20 YEARS Integrated Research and IRADe Action for Development

ग्रिड-इंडिया GRID-INDIA

North-Eastern Regional Capacity Building Workshop

Grid Stability and Balancing due to Intermittent Generation

21st November 2024

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Grid-India

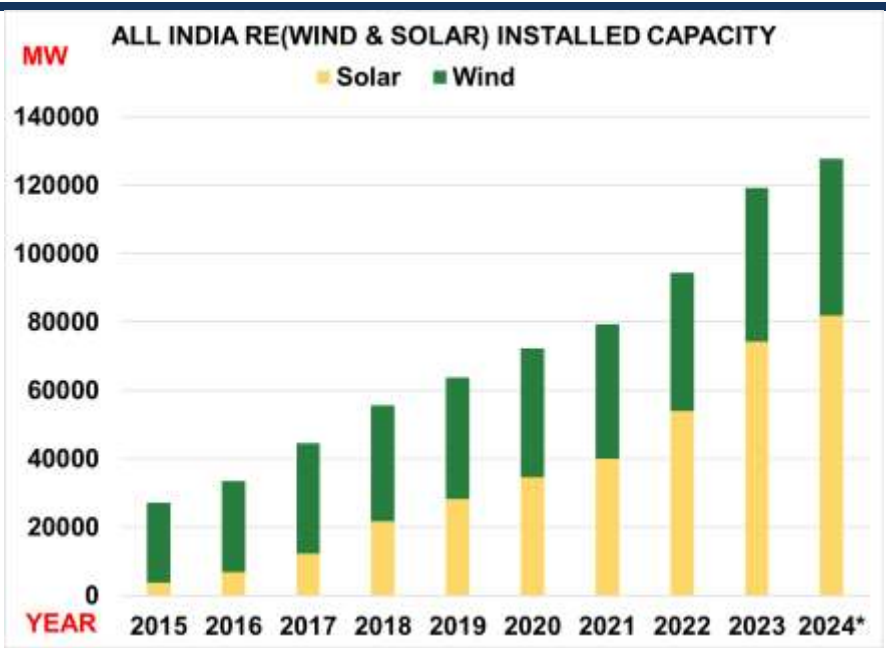
Energy Transition in India - Roadmap

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

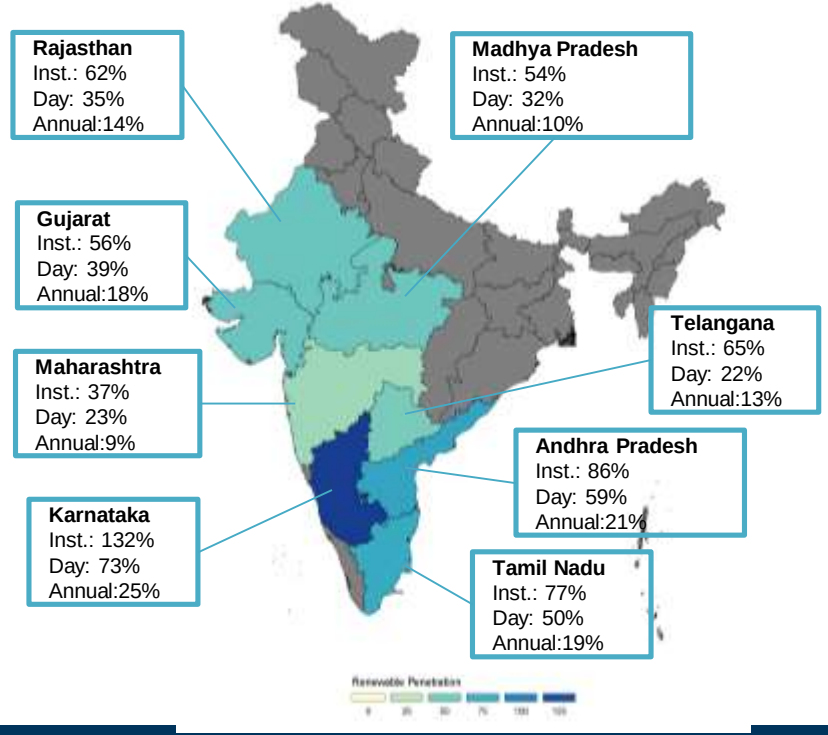
India's Journey with Renewables



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

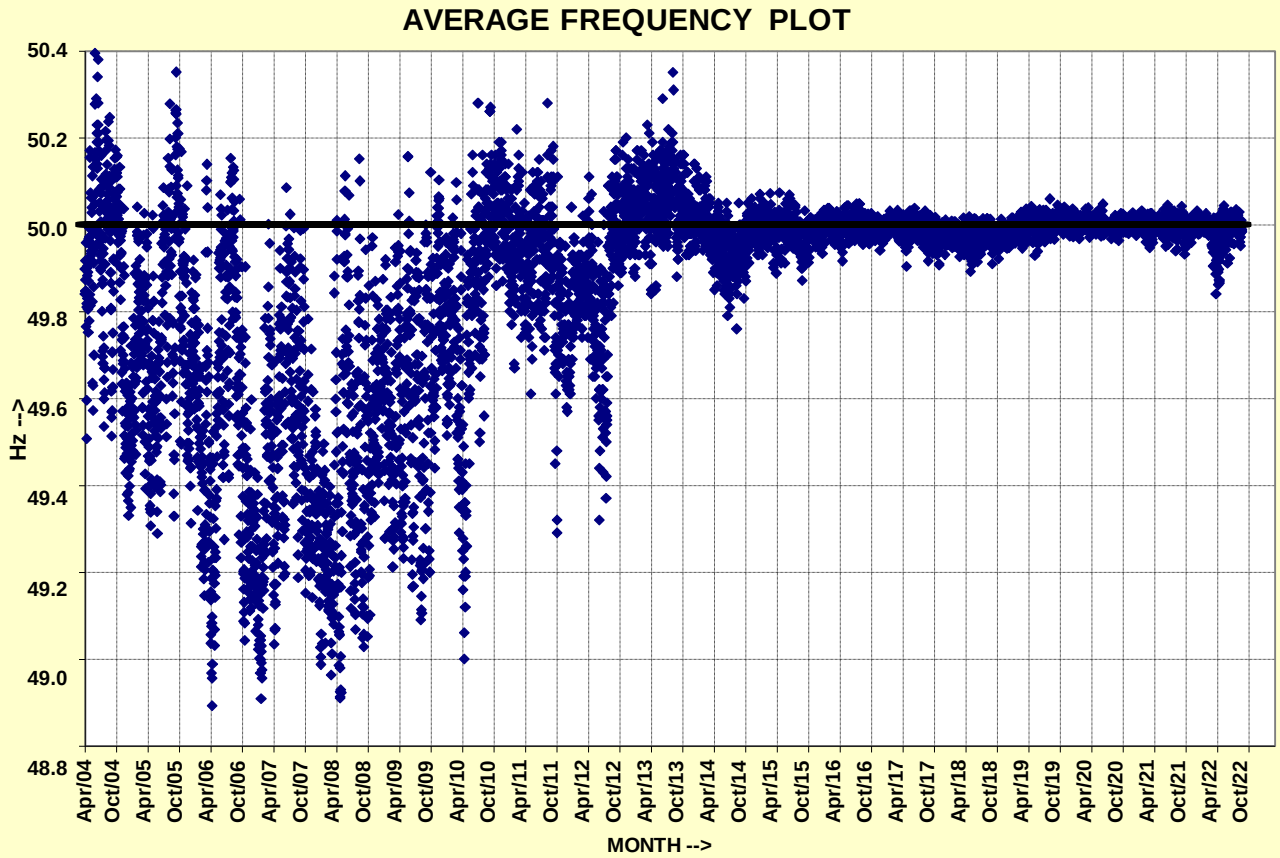
Highest Instantaneous RE penetration of ~32.4% recorded on 14th July 2023

