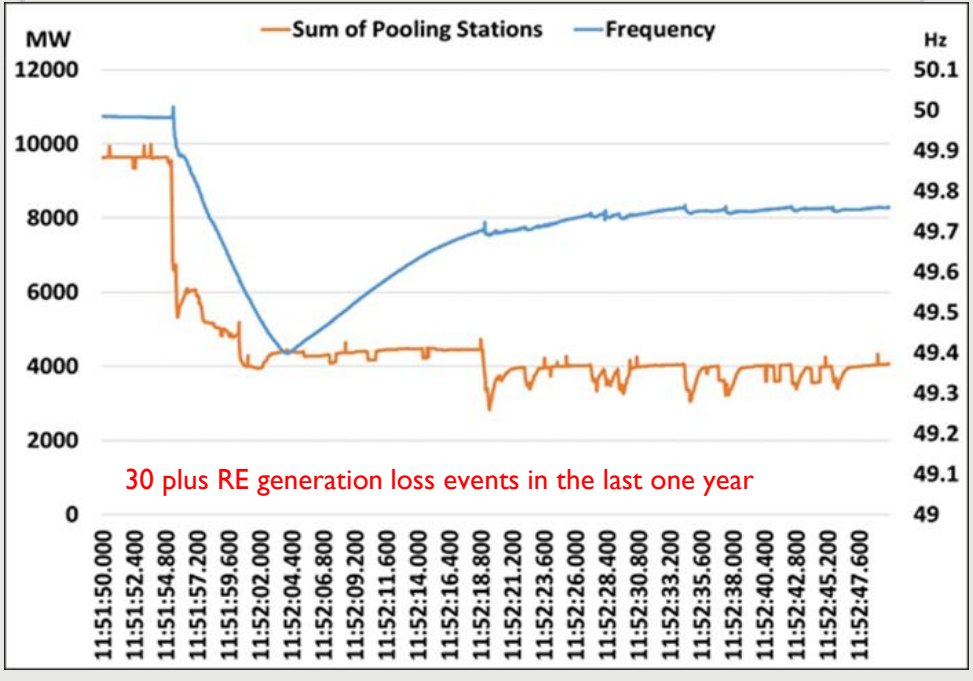
- Study analysis for rate of change of power output

Sharing of Data by CTUIL with Grid-India

Sharing of joint observations on submitted data to the RE Developer by CTUIL

India: Large Generation Loss Events in RE Complexes

Frequency dip due to ~7000 MW RE Generation Loss in Northern Region



Key Issues Identified

Non-compliance to specified CEA Standards

- Reactive Power Capability
- LVRT/HVRT Non-compliance

Issues in Post-event Analysis

- Non-availability Event Recording facility
- Exclusion of Ride-through incidents from Event Logging
- Delay in submission of Event Data

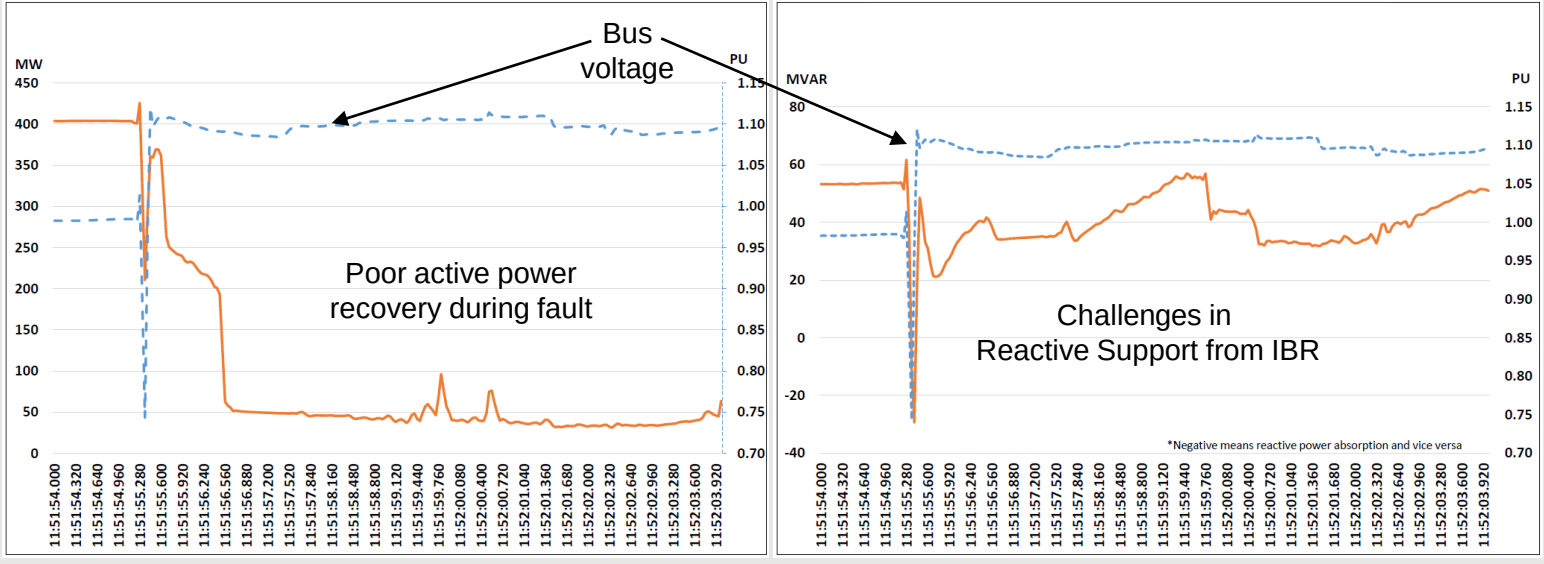
Incorrect Protection and Control Settings

- O/V Settings at 220/33 kV level/anti-islanding protection
- PPC in constant reactive power mode

Sanctity of Submitted Models

- Deviation in actual response of RE plants w.r.t simulation model response

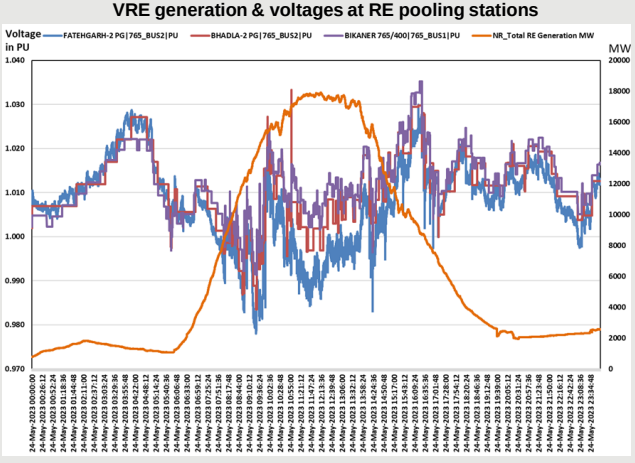
Challenges – Non compliance to Fault Ride Through



Low system strength coupled with inadequate reactive power support from IBRs during ride through conditions leading to high voltages post-fault clearance

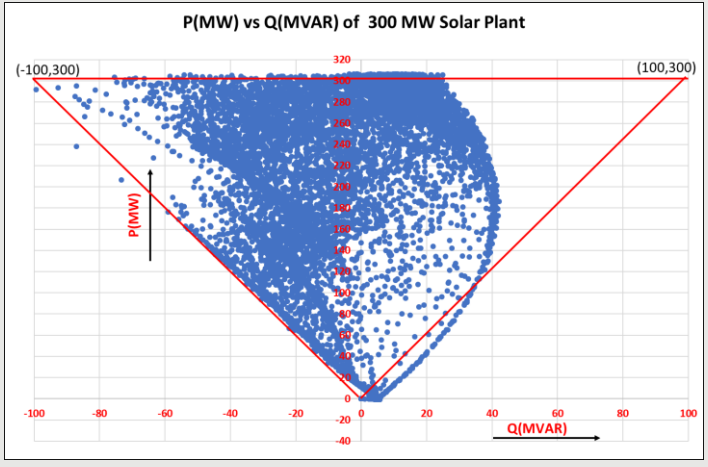
Response time of inverters during FRT also a concern

Challenges – Voltage Regulation at RE pooling stations



Large Fluctuation in Voltages (High v/s Low RE Period) – 8-10% voltage variation within same day

