20 YEARS Integrated Research and IRADe Action for Development

ग्रिड-इंडिया GRID-INDIA

Northern Regional Capacity Building Workshop

Session-2 : Grid Stability and Balancing due to Intermittent Generation

2nd July 2024

Priyam Jain
Chief Manager (SO), NLDC
Grid-India

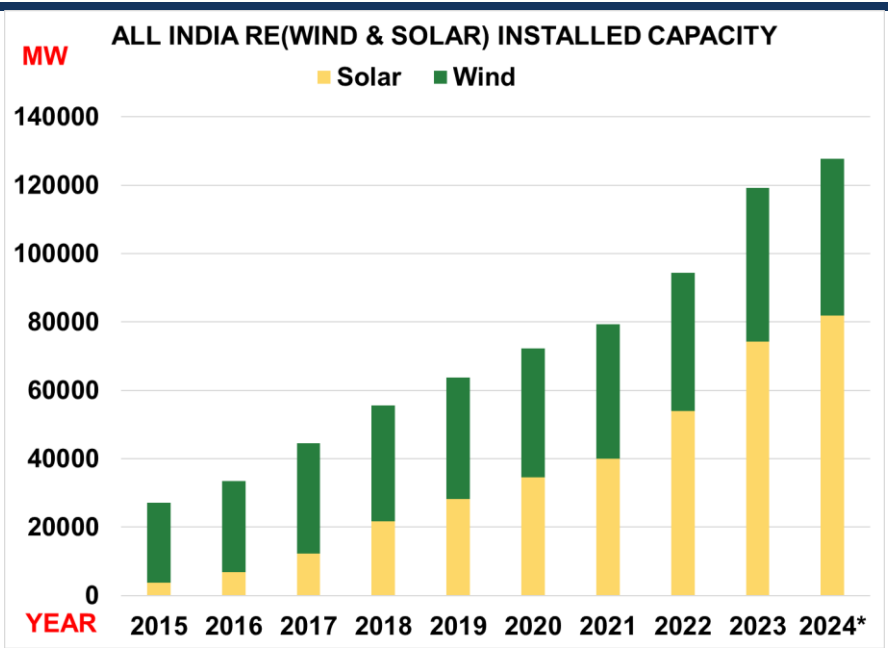
Energy Transition in India - Roadmap

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)	

	June 2024	Mar 2030
Maximum Demand Met (GW)	**~250#**	**334^**
Total Generation Installed Capacity (GW)	**443***	**777**
Non-fossil Fuel Based Generation Installed Capacity (GW)	**200***	**500**
Wind & Solar Installed Capacity (GW)	**129***	**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

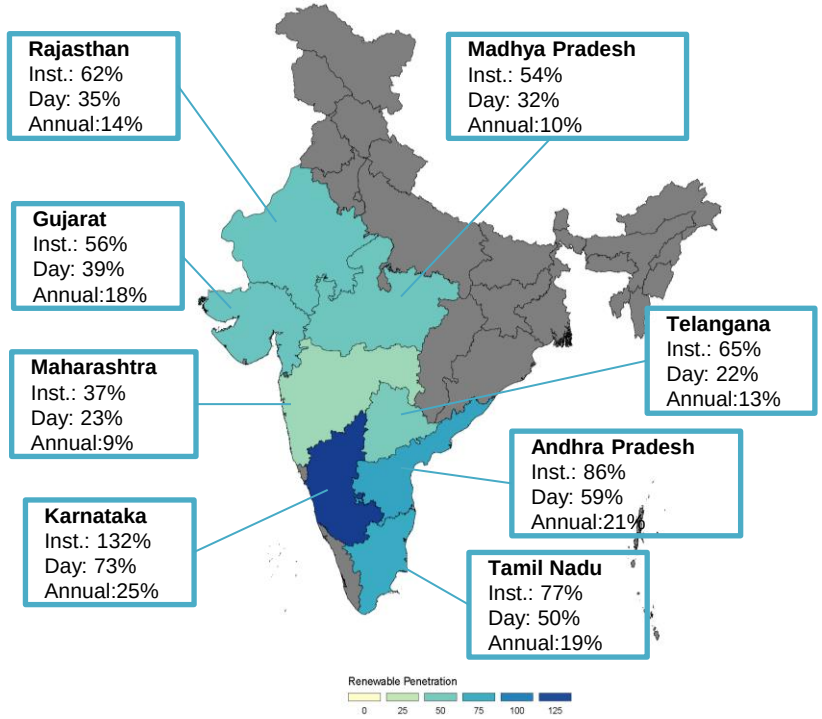
India's Journey with Renewables



*** 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

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

Grid Stability Concerns in High RE Regime

Major Operational and Planning Challenges

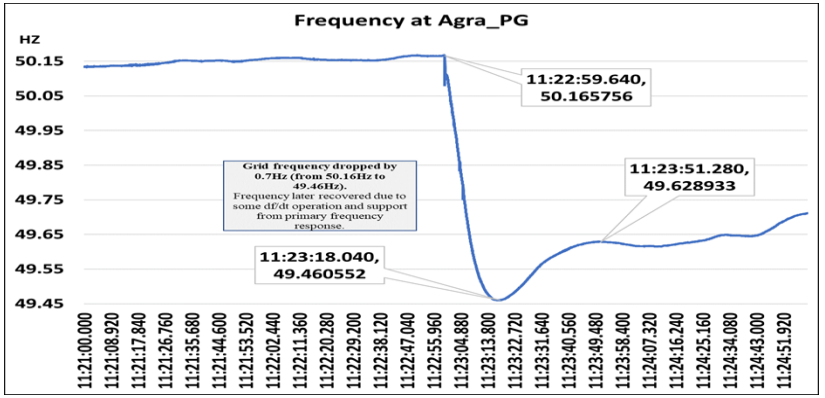
1. Renewable integration in India unique in terms of concentrated capacity addition in close vicinity (Rajasthan RE Complex SLD)

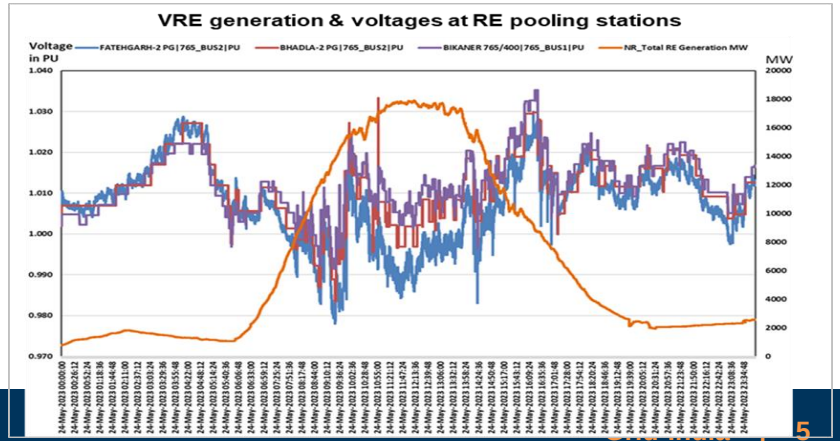
2. Possibility of large disturbance/generation loss in case of any non-compliance

3. Challenges in ensuring sufficient system strength in remotely located RE pockets
   - Large variation in steady-state voltages
   - 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**

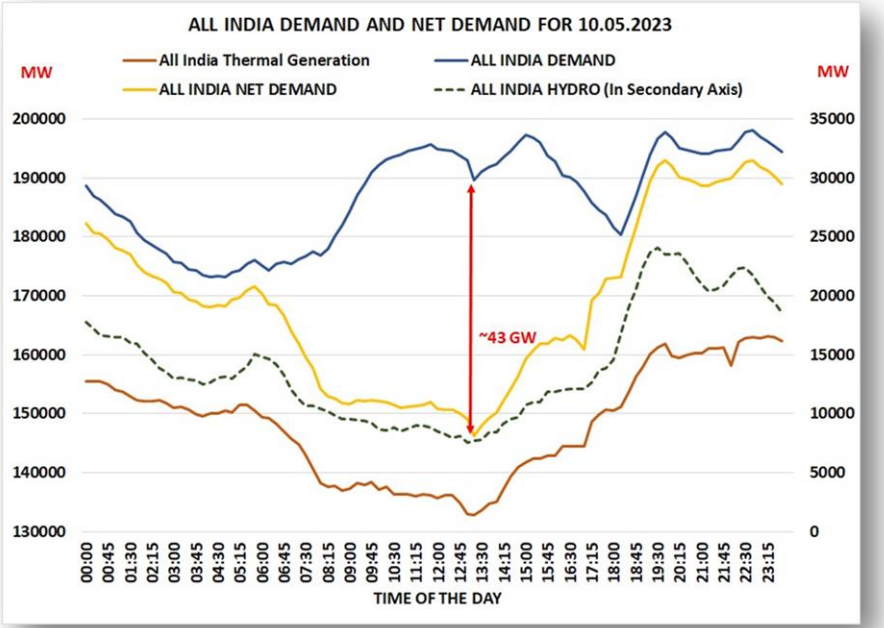
6. **Low gestation period of renewables vis-à-vis transmission**

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**

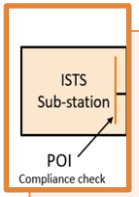
6. **Thermal Flexibility Initiatives (details)**

   - 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**

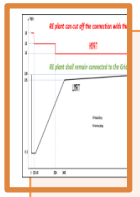
RE Integration process in India

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

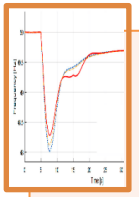


Interconnection Point / Point of Interconnection

Reactive Capability test



Voltage Ride Through Requirement (Low/High)

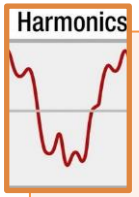


Frequency Response

Active and Reactive Power - Set Point Control

Design Requirement – Weather, Temperature Extremes etc.

Ramping Capability



Power Quality Requirements

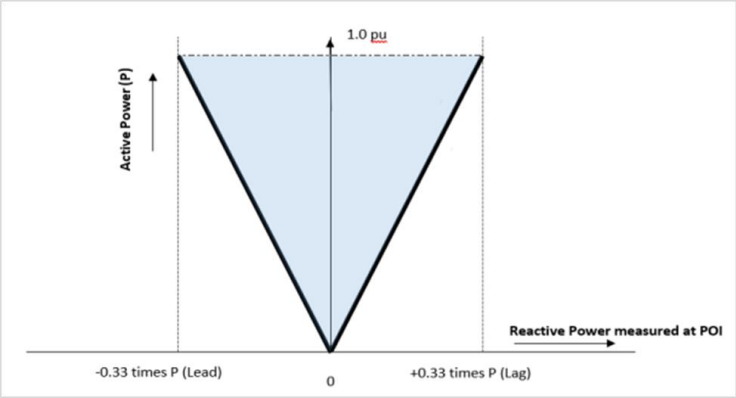
- **CEA's Construction, Safety and Grid Standards Regulations**
- **CERC's Indian Electricity Grid Code, 2023**

Regulatory Provisions

CEA, Technical Standards for Connectivity to the Grid, Regulations 2007

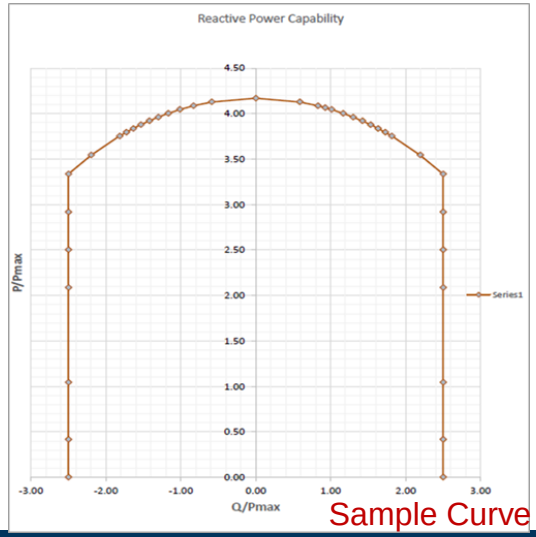
Dynamic Reactive Power Support

*"The generating station shall be capable of supplying **dynamically varying reactive power support** so as to maintain power factor within the limits of **0.95 lagging to 0.95 leading**"*



Control Modes:

- Voltage Control
- Fixed Reactive Power Control
- Power Factor (p.f.) Control



Sample Curve

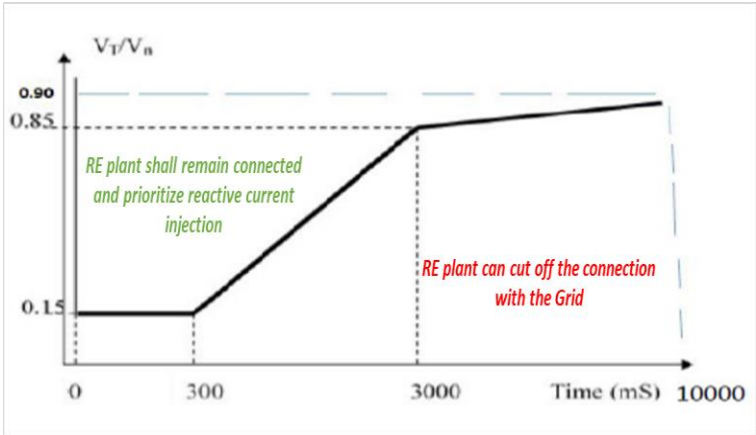
Regulatory Provisions

CEA, Technical Standards for Connectivity to the Grid, Regulations 2007

Low Voltage Ride Through

"The converter based generating station connected to the grid, shall remain connected to the grid when voltage at the interconnection point on any or all phases dips up to the level depicted by the lines in the following curve, (VT: Actual Voltage; Vn: Nominal Voltage).

During the voltage dip, supply of reactive power has first priority, while the supply of active power has second priority and active power preferably be maintained during voltage drops, provided, a reduction in active power within the plant's design specifications is acceptable and active power be restored to at least 90% of the pre-fault level within 1 sec of restoration of voltage."



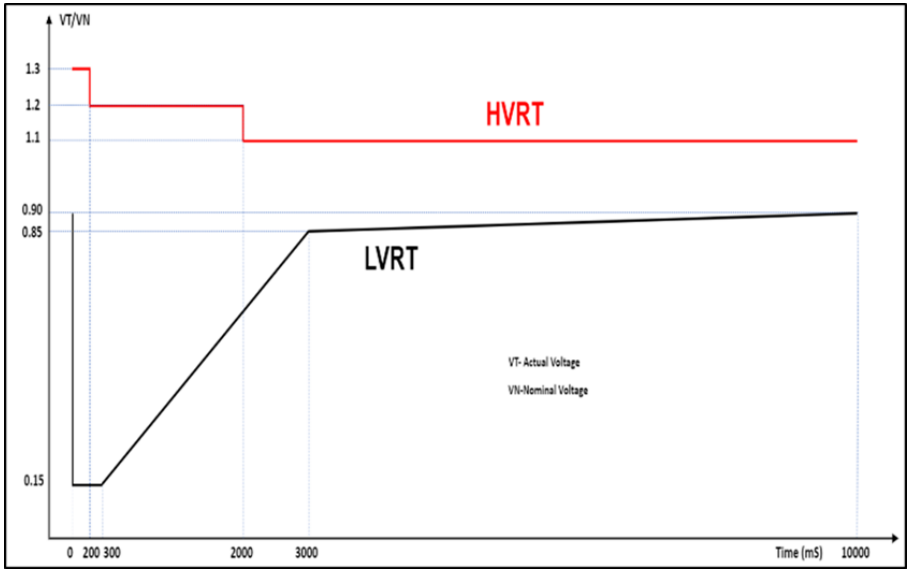
Regulatory Provisions

CEA, Technical Standards for Connectivity to the Grid, Regulations 2007

High Voltage Ride Through

"The generating station connected to the grid, shall remain connected to the grid when the voltage at the interconnection point, on any or all phases (symmetrical or asymmetrical overvoltage conditions) rises above the specified values given below for specified time."