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

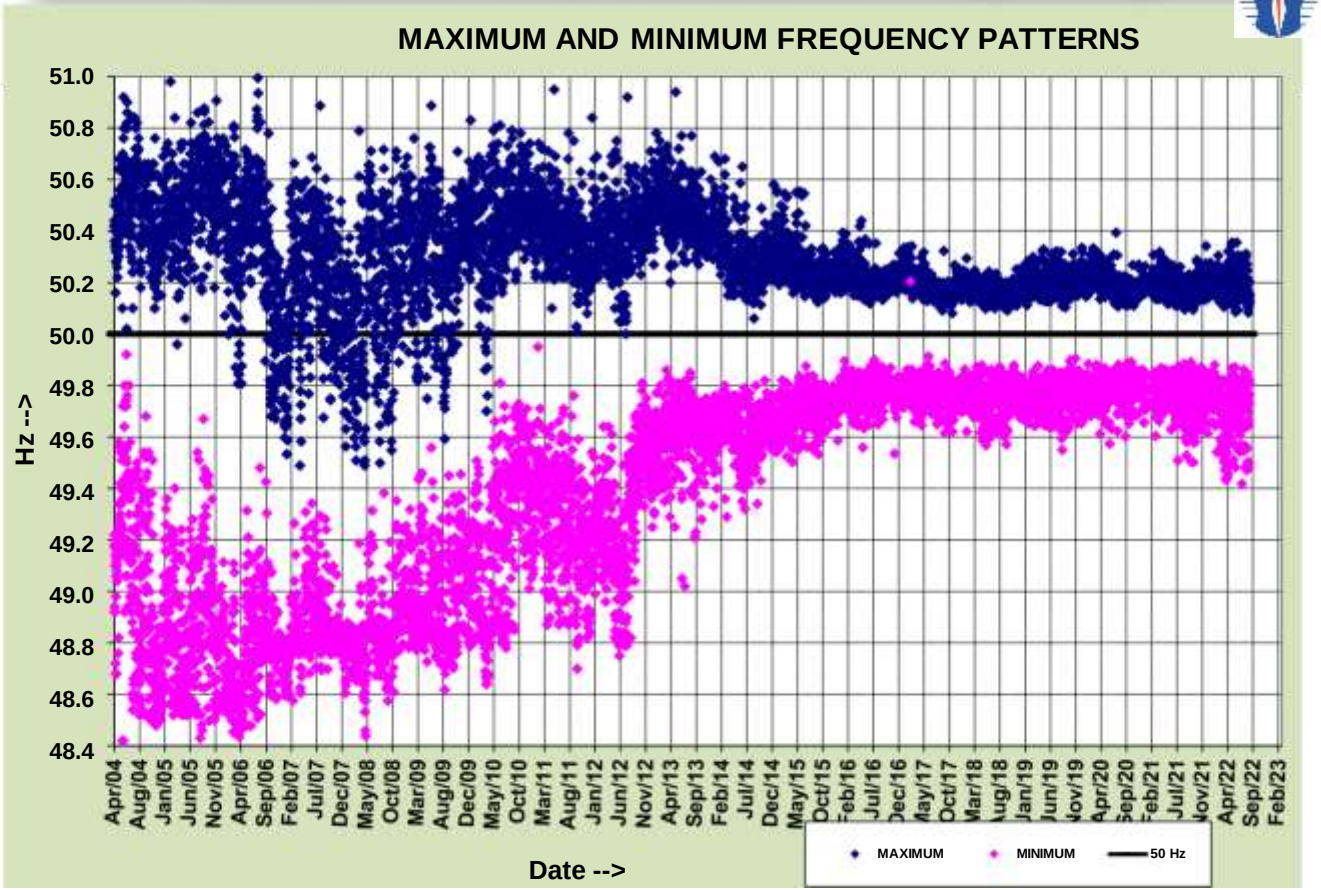


~11% all India VRE penetration on annual basis

Frequency Profile over the years…



Maximum and Minimum Frequency



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

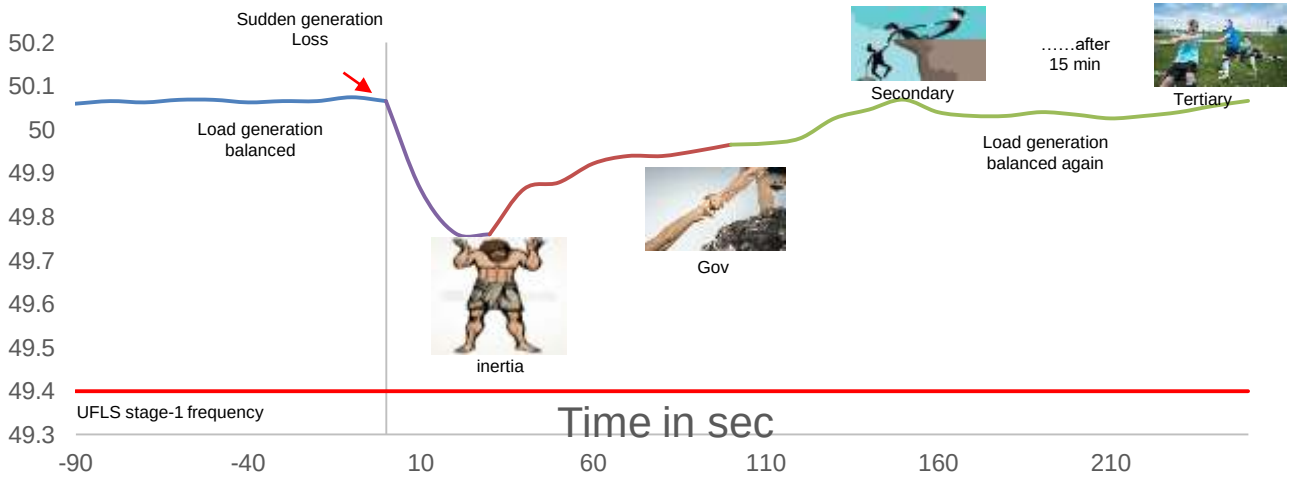
- Fault ride through failures
- Decreased damping
