ERRA
21st Annual Conference
Energy Regulators Forum
CO-LOCATED WITH FGA

Organised By ERRA

Hosted By NNW ERC

Energy Regulatory Commission
Office of the Energy Regulatory Commission

Session: The way forward for reliable operation of the power system with high variable renewables penetration in the Indian grid

R. K. Porwal, Director (System Operation)
Grid Controller of India Ltd.

Indian Grid…One of the World's Largest

Brazil | ONS
California | CAISO
China | CSG / SGCC
France | RTE
Gulf States | GCCIA
India | GRID-INDIA
Italy | Terna
Japan | TEPCO
Russia | SO UPS
South Africa | Eskom
South Korea | KPX
U.S.A | MISO / PJM Interconnection

Source: GO15

Renewable Capacity Addition > 13% CAGR since 2017

1 national synchronous grid

electricity generation

3 electricity consumption

installed generation capacity

transmission system

4 wind generation

solar generation

6 hydro generation

10 pumped storage capacity

Dimensions of Indian Power System

~442 GW
generation capacity

3.2 million km²
area footprint

240 GW+
peak demand

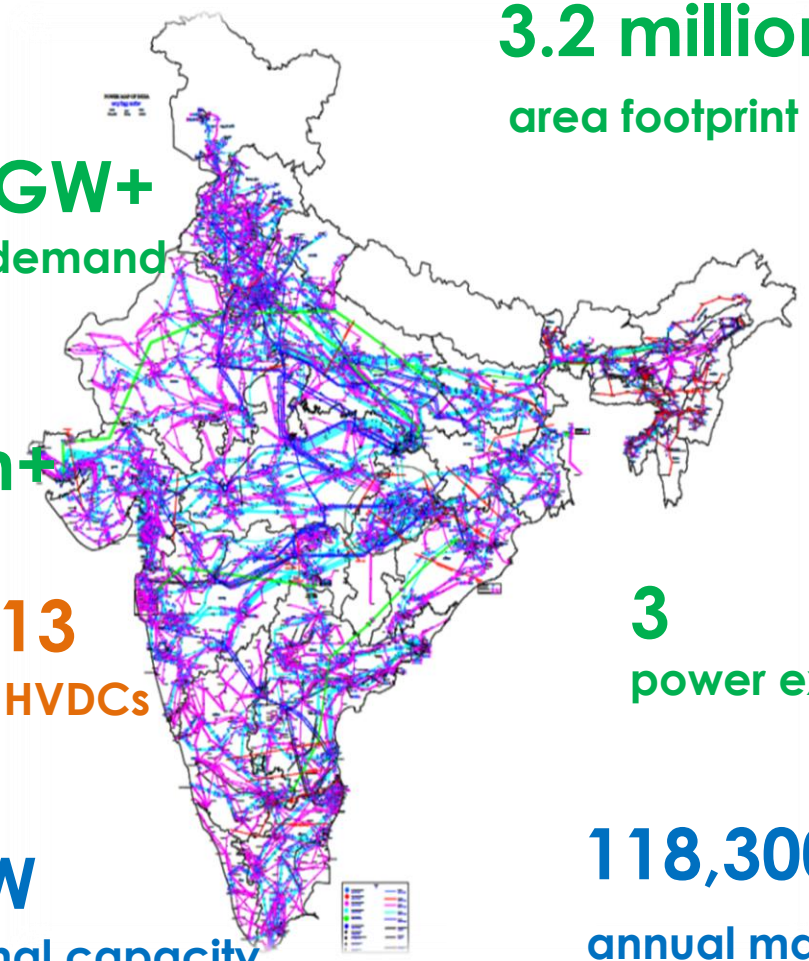
1.4 Billion+
people served

> 5.3 TWh
daily energy met

4.5 GW+
international exchanges

471817 ckm+
EHV transmission

171 TWh+
annual market trades



~191 GW
renewables
(including large Hydro)

13
HVDCs

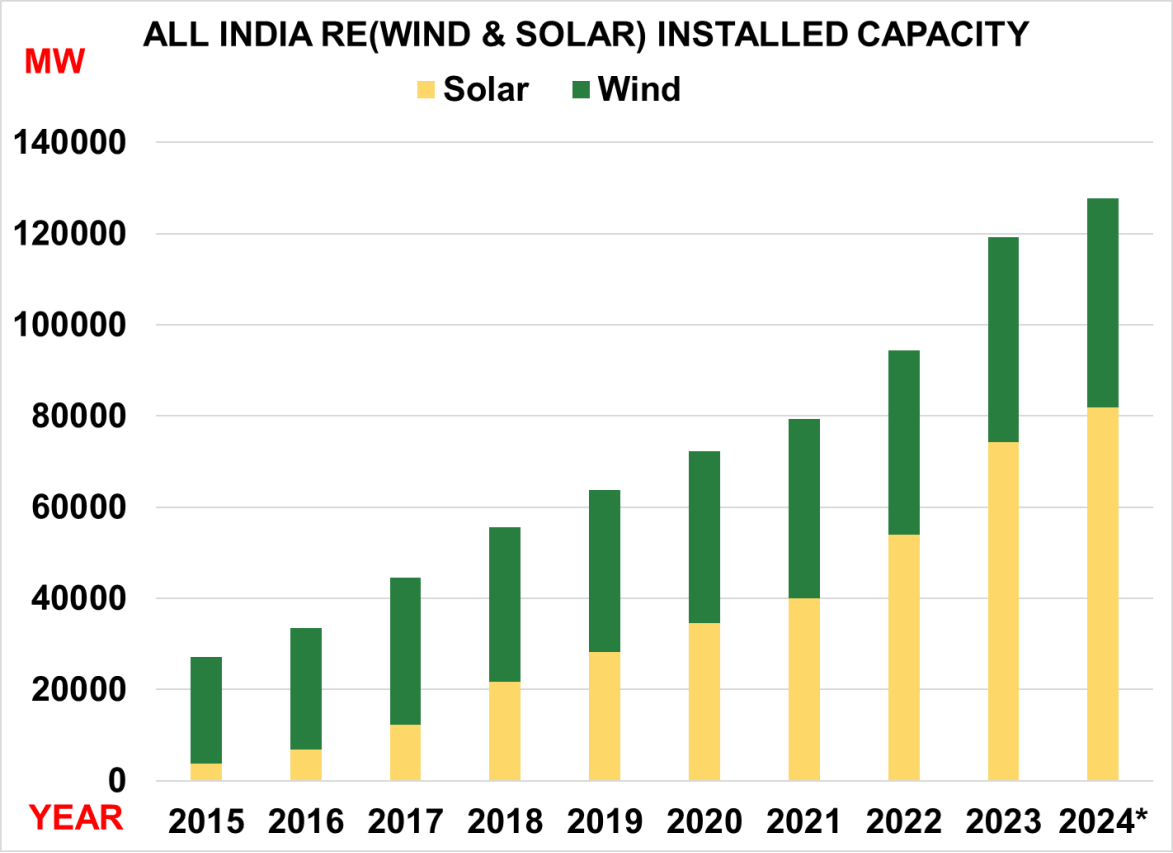
3
power exchanges

6000+
market participants

~ 112 GW
inter-regional capacity

118,300+
annual market transactions

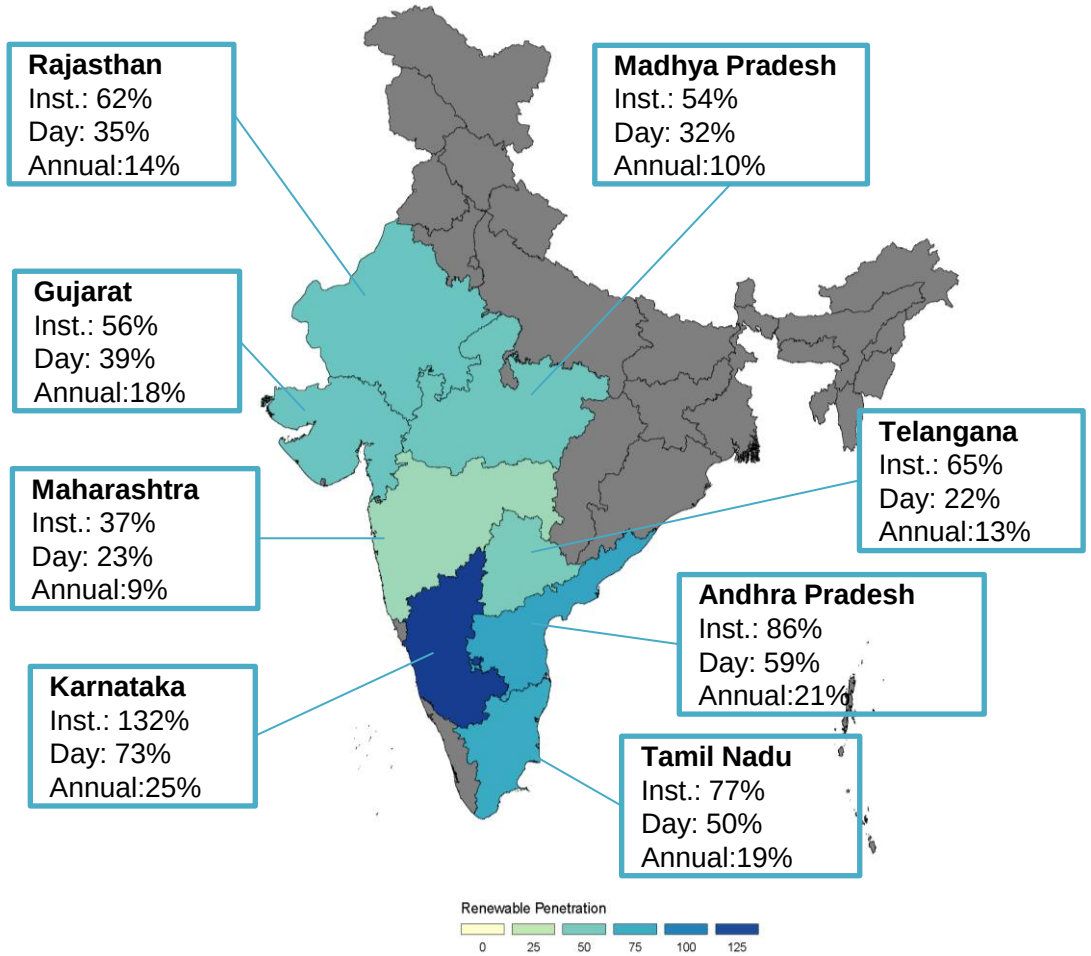
India's Journey with Renewables



* Till Mar 2024
Source: CEA Installed Capacity Report (data as on Apr 2024)
https://cea.nic.in/installed-capacity-report/?lang=en