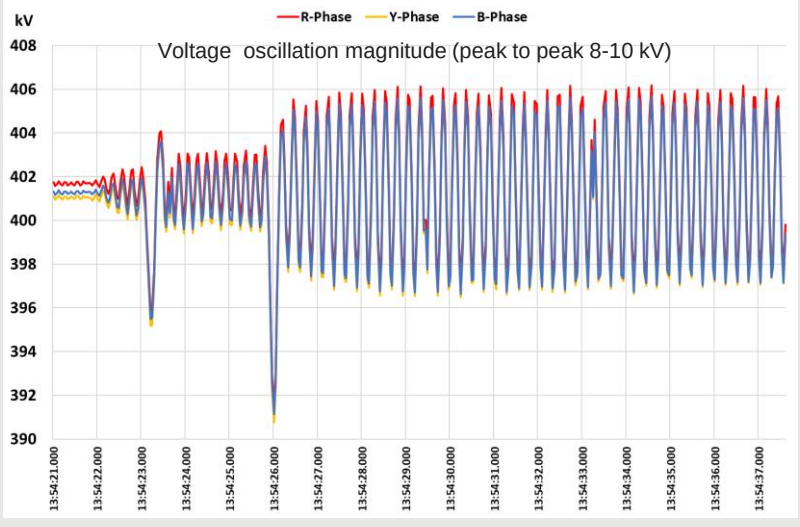
Several 765 kV lines opened daily for voltage regulation as last resort



Need for compliance to technical standards by RE plants – dynamic reactive support required to maintain power factor at POI between 0.95(lag) to 0.95(lead)

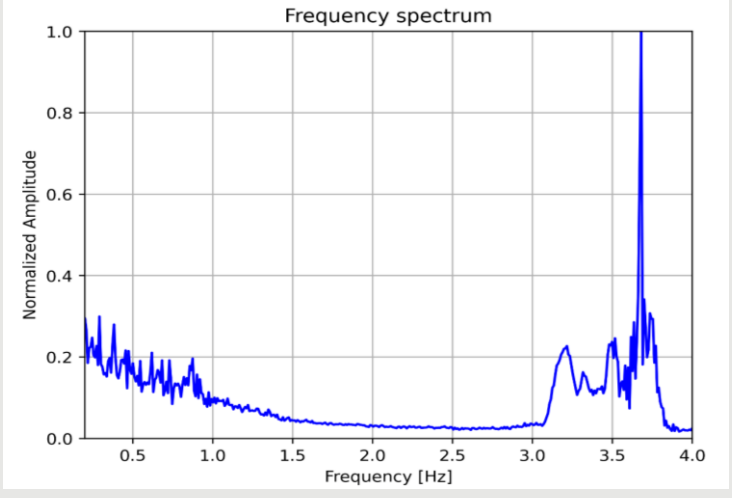
Challenges – Voltage oscillations in RE complex

Intermittent Forced Low Frequency Oscillations during solar hours

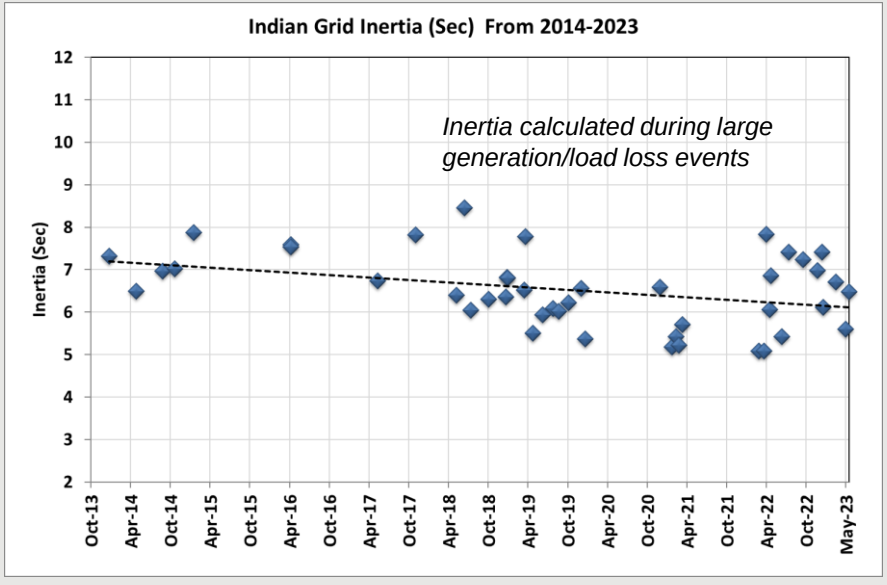


Dominant Modes

- 0.069 Hz
- 0.03 – 0.08 Hz
- 2.5 -5 Hz



Inertia in the Indian Power System



Local inertia may influence oscillatory modes and their damping

Xu, Jang & Overbye, Location-Dependent Impacts of Resource Inertia on Power System Oscillations, 51st Hawaii International Conference on System Sciences, 2018

System inertia on a decreasing trend

- Increasing penetration of non-synchronous generation
- Present levels of inertia not of particular concern

Indian Electricity Grid Code 2023

- Online monitoring of Inertia
- Minimum level of inertia to ensure frequency remains above UFLS threshold after reference contingency
- Synchronous generation to be quick started to maintain minimum inertia
  - Including curtailment of renewables

https://cercind.gov.in/Regulations/180-Regulations.pdf

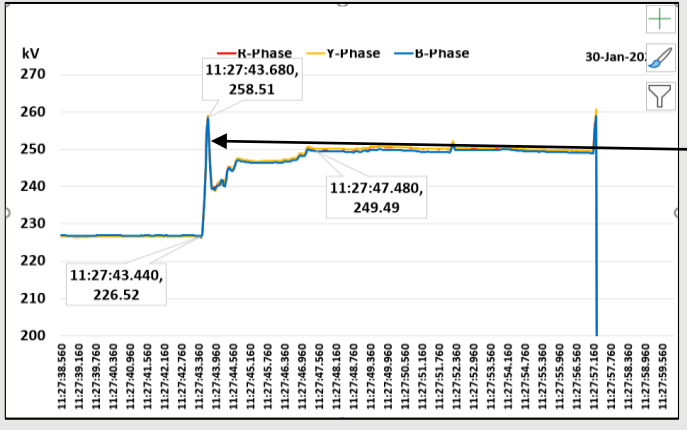
Challenges – Low Short Circuit level at RE pooling stations

SCR of ISTS RE pooling station						
Region	Voltage level	Station Name	3-ph fault current (kA)	3-Ph fault MVA	Generation being pooled (MW)	SCR
NR	220	Fatehgarh-II_A	20	7483	2651	2.8
	400	Fatehgarh-II	19	13082	4822	2.7
	220	Bhadla	31	11770	3130	3.8
	220	AREPRL	13	5103	1406	3.6
	400	Bikaner	25	17436	3215	5.4

Large change in voltages during switching of network elements

Inverter controls may not function in stable manner under low system strength conditions, increasing chance of undesirable behavior and control interactions.
NERC Whitepaper on short circuit modeling and system strength