- Oscillations
- Control of bi-directional flows
- Lack of power system restoration sources

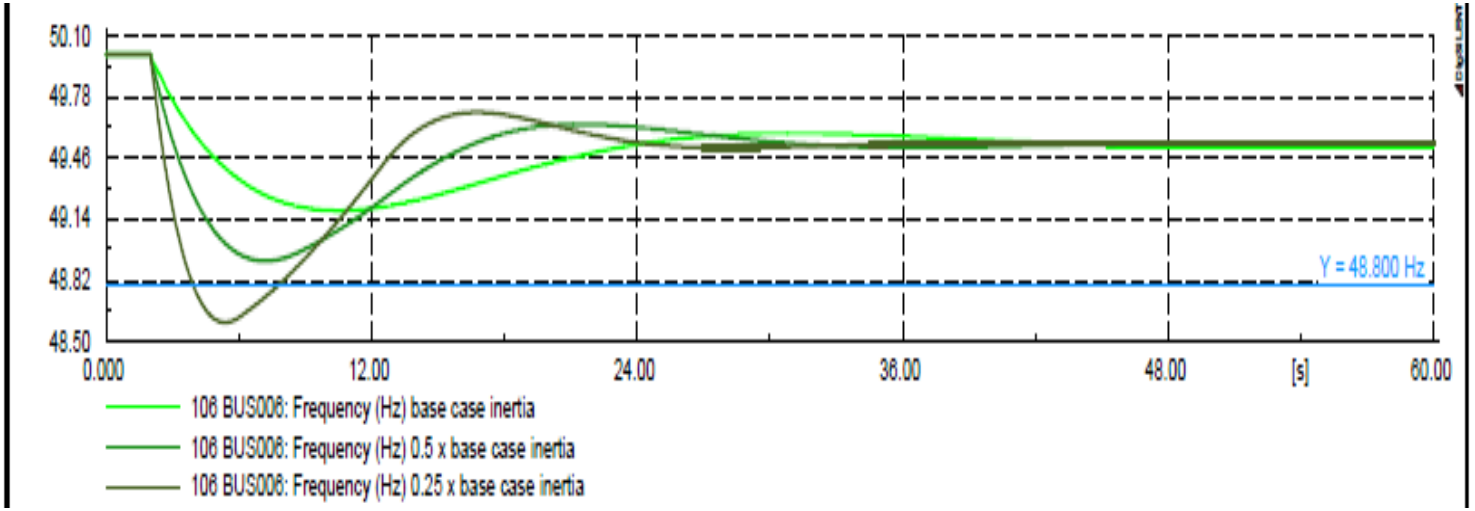
Bulk of essential reliability services such as inertia, frequency, and voltage control, system restoration support, power oscillation damping, short-circuit power, etc. were being provided by conventional generation sources