S. No.	Over Voltage (p.u.)	Minimum time to remain Connected (seconds)
1.	1.30 < V	0 (instantaneous trip)
2.	1.30 ≥ V > 1.20	0.2 Sec
3.	1.20 ≥ V > 1.10	2 Sec
4.	V ≤ 1.10	Continuous



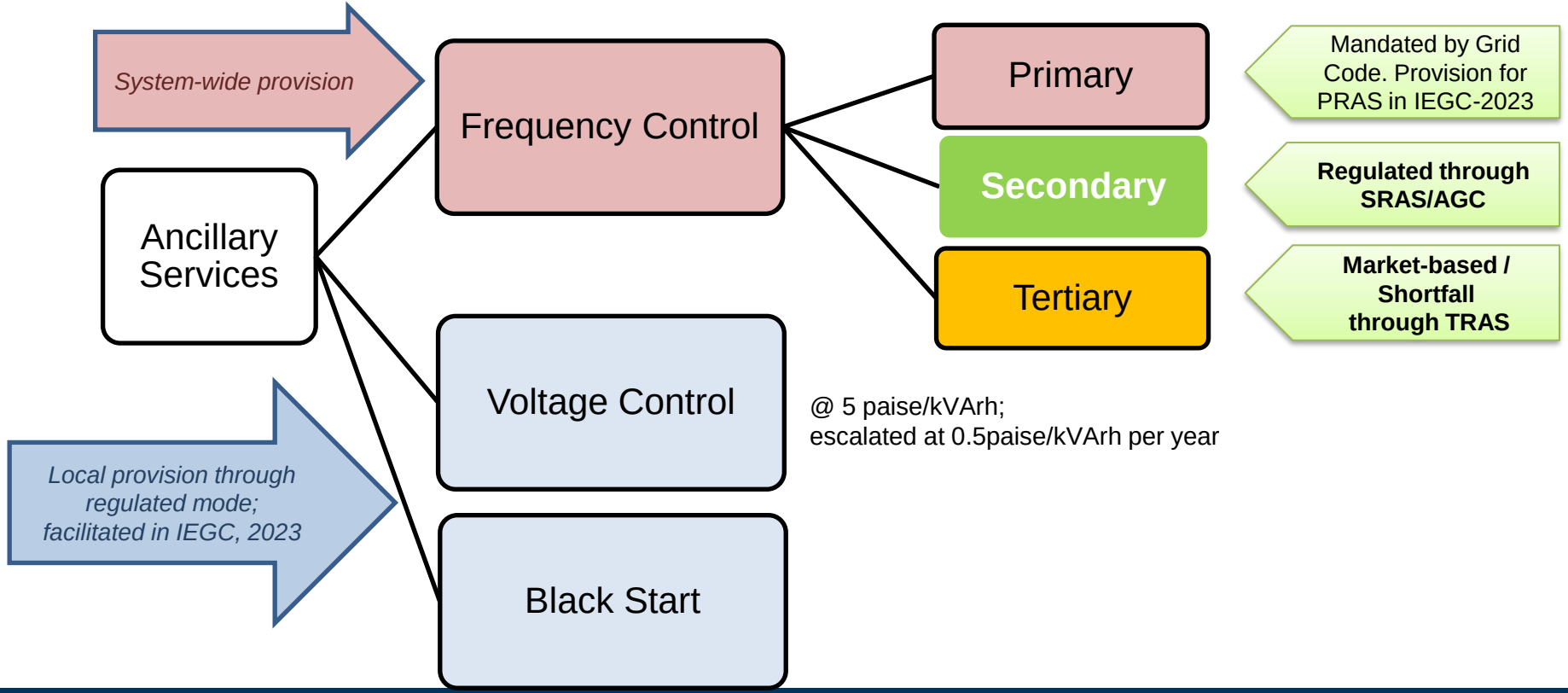
Regulatory Provisions

CERC, Indian Electricity Grid Code, 2023

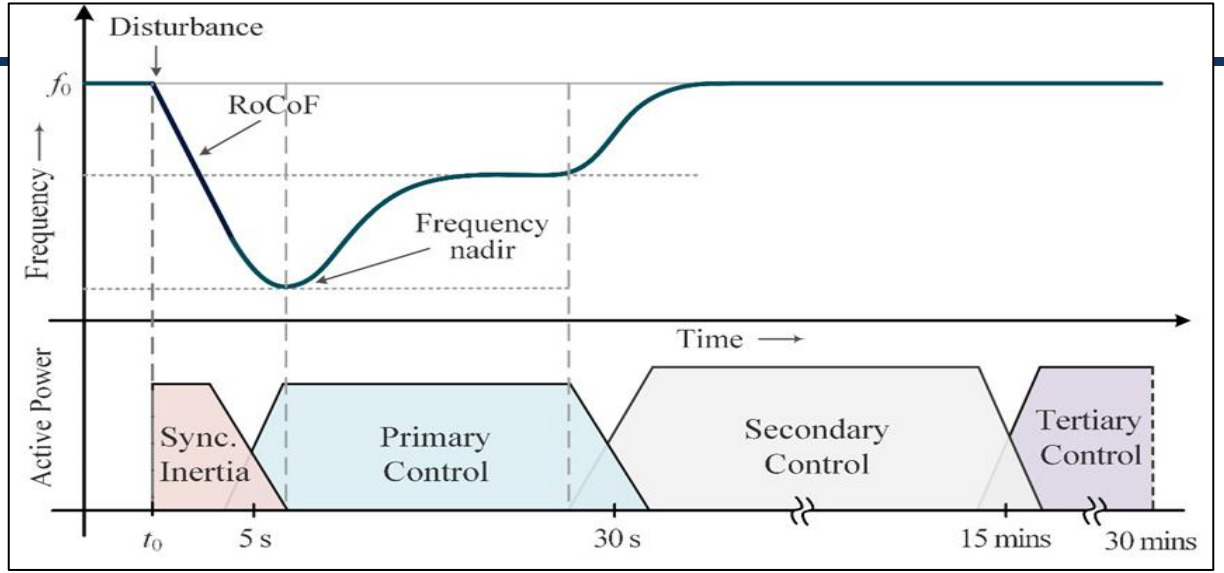
Reactive Power Management

“All the Inverter Based Resources (IBRs) covering wind, solar and energy storage shall ensure that they have the necessary capability, as per CEA Connectivity Standards, all the time including non-operating hours and night hours for solar. The active power consumed by these devices for purpose of providing reactive power support, ***when operating under synchronous condenser/night-mode,*** *shall not be charged under deviations and* ***shall be treated as transmission losses in the ISTS****.”*

Ancillary Services in India - Classification

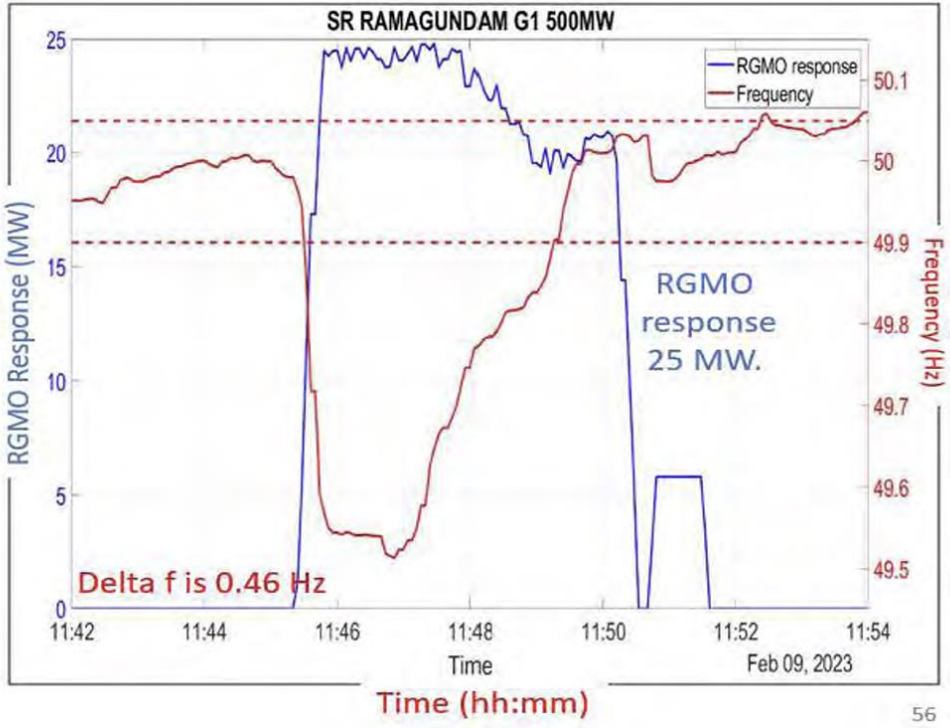


Reserves in Indian Power System



Reserve	Start of activation	Full Availability/ deployment	Ability to sustain the full deployment
Primary Response	Immediately as soon as frequency crosses the dead band	Within 45 seconds	Up to 5 min
Secondary control Reserve	Within 30 seconds after the receipt of Automatic Generation Control (AGC) signal	within 15 Minutes	Up to 30 min or till replaced by Tertiary Reserves
Tertiary control Reserve	Within 15 minutes of dispatch instruction from NLDC/RLDC		Up to 60 minutes

Primary Frequency Control



- Response from governor is automatically driven.
- Third-party assessment of ~ 240 generating units carried out coordinated by RLDCs/NLDC
- Presently mandated as per Grid Code
- Primary Response as an Ancillary Service – a future option in light of high RE penetration
- RE and ESS to provide Primary Response in future

Reserve Estimation, and Planning

Planning for Reserves

Year- Ahead — Resource Adequacy/LGBR

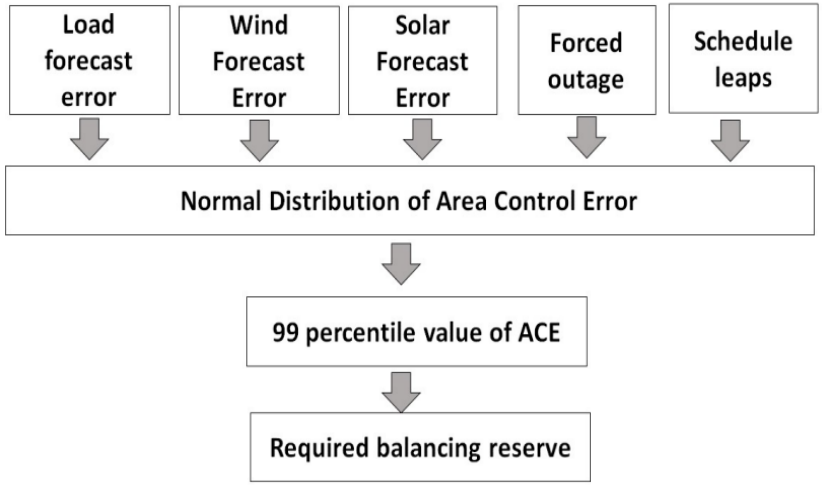
Three Day - Ahead — Operational planning/Unit Commitment

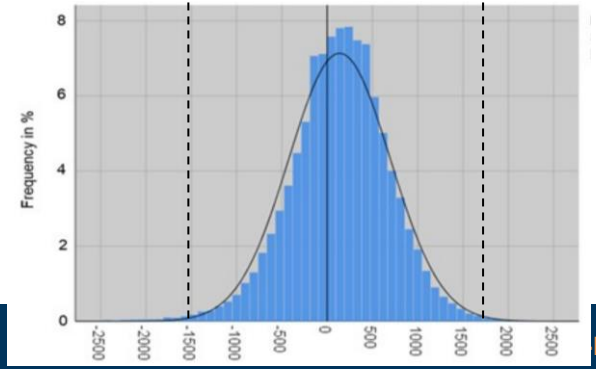
Procurement of Reserves

Day- Ahead — Day Ahead Procurement (DAM - AS)

Intra - Ahead — Incremental Procurement (RTM - AS)

Basis of Estimation





Primary Response - Regulatory Provisions

CERC, Indian Electricity Grid Code, 2023

Primary Frequency Response

All renewable energy generating stations and ESS shall be equipped with the facility to control active power injection in accordance with the CEA Connectivity Standards and the communication system shall be established in accordance with the CEA Technical Standards for Communication.

Fuel/ Source	Minimum unit size/Capacity	Up to
Coal/Lignite Based	200 MW and above	±5% of MCR
Hydro	25 MW and above	±10% of MCR
Gas based	Gas Turbine above 50 MW	±5% of MCR (corrected for ambience

Fuel/ Source	Minimum unit size/Capacity	Up to
WS Seller (commissioned after the date as specified in the CEA Technical Standards for Connectivity)	Capacity of Generating station more than 10 MW and connected at 33 kV and above	As per CEA Technical Standards for Connectivity

Regulatory Provisions

CEA, Technical Standards for Connectivity to the Grid, Regulations 2007

…(2) The generating unit shall be capable of operating in the frequency range 47.5 to 52 Hz and be able to deliver rated output in the frequency range of 49.5 Hz to 50.5 Hz: Provided that in the frequency range below 49.90 Hz and above 50.05 Hz, or, as prescribed by the Central Commission, from time to time, it shall be possible to activate the control system to regulate the output of the generating unit as per frequency response requirement as provided in sub-clause

(4):…The generating stations with installed capacity of more than 10 MW connected at voltage level of 33 kV and above –

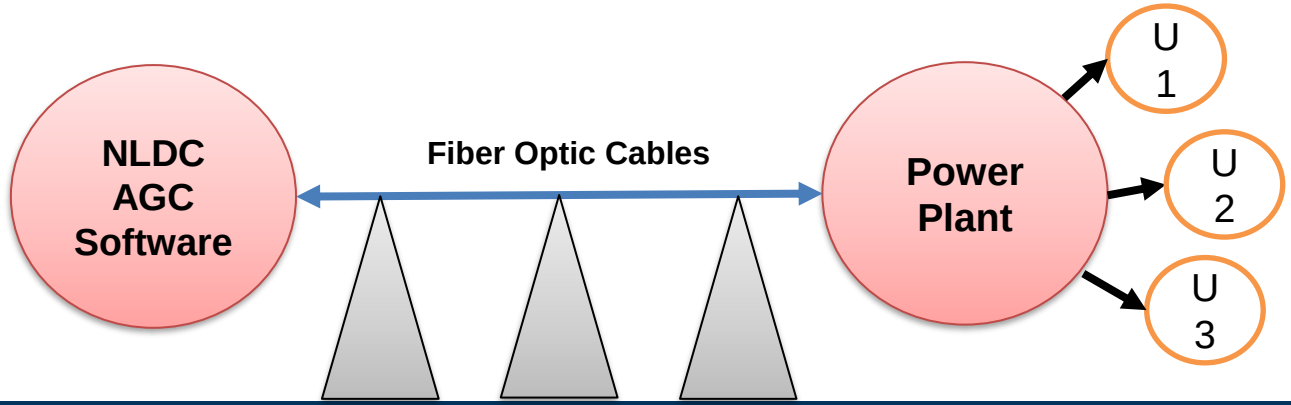
(i) shall be equipped with the facility to control active power injection in accordance with a set point, capable of being revised based on directions of the State Load Dispatch Centre or Regional Load Dispatch Centre, as the case may be;

(ii) shall have governors or frequency controllers of the units at a droop of ***3 to 6%*** *and a* ***dead band not exceeding ±0.03 Hz:***

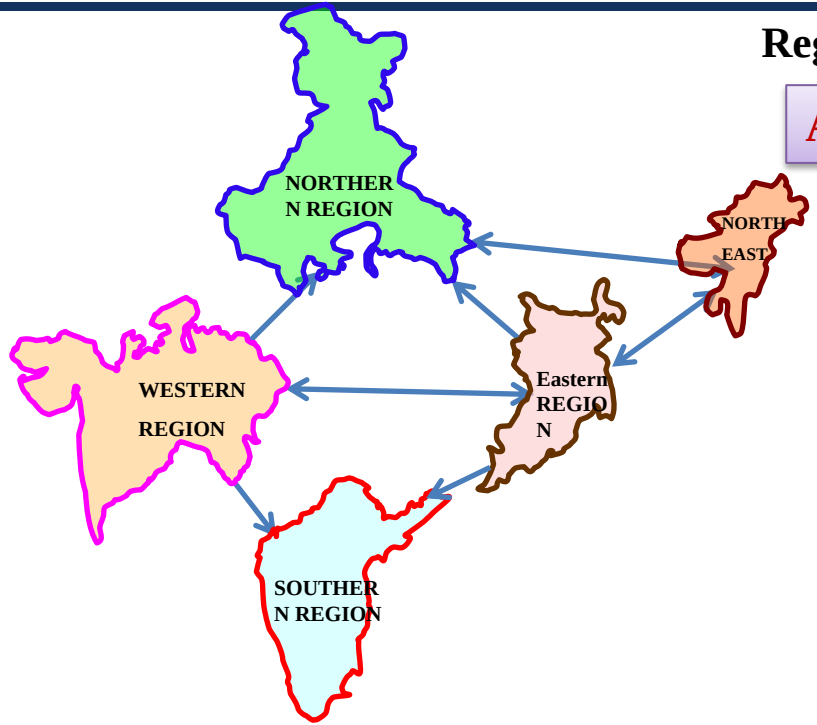
Provided that for frequency deviations in excess of 0.3 Hz, the Generating Station shall have the facility to provide an immediate (within 1 second) real power primary frequency response of at least 10% of the maximum Alternating Current active power capacity;

Automatic Generation Control (AGC) in Brief

- Automatic and supplementary control mechanism, 24x7
  - To control frequency and tie-line flows
- Several signals exchanged with generators every 4 seconds
- AGC helps replenish the exhausted primary reserves
  - Be ready for any next contingency
- Efficient and automatic frequency control during high RE periods
- AGC improves the reliability of the Indian power system.



Area Control Error (ACE) Calculation



Region considered as an Area for secondary control

ACE = (Ia - Is) - 10 * Bf * (Fa - Fs) + Offset

- Ia = Actual net interchange in MW (positive for export)
- Is = Scheduled net interchange in MW (positive for export)
- Bf = Frequency Bias Coefficient in MW/0.1 Hz (negative value)
- Fa = Actual system frequency in Hz
- Fs = Schedule system frequency in Hz (default 50 Hz)
- Offset = Provision for compensating errors such as measurement error; default value zero
- ACE positive means area is in surplus and its internal generation has to back down
- ACE negative means area is in deficit and its internal generation has to increase

Balancing Reserves Dimensioning (2024-25)

Type of reserve	Inter-state level (MW)	Intra state level (MW)	Total All India level (MW)
Secondary	3788	3211	7000
Tertiary	3788	8887	12676
Total	**7576**	**12099**	**19676**

- All India reserves capture diversity benefit at regional level which otherwise would have been **27864 MW**
- Reference contingency for 2024-25 (**7000 MW** (for Solar hours) / **4500 MW** (for non- Solar hours)) published on NLDC website

Regulations and Procedures – SRAS and TRAS

Central Electricity Regulatory Commission (Ancillary Services) Regulations, 2022.