Further reduction in SCR during network depletion



Switching of 240 MVAR Line reactor

Depleted network before event

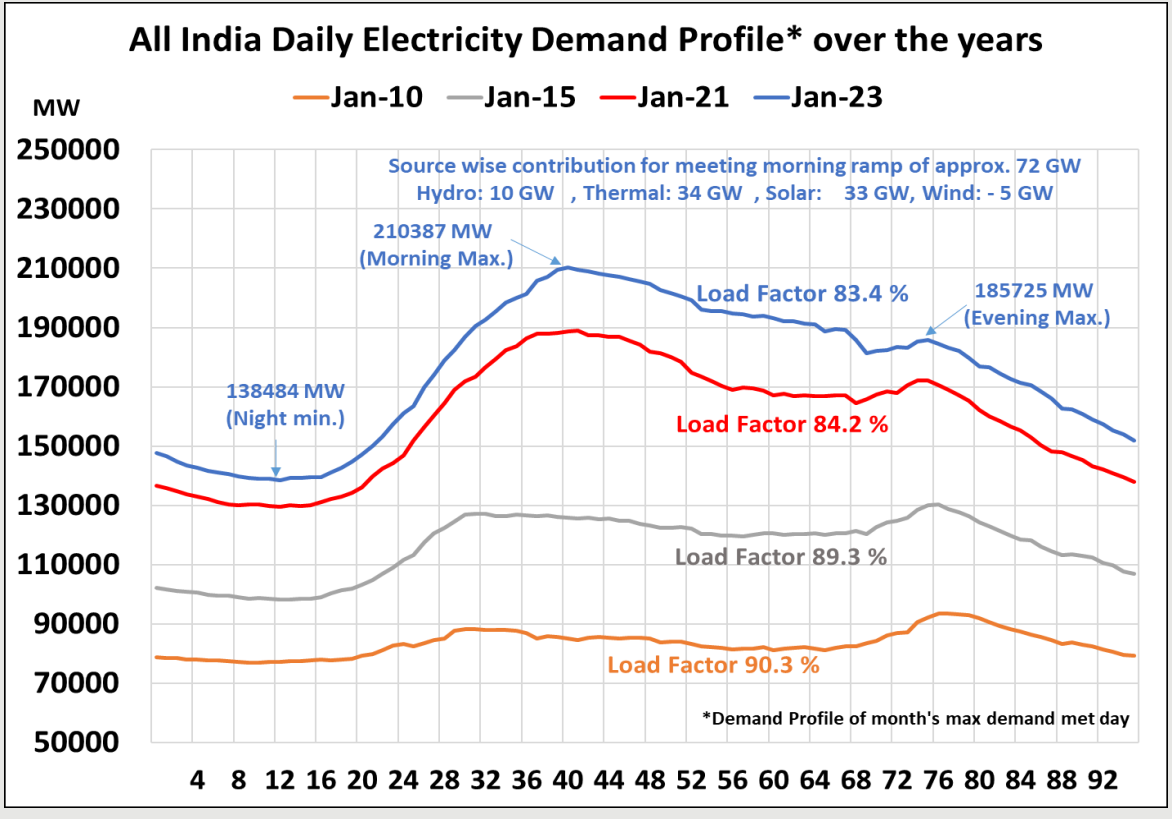
32 kV Voltage rise in phase to neutral

EHV Lines tripped on Overvoltage

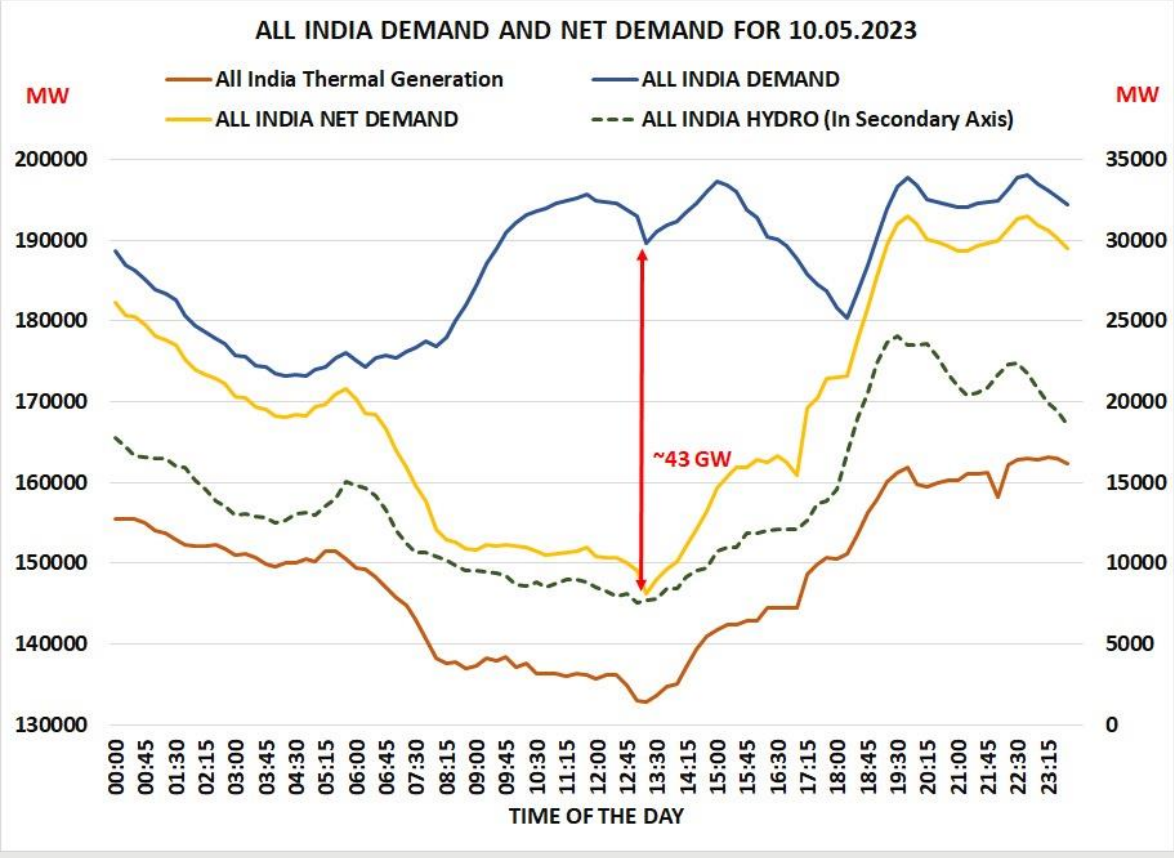
Triggered HVRT and consequent loss of 2000 MW generation

Several incidents of RE generation loss due to large voltage fluctuations during faults and LVRT/HVRT non-compliance

Changing load shape



Flexibility – Growing Need

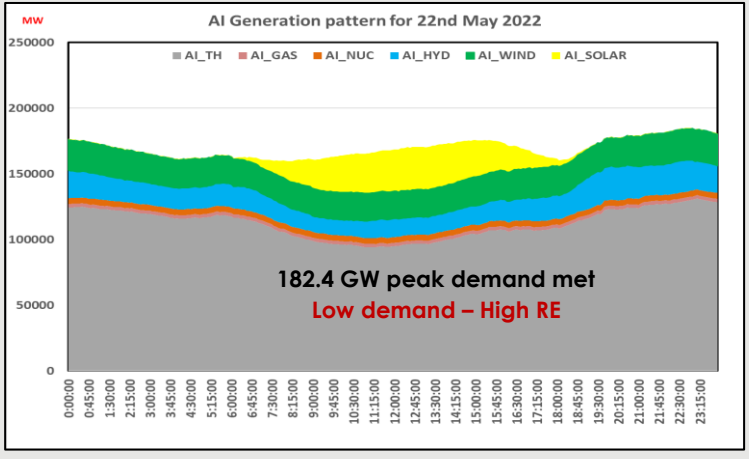


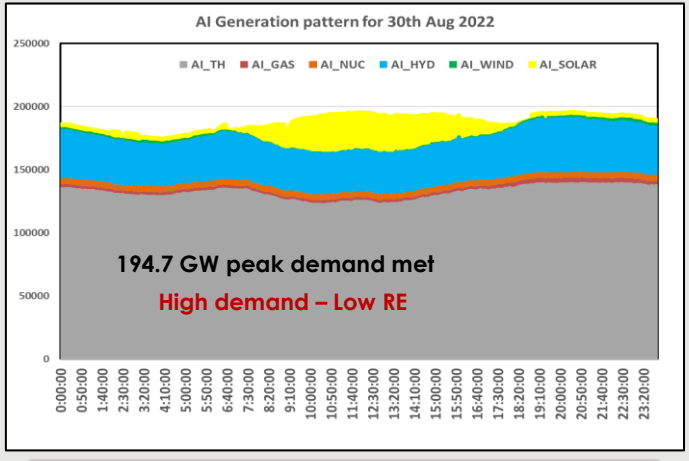
Major Concerns

- Increasing "Duck Curve" Belly
- Increasing difference b/w Max. and Min Demand
- Issues in absorbing additional RE (solar) beyond a certain quantum
- Storage + Reduction in Minimum Operational Level of both inter & intra state coal-fired plants required
- Improvement in 1% ramp rate of coal-fired plants

Resource Adequacy to be ensured in all Time-Frames

- Resource Adequacy Challenges due to the variability of RE
- Reserve requirements and system constraints would also vary

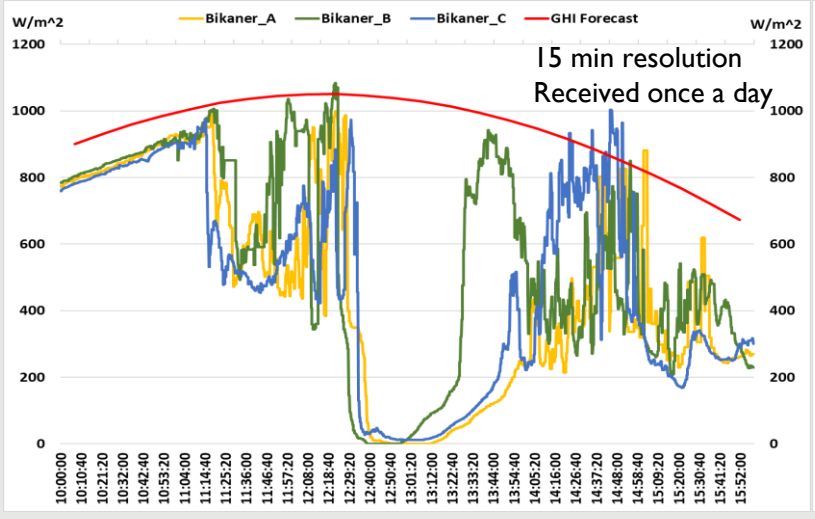


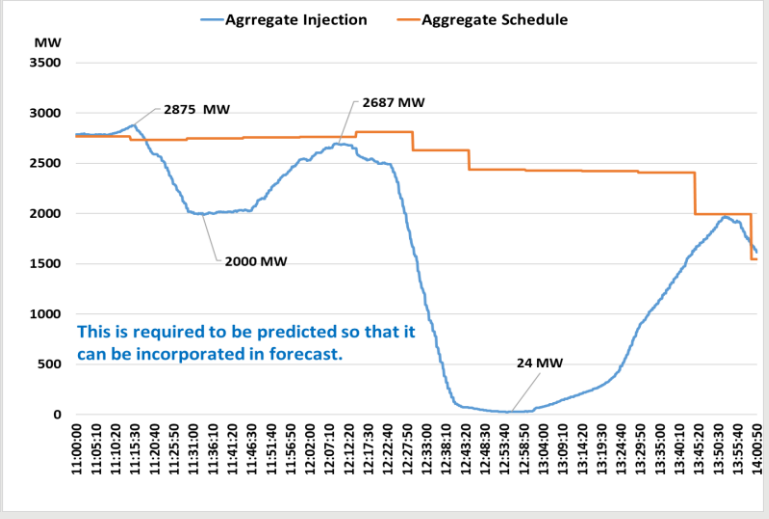


Highest Instantaneous RE penetration (in Q1 FY 2022-23) of ~31.8 % was recorded on **22nd May 2022 (Sunday)**