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

(1)Reduced Inertia

Inertia is the stored rotating energy in the system.
Following a System loss, the higher the System Inertia (assuming no frequency response) the longer it takes to reach a new steady state.
Higher frequency excursions.



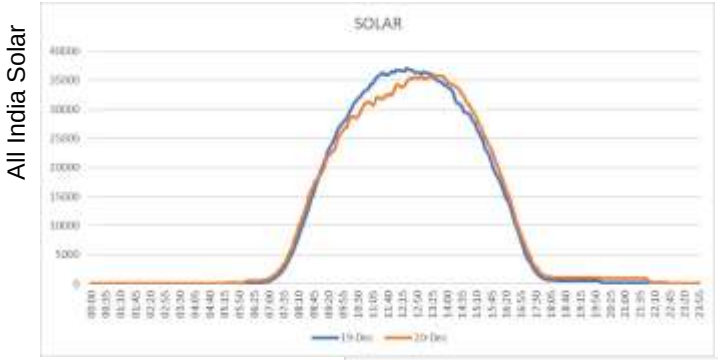


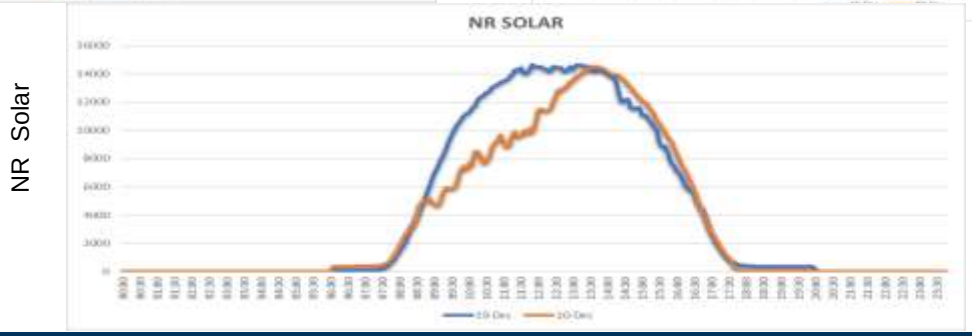
Challenges:

- Reducing Inertia .
- Reducing load response with Power electronic devices .
- Need of synthetic Inertia .
- Need of critical Inertia calculation and use of Old thermal generators as Synchronous condenser mode. Flywheel.
- Ancillary market for Inertia and frequency control.

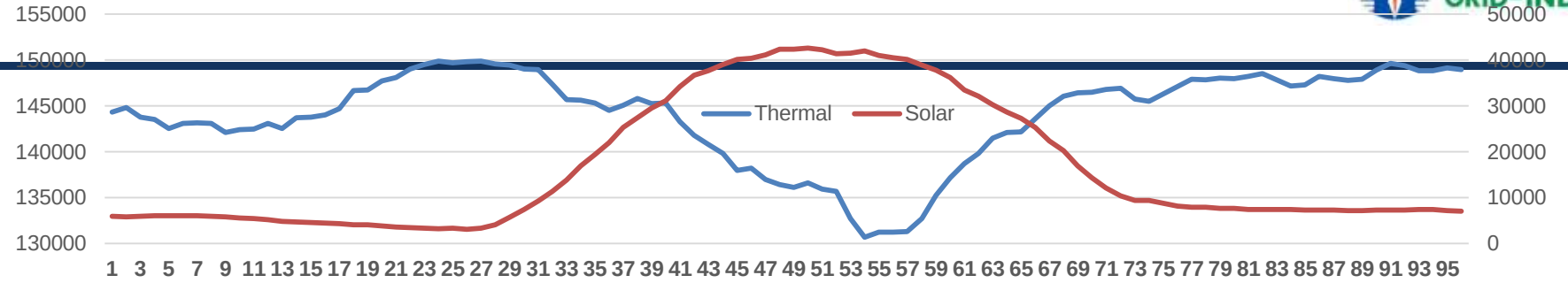
(2) High Variability needs flexible generation and storages & Secondary Reserves:

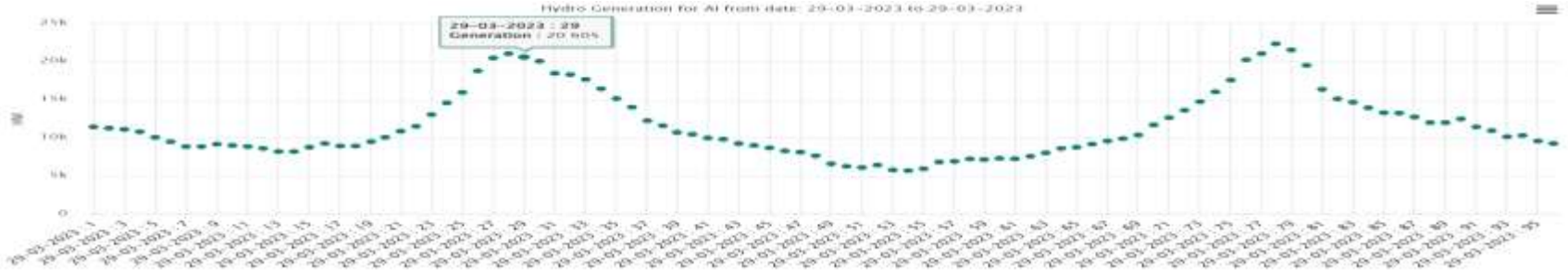
- Requirement of fast responsive reserves such as AGC/Storage /BESS to stabilize frequency which Mitigates uncontrollable moment-to-moment variability in RE generation output.
- SPINNING RESERVE.

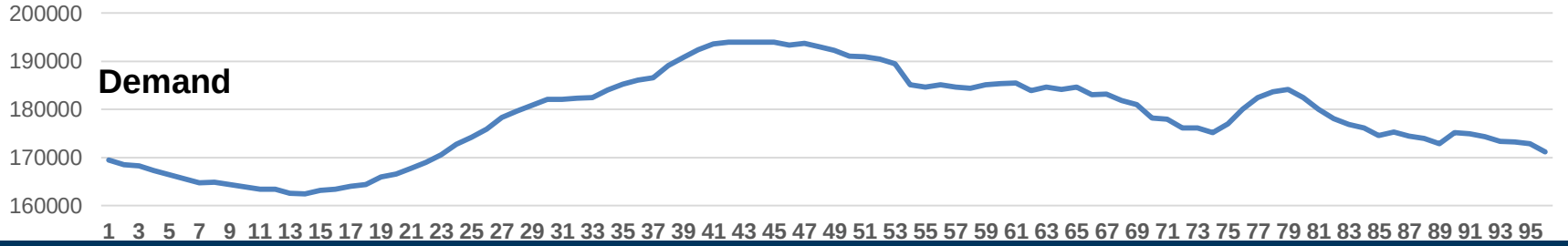




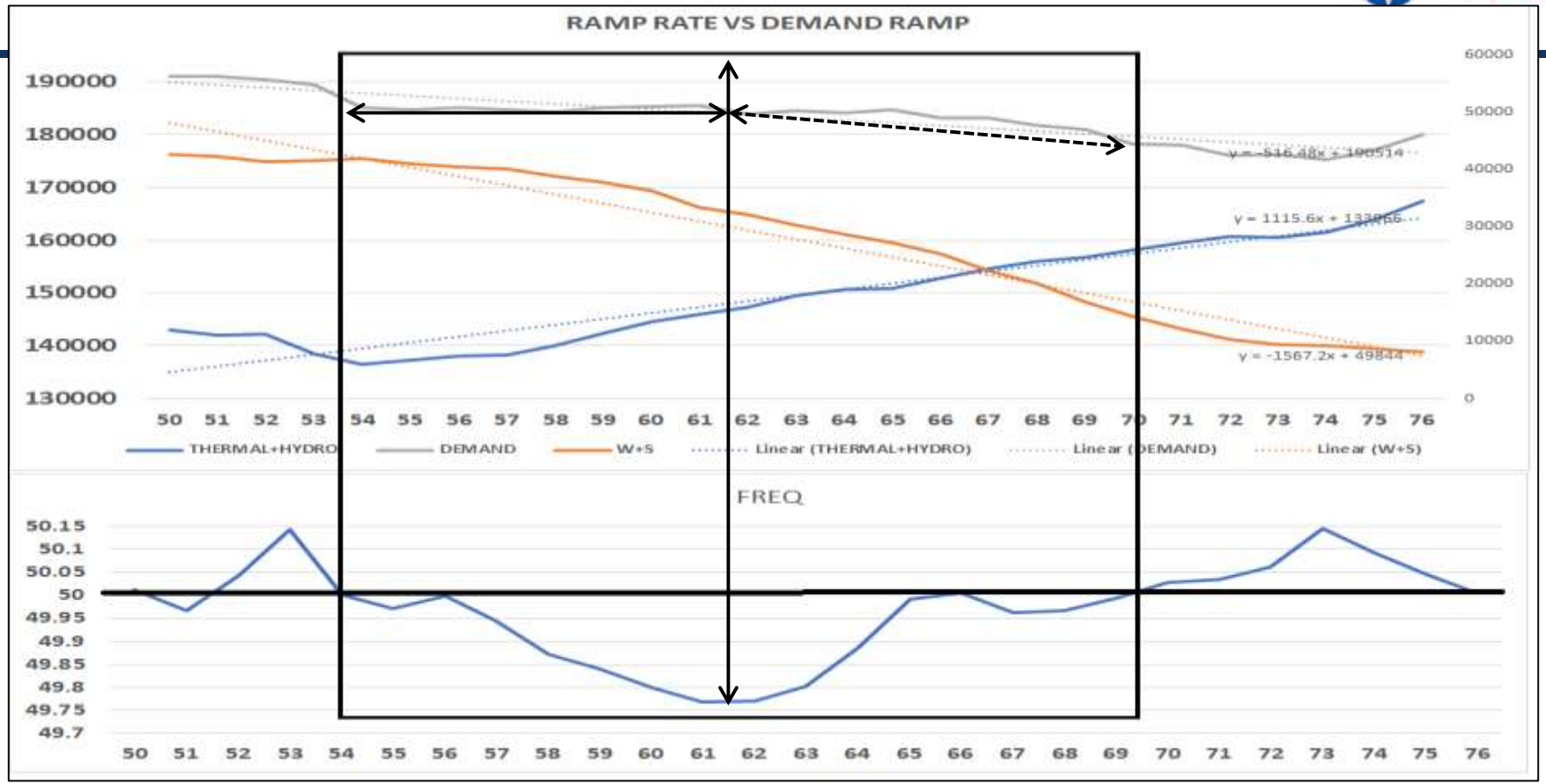
(3) FAST Ramping Requirement :