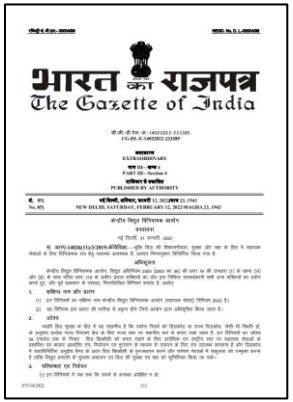
Gazette Notification Statement of Reasons

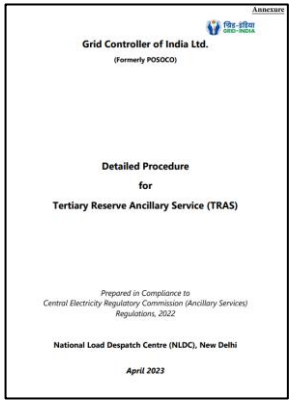
Notification - effective date 05.12.2022 --- SRAS

Notification - effective date 01.06.2023 --- TRAS

CERC orders on implementation aspects

Introduction of AS contracts Expansion of scope


भारत का राजपत्र
The Gazette of India


Grid Controller of India Ltd.
(Formerly POSOCO)

Detailed Procedure
for
Tertiary Reserve Ancillary Service (TRAS)

Prepared in Compliance to
Central Electricity Regulatory Commission (Ancillary Services) Regulations, 2022

National Load Despatch Centre (NLDC), New Delhi

April 2023

Detailed Procedure for Secondary Reserve Ancillary Services (SRAS) – Dec 2022 - Link

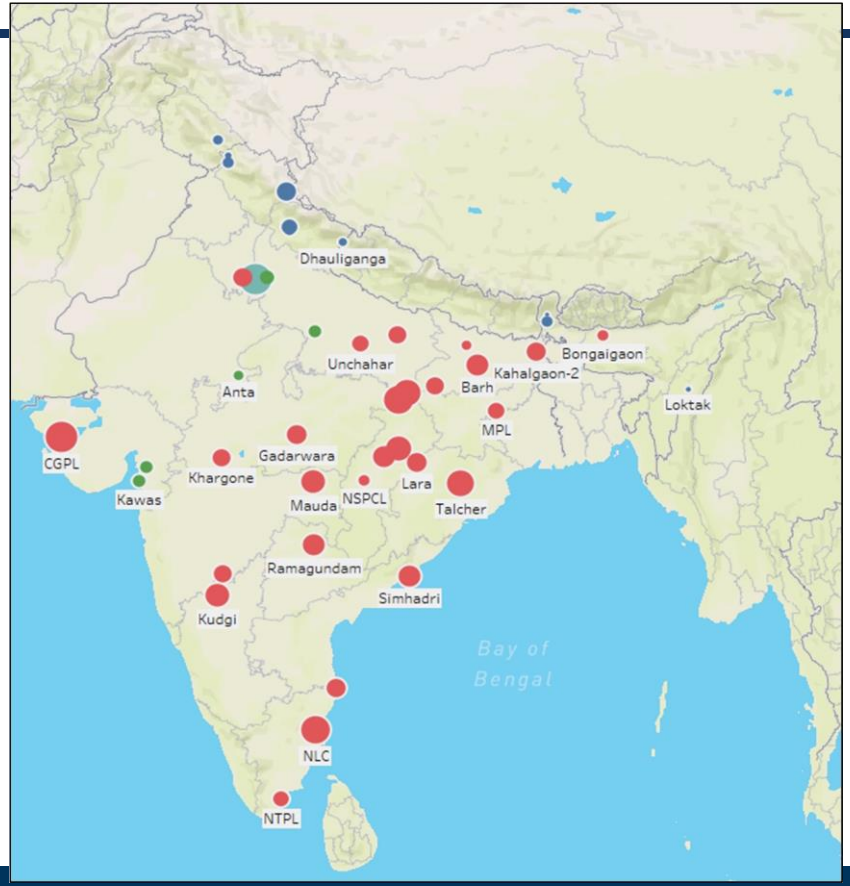
Detailed Procedure for Tertiary Reserve Ancillary Services (TRAS) – April 2023 – Link

Central Electricity Regulatory Commission (Indian Electricity Grid Code) Regulations, 2023 – Link

Procedure for Assessment and Procurement of Reserves – IEGC 2023 – Link

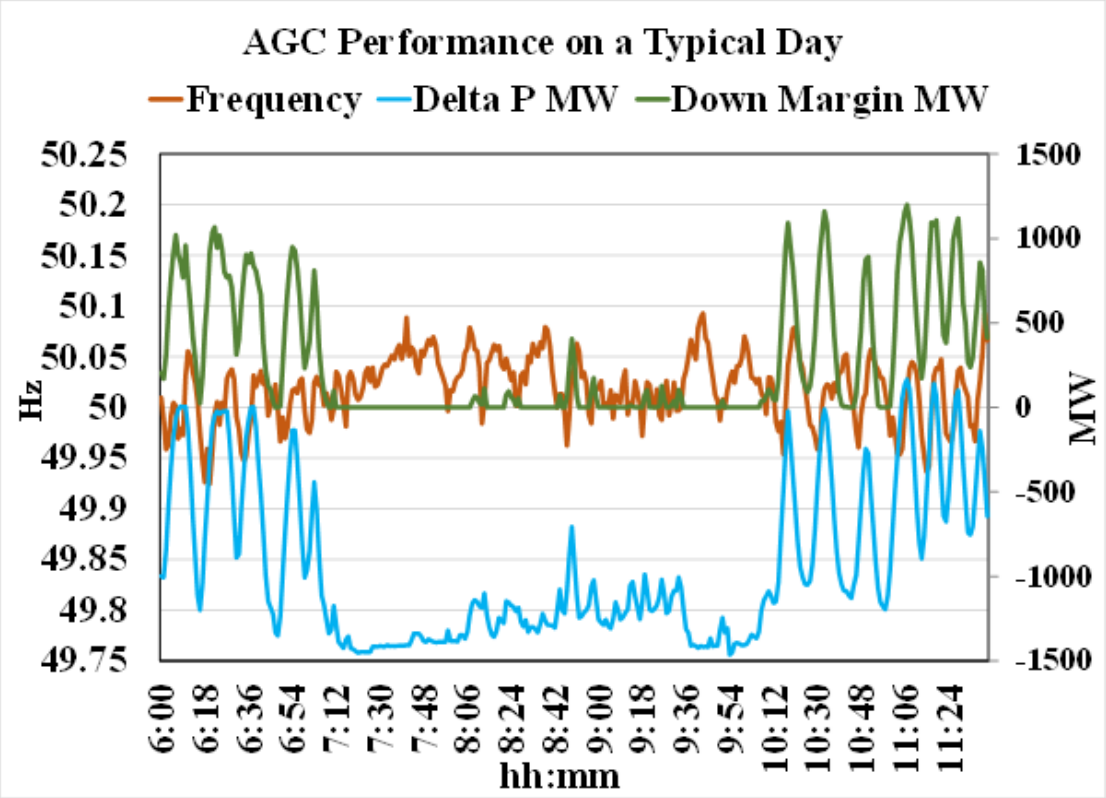
Procedure for Performance Assessment of TRAS and SRAS Providers – IEGC 2023 - LINK

SRAS (AGC) Status Update



- Pan India distributed AGC
- 70 power plants, 185 units, and 67996 MW capacity under AGC
  - ~ 58 GW coal, ~ 6 GW hydro and ~ 3 GW gas
  - 24x7 operation of AGC from 20th July 2021
  - Far away plants in remote from NLDC !
    - NTPL 2760 kms, Loktak 2500 kms
- Robust communication infrastructure through optical fiber
- Signals sent from NLDC to the power plants every 4 seconds for AGC-Up or AGC-Down
- Up & Down Regulation up to 2000 MW pan-India

Load Following during RE Integration

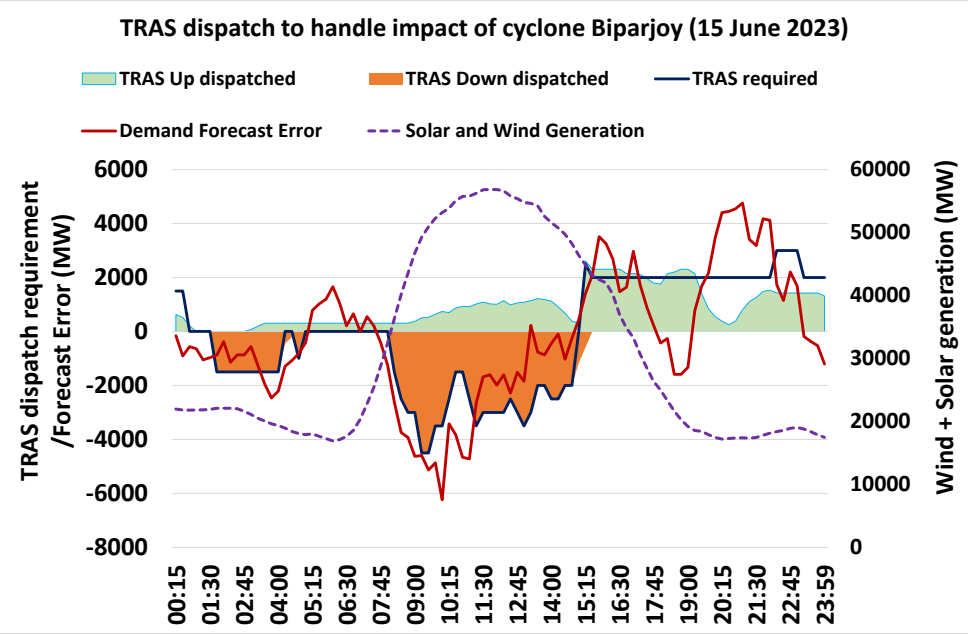


- Up and down regulation of around +/-1300 MW in response to frequency changes
- Down reserve fully utilised
- AGC helps in controlling high frequency during such solar pickup periods.

Typical grid Operation with and without Ancillary Services

16th July 2023

S.No.	With & without Ancillary Support	% time frequency remained within the band	No. of 50 Hz crossings
1	Without Ancillary support	26.8 %	84
2	With SRAS support	73.1 %	184
3	With SRAS & TRAS support	83.8 %	379



- Extremely Severe Cyclonic Storm "Biparjoy" on 15th June 2023
- Low demand, high wind, after Landfall
  - Regulation Down Applied
  - Technical Minimum Support provided to thermal generators to provide evening peaking
- Peaking requirement in the evening
  - Regulation Up Applied
  - Gas generation despatched

Need for Procurement of Reserves on Advance Basis

- Reserves are key for system security especially during clean energy transition
- The reserves have to be identified in advance, kept available and deployed in real time as per the system requirement by the System Operator.
- International experience is that there is reserve tendering / procurement on various time frames such as Annual, Monthly, Weekly and Day-Ahead basis

Regulatory Provisions

CERC, Indian Electricity Grid Code, 2023

Periodic Testing

Power System Elements	Tests	Applicability
Synchronous Generator	(1) Real and Reactive Power Capability assessment. (2) Assessment of Reactive Power Control Capability as per CEA Technical Standards for Connectivity (3) Model Validation and verification test for the complete Generator and Excitation System model including PSS. (4) Model Validation and verification of Turbine/Governor and Load Control or Active Power/ Frequency Control Functions. (5) Testing of Governor performance and Automatic Generation Control.	Individual Unit of rating 100MW and above for Coal/lignite, 50MW and above gas turbine and 25 MW and above for Hydro.
Non synchronous Generator (Solar/Wind)	(1) Real and Reactive Power Capability for Generator (2) Power Plant Controller Function Test (3) Frequency Response Test (4) Active Power Set Point change test. (5) Reactive Power (Voltage / Power Factor / Q) Set Point change test	Applicable as per CEA Technical Standards for Connectivity.

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. **Robust Compliance Verification for Renewable Plants**

3. **Ensuring availability and activation of Reserves at State Level**

4. **Participation of intra-state plants, wind & solar plants, BESS, Electrolyzers etc. in providing ancillary services**

Way Forward

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

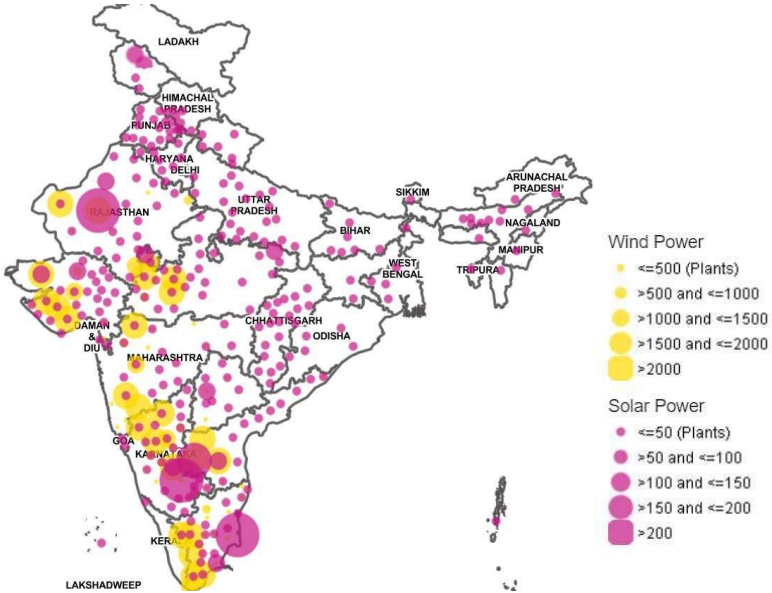
6. Identifying and periodically reviewing the right resource mix for medium and long-term duly factoring in resource adequacy and flexibility requirements

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

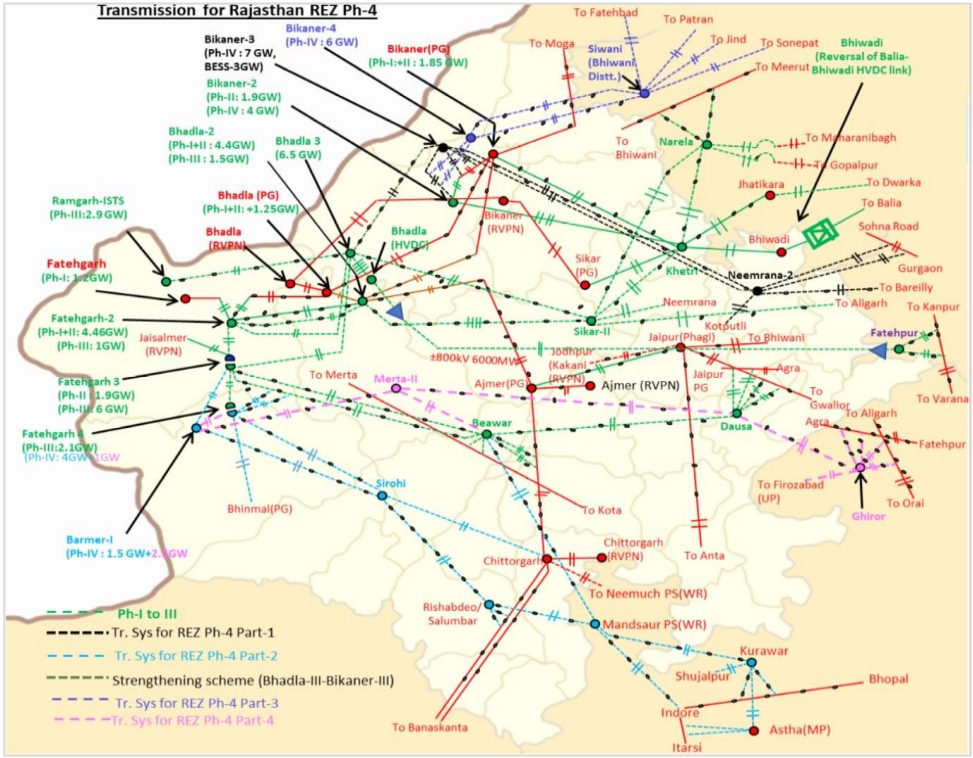
Thank You !!