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

Maximum Wind + Solar penetration in instantaneous MW and energy (day/year) terms – FY 2023-24



~11% all India VRE penetration on annual basis

Energy Transition in India - Roadmap

ALL INDIA INSTALLED CAPACITY (MW)			
Resource	**March 2024**	**March 2030**	**% Addition**
Hydro (including PSP)	46928	59210	26%
Small Hydro	5003	18986	279%
Solar PV	81813	292566	258%
Wind	45887	99895	118%
Biomass	10940	14500	33%
Nuclear	8180	15480	89%
Coal+Lignite	218178	251683	15%
Gas	25038	25038	0%
Total	**441967**	**777358**	**76%**
BESS	0	41650 (5-hr)	

		April 2024	Mar 2030
	**Maximum Demand Met (GW)**	**~240#**	**334^**
	**Total Generation Installed Capacity (GW)**	**442***	**777**
	**Non-fossil Fuel Based Generation Installed Capacity (GW)**	**199***	**500**
	**Wind & Solar Installed Capacity (GW)**	**127***	**393**

Source: CEA Report On Optimal Generation Capacity Mix for 2030 (Ver 2.0)
As on Mar 2024 as per Operational Data of Grid-India
* **As on Mar 2024** from CEA Installed Capacity Report
^ 20th EPS Survey by CEA

Grid Stability Concerns in High RE Regime

Major Operational and Planning Challenges

1. **Renewable integration in India unique in terms of concentrated capacity addition in close vicinity (Rajasthan RE Complex SLD)**

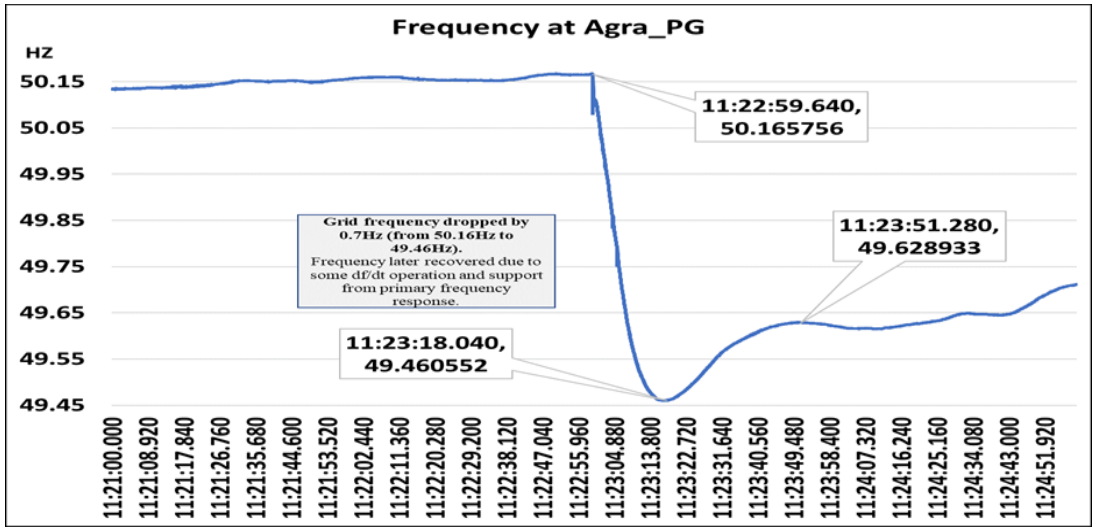
2. **Possibility of large disturbance/generation loss in case of any non-compliance**

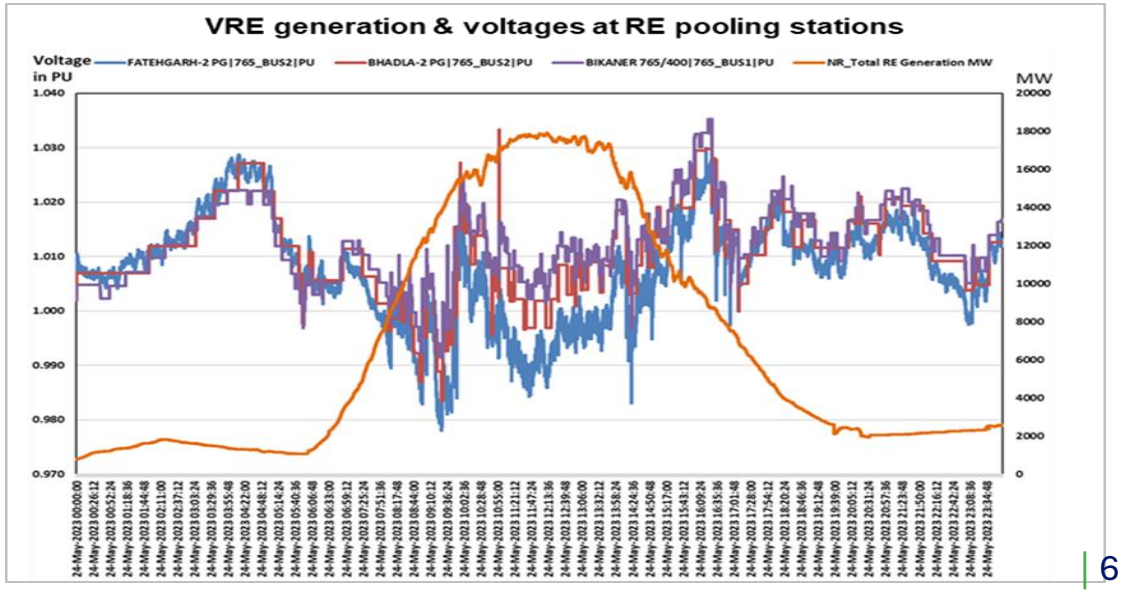
3. **Challenges in ensuring sufficient system strength in remotely located RE pockets**

   - **Large variation in steady-state voltages due to low system strength**
   - **Transient voltage overshoot during switching operation leading to HVRT conditions**

4. **Lack of Black Start sources in remote RE pockets**

6000 MW RE Generation Loss on 11th Aug 2022

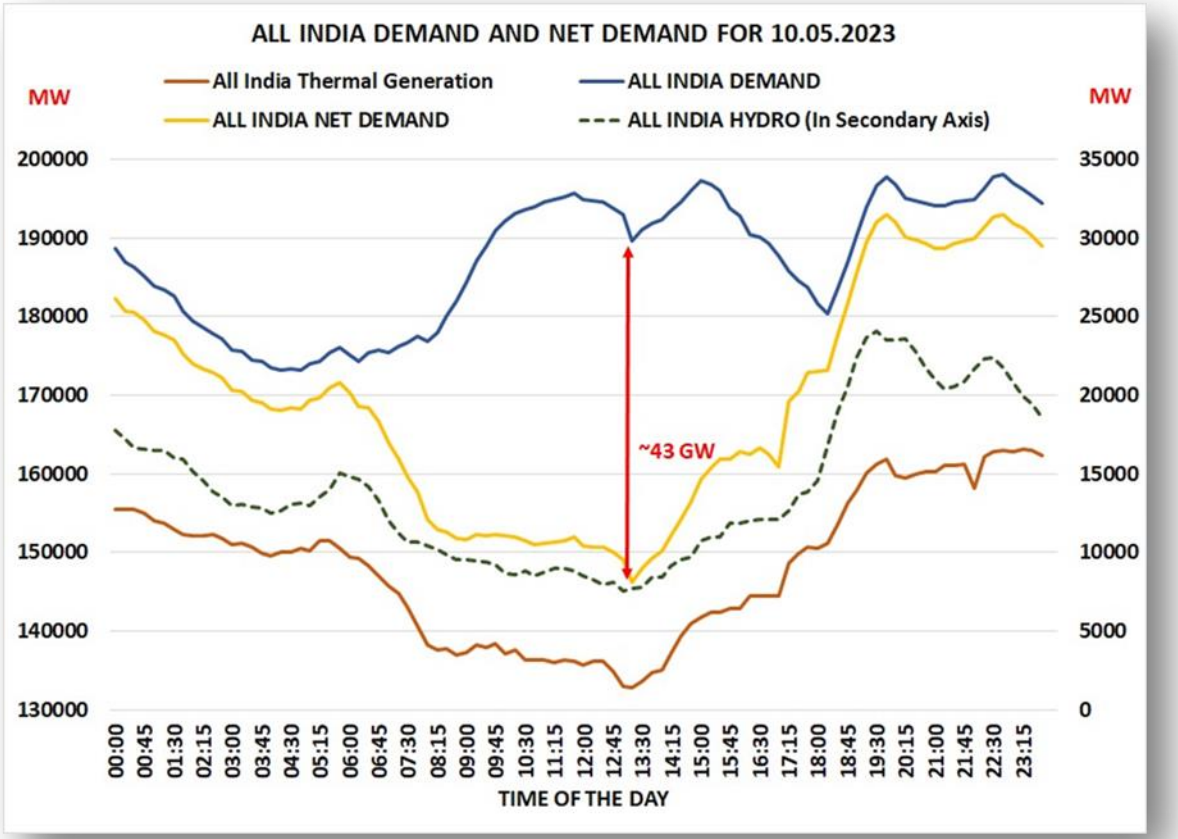




Grid Stability Concerns in High RE Regime

Major Operational and Planning Challenges

5. Power quality issues due to large number of converter based devices
6. Low gestation period of renewables vis-à-vis transmission
7. Behavioral change in corridor power flows
8. Resource Adequacy concerns especially in low renewable generation periods
9. Increasing ramping requirement and lack of commensurate flexible generating resources
10. Renewable forecasting accuracy related challenges



Increasing "Duck Curve" Belly !!