Lowest wind generation (34.8 MU) in entire calendar year* was recorded on **30th Aug'22 (Tuesday)**

RE forecasting challenge

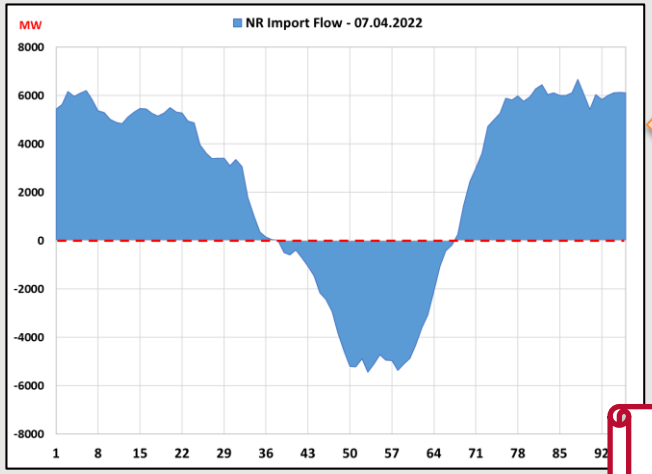




- Dust storm and cloud cover over Bikaner area during 1115 to 1400 hrs on 06th June 2023
- Large variation in GHI
  - 1000 W/m^2 at 1115 hrs to almost 500 W/m^2 by 11:30 hrs.
  - GHI recovered by 12:00 hrs and then reduced almost to zero by 12:50 hrs.

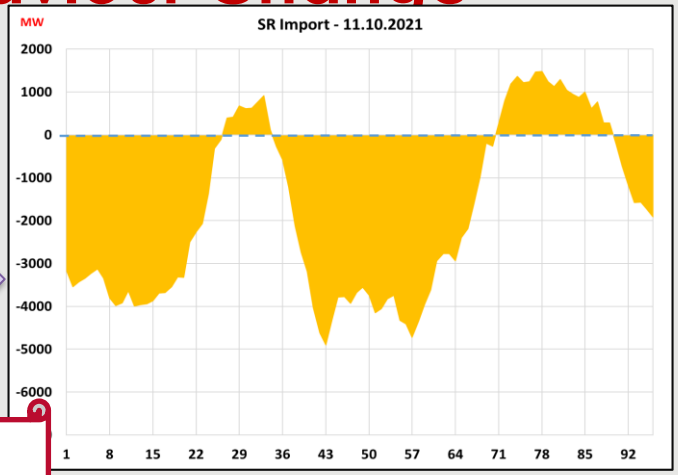
- Before 1115 hrs: Forecast error = Negligible
- 11:15 to 11:30 hrs : Maximum forecast error = - 875 MW
- 12:10 to 12:54 hrs : Maximum forecast error = - 2650 MW

Transmission Flows – Behaviour Change

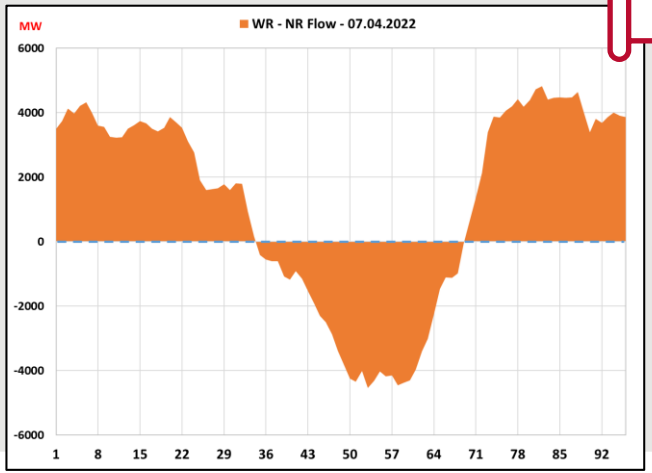


NR Import

SR Import

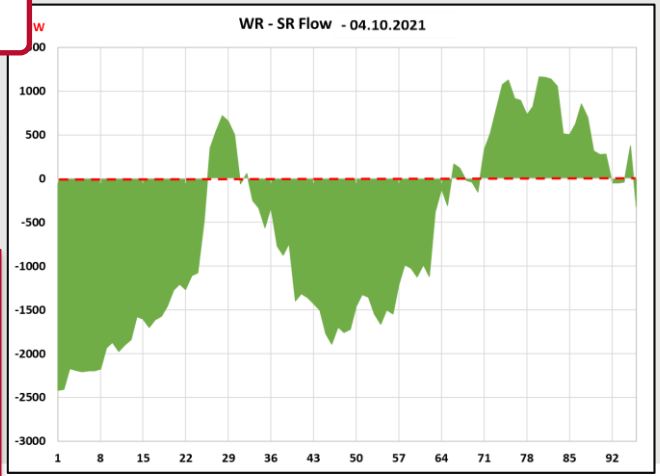


Bi-directional Flows The New Normal !!