www.grid-india.in

Renewable Energy Integration in India – Unique Case



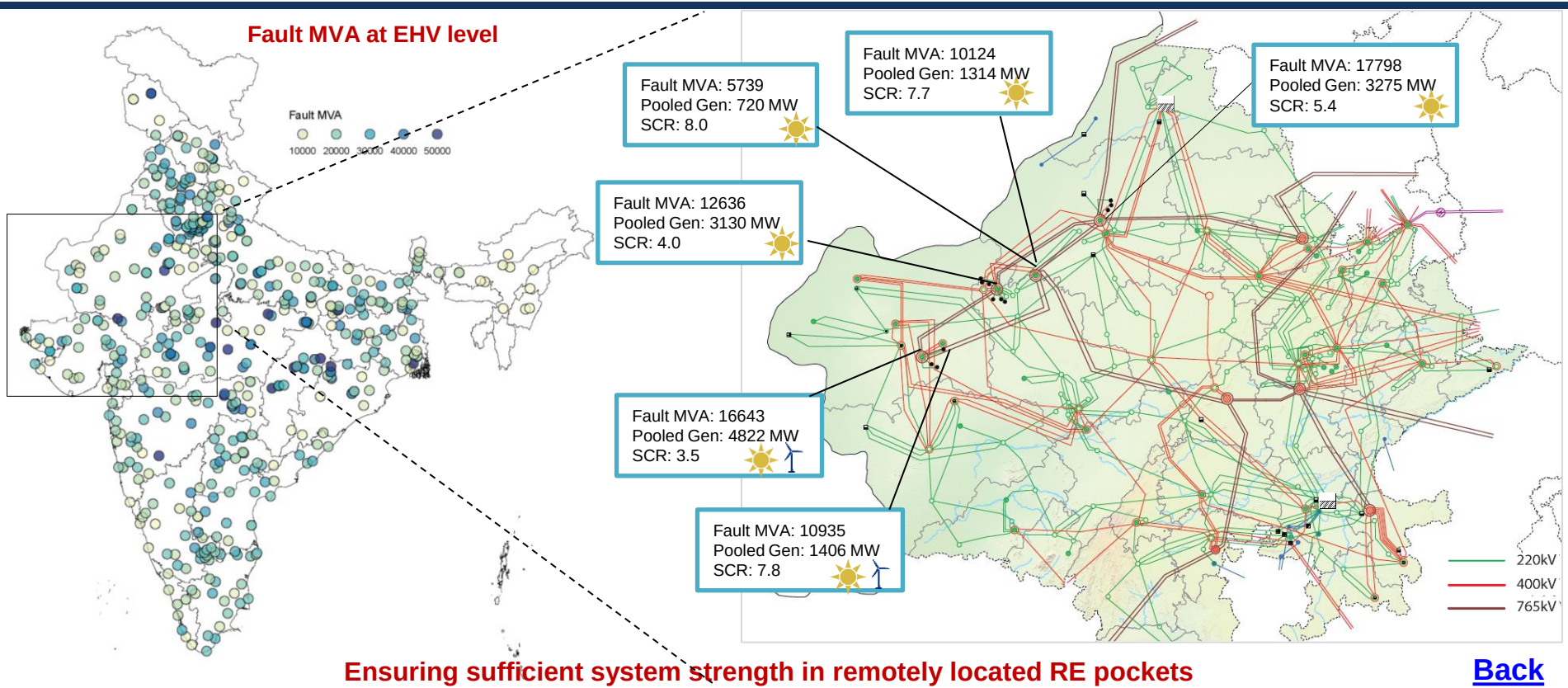
Source: VEDAS portal of ISRO and NITI Aayog
https://vedas.sac.gov.in/energymap/view/powergis.jsp#



- **Large RE pooling stations at EHV level**
- **Remotely located, far from load centres**
- **Long UHV/EHV lines to evacuate bulk intermittent/variable power from IBR to grid**

Back

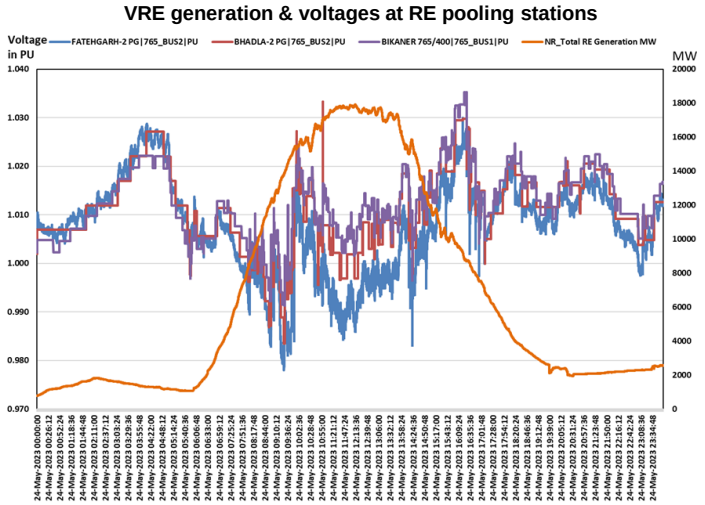
System Strength Concerns



Ensuring sufficient system strength in remotely located RE pockets

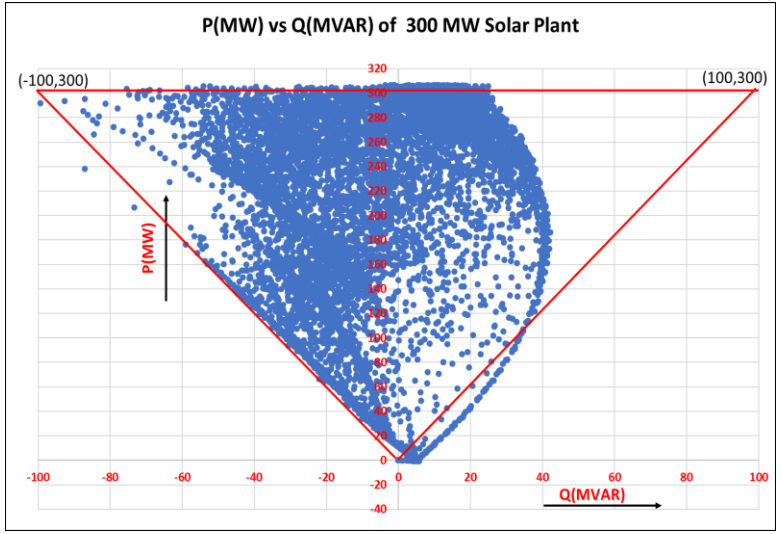
Back

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

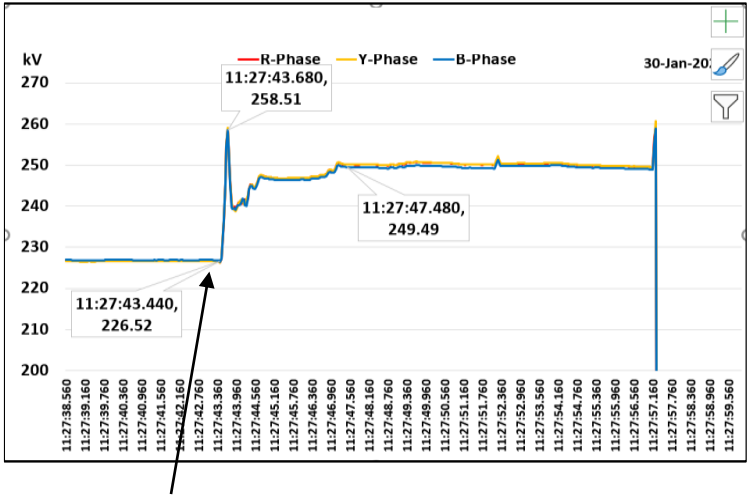


Inadequate Reactive Power Support from RE Plants

Back

System Strength Concerns

Reduction in SCR due to depleted network

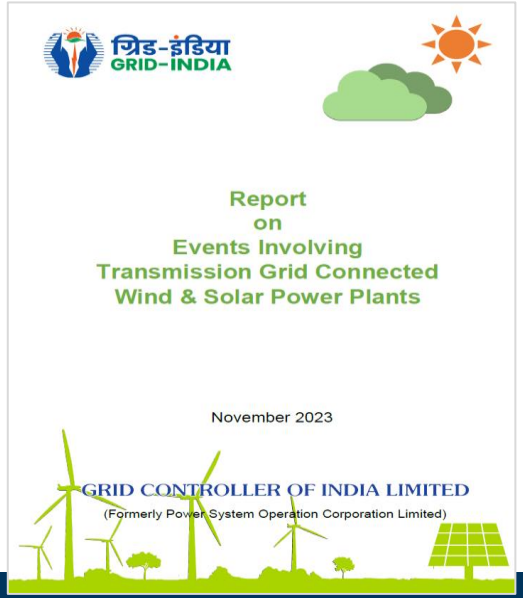


Switching of 240 MVAR Line reactor

- 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

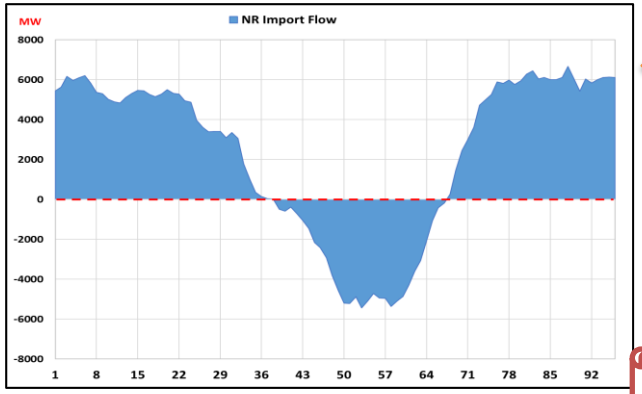
Transient voltage rise leading to tripping of EHV lines and Renewable plants on overvoltage



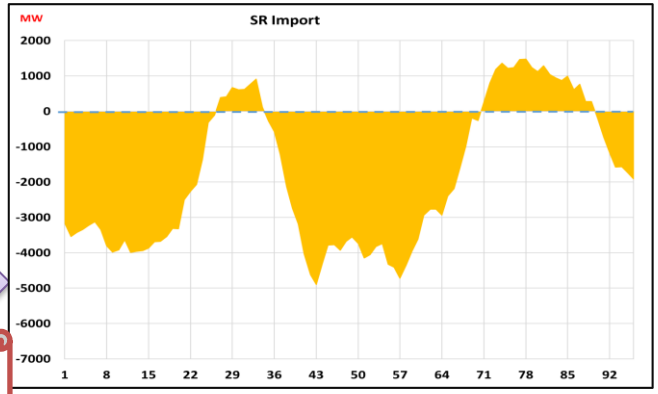
Several incidents of RE generation loss due to large voltage fluctuations during switching operations

Back

Transmission Planning – Behavioral Change in Flow Patterns

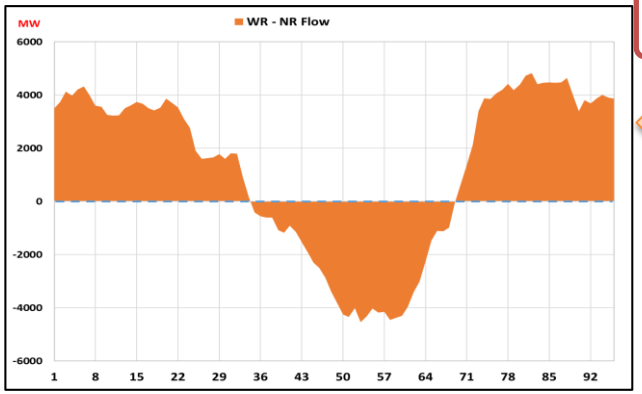


NR Import

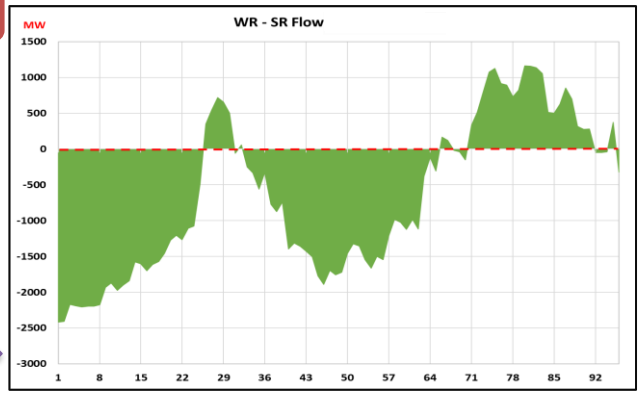


SR Import

Bi-directional Flows
The New Normal !!



WR - NR



WR -SR

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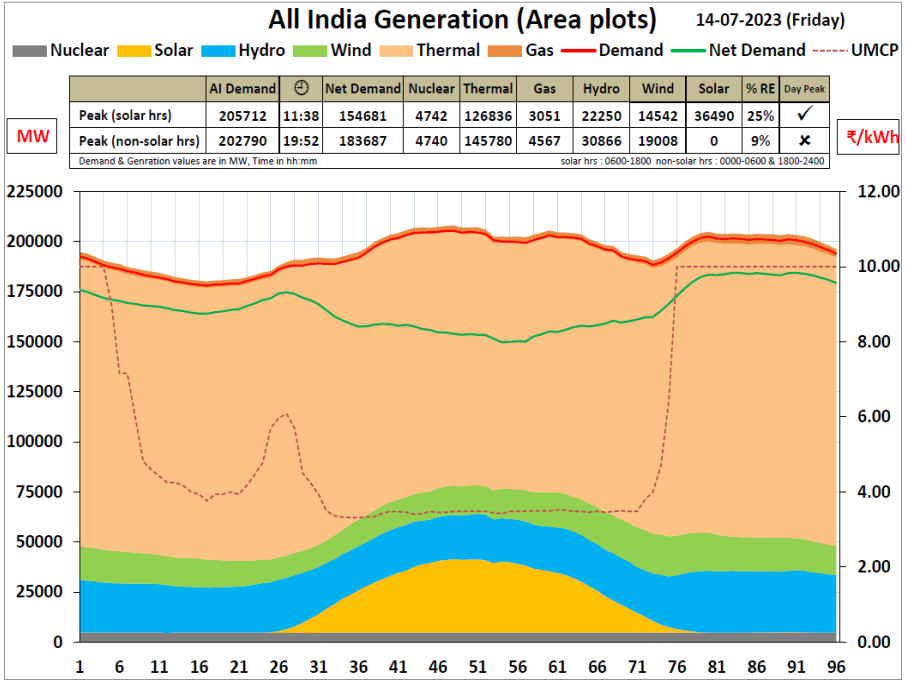
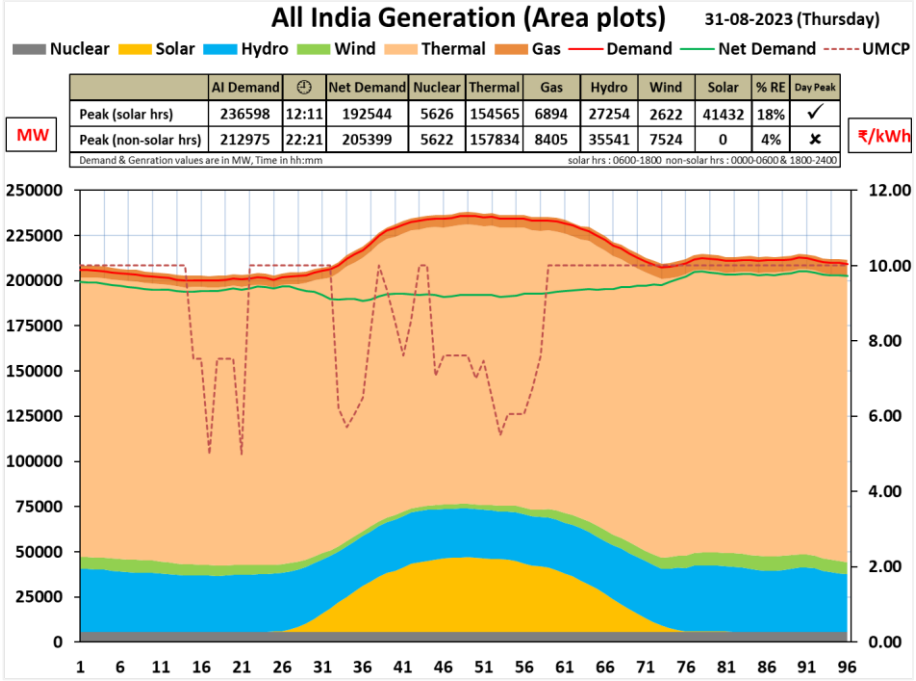
Resource Adequacy – Concerns

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

Back



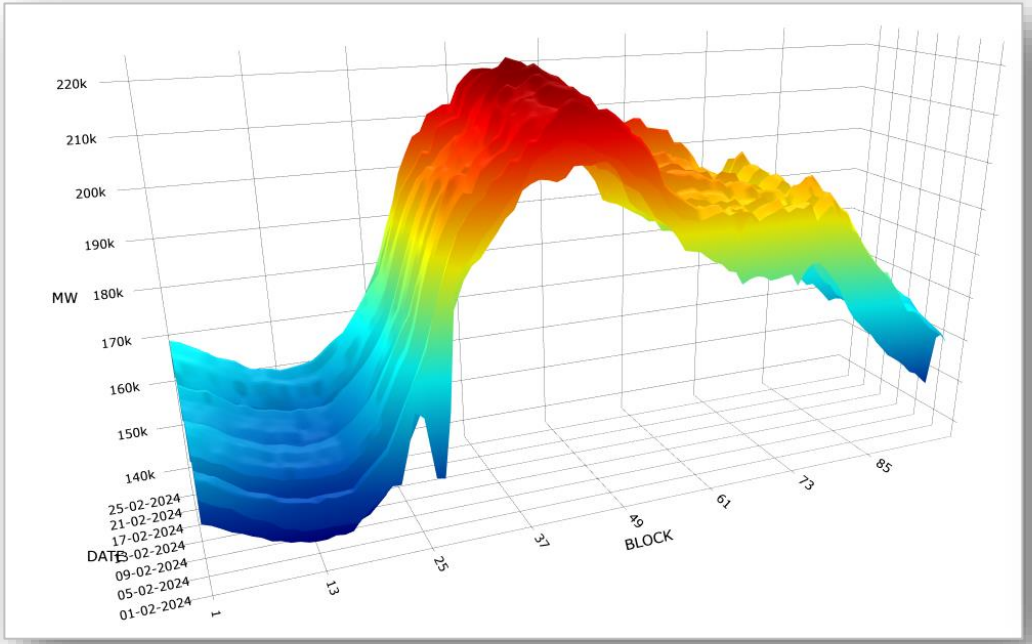


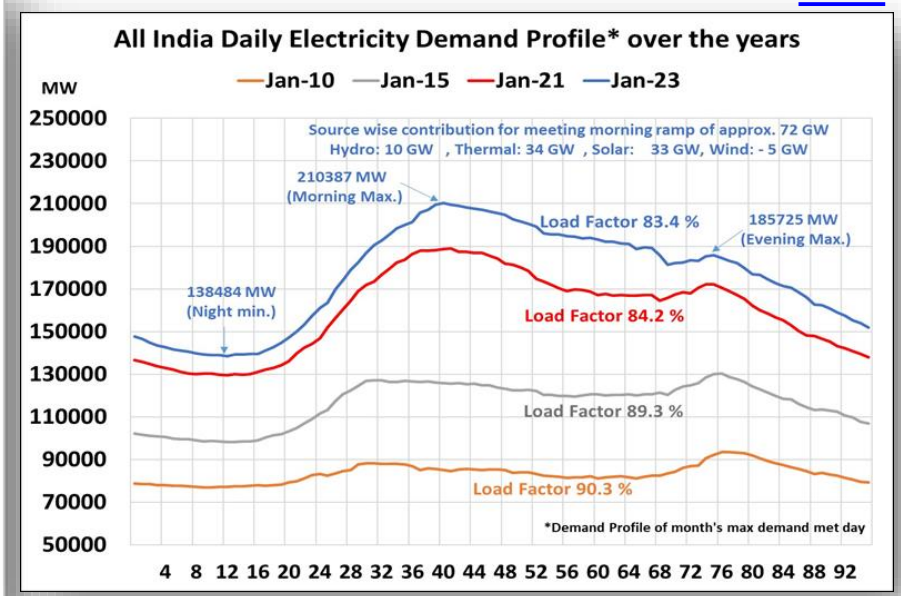
Highest Instantaneous RE penetration (in 23-24) of ~32.4% was recorded on 14th July 2023