Initiatives for facilitating Reliable Renewable Integration

1. **Comprehensive set of regulations and standards governing interconnection and operations of the renewable plants**

2. **Robust Compliance Verification Process**

   - **Established procedures for technical data and reports submission**
   - **Commencement of compliance verification process at least 01 year before physical interconnection of the plant**
   - **Independent compliance verification by both system planner and operator**
   - **Widespread synchro-phasor initiative to assist in post-commissioning performance validation and event analysis**

3. **Perspective transmission planning on a rolling basis - based on potential RE zones - to ensure timely availability of transmission (details)**

4. **Planning and deployment of innovative solutions for Grid Stability – VSC based HVDCs, Storage, FACTS Devices, Synchronous Condensers etc.**

Initiatives for facilitating Reliable Renewable Integration

5. **Comprehensive regulatory framework for ensuring Short and Long term Resource Adequacy**

6. **Thermal Flexibility Initiatives (details)**

   - Pilot projects on Thermal Flexibilization
   - Phasing Plan for Implementation of 40% Technical Minimum Level in Coal-fired plants
   - Incentive for providing higher ramp rates

7. **Dedicated Renewable Energy Management Centers (co-located with LDCs) for dedicated monitoring, forecasting and scheduling of solar and wind plants**

Way Forward

1. **Regular strengthening of regulations and standards governing grid operations and renewable interconnection to keep with the evolving grid requirements**
   - Enabling provisions for model data submission and validation
   - Enabling provisions for high resolution data recording at IBR level for facilitating post event analysis
   - Black Start Capability / Grid Forming Capability of Inverters

2. **Periodic consultation/workshops with stakeholders (plant developers, equipment manufacturers etc.) for mutual knowledge sharing and capacity building**

3. **Identifying and periodically reviewing the right resource mix for medium and long-term duly factoring in resource adequacy and flexibility requirements**

4. **Flexibility Initiatives – Requisite changes in regulations; Valuing hydro flexibility etc.**

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Adaptive Regulation in Energy Transition

15 - 17 MAY 2024 | Bangkok, Thailand

Thank You

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Energy Regulatory Commission

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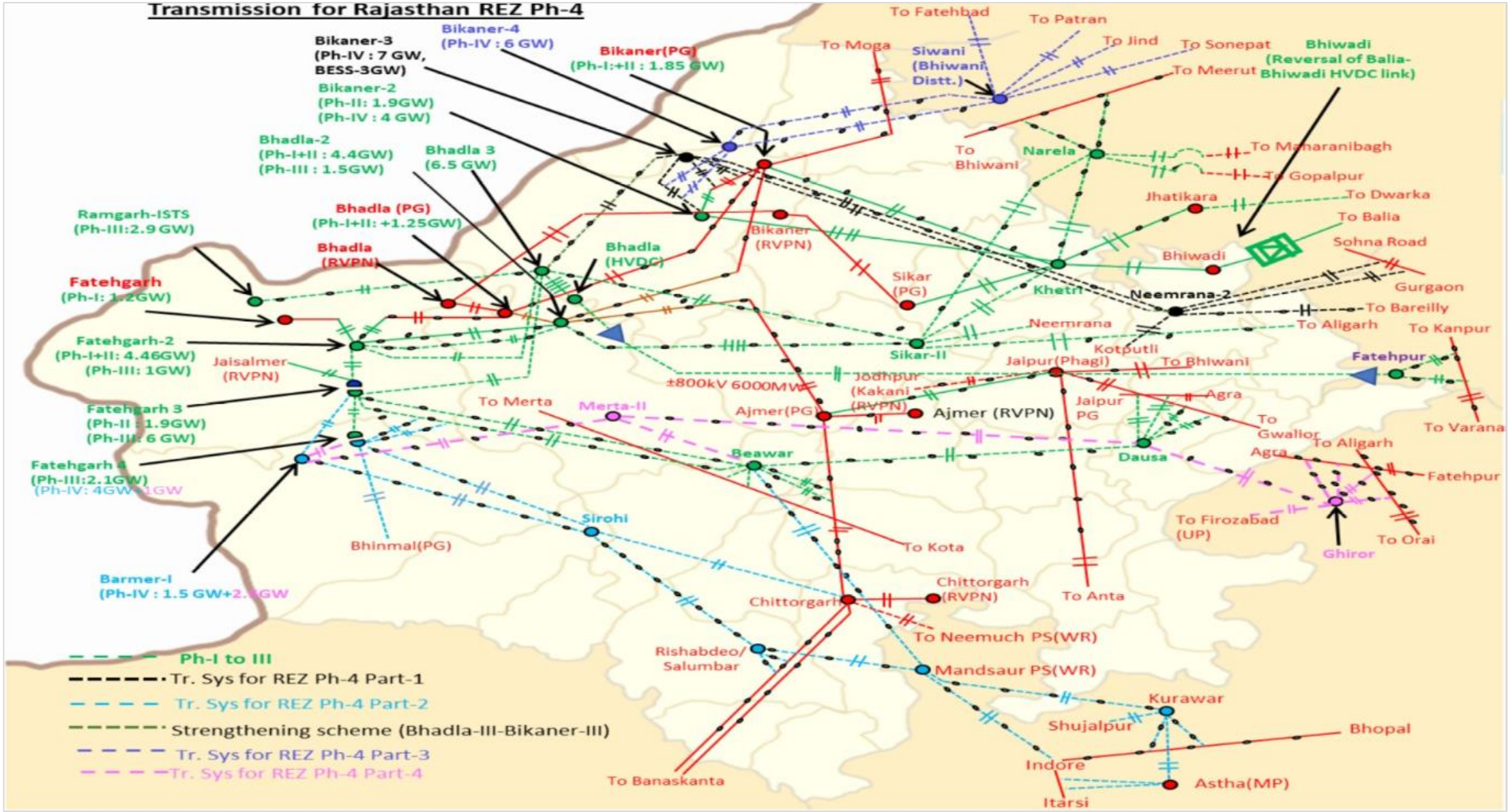
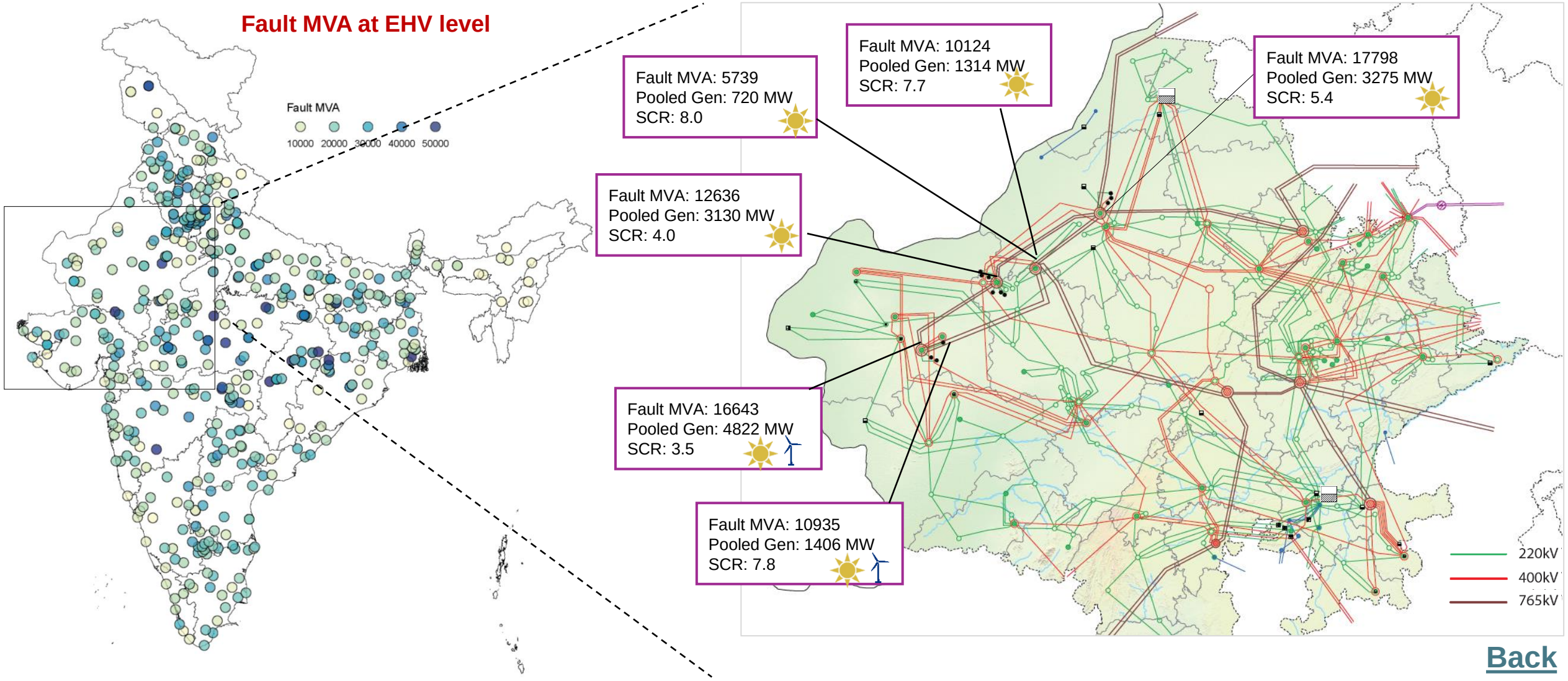
Rajasthan Renewable Complex



System Strength Concerns

Fault MVA at EHV level



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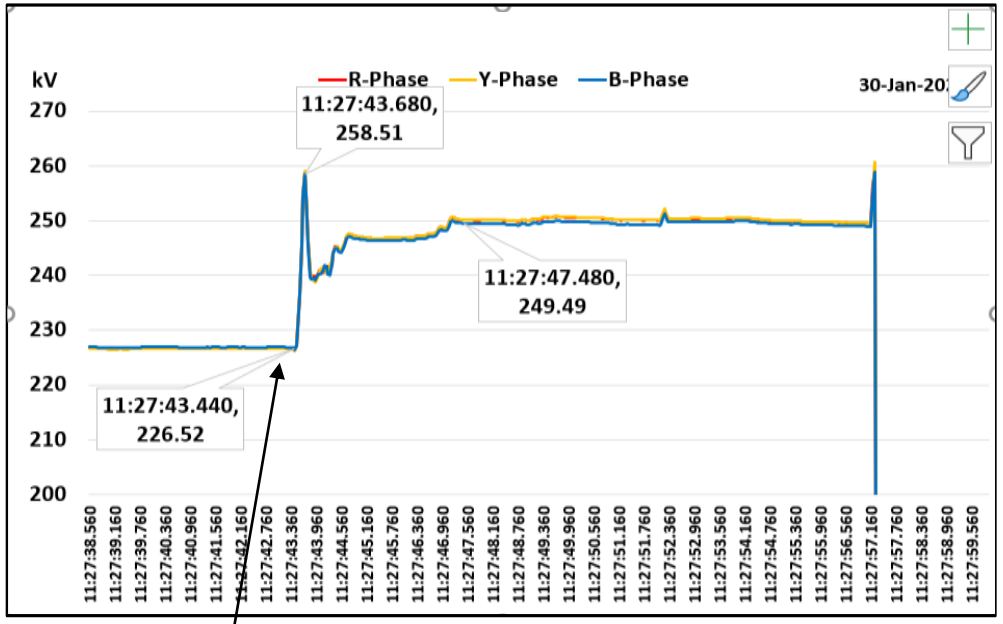
Challenges in ensuring sufficient system strength in remotely located RE pockets