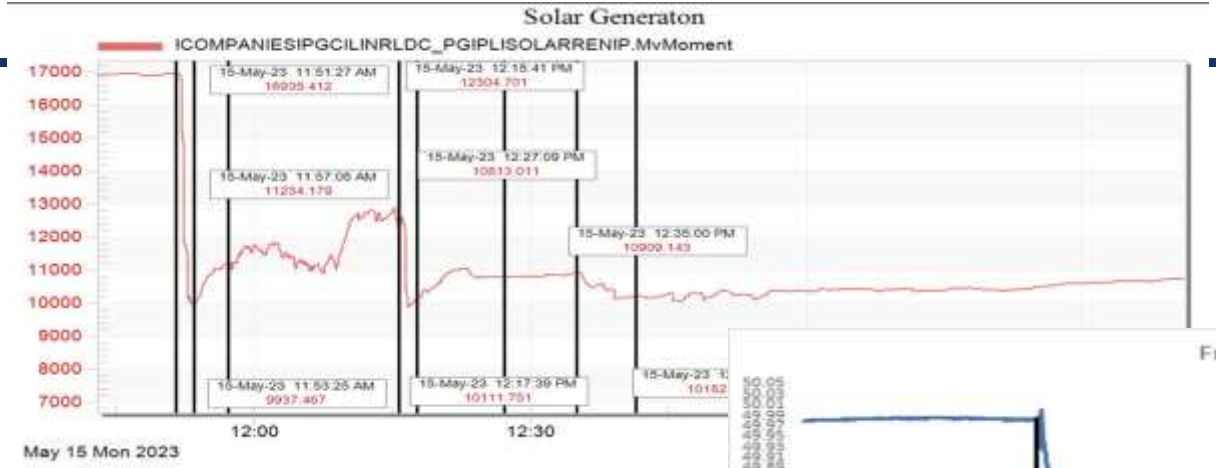


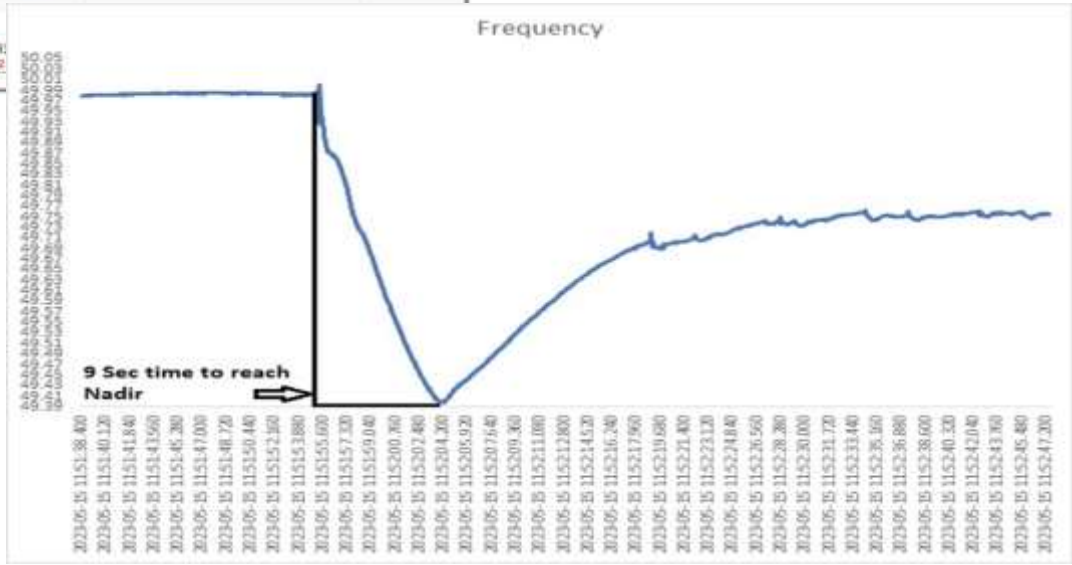


(3)FAST Ramping Requirement



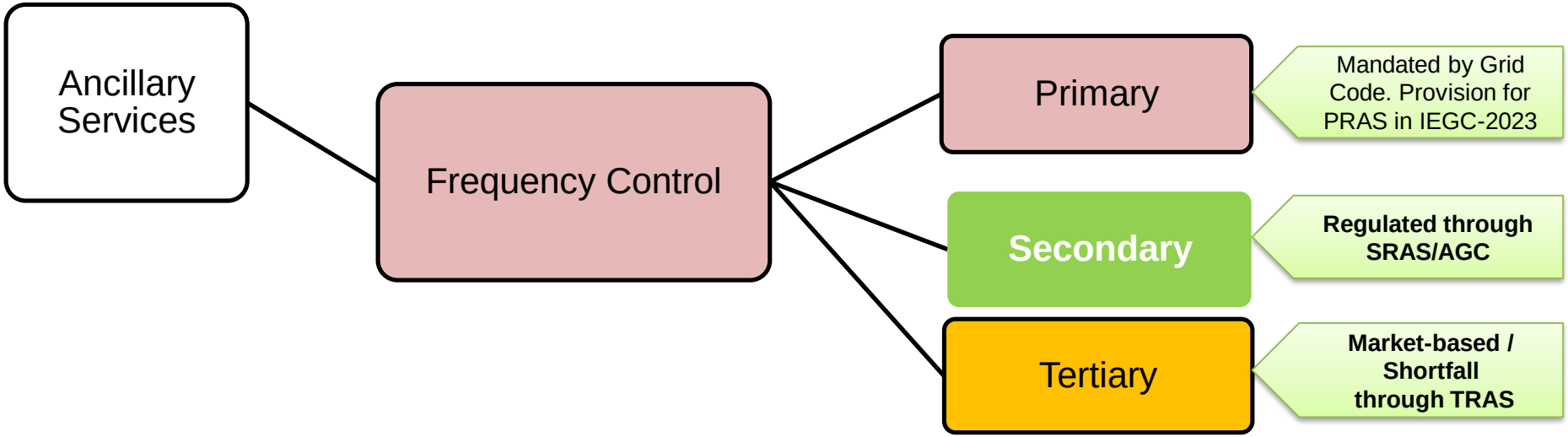