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

Flexibility – Growing Need

Back





All India Demand

Typical Ramp rate ~ 250-300 MW/min

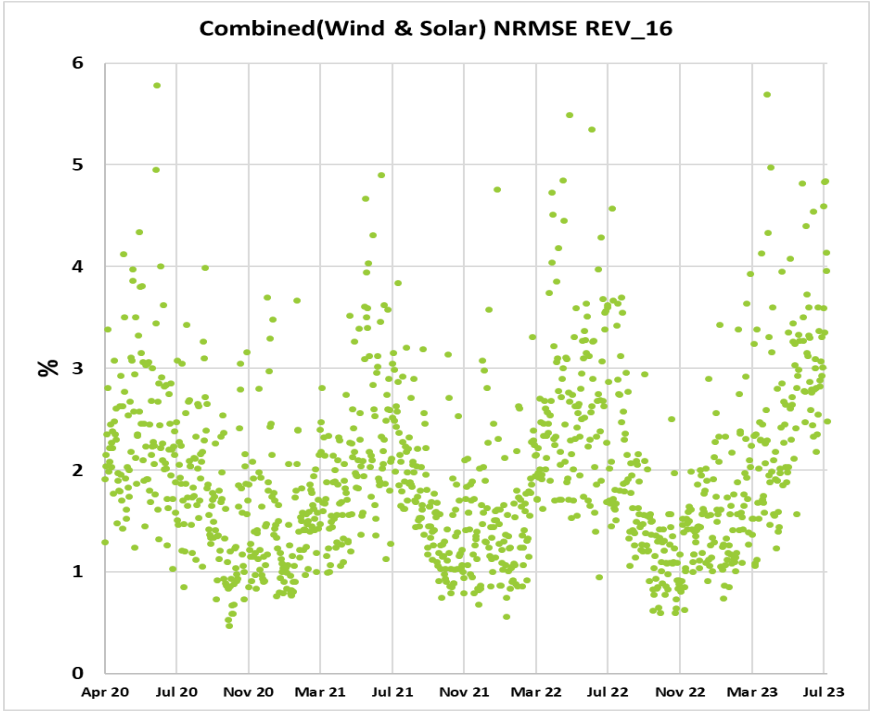
Special Days ~ 500 MW/min

Change in Load Shape

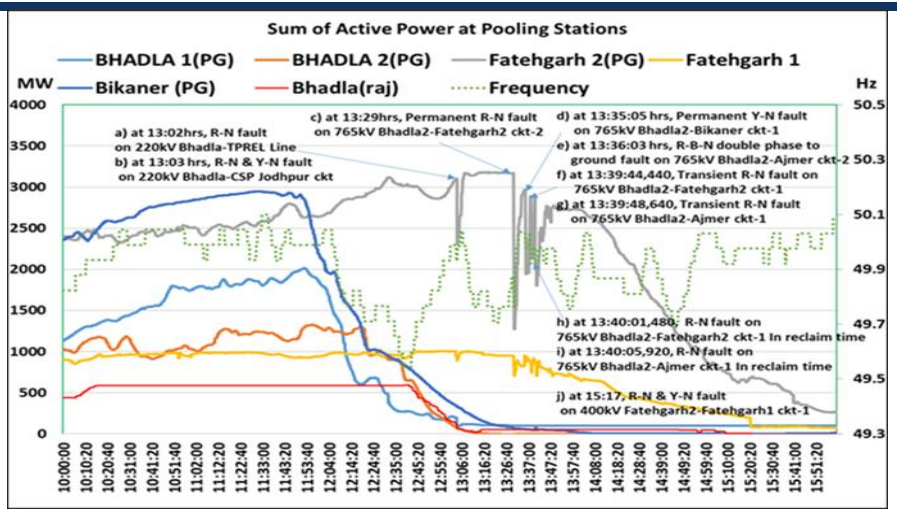
Increasing uncertainty on demand side

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

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Key to Renewable Integration

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

Back

Compliance Verification Process

Type Test Reports

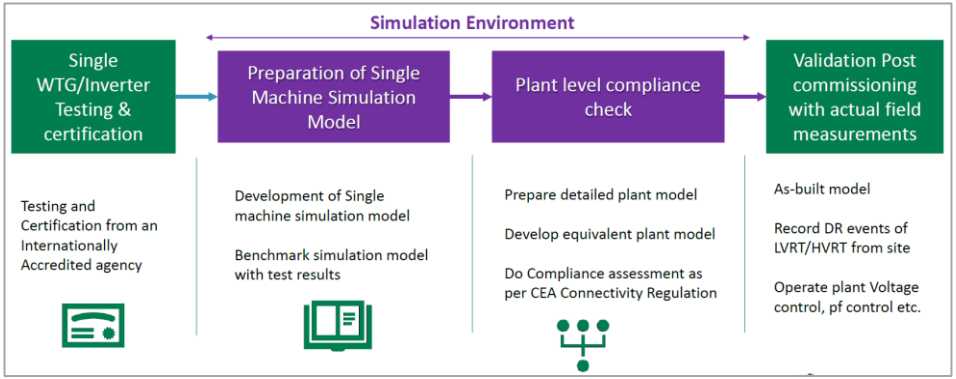
(Factory or Lab Environment)

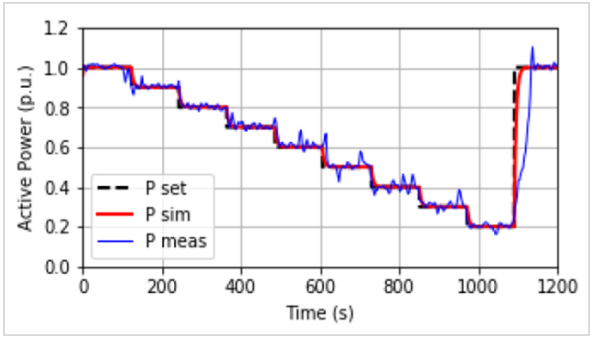
Evaluation Reports & Statement of Compliance

(by an Accredited Certification Agency)

Simulation Reports and Models

Verification through independent Simulations by System Planner and Operator

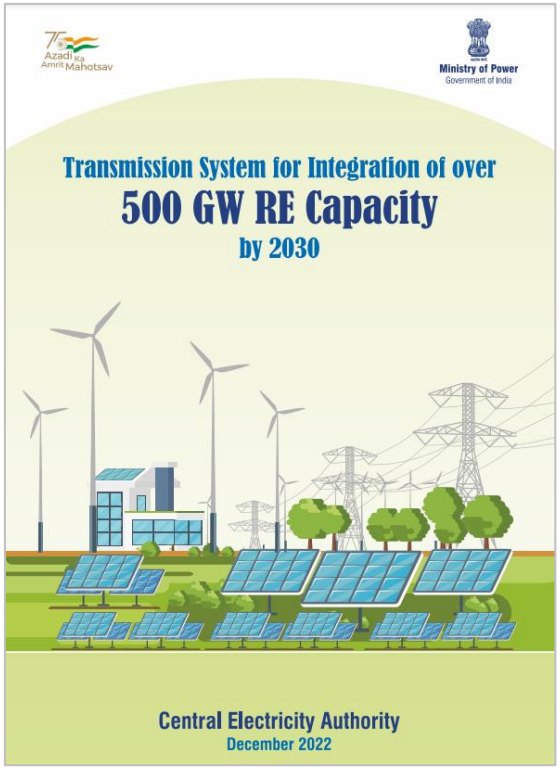




Back

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

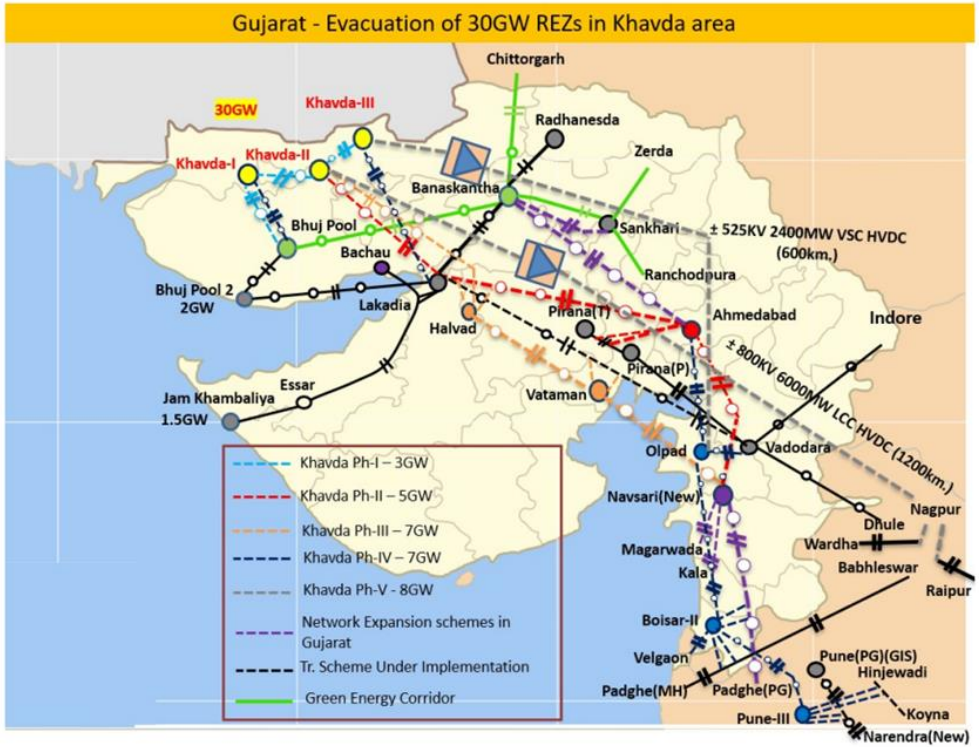
Transmission Planning – Regulatory Initiatives

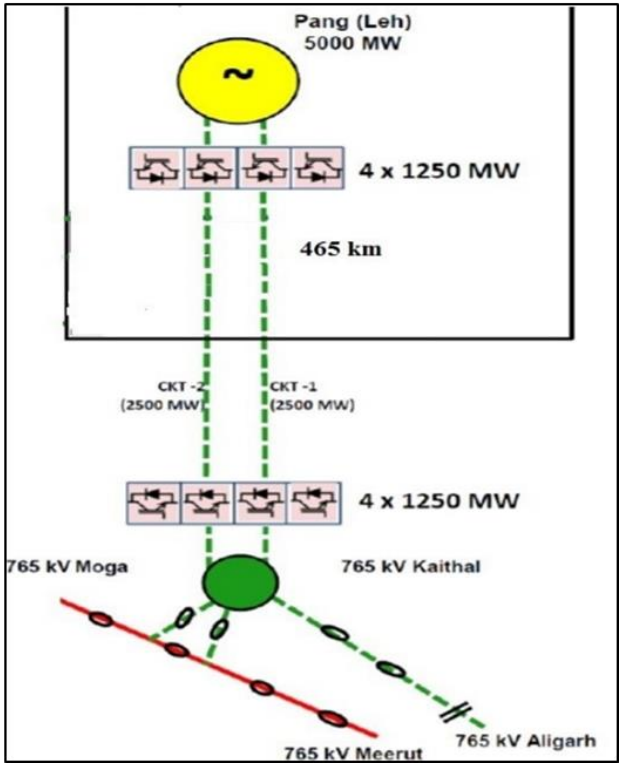


- **Perspective Planning - Central Electricity Authority's report on Transmission Plan for 500 GW RE by 2030**
- **Recognition of Low Gestation Period of RE and BESS vis-à-vis Transmission**
  - Fast tracking of approvals of transmission schemes through empowerment of system planner (CTUIL)
  - **Short-term 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**

Back

Transmission Planning Initiatives





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

Back

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

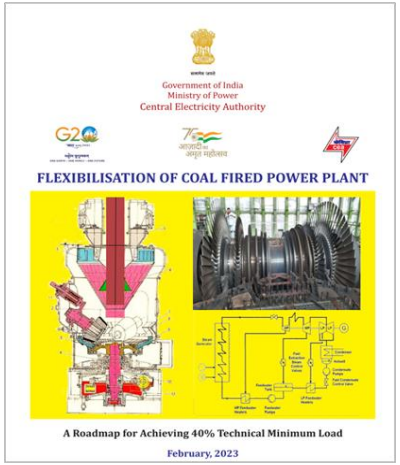
Flexibility Initiatives

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

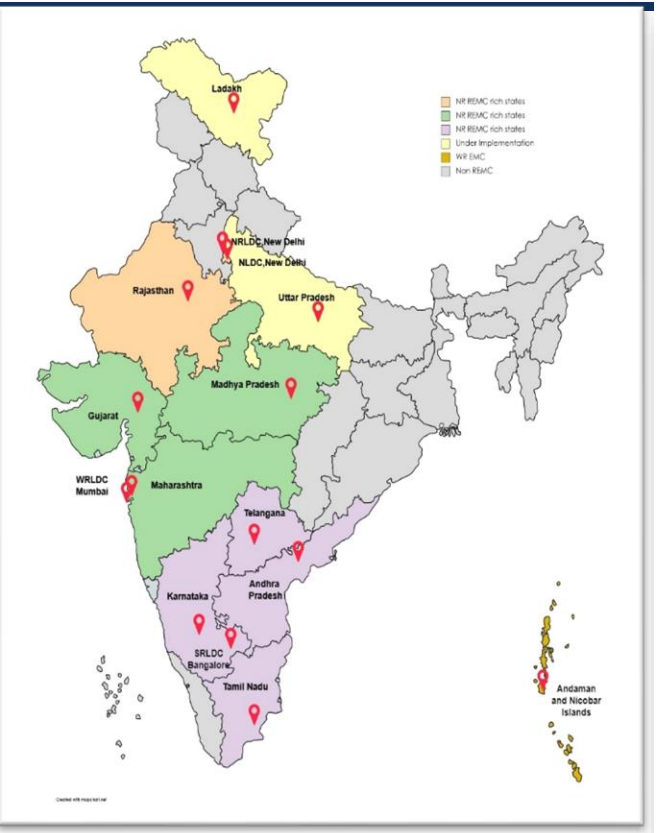
- Incentivized generators to provide ramping capability beyond the threshold of 1% and to penalize in case of failure to provide 1%, in terms of return on equity
  - rate of return on equity shall be **reduced by 0.25%** in case of failure to achieve the ramp rate of 1% per minute;
  - an **additional 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%

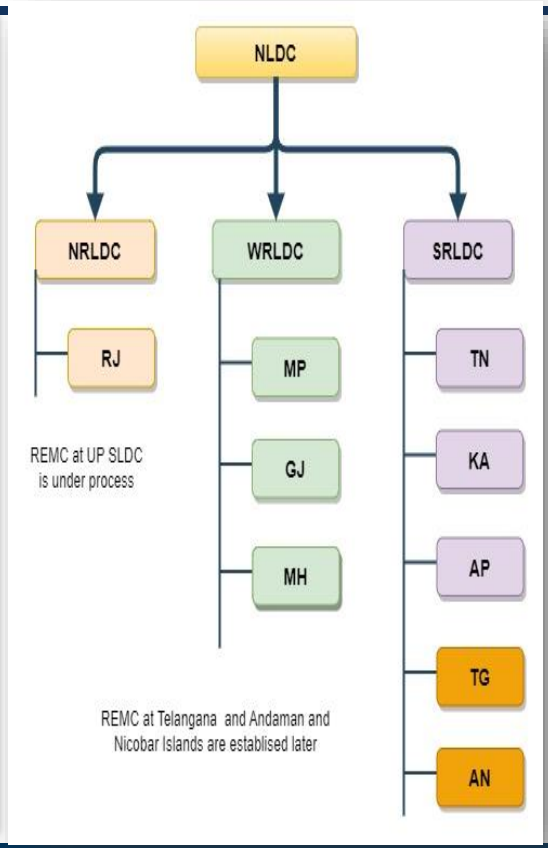


Central Electricity Authority – Phasing Plan for Implementation of 40% Technical Minimum Level