System Strength Concerns

Reduction in SCR due to depleted network

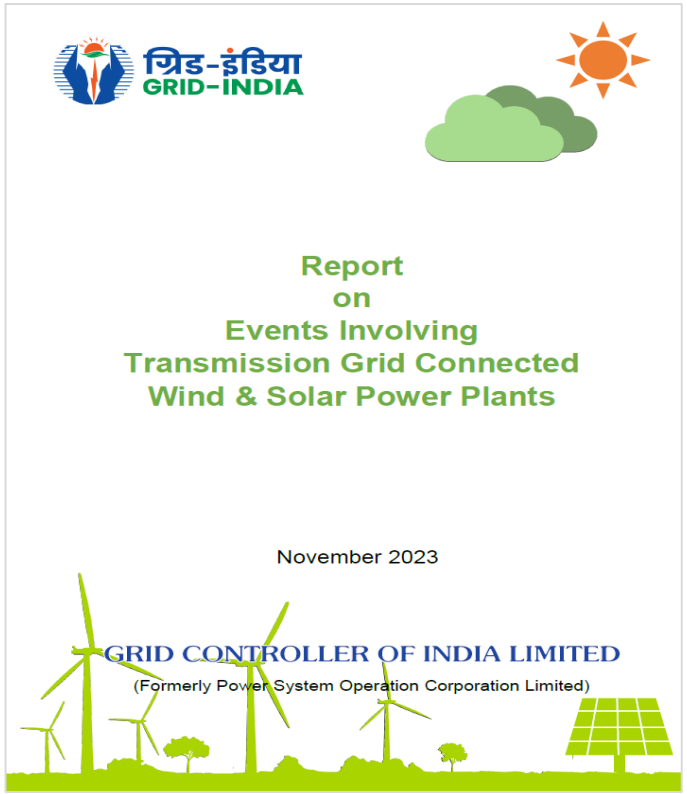


Switching of 240 MVAR Line reactor

- 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

Large change in voltages during switching of network elements

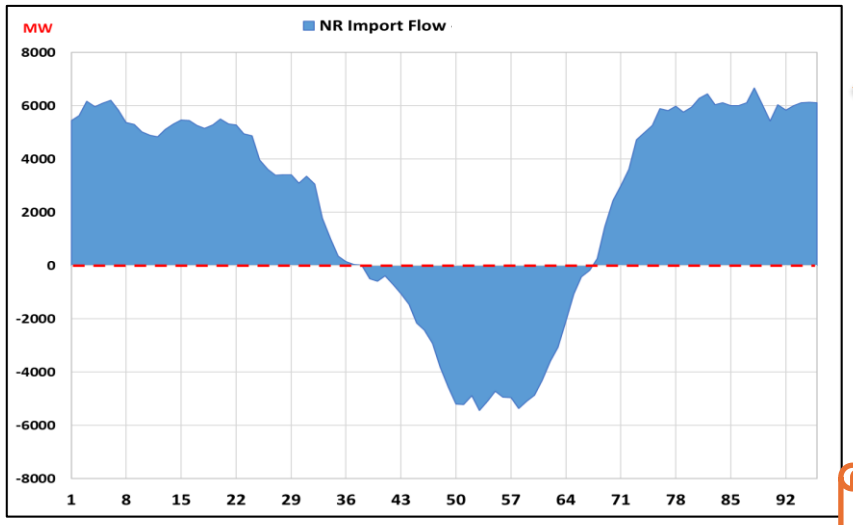
Transient voltage rise leading to tripping of EHV lines and Renewable plants on overvoltage



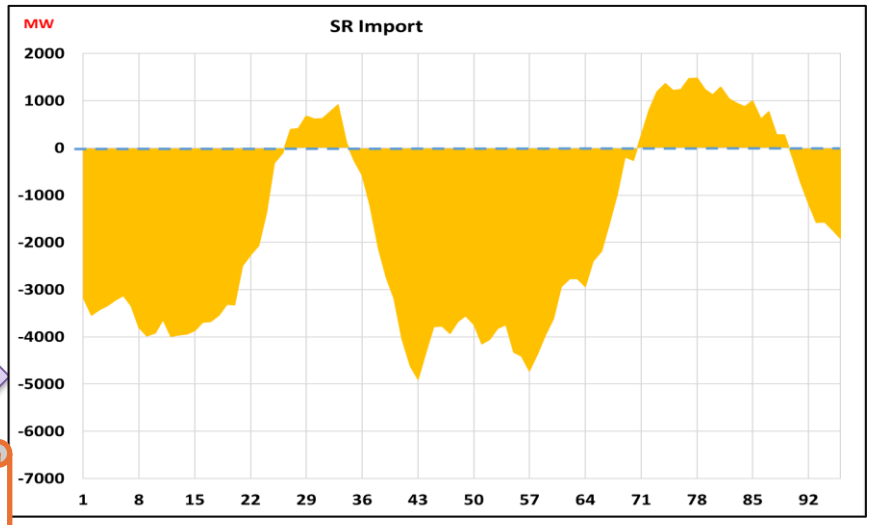
Several incidents of RE generation loss due to large voltage fluctuations during switching operations

Back

Transmission Planning – Behavioral Change in Flow Patterns

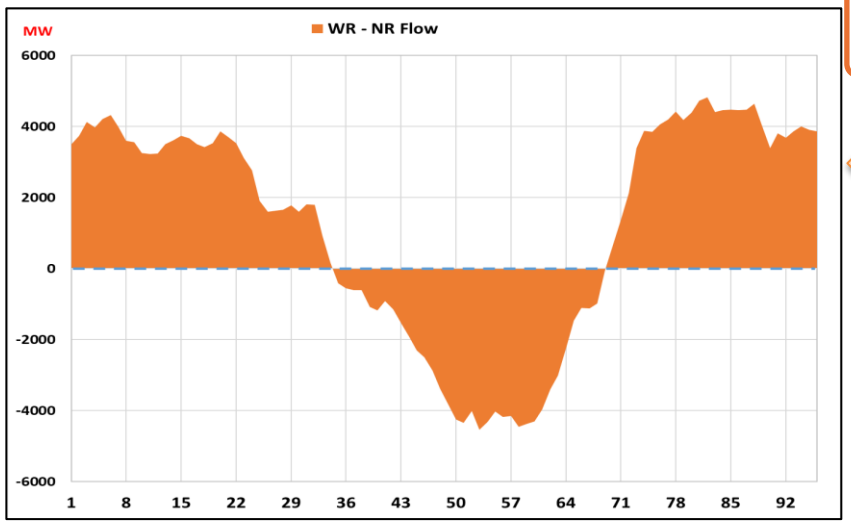


NR Import

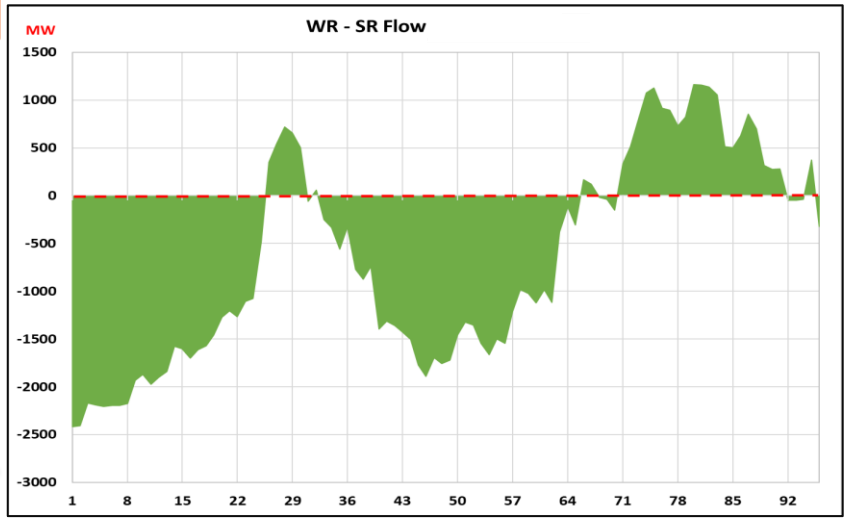


SR Import

Bi-directional Flows
The New Normal !!