Sudden Solar loss: Frequency excursions



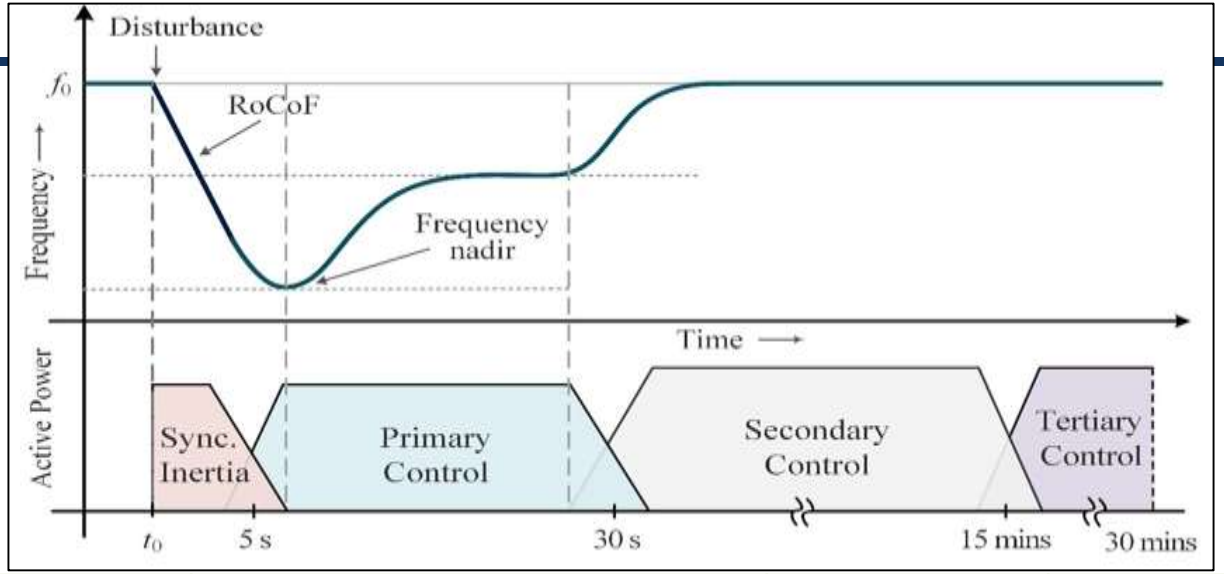


- Non-compliance of Fault ride through, LVRT/HVRT.
- System strength Issues.