Back

Real-time Monitoring, Visualization and Situational Awareness





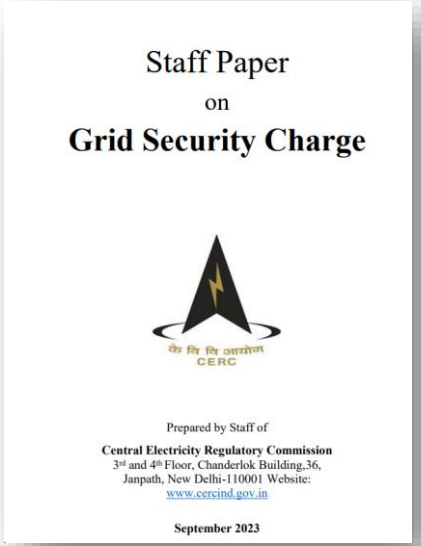
Renewable Energy Management Centers

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

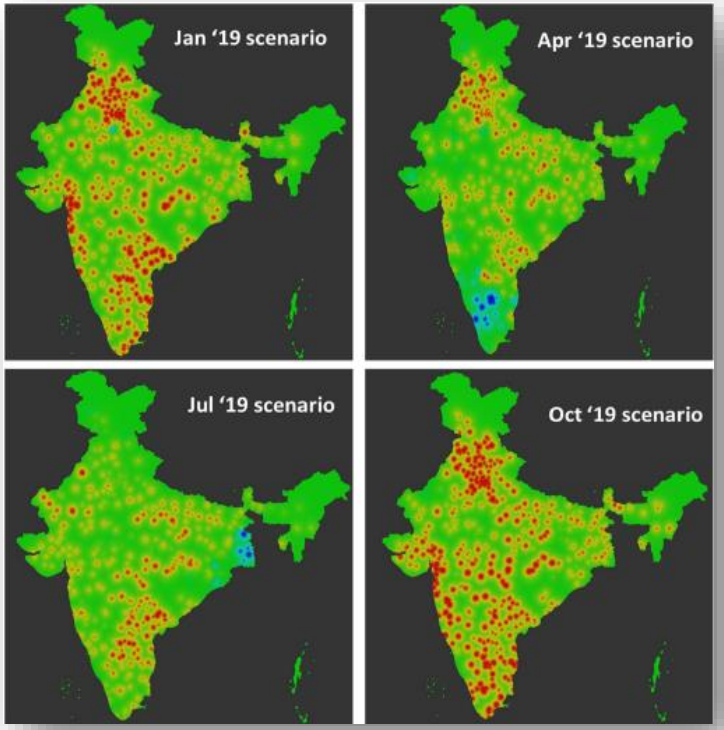
Back

Proposal for Grid Security Charge

- Concerns about maintaining adequate reserves to ensure reliable grid operations in India, especially considering the significant rise in peak power demand.
- Need to ensure sufficient reserves to handle contingent situations and maintain grid stability.
  - Dispatching gas-based generation for reserve purposes incurs additional costs.
- To address above concerns, Central Commission floated a staff paper on **Grid Security Charge** in September 2023
- To recover the expenses associated with reserves and ancillary services by Grid-India with a two-step approach
  - Utilize surplus funds available in the Deviation and Ancillary Services Pool Account.
  - If the surplus in pool account is insufficient, a "***Grid Security Charge"*** will be levied to recover the remaining cost
- Various options for recovery of "Grid Security Charge" from the drawee Designated ISTS Customers (DICs):
  - Option-I: In proportion to their allocated share of reserves as estimated and published by NLDC.
  - Option-II: In proportion to their GNA quantum.
  - Option-III:


Staff Paper
on
Grid Security Charge
केन्द्रीय विद्युत आयोग
CERC
Prepared by Staff of
Central Electricity Regulatory Commission
3rd and 4th Floor, Chanderlok Building,36,
Janpath, New Delhi-110001 Website:
www.cercind.gov.in
September 2023

Voltage Control Ancillary Services



- Voltage control strategy in regulated mode
  - Mandatory support from grid connected generators.
  - Charges for reactive drawal / exchanges, depending on the voltage conditions (outside band of 0.97 to 1.03 p.u.)
- Need to bring in a different approach
  - 500 GW RE by 2030
- Procedure on Dynamic reactive power reserve assessment as per IEGC, 2023 in place. LINK
- Need for suitable compensation mechanism
  - Dynamic Var Support
  - Synchronous condenser operation of hydro
  - E during no generation period

Reactive power is like chlorophyll for the GREEN future

Suggestions and Way Forward

Regulations and Standards

- **Strengthening of CEA Connectivity Standards**
  - Specifications for LVRT/HVRT response time, “K” factor, coordinated settings etc.
  - Standards for PPC Response Time / Performance Metrics
  - Standards for Battery Energy Storage System, upcoming IBR interface loads such as electrolyzers, data centers etc.
  - Standards for Grid-Forming Capability of Inverters, Synthetic Inertia, FFR etc.
  - Review of Short Circuit Ratio (SCR) Metric

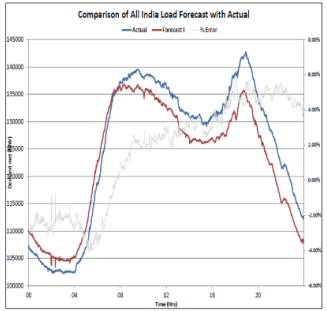
- **Formulation of Construction Standards for RE**
  - Design Temperature Specifications
  - Standards for Protection Settings, Data Retention Schemes etc.
  - Other aspects

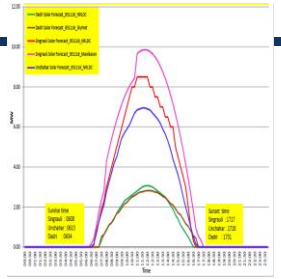
Cues for System Operator to Despatch TRAS

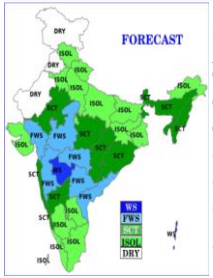
- SRAS deployed continuously in one direction for fifteen (15) minutes for more than 100 MW
  - In order to replenish the secondary reserve

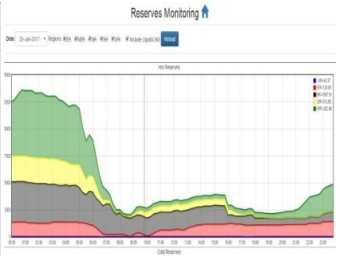
- Balancing Requirements
  - Weather Forecast errors
  - Load Forecast errors
  - Outages of Transmission Lines / Generating units

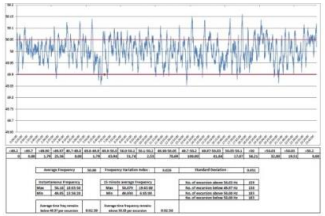
- Extreme weather conditions
- Load and net-load variation
- Renewable energy variation
- Ramp mismatches
- Congestion











For TRAS

DeltaP Crossing +/- 100 MW			
Number of Minutes	Number of Time Blocks	All India Smooth ACE MW	DeltaP MW
65	5	-4024	-185

Regulatory Provisions

Normal Operating Range

S. No.	Nominal System Voltage (kV rms)	Maximum (kV rms)	Minimum (kV rms)
1	765	800	728
2	400	420	380
3	220	245	198
4	132	145	122
5	110	121	99
6	66	72	60
7	33	36	30

CEA, Grid Standards, 2010

Regulatory Provisions

Temporary over voltage due to sudden load rejection

S. No.	Nominal System Voltage (kV rms)	Phase to Neutral Voltage (kV peak)
1	765	914
2	400	514
3	220	283
4	132	170

CEA, Grid Standards, 2010

Regulatory Provisions

CEA, Technical Standards for Connectivity to the Grid, Regulations 2007

Generating Units - Conventional

*"shall have **Automatic Voltage Regulator (AVR).** Generators of **100 MW rating and above** shall have Automatic Voltage Regulator with digital control and two separate channels having independent inputs and automatic changeover"*

*"Generating Units located **near load center**, shall be capable of operating at rated output for power factor varying between **0.85 lagging (over-excited) to 0.95 leading (under-excited)** and Generating Units located **far from load centers** shall be capable of operating at rated output for power factor varying between **0.9 lagging (over-excited) to 0.95 leading (under-excited).***

Regulatory Provisions

CEA, Technical Standards for Connectivity to the Grid, Regulations 2007

Distribution Systems and Bulk Consumers

Reactive Power

"The distribution licensee and bulk consumer shall provide adequate reactive compensation to compensate reactive power requirement in their system so that they do not depend upon the grid for reactive power support. The power factor for distribution system and bulk consumer shall be within ± 0.95"

Voltage Unbalance

"The Voltage Unbalance at 33 kV and above shall not exceed 3.0%."

Voltage Fluctuations

"The permissible limit of voltage fluctuation for step changes which may occur repetitively is 1.5%. For occasional fluctuations other than step changes the maximum permissible limit is 3%."

Regulatory Provisions

CEA, Technical Standards for Connectivity to the Grid, Regulations 2007

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Regulatory Provisions

CERC, Indian Electricity Grid Code, 2023

Reactive Power Management

Clause 39

*"**Hydro and gas generating units** having this capability shall operate in **synchronous condenser mode** operation as per instructions of the RLDC or SLDC of the respective control area. Standalone synchronous condenser units shall operate as per the instructions of RLDC or SLDC, as per the respective control area."*

Regulatory Provisions

CERC, Indian Electricity Grid Code, 2023

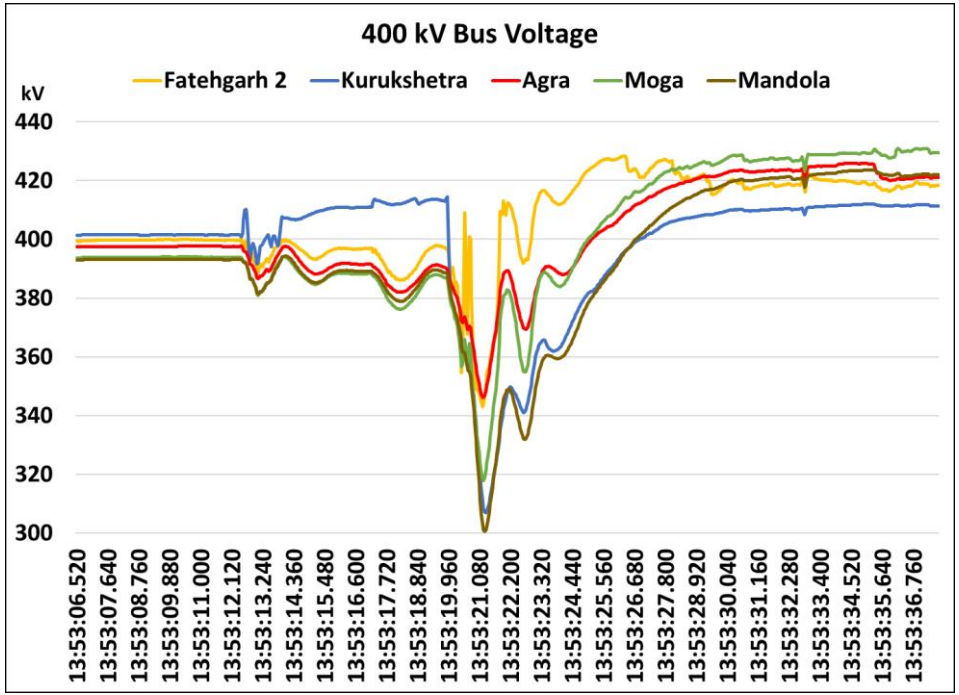
Regional entities supporting voltage get reactive power charge:

- The regional entity pays for VAr drawal when voltage is below 97%
- The regional entity gets paid for VAr return when voltage is below 97%.
- The regional entity gets paid for VAr drawal when voltage is above103%.
- The regional entity pays for VAr return when voltage is above 103%.

- Reactive power charge is INR 50/MVARh – Escalated by INR 5 every year

Grid Events

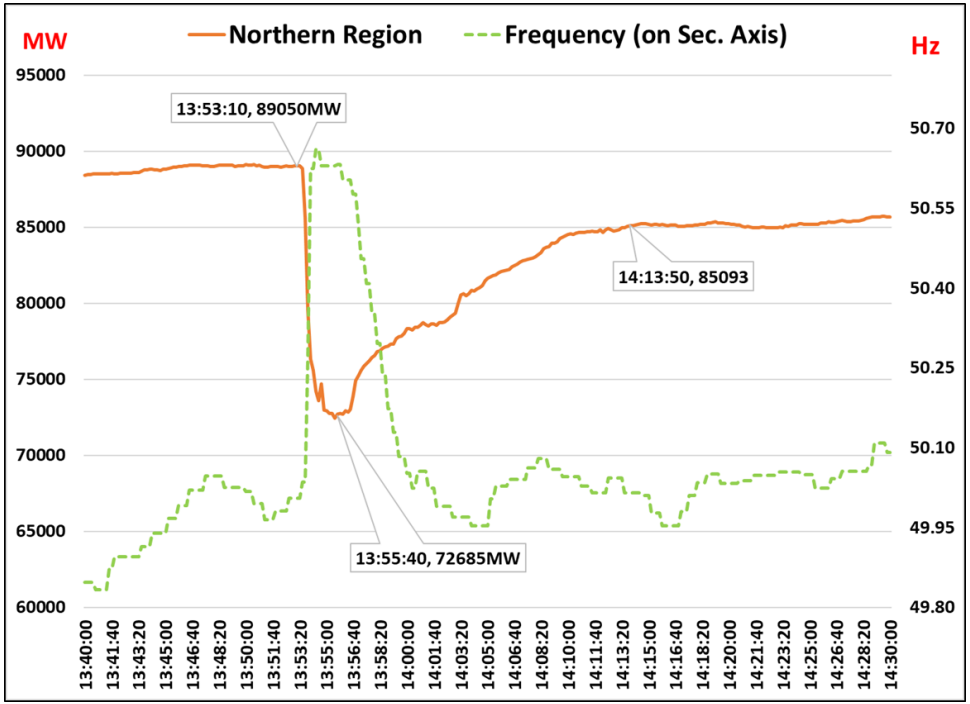
17th June 2024 – Load Loss Event in NR



Substation Name	Voltage recorded at 13:53:21 hrs (as per PMU data)
Mandola	302 kV
Ballabhgarh	313 kV
Nallagarh	335 kV
Moga	320 kV
Mahendargarh	330 kV
Ratangarh	323 kV
Lucknow	380 kV
Barellly	360 kV
Rishikesh	327 kV
Koldam	328 kV
Wagoora	389 kV

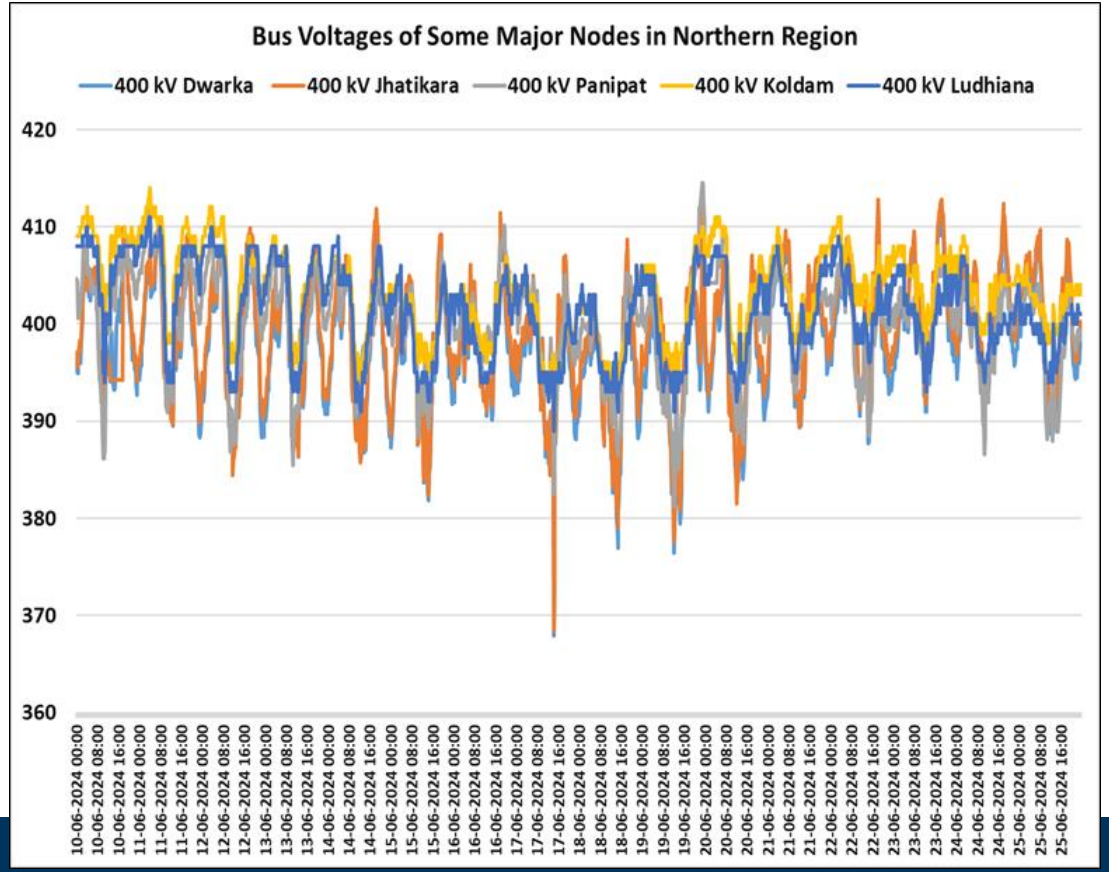
Grid Events

17th June 2024 – Load Loss Event in NR



STATE	Pre-Event Demand (MW)	LOAD LOSS (MW)	Percentage of Demand Loss
PUNJAB	15320	3780	25%
HARYANA	13138	4384	33%
UTTAR PRADESH	28939	2481	9%
RAJASTHAN	17636	3150	18%
DELHI	7513	2388	32%
UTTRAKHAND	2237	350	16%
HIMACHAL PRADESH	1743	240	14%
JAMMU & KASHMIR	2520	370	15%
NORTHERN REGION	89410	16518	18%