WR - NR

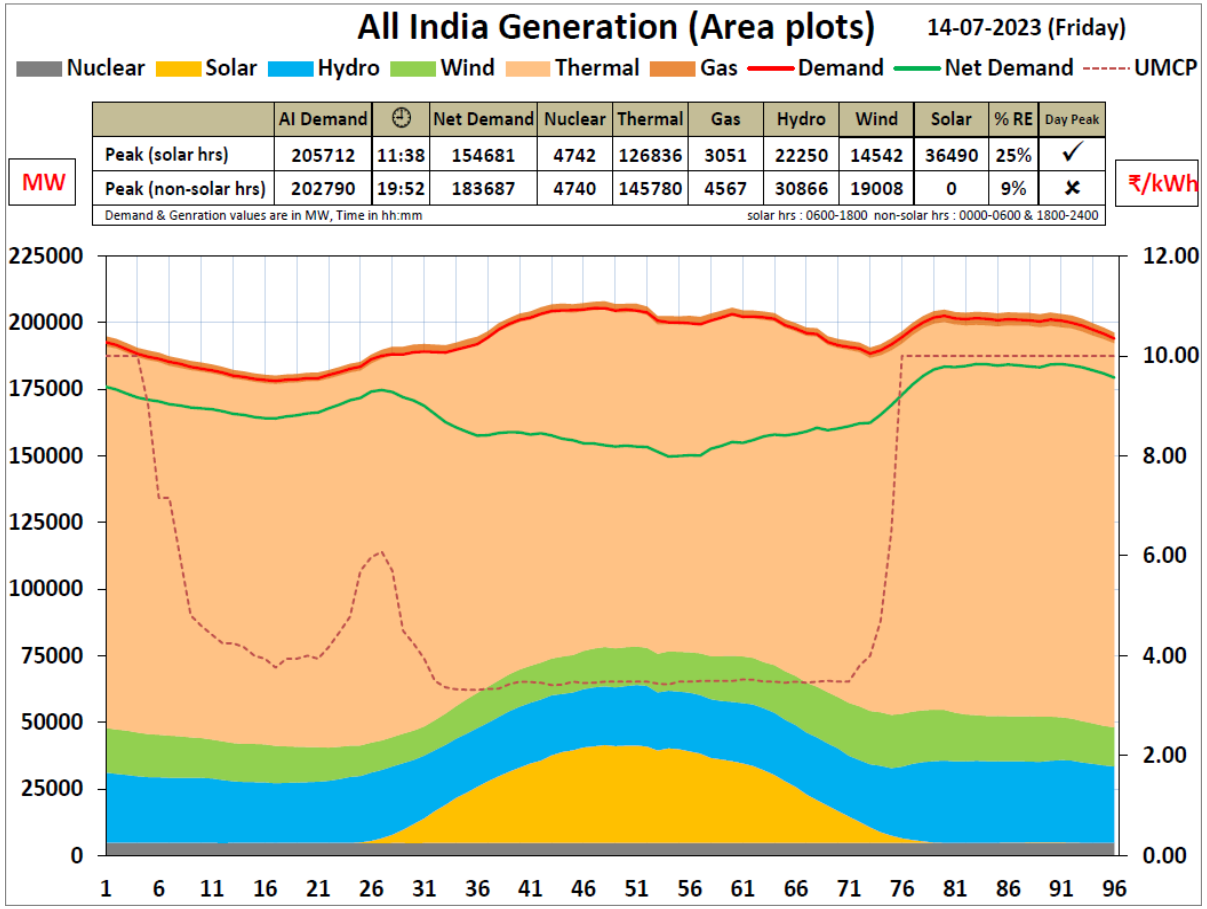


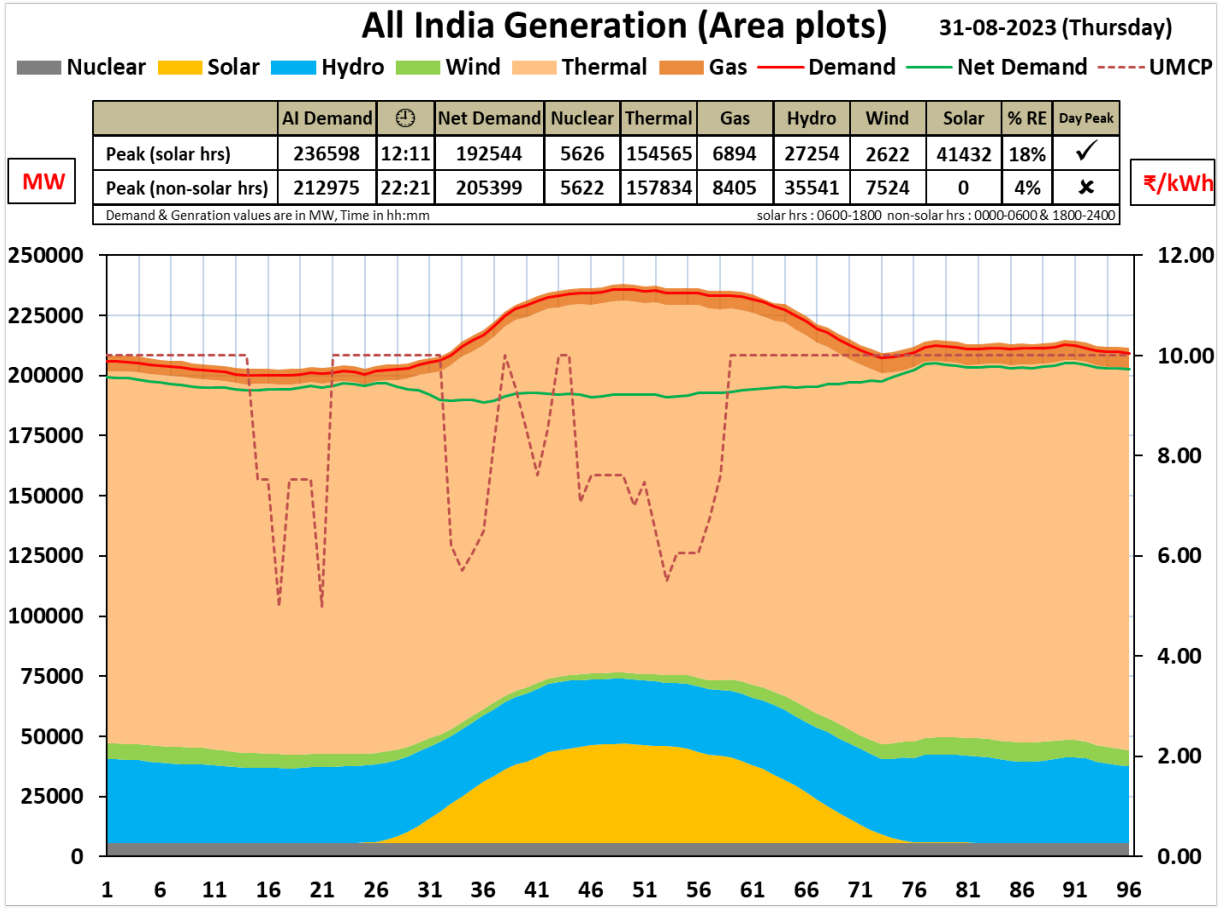
WR -SR

Resource Adequacy – Concerns

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

Back



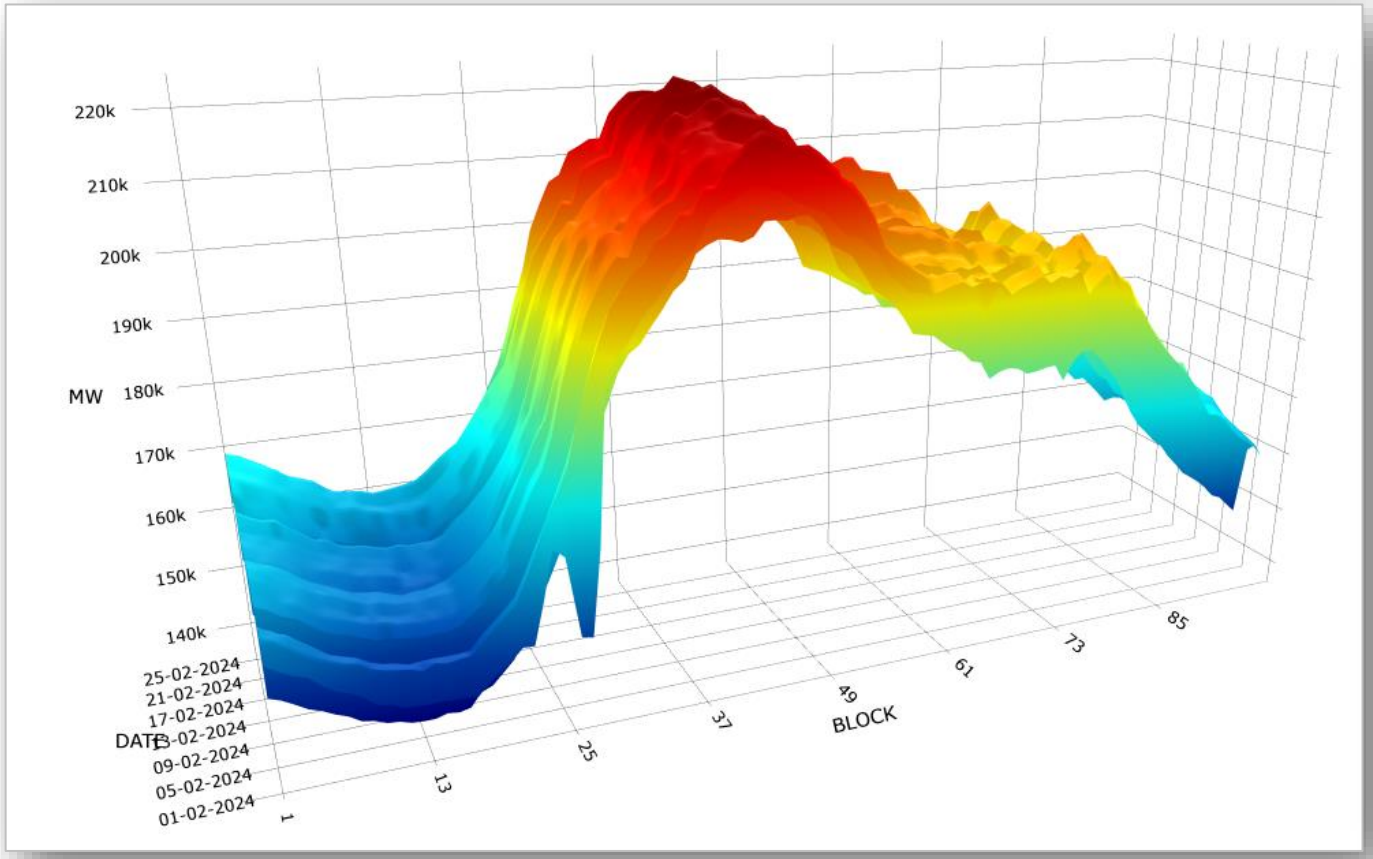


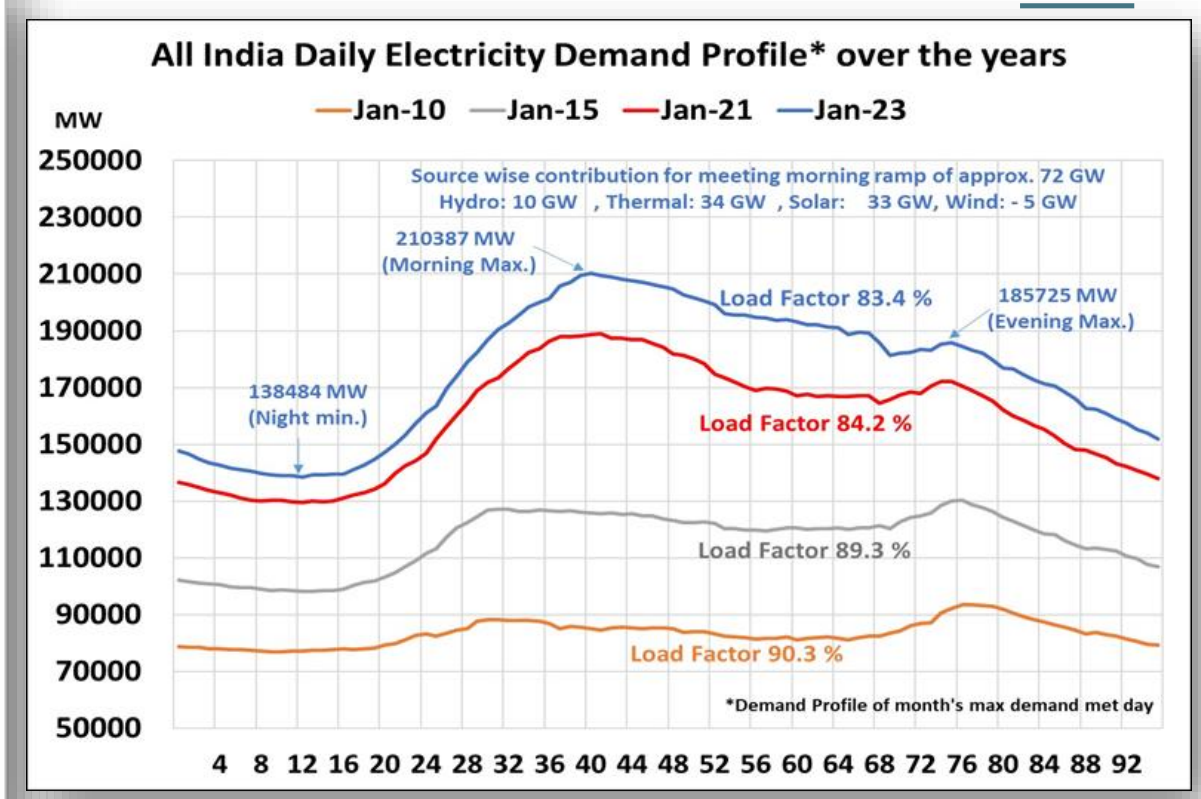
Highest Instantaneous RE penetration (in 23-24) of ~32.4% was recorded on 14th July 2023