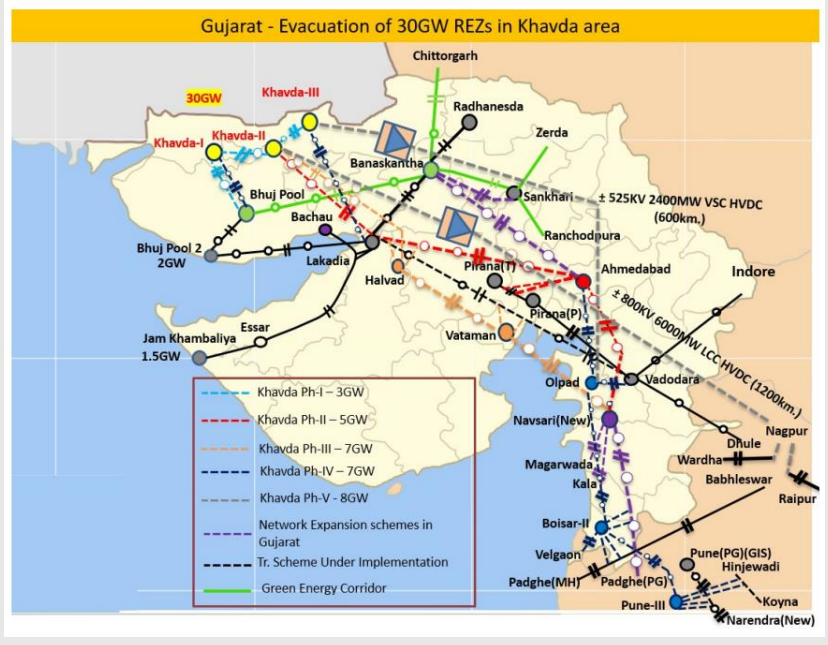
WR -SR

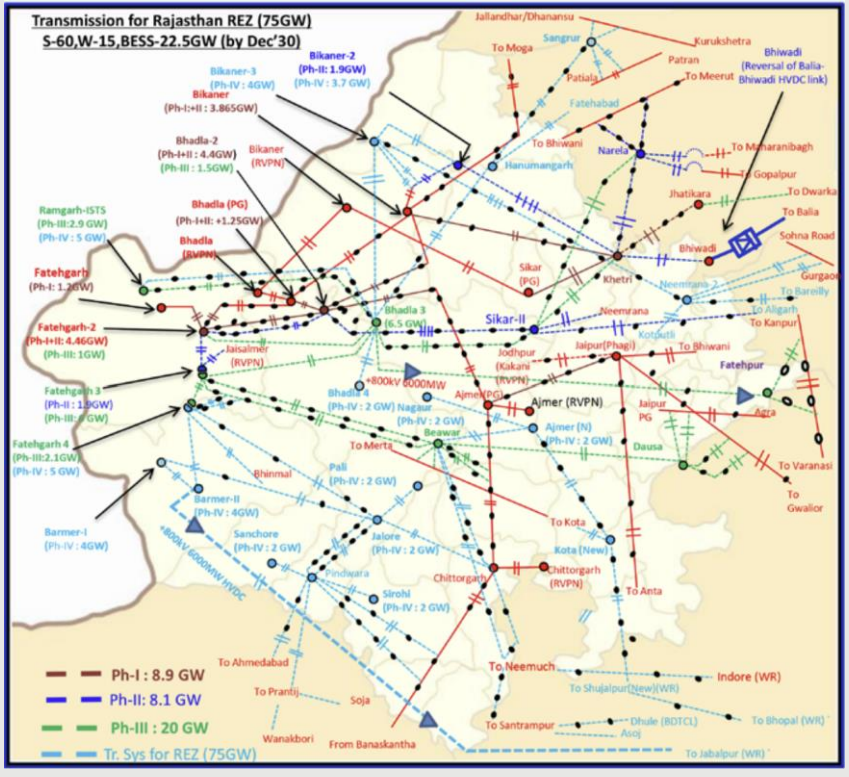
WR - NR



Large Diurnal and Seasonal Variation in IR Flows

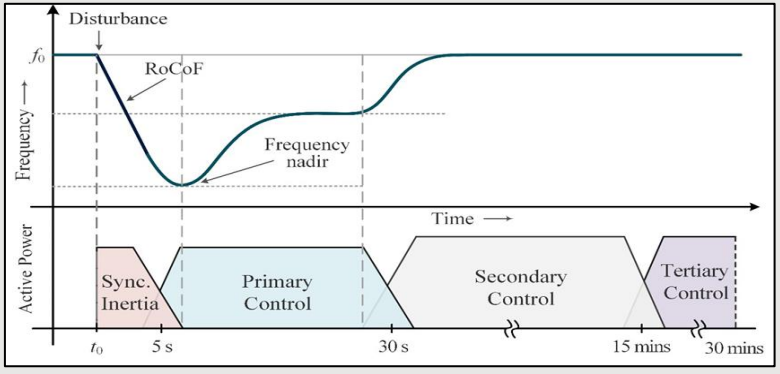
Requirement of Look Ahead Transmission Planning





Innovative Solutions for Grid Stability – VSC Based HVDC, RE + Storage, FACTS Devices, Synchronous Condensers etc.

System Balancing Continuum



Reserve	Start of activation	Full Availability/ deployment	Ability to sustain the full deployment	Providers
Primary Response (Automatic)	Instantaneous after frequency crosses dead band	Within ~~30 sec~~ *45 sec*	5 min	All generators, Energy Storage
Secondary Reserve Ancillary Service (Automatic)	Within 30 sec	Within 15 Min	30 min or till replaced by Tertiary Reserves	All generators, Energy Storage, DR
Tertiary Reserve Ancillary Service (Manual)	Within 15 Min		60 min	All generators, Energy Storage, DR

Reserve Estimation, Planning and Procurement

- Year-ahead
- Three day-ahead

Resource Adequacy/LGBR

Operational planning/Unit Commitment

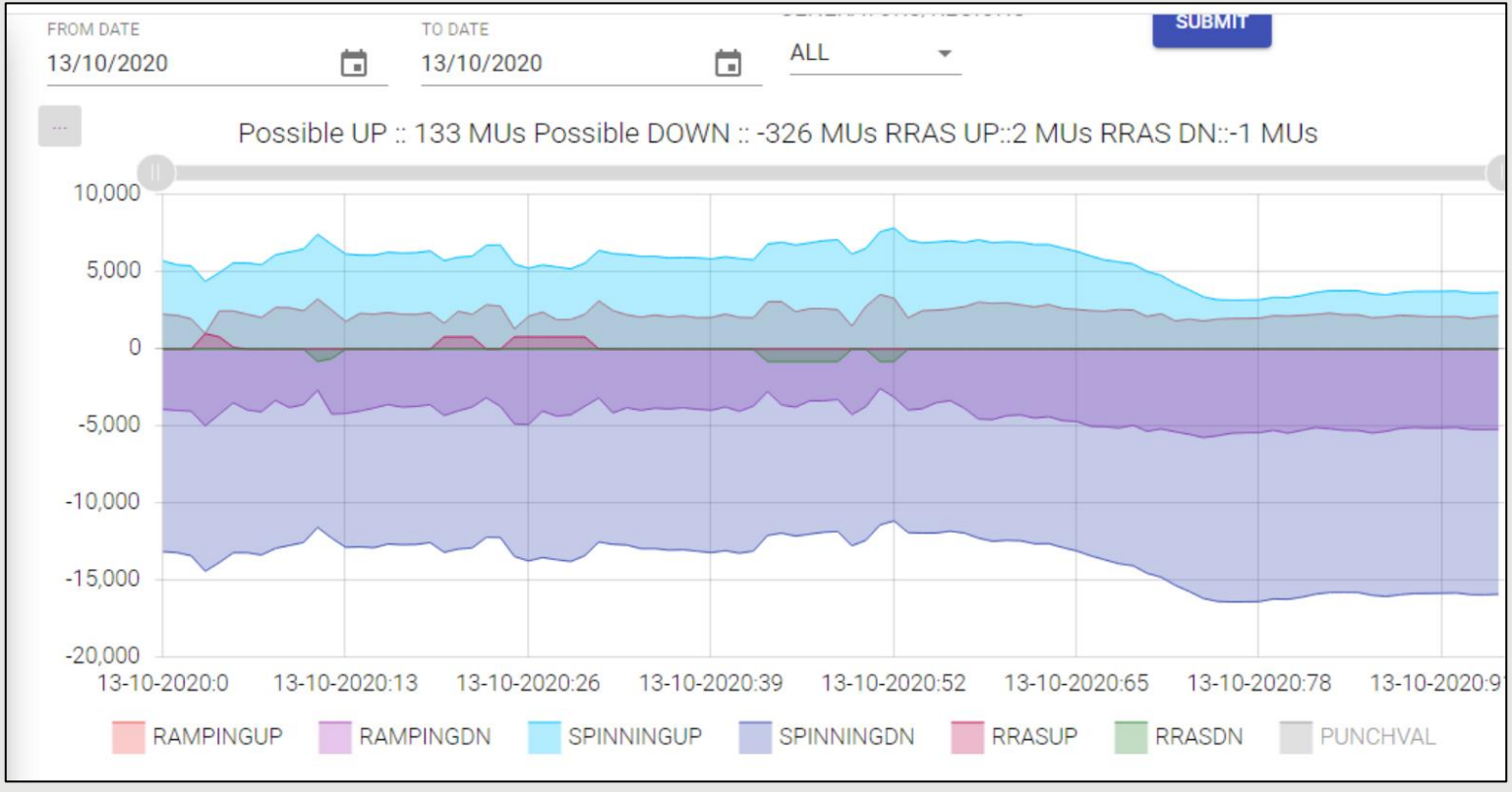
- Day-ahead
- Intra-day

Reserve Procurement (DAM-AS)

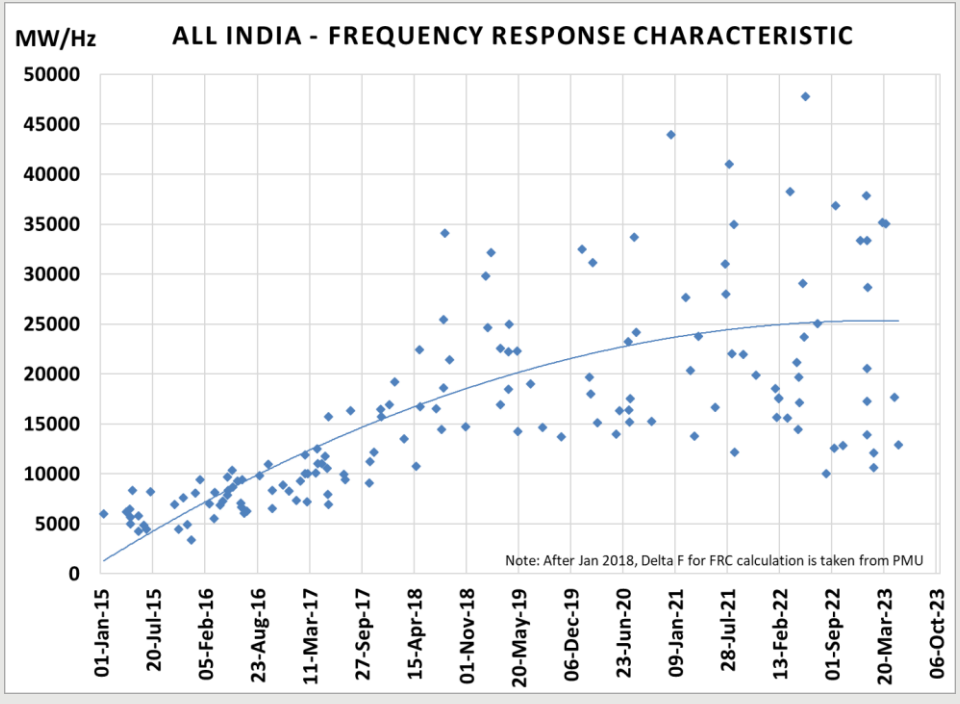
Incremental Procurement (RTM-AS)