Grid Events


Bus Voltages of Some Major Nodes in Northern Region
400 kV Dwarka
400 kV Jhatikara
400 kV Panipat
400 kV Koldam
400 kV Ludhiana
420
410
400
390
380
370
360
10-06-2024 00:00
10-06-2024 08:00
10-06-2024 16:00
11-06-2024 00:00
11-06-2024 08:00
11-06-2024 16:00
12-06-2024 00:00
12-06-2024 08:00
12-06-2024 16:00
13-06-2024 00:00
13-06-2024 08:00
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Regulatory Provisions

CERC, Indian Electricity Grid Code, 2023

Reactive Power Management

Clause 39

1. *“All users shall endeavor to maintain the voltage at the interconnection point in the range specified in the Grid Code”*

2. *“All generating stations shall be capable of supplying reactive power support so as to maintain power factor at the point of interconnection within the limits of 0.95 lagging to 0.95 leading as per the CEA Connectivity Standard Regulations.”*

3. *“All generating stations connected to the grid shall generate or absorb reactive power as per instructions of the concerned RLDC or SLDC, as the case may be, within the capability limits of the respective generating units, where capability limits shall be as specified by the OEM.”*

Regulatory Provisions

CERC, Indian Electricity Grid Code, 2023

Reactive Power Management

Clause 39

4. *“The reactive interchange of the users shall be measured and monitored by the SLDC and the RLDC.*

5. *“NLDC, RLDCs or SLDCs may direct the users about reactive power set-points, voltage set-points and power factor control to maintain the voltage at interconnection points.”*

6. *“NLDC, RLDCs and SLDCs shall assess the dynamic reactive power reserve available at various substations or generating stations under any credible contingency on a regular basis based on technical details and data provided by the users, as per the procedure specified by NLDC.”*

Regulatory Provisions

CERC, Indian Electricity Grid Code, 2023

Reactive Power Management

Clause 39

7. *NLDC, RLDCs and SLDCs shall take appropriate measures to maintain the voltage within limits, inter-alia, using the following facilities – static and dynamic reactive power reserves, tap optimization etc.*

8. *Reactive power facility shall be in operation at all times and shall not be taken out without the permission of the concerned RLDC or SLDC.*

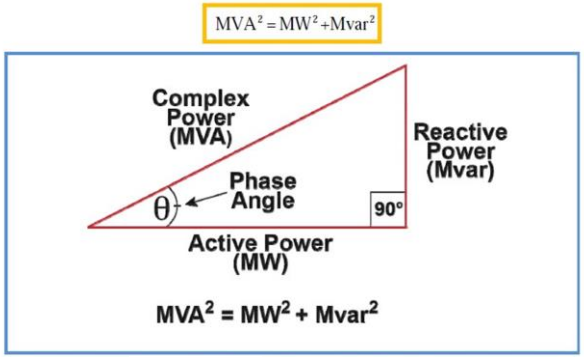
9. *"NLDC, RLDCs and SLDCs shall assess the dynamic reactive power reserve available at various substations or generating stations under any credible contingency on a regular basis based on technical details and data provided by the users, as per the procedure specified by NLDC."*

Reactive Power - Definition

CEA, Technical Standards for Connectivity to the Grid, Regulations 2007

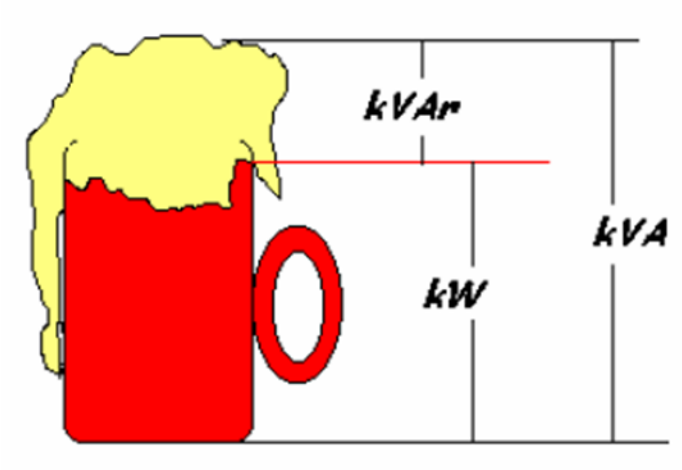
"Reactive Power" means in relation to an AC electrical system, the product of root mean square (r.m.s.) voltage, root mean square (r.m.s.) current and the sine of the electrical phase angle between the voltage complex or and current complex or, measured in volt-amperes reactive (VAr);

- VAR = Volt-Amperes Reactive = Reactive Power
- Byproduct of Non-Linear Nature of Power System
- Produced when the current waveform is out of phase with the voltage waveform due to the presence of inductive or capacitive elements
- Consumed – **Current lags Voltage (Inductive Load)**
- Produced – **Voltage lags Current (Capacitive Load)**



The Power Triangle

Reactive Power - Analogy



Power Factor = Active power/Apparent power = kW/kVA
= Active power/$\sqrt{}$ (Active Power^2 +Reactive Power^2)
= kW/$\sqrt{}$ (kW^2+kVAr^2)
= Beer/$\sqrt{}$ (Beer^2 +Foam^2)

- Here, reactive power is like the head on a beer because it takes up space in the glass leaving less room for the real beer
- Reactive power takes up space on transmission lines / limits generator capability
- When thermal capacity is exceeded significantly for a long time, the line will sag, possibly into vegetation, causing a short circuit, or anneal
- The more foam (higher kVAr) indicates low power factor and vice versa

Reactive Power - Analogy

Consequences:

- A pedaling figure leaning to one side cannot work as comfortably as before i.e. limiting the capacity of the transmission line
- The bike catches more headwind i.e. extra losses.

Reactive Power Balance

- In an AC system, voltage is controlled by managing production and absorption of Reactive Power
- Equipment, both at consumer and power system end, are designed to operate within a specified limit

  (During low voltage conditions, motors may stall, generating units may trip etc. Under high voltage, insulation failure, equipment damage may take place)

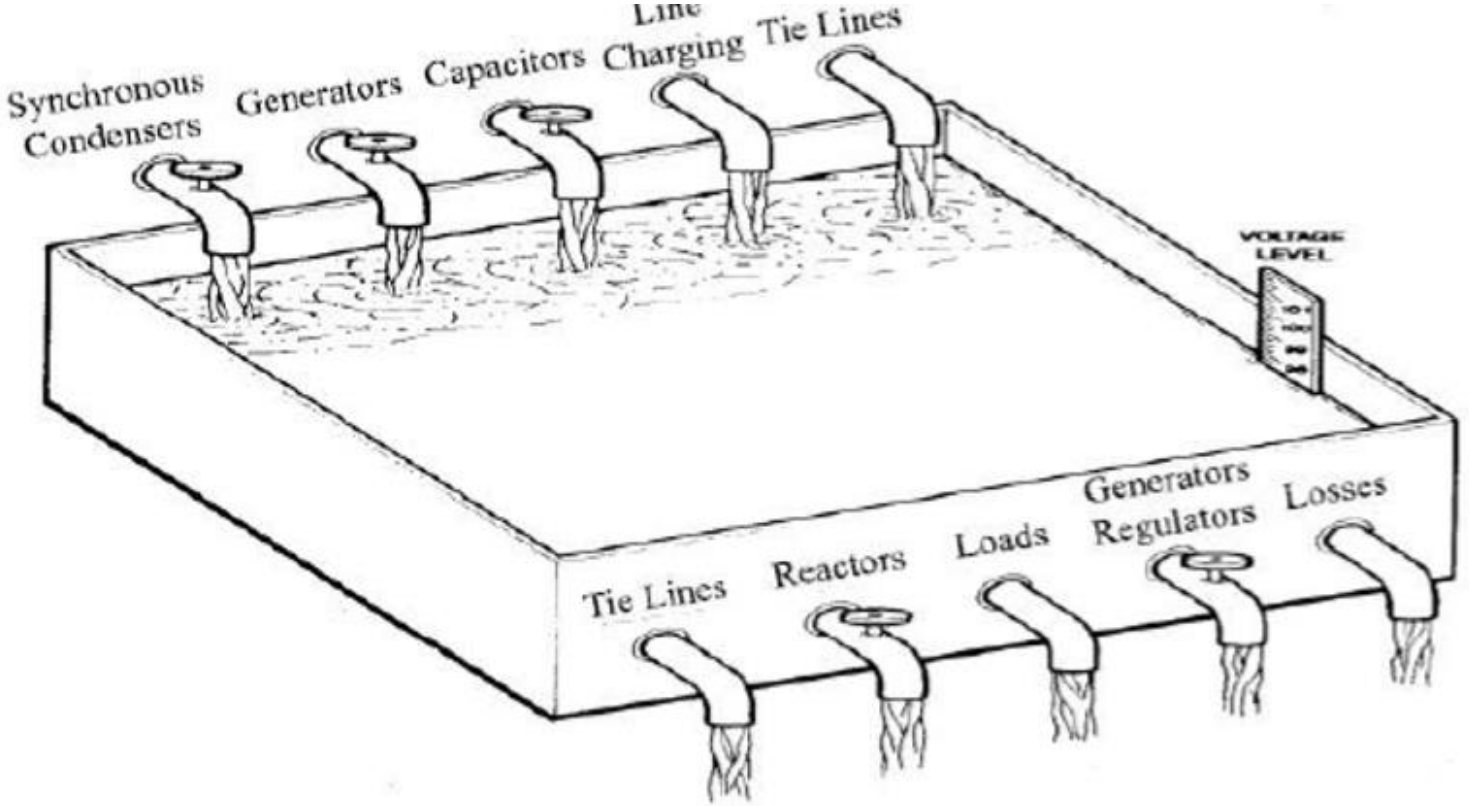
- Reactive Power supports **Voltages** that must be controlled within limits for system reliability
  - Limits set by Grid Code / CEA Grid Standards
  - More reactive power => Voltage goes up
  - Less reactive power => Voltage goes down
  - MVAr balance => Good voltage => Lower system losses => Effective Utilization of Lines

Reactive Power Balance

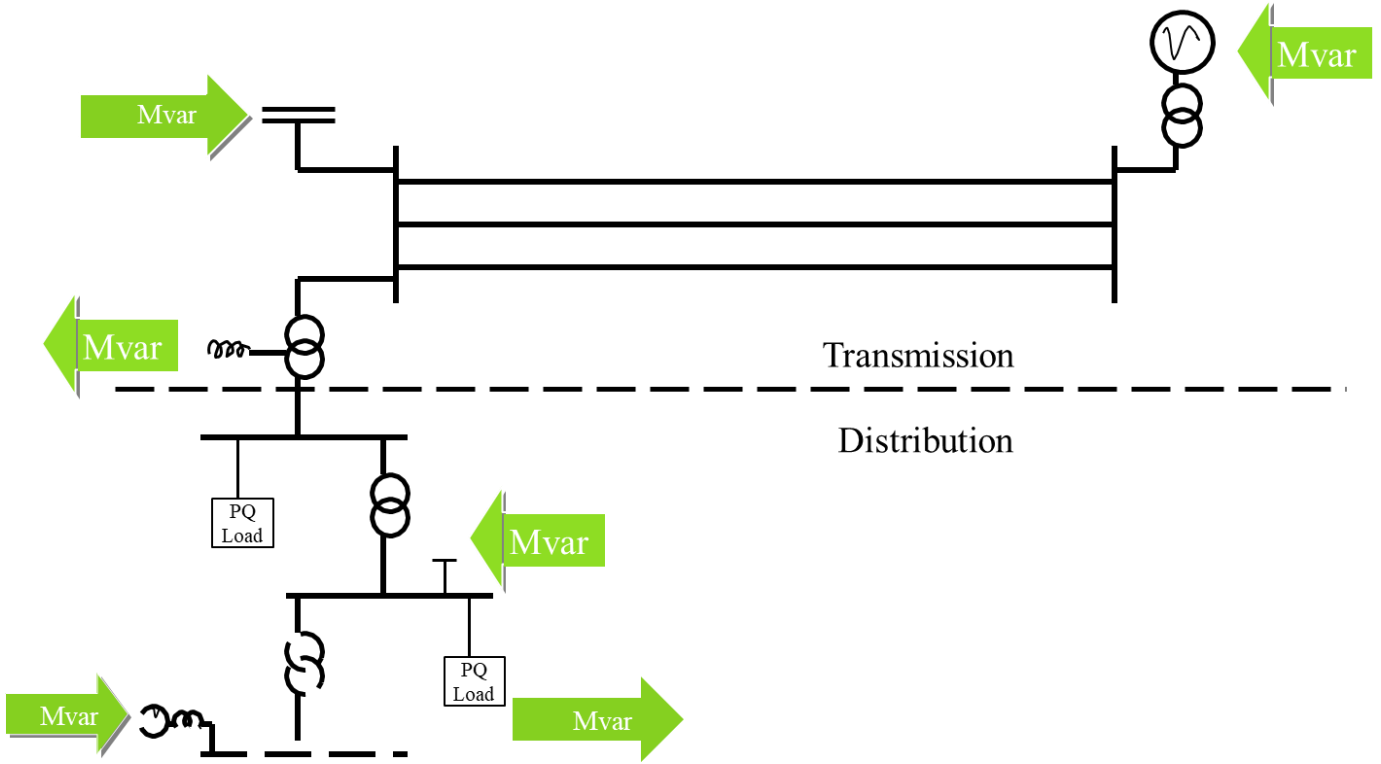
- Active Power Balance – Generators and Loads alone
- **Reactive Power Balance** - Generators and dispersed special Reactive Devices, producing or absorbing reactive power
- The reactive power sources are classified into two types, **static and dynamic**

Source	Sink
Static: • Shunt capacitors • Transmission Lines - charging • Underground cables • Filter banks • Loads – Capacitive **Dynamic:** • Gen. Overexcited • Synchronous condensers • Static Thyristor based devices (SVC, STATCOM)	• Loads - Induction motors (pumps, fans etc.) Inductive loads (chokes etc.) • Transformers • Transmission lines • Static Thyristor based devices (SVC, STATCOM) • Reactors • Synchronous machines