Low RE penetration during High Demand Season - 31st August 2023

Flexibility – Growing Need

Back





All India Demand

Typical Ramp rate ~ 250-300 MW/min

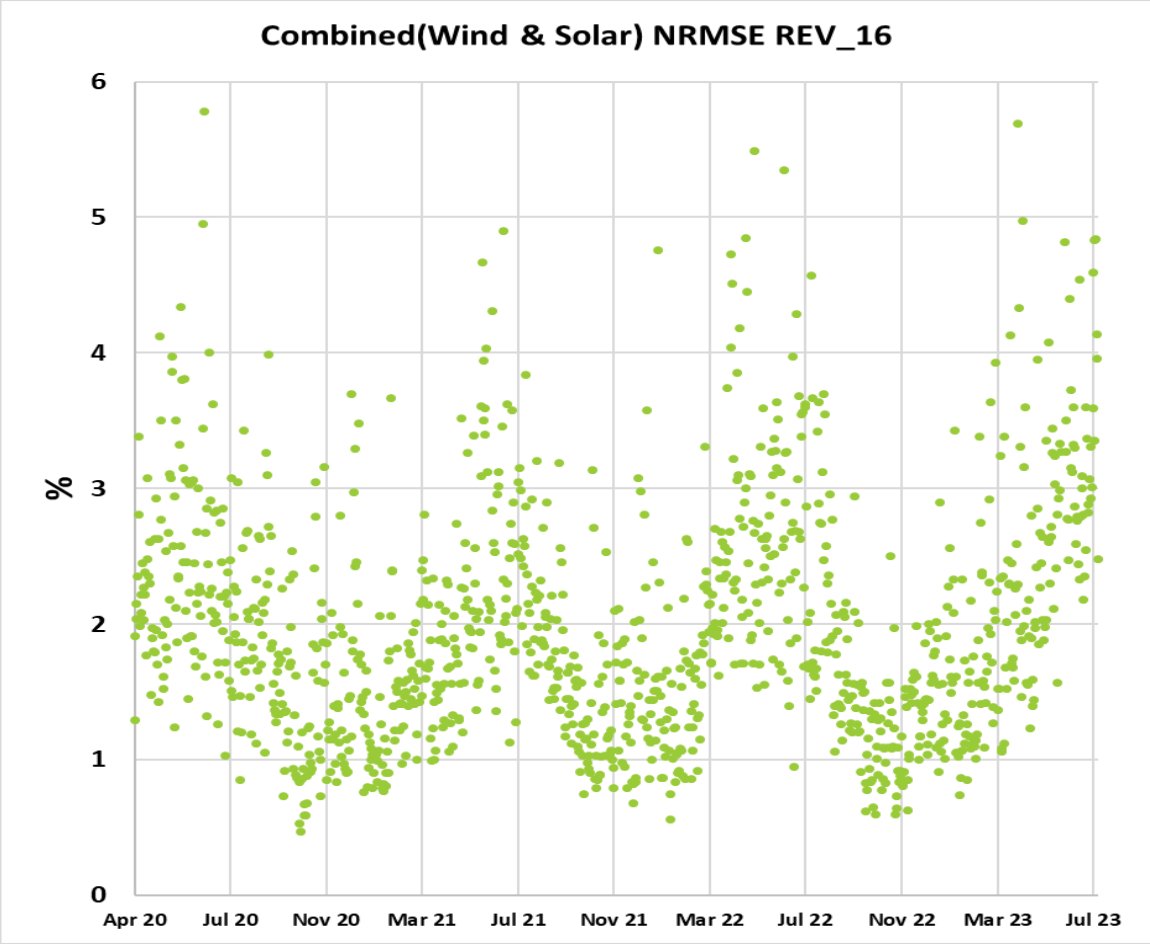
Special Days ~ 500 MW/min

Change in Load Shape

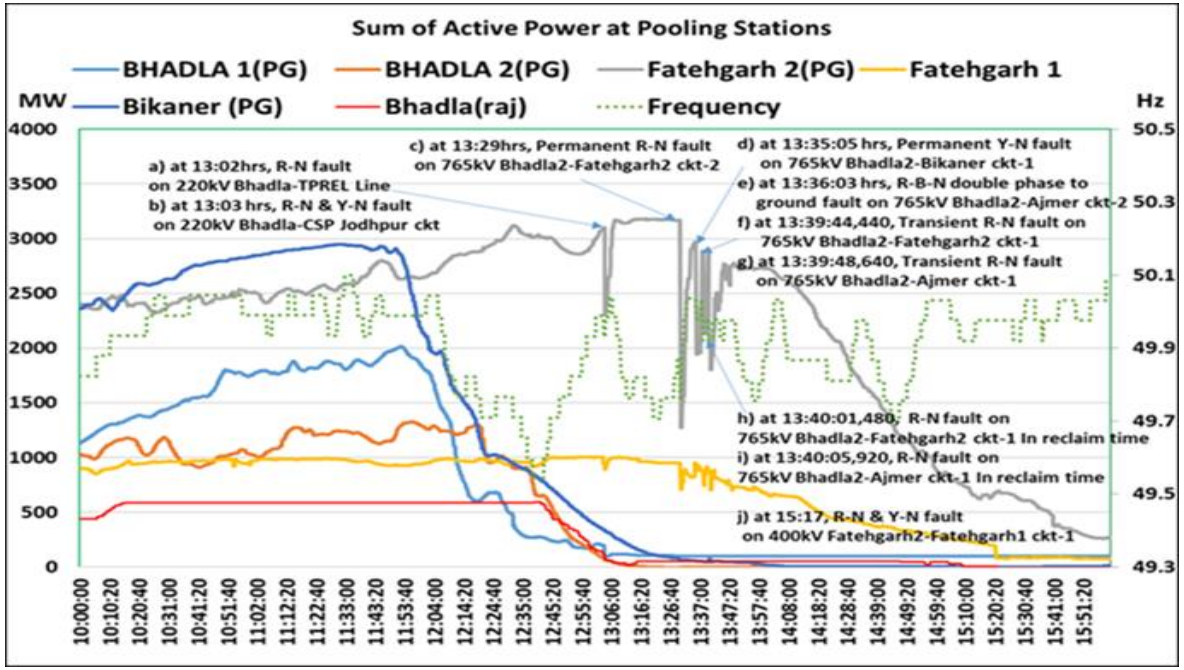
Increasing uncertainty on demand side

Near Future –
EV Charging?
Induction Cooking?

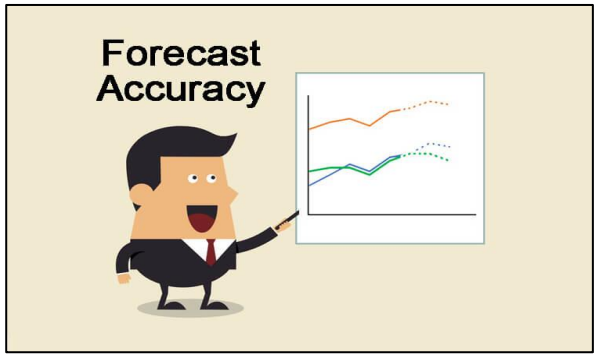
Forecasting Accuracy



❑ NRMSE = $\frac{1}{n}\sum_{1}^{n}\sqrt{\left(\frac{Act - Forecast}{AvC}\right)^2}$



Approx. 8000 MW reduction in solar generation in 1 hour due to Cloud Cover



Key to Renewable Integration

Back

Set of Technical Regulations and Standards

1. **Central Electricity Authority (CEA), Technical Standards for Connectivity to the Grid Regulations, 2007 and subsequent amendments**

   - Low and High Voltage Ride Through Requirements (LVRT/HVRT)
   - Reactive Power Capability
   - Dynamic Reactive Power Support
   - Active Power and Frequency Control
   - Power Quality Requirements

2. **Central Electricity Regulatory Commission (CERC), Indian Electricity Grid Code, 2023**
   - Trial run operation of wind, solar and BESS
   - Frequency response from RE plants
   - Periodic testing of RE plants

3. **Other Regulations - Central Electricity Authority's**

   - Flexible Operation of Coal based Thermal Power Generating Units Regulations, 2023
   - Technical Standards for Construction of Electrical Plants and Electric Lines Regulations, 2022
   - Grid Standards Regulations, 2010
   - Technical Standards for Communication System in Power System Operation Regulations, 2020

Compliance Verification Process

Type Test Reports

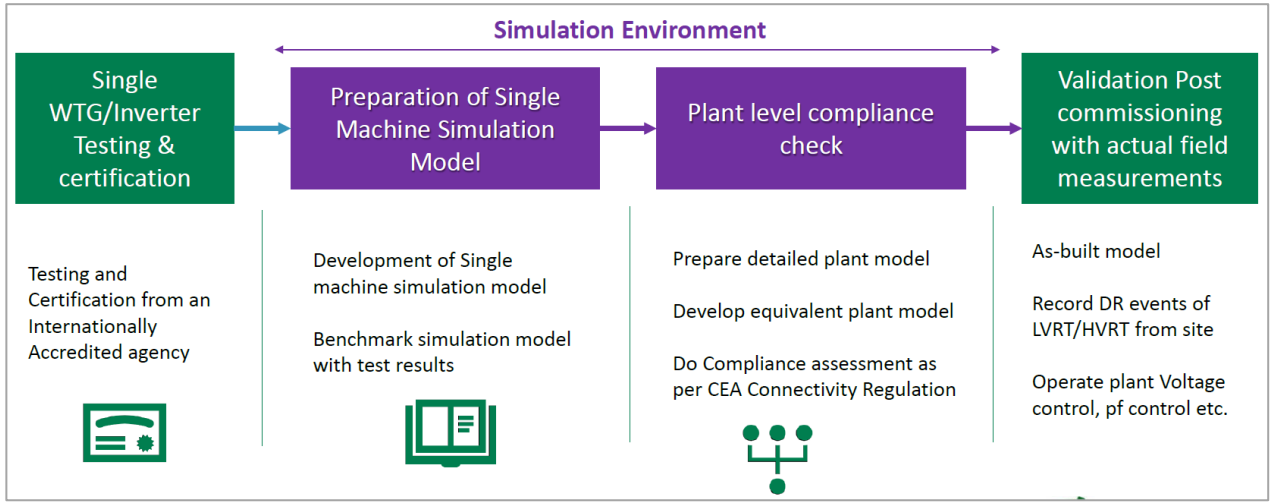
(Factory or Lab Environment)