Type of reserve	Inter-state level MW	Intra state level MW	Total All India level MW
Secondary	3788	3211.6	7000
Tertiary	3788	8887.6	12676
Total	7576	12099.2	19676

Visualization of Reserves



Primary Response



- First line of defence following disturbance
- Mandatory service in most systems worldwide

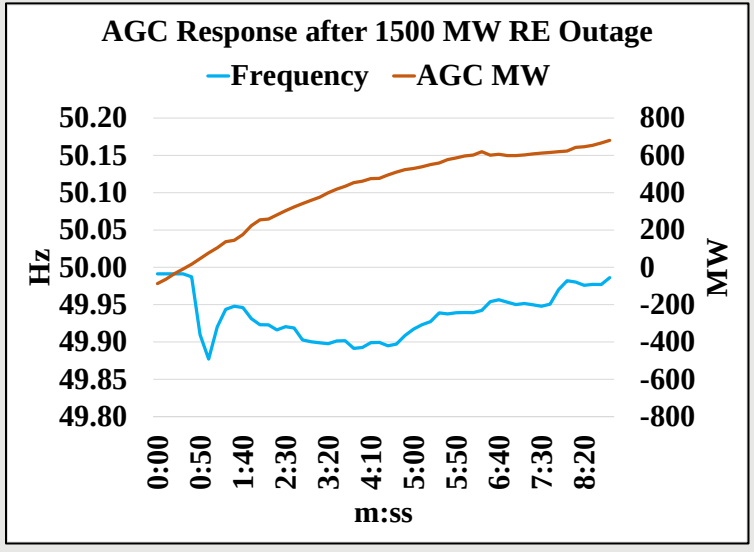
FRC- Quantifies response from generators following disturbance

Consistent improvement in primary response over the years

- **Testing of primary response in India started for the first time on 23rd September 2020**
- **By Nov 2023, testing has been completed at 218 number of units with 72 GW generation capacity.**

Automatic Generation Control – balancing system with high RE

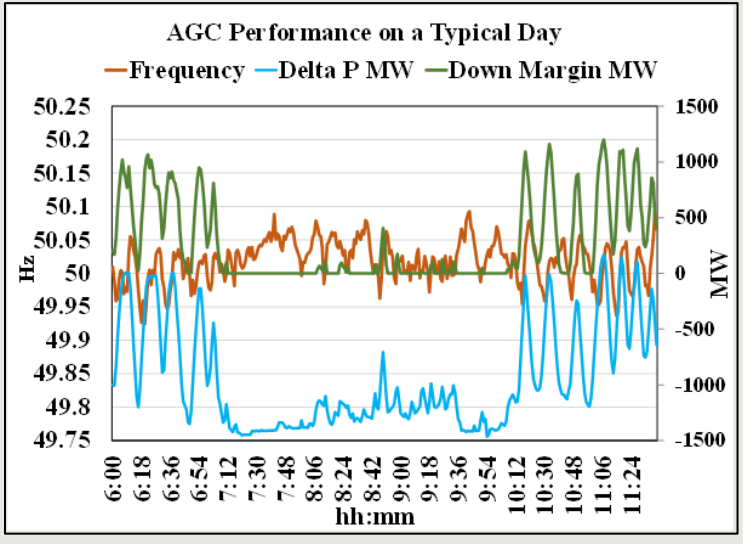
Support during RE generation loss events



During contingencies like generation loss or load loss, AGC quickly reacts by changing the load set points of the generators under remote and thereby helps in driving frequency to 50 Hz.

Load following during RE generation ramping

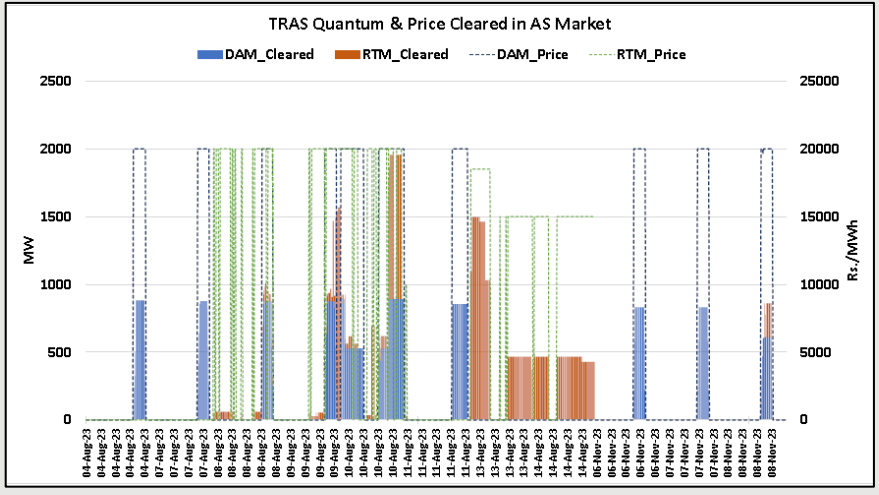
~ AGC helps in controlling high frequency during such solar pickup periods.



Maximum Up and down regulation up to +/-2000 MW in response to frequency changes - available reserves fully utilised

Interest towards intra-state AGC expressed by **Maharashtra, West Bengal, Uttar Pradesh, Delhi & Haryana**

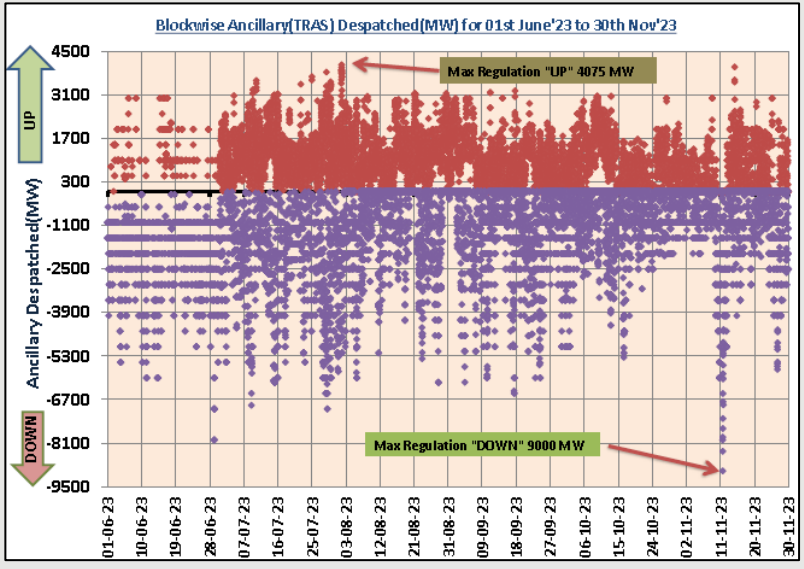
Frequency Control with Tertiary Reserves Ancillary Services



TRAS implemented from 1st June 2023 onwards

Bids for TRAS received only on 11 days since 1st June '23

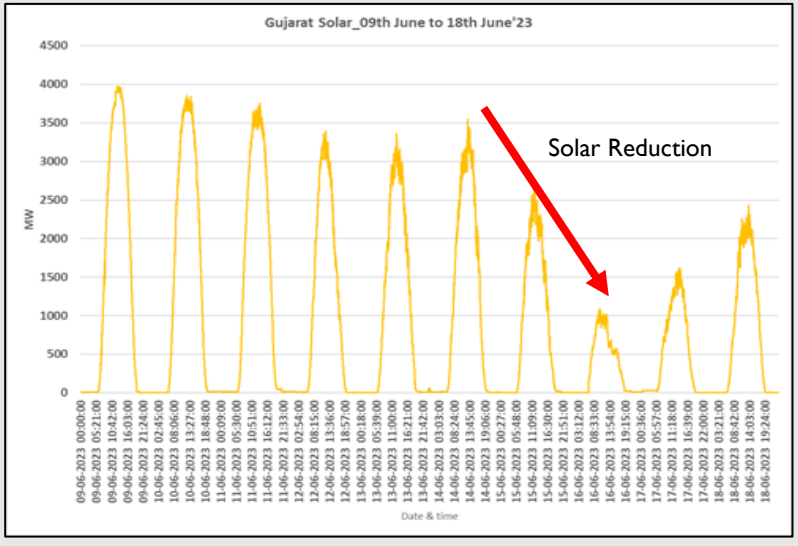
Need to enhance participation of generators, especially at intra-state level for providing reserves