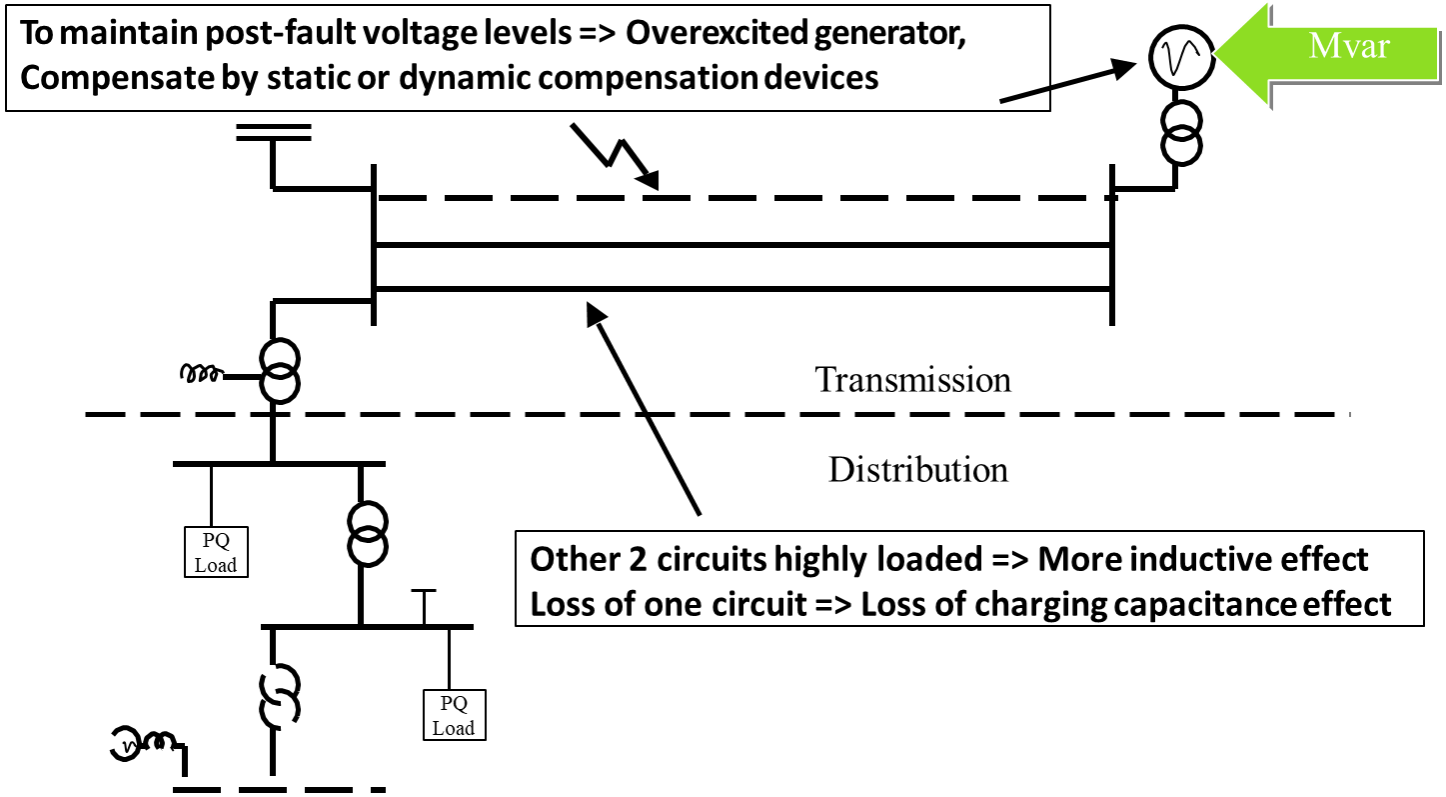
Reactive Power Balance



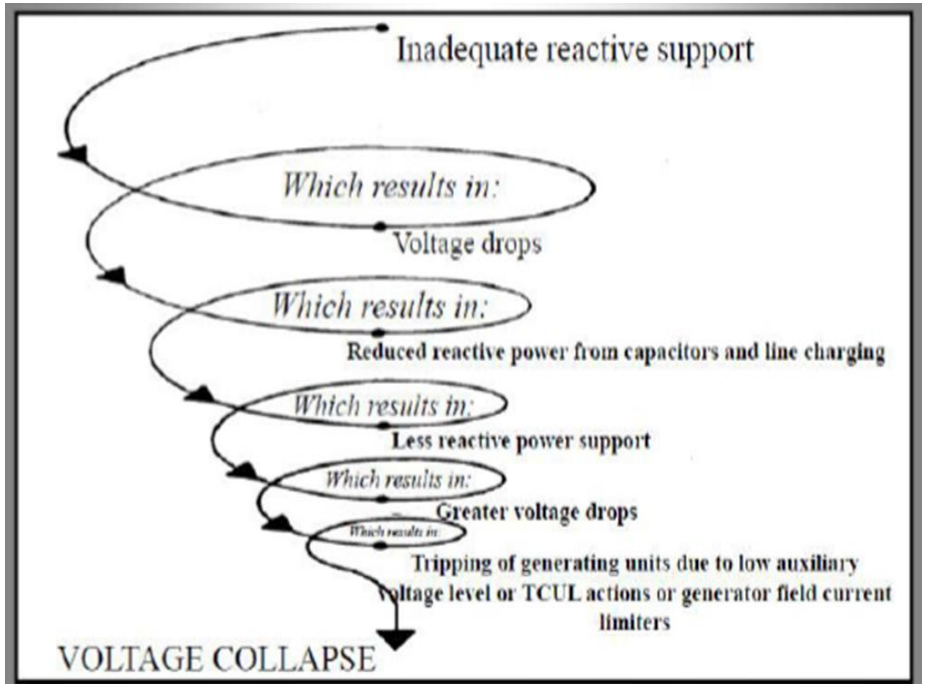
Reactive Power Balance

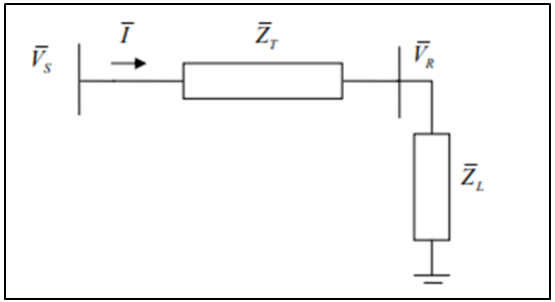


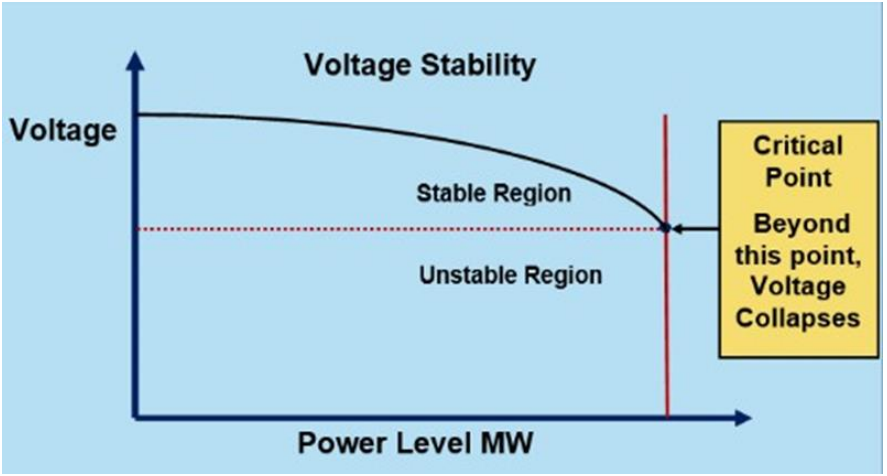
Reactive Power Balance



Voltage Collapse







Overview

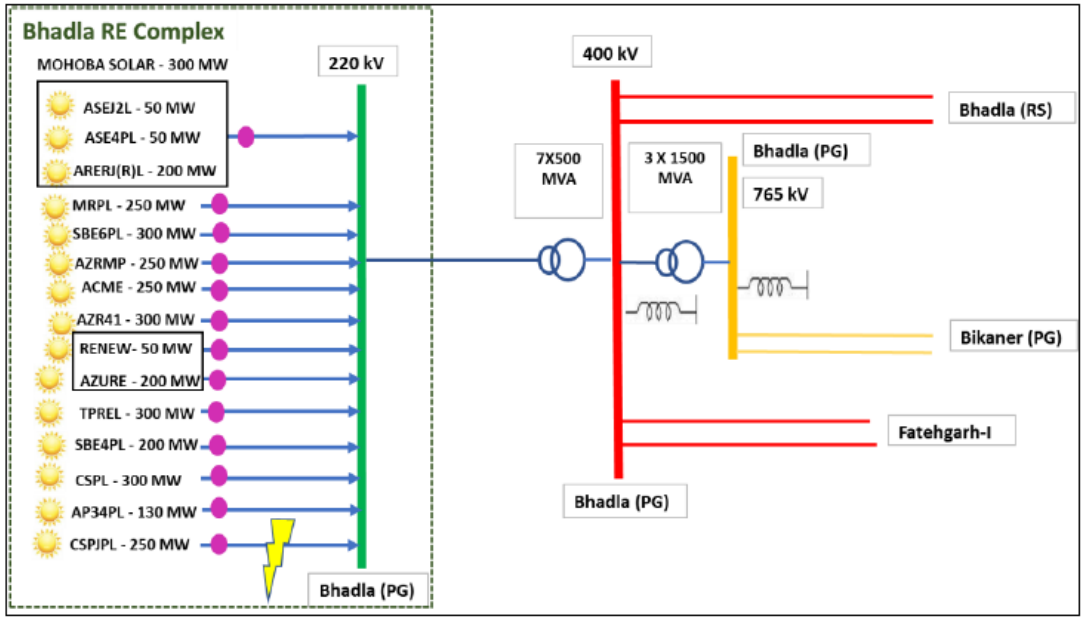
1. Reactive Power - Overview
2. Regulatory Provisions
3. Current Regulatory Provisions
4. Assessment Methodology
5. TTC/ATC Declaration by Grid-India
6. Congestion in Real-Time Operations
7. Way Forward

RE Related Grid Events

- **~47 events** involving **generation loss of above 1000 MW** from renewable power plants - **January'22 to May'2024**
- **Events could be broadly classified into following types:**
  - Fault within the RE plant
  - Fault external to the RE plant
  - Multiple fault ride through
  - Low frequency (voltage and reactive power) oscillations
  - Over voltage during line or reactor switching followed by RE generation loss
- **Major Observations:**
  - **Faults**
    - Faults cleared in 40 - 50 milli seconds
    - Voltage rise observed post fault (delayed active power recovery + high response time) and subsequent tripping
    - Successive faults - Unsuccessful Auto-reclose
  - **Oscillations**
    - Modes with oscillation frequency of 2-4 Hz; peak to peak amplitude of 0.01-0.015 p.u. in phase voltage
    - Modes with oscillation frequency of 0.03-0.1 Hz; peak to peak amplitude of 0.1 p.u. in phase voltage
    - Sudden large variations in voltage (without any periodicity) with peak-to-peak magnitude of 0.15 p.u.
    - Last 2-3 months - high frequency low/high amplitude oscillations (4-6Hz) are being observed
  - **Over voltage due to switching operation**
    - Rise in voltage after opening of line reactor; Rise in voltage after line restoration etc.

Measurement Based Analysis of Grid Events

Fault within the RE plant – 11th Aug 2022 (~6000 MW generation loss)

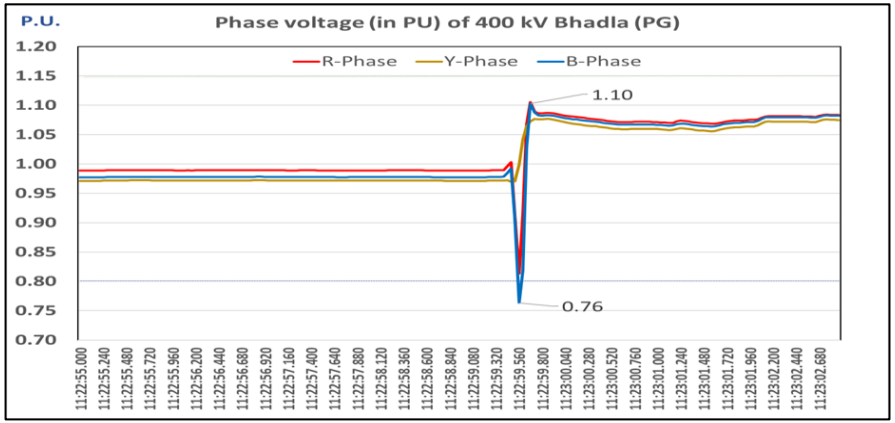


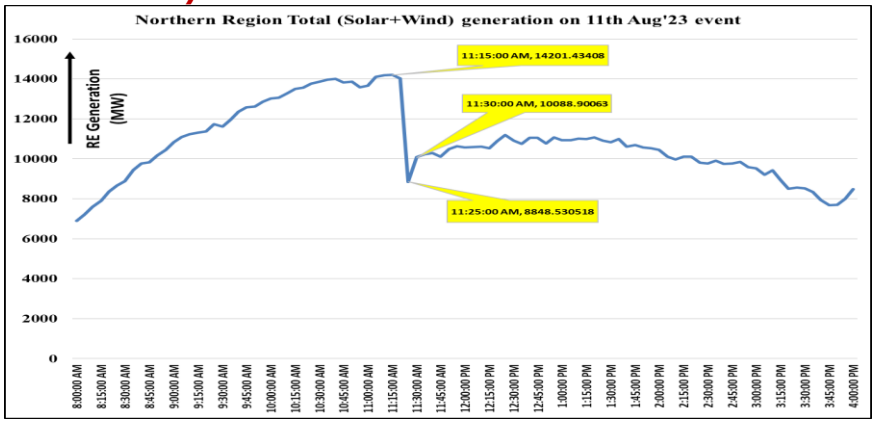
Event Description

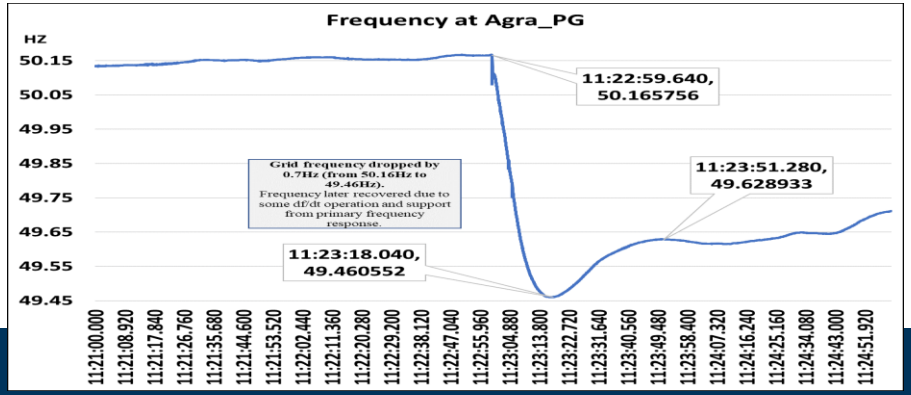
- R-B phase fault on 220 kV Bhadla (PG) - Clean Solar Power (Jodhpur) Pvt. Ltd. circuit due to snapping of B-ph jumper.
- Bus voltage at 400 kV Bhadla (PG) dipped to 0.77 pu (below LVRT threshold).
- Sharp rise in voltage immediately after fault clearance (within 160 ms)
- Generation loss: **6157 MW** (Solar : 5807MW, Wind : 350 MW)
- Frequency drop: **0.7 Hz** (50.16 Hz to 49.46)
- Triggering of under frequency load shedding (~750 MW).
- Sustained overvoltage (~105-107%) due to significant generation loss, tripping of multiple EHV lines on over voltage

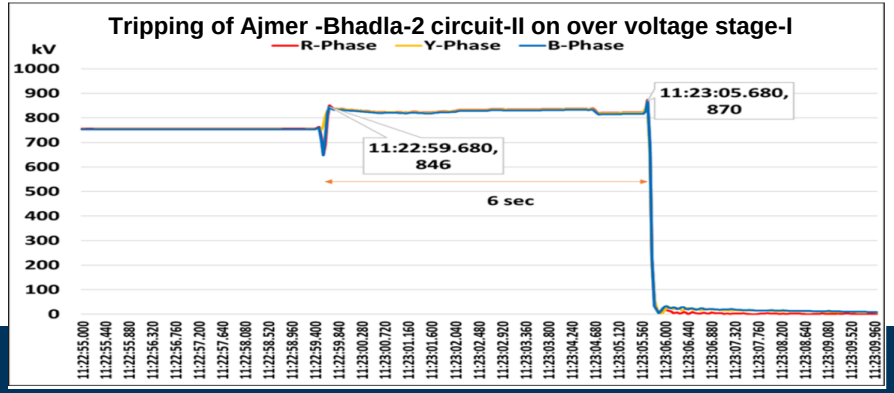
Measurement Based Analysis of Grid Events

Fault within the RE plant – 11th Aug 2022 (~6000 MW generation loss)



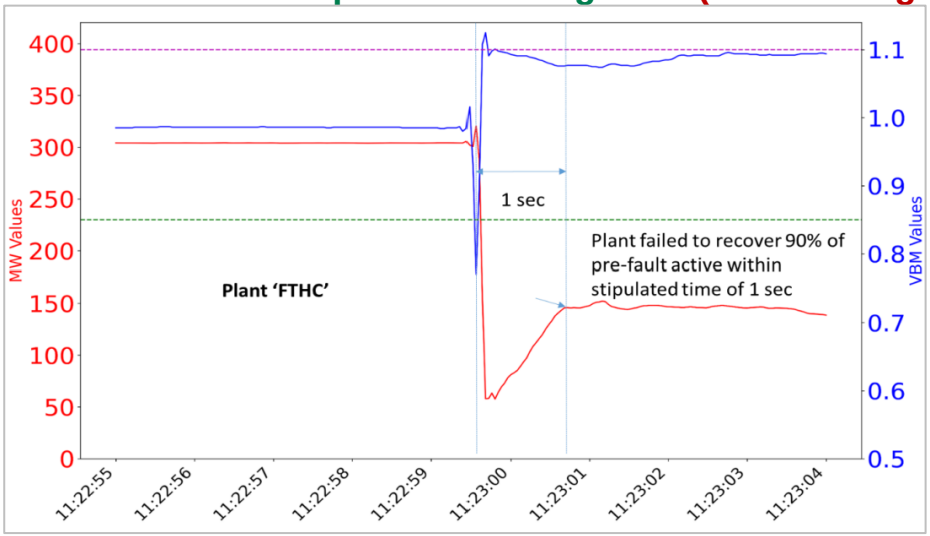


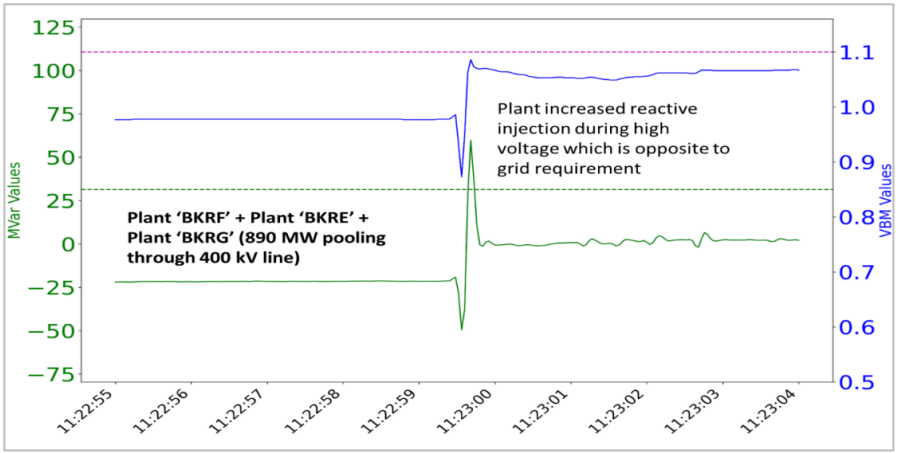




Measurement Based Analysis of Grid Events

Fault within the RE plant – 11th Aug 2022 (~6000 MW generation loss)





- Sharp reduction of active power without commensurate reactive power support during the fault event
- Delayed active power recovery
- Opposite reactive power response during fault
- IBRs entering HVRT mode despite POI voltage <1.1 p.u. at few pooling stations
- No reactive power support during HVRT
- Reduction in EHV line loading resulting in rise in voltage
- Tripping of evacuating lines on over voltage