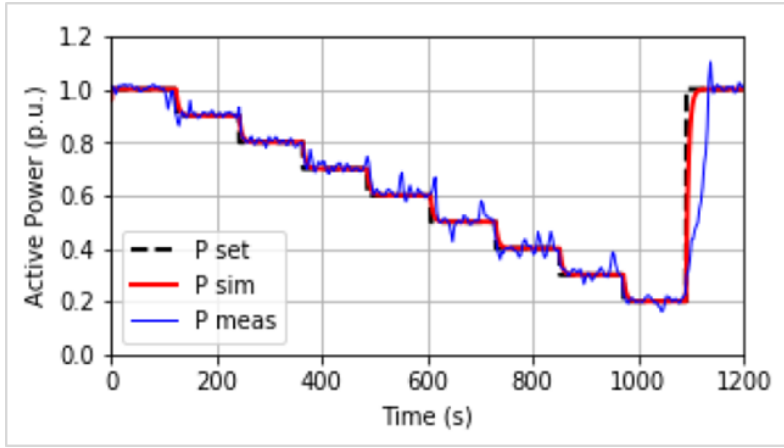
Evaluation Reports & Statement of Compliance

(by an Accredited Certification Agency)

Simulation Reports and Models

Verification through independent Simulations by System Planner and Operator

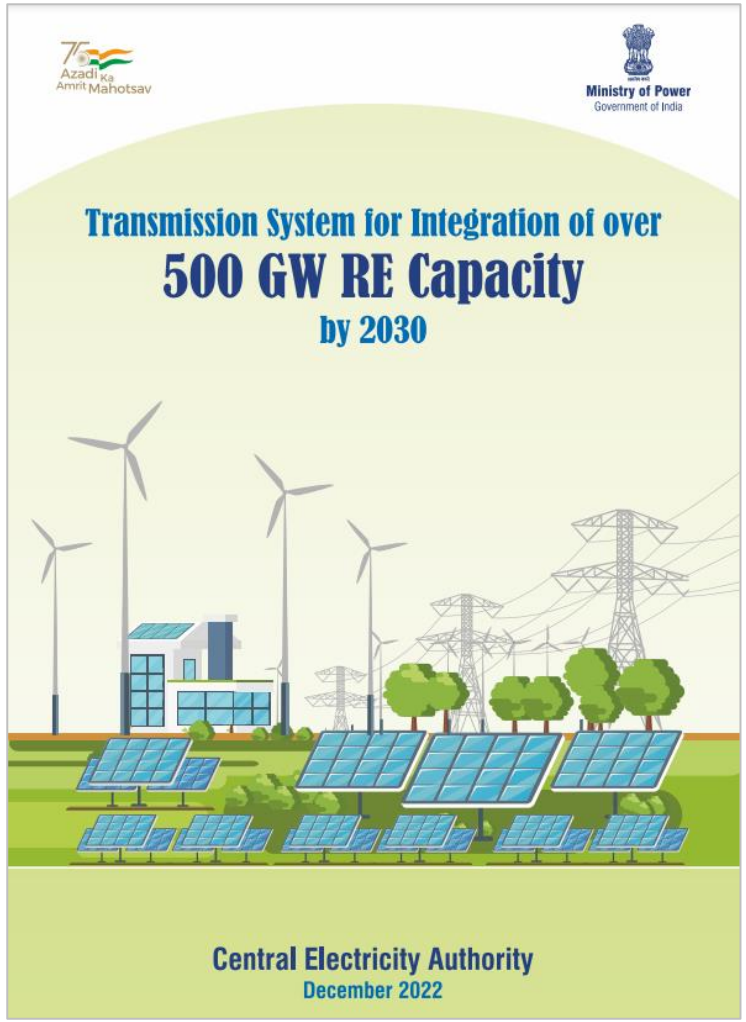




Back

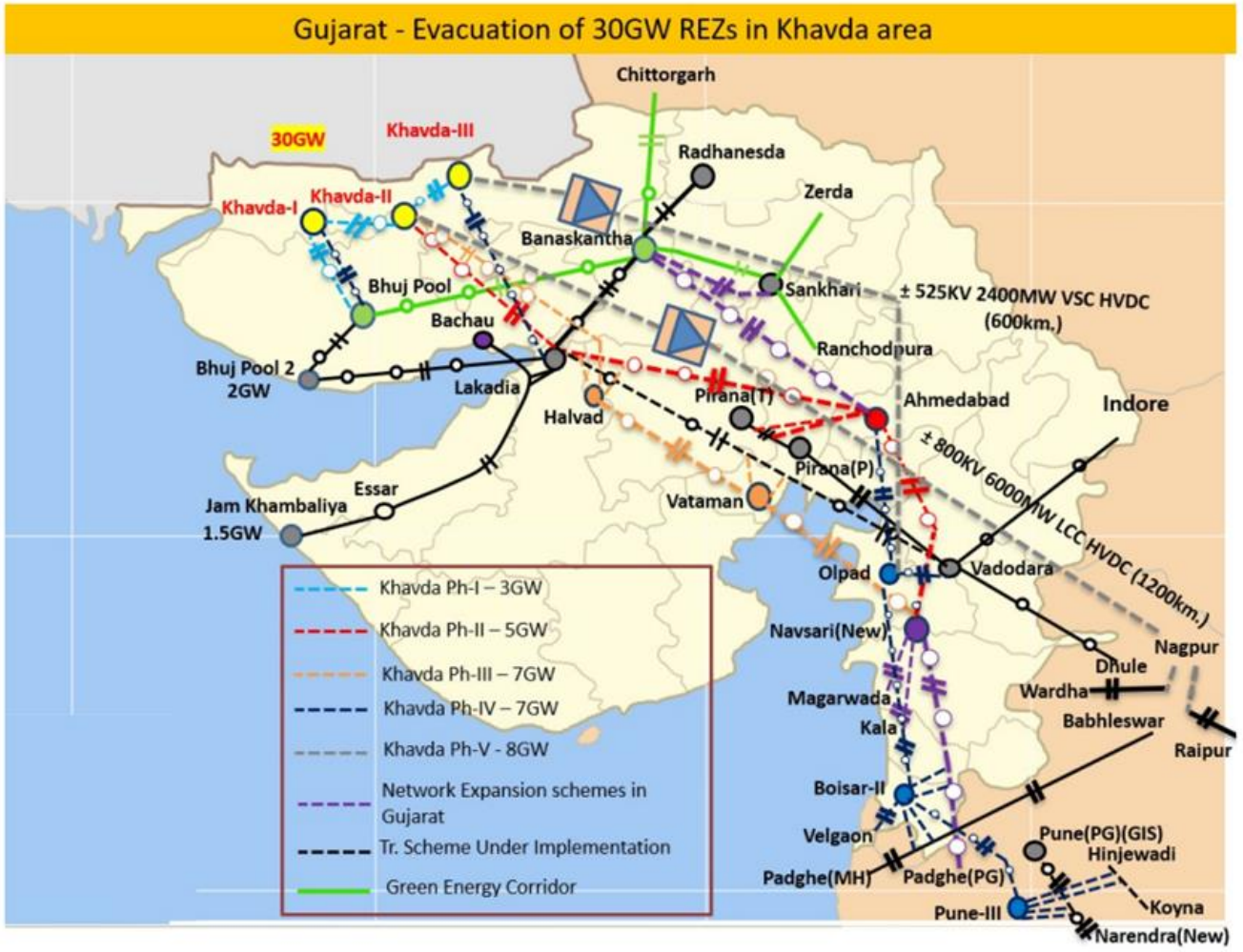
Detailed requirements specified in Grid-India's procedure for "First-Time Energization of New and Modified Elements"

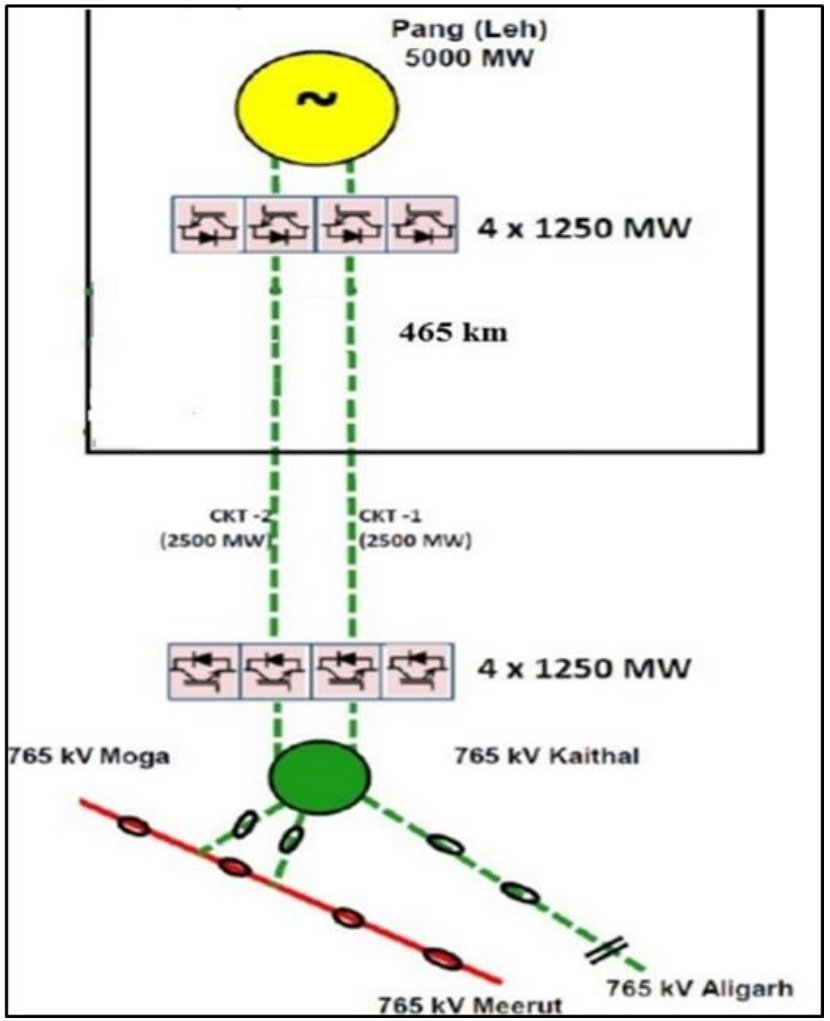
Transmission Planning – Regulatory Initiatives