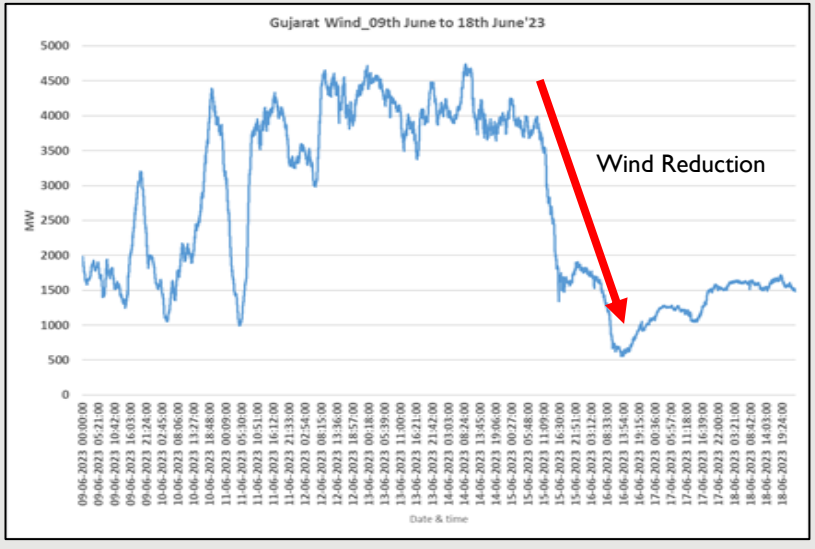


Shortfall TRAS being dispatched from unrequisitioned capacity of ISGS

Constraints in reserve availability, especially in up reserves during non-solar hours

Grid Resilience – RE Generation during ‘Biparjoy’ Cyclone ~ 09 June to 18 June ‘23

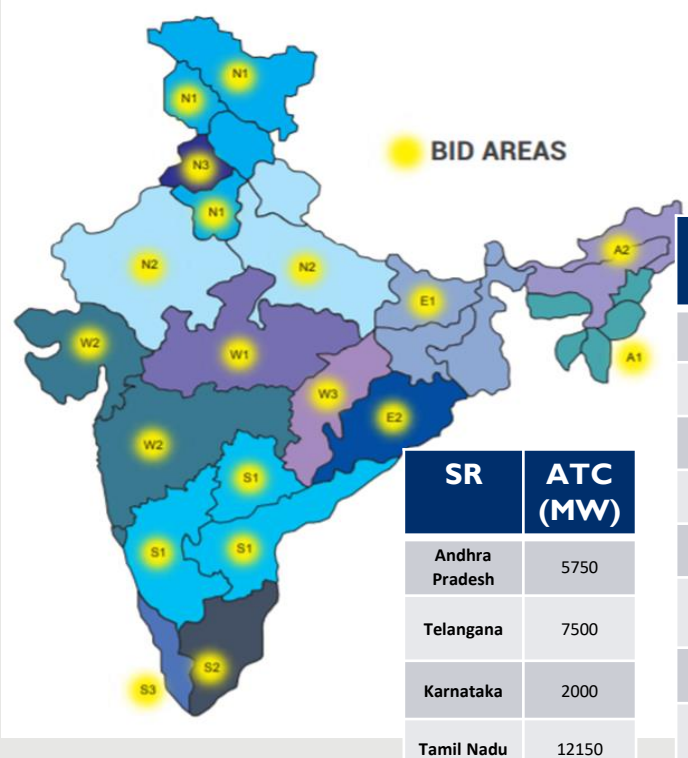




Prolonged outage of RE generation facilities for maintenance check post cyclone

General Network Access (GNA) : Congestion Management

- Assessment and declaration of total transfer capability (TTC), available transfer capability (ATC), Transmission reliability margin (TRM) of all States/Regions - 11 months in advance, multiple scenarios
- All states to be configured as bid areas under GNA regime
- Coordination for transmission line outages to facilitate infrastructure (highway, railway etc.) augmentation



SR	ATC (MW)
Andhra Pradesh	5750
Telangana	7500
Karnataka	2000
Tamil Nadu	12150
Kerala	3860

NR	ATC (MW)
Punjab	9000
UP	15500
Haryana	8850
Rajasthan	7000
Delhi	7000
Himachal Pradesh	1300
Uttarakhand	1600
Jammu & Kashmir	2800
Chandigarh	380

WR	ATC (MW)
Maharashtra	9760
Gujarat (00:09 Hrs & 17:24 Hrs)	12450
Gujarat (09:17 Hrs)	12050
Madhya Pradesh	12118
Chattisgarh	3536
Goa	695

ER	ATC (MW)
West Bengal	6826
Sikkim	175
Odisha	3698
Jharkhand	1811
Bihar	7419
DVC	1692

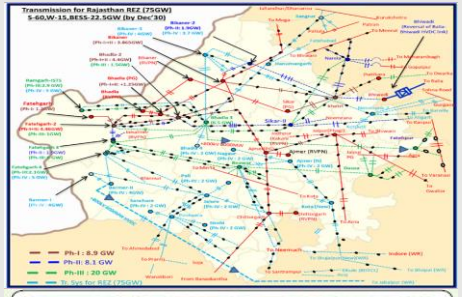
NER	ATC (MW)
Arunachal Pradesh	315
Assam	1710 (00 - 17 & 21-24 hrs) 1660 (17-21 hrs)
Manipur	305
Meghalaya	320 (00 - 17 & 21-24 hrs) 240 (17-21 hrs)
Mizoram	150 (00 - 17 & 21-24 hrs) 140 (17-21 hrs)
Nagaland	285 (00 - 18 & 22-24 hrs) 290 (18-22 hrs)
Tripura	329 (00 - 18 & 22-24 hrs) 304 (18-22 hrs)

Congestion management during transition phase

"Transmission System for Integration of over 500 GW RE Capacity by 2030"

Source: Central Electricity Authority, 2022

- Major upcoming non-fossil based generation centres -Fatehgarh, Bhadla, Bikaner in Rajasthan, Khavda in Gujarat, Anantapur, Kurnool RE Zones in Andhra Pradesh, offshore wind potential in Tamil Nadu and Gujarat, and RE parks in Ladakh by 2030.
- Addition of 8,120 circuit-km (c-km) of High Voltage Direct Current (HVDC) transmission corridors (+800 kV and +350 kV), 25,960 c-km of 765 kV AC lines, 15,758 c-km of 400 kV AC lines and 1,052 c-km of 220 kV AC lines.
- Evacuation of 10 GW of offshore wind capacity located in Gujarat and Tamil Nadu.



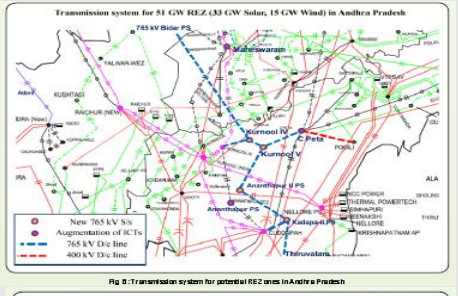


Fig 8 : Transmission system for potential REZ ones in Andhra Pradesh

Fig8: Transmission system for off-shore wind potential zones in Tamil Nadu

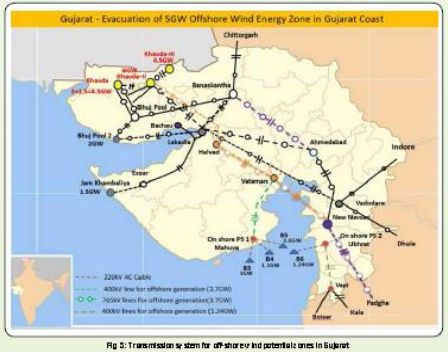
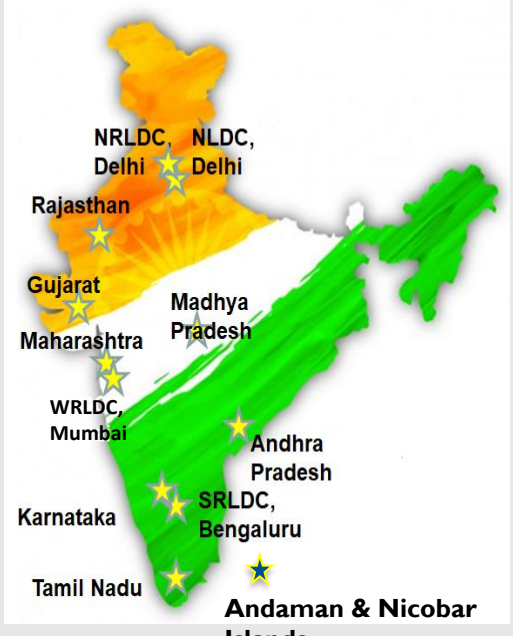