- **Perspective Planning - Central Electricity Authority's report on Transmission Plan for 500 GW RE by 2030**
- **Recognition of Low Gestation Period of RE and BESS vis-à-vis Transmission**
  - Fast tracking of approvals of transmission schemes through empowerment of system planner (CTUIL)
  - **Short-term transmission plan** every year on a rolling basis for the next 5 years
  - **Perspective transmission plan** every alternative year on a rolling basis for the next 10 years
  - **Implementation plan for inter-state transmission system** every year on a rolling basis for up to the next 5 years
- **Implementation of CERC's General Network Access Regulations w.e.f. 1st Oct 2023**

Transmission Planning Initiatives





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

Resource Adequacy Initiatives

1. Regulatory Framework for Long and Short-term Resource Adequacy Studies

- Electricity (Amendment) Rules, 2022 notified by the Government of India, Ministry of Power
- Indian Electricity Grid Code, 2023 notified by the Central Electricity Regulatory Commission
- CEA - Guidelines for Resource Adequacy

2. Other Initiatives w.r.t. Resource Adequacy

- Shifting of load to high generation (solar) period
- Notifying trajectory for Storage
- Pilot project on 4000 MWhr grid scale Battery Energy Storage

Back

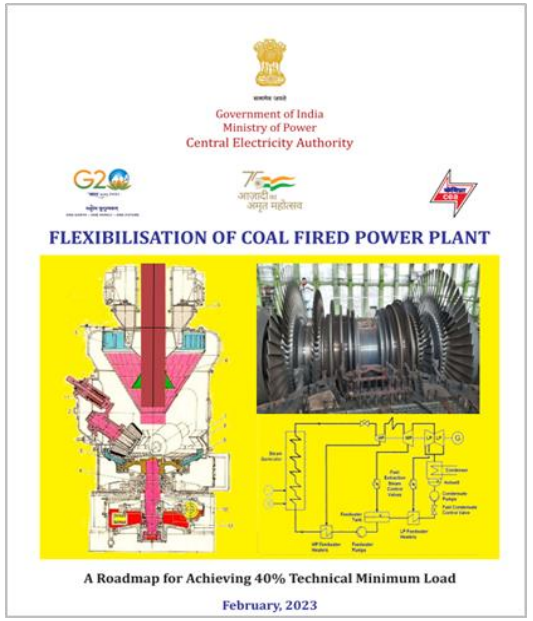
Flexibility Initiatives

1. CEA (Flexible Operation of Coal based Thermal Power Generating Units) Regulations, 2023

- Specified **Minimum Power Level of 40% for Thermal Generating Units**
- Requires thermal generators to be capable of providing **1%–3% ramp rate**

2. CERC (Terms and Conditions of Tariff) Regulations, 2019

- Incentivized generators to provide ramping capability beyond the threshold of 1% and to penalize in case of failure to provide 1%, in terms of return on equity
  - rate of return on equity shall be **reduced by 0.25%** in case of failure to achieve the ramp rate of 1% per minute;
  - an **additional rate of return on equity of 0.25%** shall be allowed for every incremental ramp rate of 1% per minute achieved over and above the ramp rate of 1% per minute, subject to ceiling of additional rate of return on equity of 1.00%



Central Electricity Authority – Phasing Plan for Implementation of 40% Technical Minimum Level

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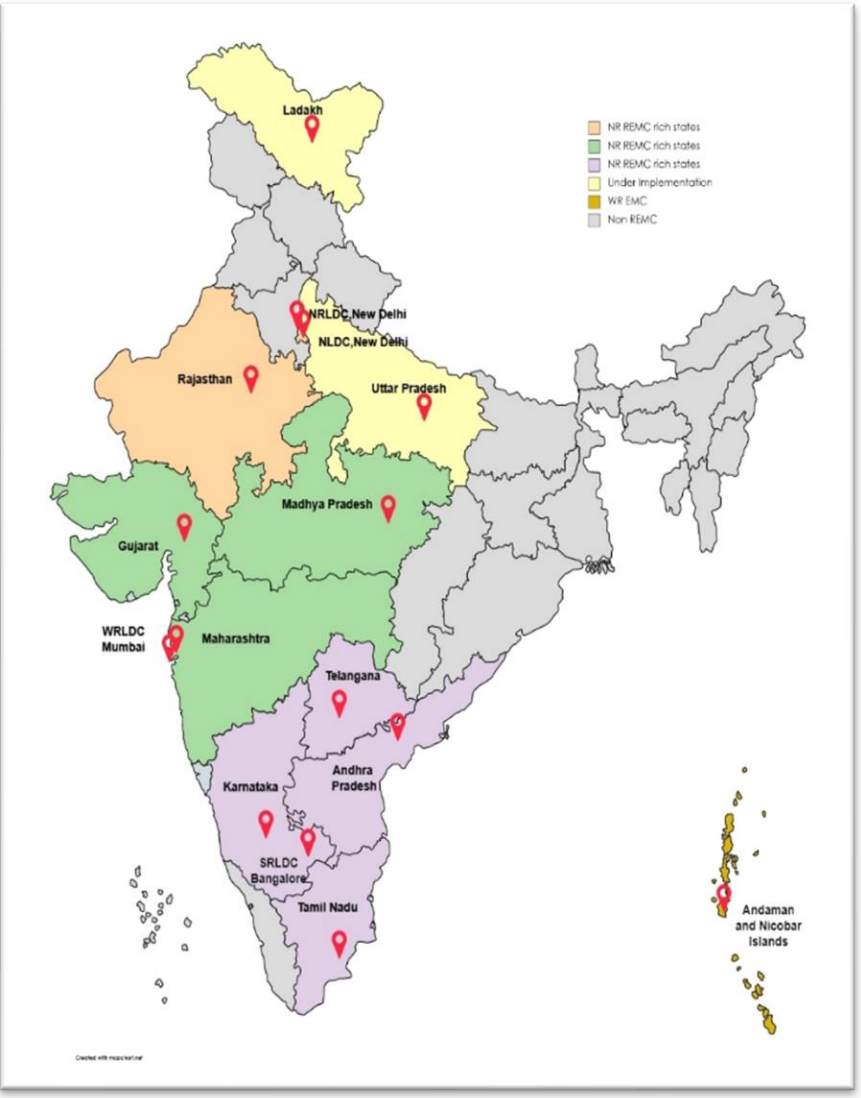
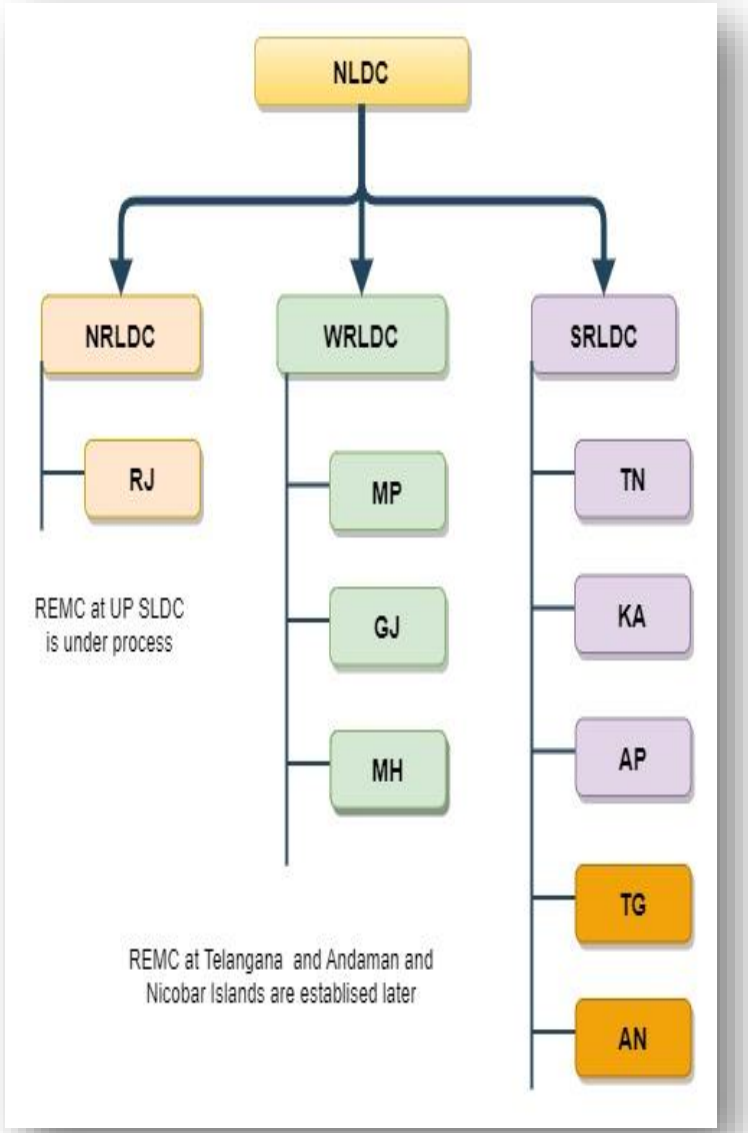
Real-time Monitoring, Visualization and Situational Awareness





Renewable Energy Management Centers

- Co-located with the Load Despatch Centers at 12 locations
- One Energy Management Centre at Andaman and Nicobar Islands.
- **106 GW Wind and Solar Capacity monitored**
- **1490 Pooling stations**
- **79 GW scheduled at Intra-state level**
- **27 GW Scheduled at Inter-state level**
- **Facilities**
  - Day ahead/intra-day forecasting, scheduling
  - Telemetry
  - Analog : P, Q, V, Weather
  - Status: Transmission, Inverter / WTG

Challenges in High RE Regime

Frequency Support

- Increasing Rate of Change of Frequency (RoCoF)
- Decreasing nadir frequency
- Excessive frequency deviations

Voltage Support

- Static reactive power balance
- Dynamic reactive power balance
- Larger voltage dips

New Behavior of the Power System

- Fault ride through failures
- Decreased damping
- Oscillations
- Control of bi-directional flows
- Lack of power system restoration sources

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

Renewables + Transmission (FACTS + HVDCs) to play a critical role in providing the necessary support in the new regime