Fig 5: Transmission system for off-shore wind potential zones in Gujarat

Renewable Energy Management Centre (REMC)

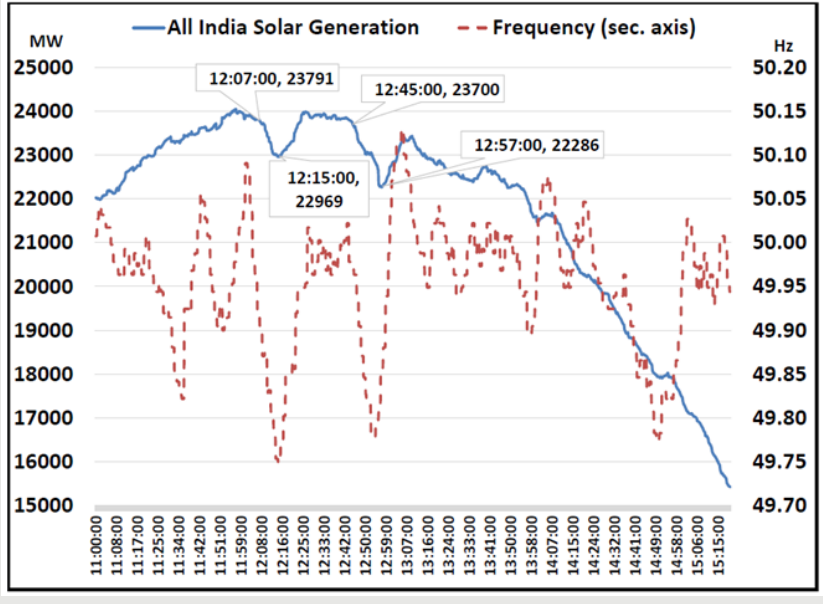
Real-time Monitoring, Visualization and Situational Awareness of Renewables



- 13 REMCs (State/Regional/National): Co-located with LDC
- ~ 100 GW of wind and solar monitored through 11 REMCs
- ~ 25 GW+ scheduling at Inter-State level

Cloud cover events

Approx. 800 MW reduction in solar generation in 8 minutes and restoration in 13 minutes



Large Generation Loss in RE Pocket: Way Forward

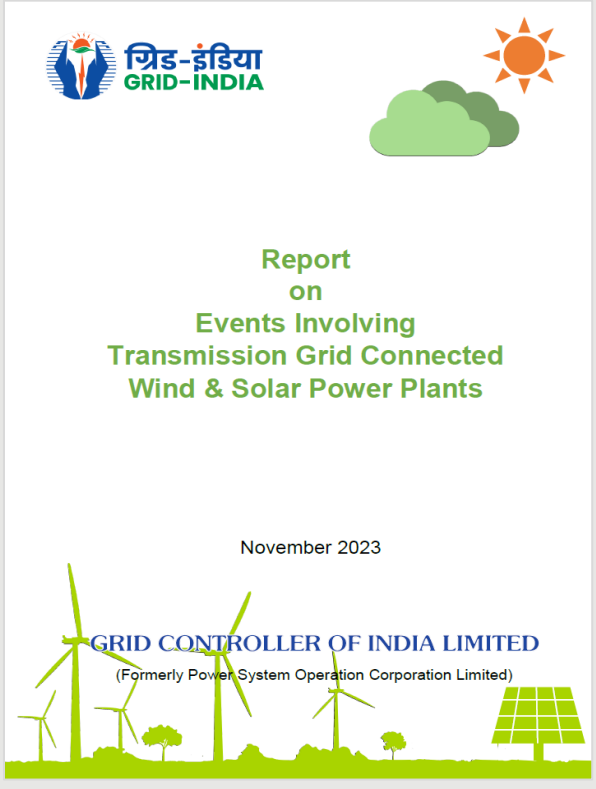
1. **RE Original Equipment Manufacturers (OEM)**
   - Equipment design to handle supply of rated MW, and required MVAR
   - Equipment customization for ambient conditions in India
   - High resolution recording instruments

2. **RE Developers**
   - Type testing, model validation, time submissions of model data
   - Configuration of converter & plant controls to reflect realistic conditions
   - Protection of Inverter/WTG terminal and co-ordination with POI
   - Sharing of High-resolution disturbance records
   - Compliance to Cyber Security Guidelines

3. **Strengthening of Technical standards**
   - Construction standards for Renewable facilities
   - Standards for new facilities – BESS, Electrolysers
   - Short Circuit Ratio
   - Enforcing compliance

4. **Institutional Capacity Building**
   - Strengthen Ecosystem for testing and type certification of RE based resources
   - Agencies within India need to be developed and accredited by CEA/NIWE/NISE for testing and certification
   - Human resource development for personnel in renewable energy sector

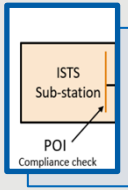
31 events involving RE generation loss of > 1000 MW between Jan 2022 to March 2023: Challenge in Future: Short Circuit Level, System Inertia, Dynamic VAR Support



Link: https://posoco.in/report-on-events-involving-transmission-grid-connected-wind-solar-plants-2/

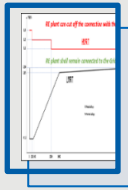
CEA Technical Standards for Connectivity to the Grid

Technical requirements specified for Wind and Solar Generating Stations in CEA Connectivity Standards

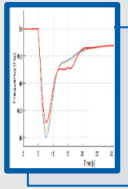


Interconnection Point / Point of Interconnection

Reactive Capability test



Voltage Ride Through Requirement (Low/High)

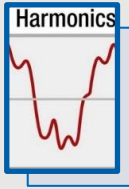


Frequency Response

Active and Reactive Power - Set Point Control

Design Requirement – Weather, Temperature Extremes etc.

Ramping Capability



Power Quality Requirements

Clean Energy Transition – Way Forward

S. No.	Voltage & Frequency Support	New behavior of the Power System
1.	Increasing Rate of Change of Frequency (RoCoF)	Identifying power system restoration services near RE rich areas
2.	Decreasing nadir frequency	Reduced fault currents, LCC commutation failures, Fault ride through failures etc.
3.	Excessive frequency deviations	Decreased damping
4.	Static reactive power balance	Resonances due to cables and PE
5.	Dynamic reactive power balance	Sub-synchronous control interaction
6.	Larger voltage dips	Control of bi-directional flows
7.	Ramp management / Flexibility	
8.	Portfolio management, day-ahead resource adequacy, unit commitment	
9.	Estimation of generation reserves	

Bulk of essential reliability services such as inertia, frequency and voltage control, system restoration support, power oscillation damping, short-circuit power, etc. being provided by conventional generation sources

With transition to a high renewables system, VRE plants need to be equipped to provide these essential grid services

RE Integration – Way Forward

Perspective Transmission Plan for next 10 years on a rolling basis

Measures for Enhancing Resiliency

Measures to address reduction in System Inertia, Short Circuit Levels

Innovative Solutions – VSC HVDC, SynCons, RE + Storage etc.

Increasing cross-border footprint

Transmission Planning

Standards & Regulations - Strengthening

Development of Field-Testing Facilities

Availability of Accurate Model Data

Regular Strengthening of Extant Standards
(Grid Forming, MRT Capability etc.)

Standards for BESS, DERs and Grid Forming Capability of Inverters

Development of Test Procedures

Strict Adherence to Specified Standards

RE Integration – Way Forward

Energy Storage – Timely Implementation

Reduction in Minimum Operational Level of both Inter & Intra state Coal-fired plants

Improvement in Ramp Rate of coal-fired plants

Metrics for Measurement and Remunerating Flexibility services

Valuation of Hydro Flexibility

Resource Adequacy and Flexibility

Frequency Control and Reserves

Estimation of Generation Reserves

Participation of plants in providing all type of Reserves

Frequency Control Services by RE Plants and BESS

Sharing of Responsibility by all Control Areas to provide Reserve Response

Demand Response

Prof Janusz Bialek Quotes

- Prof Janusz Bialek in his Nov 2014 posting on PowerGlobe while discussion on Bangladesh blackout.

"Generally, it is worth noting the obvious that blackouts happen even when (N-1) contingency rule is obeyed but more than one element fails. However N is quite general as power system is a complicated large-scale cyber-physical system so N contains not only power equipment failures (which are relatively easy to understand and deal with) but also people, communication, markets, other infrastructures (e.g. gas), weather and anything else that influences power system operation. Analysing those dependencies is fascinating and requires an interdisciplinary approach combining efforts of engineers, mathematicians, physicists, computer scientists, social scientists and economists. Concentrating only on power engineering is so much last-century…'

- *From 'known unknowns' to 'unknown unknowns'…….Jan 2020*

Thank You

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