Frequency Control Measures : Ancillary Services

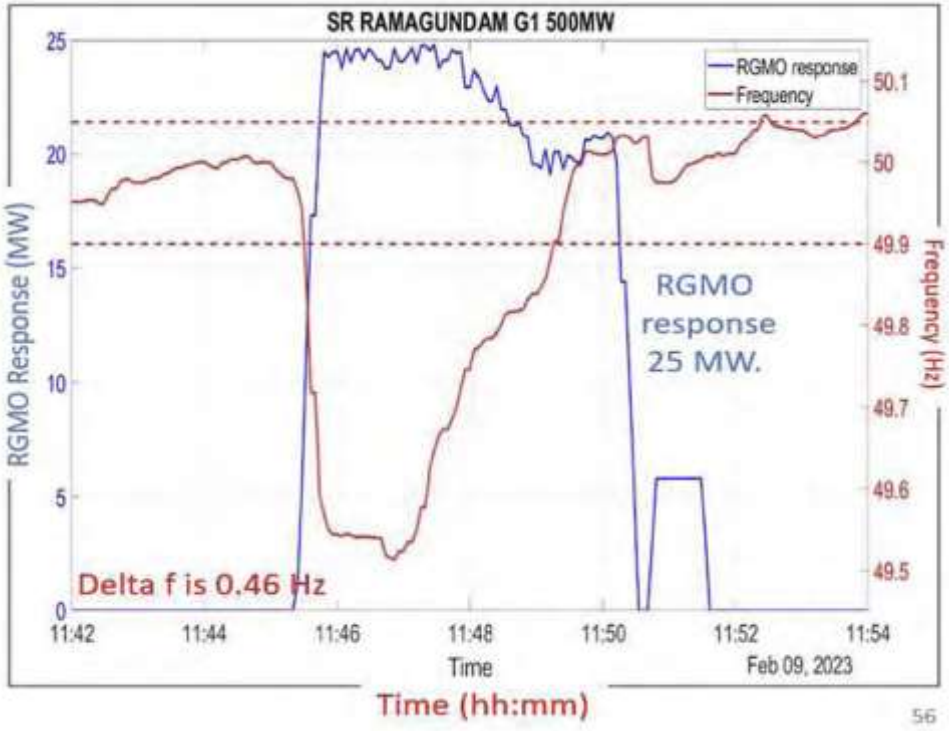


Reserves in Indian Power System



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

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 –

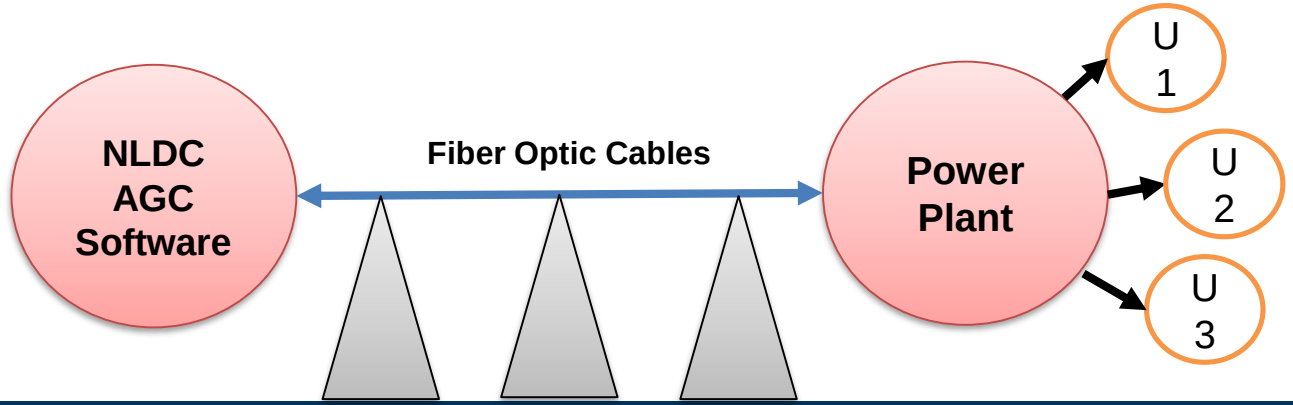
(i) shall be equipped with the facility to control active power injection in accordance with a set point, capable of being revised based on directions of the State Load Dispatch Centre or Regional Load Dispatch Centre, as the case may be;

(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:***

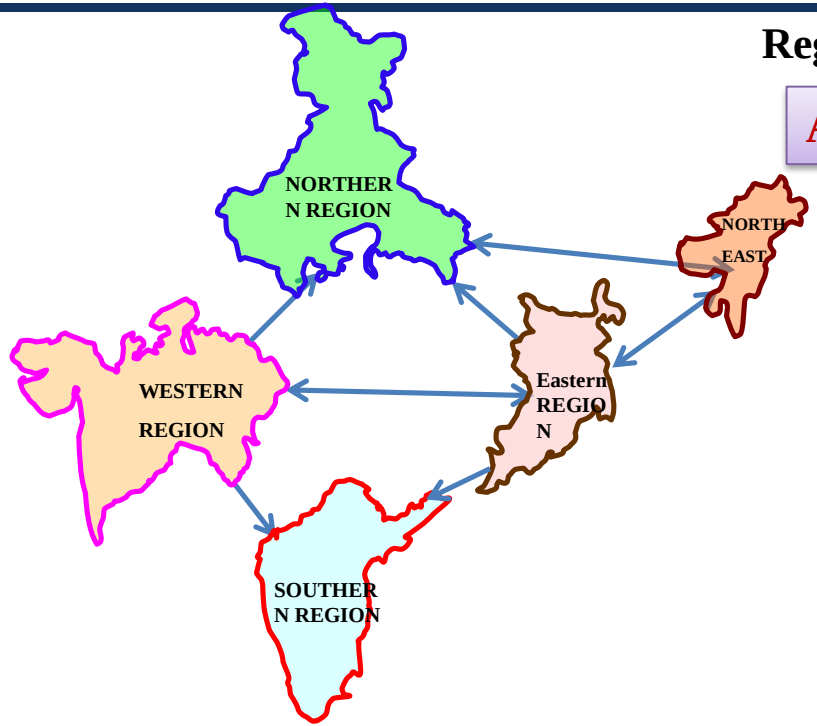
Provided that for frequency deviations in excess of 0.3 Hz, the Generating Station shall have the facility to provide an immediate (within 1 second) real power primary frequency response of at least 10% of the maximum Alternating Current active power capacity;

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

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

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

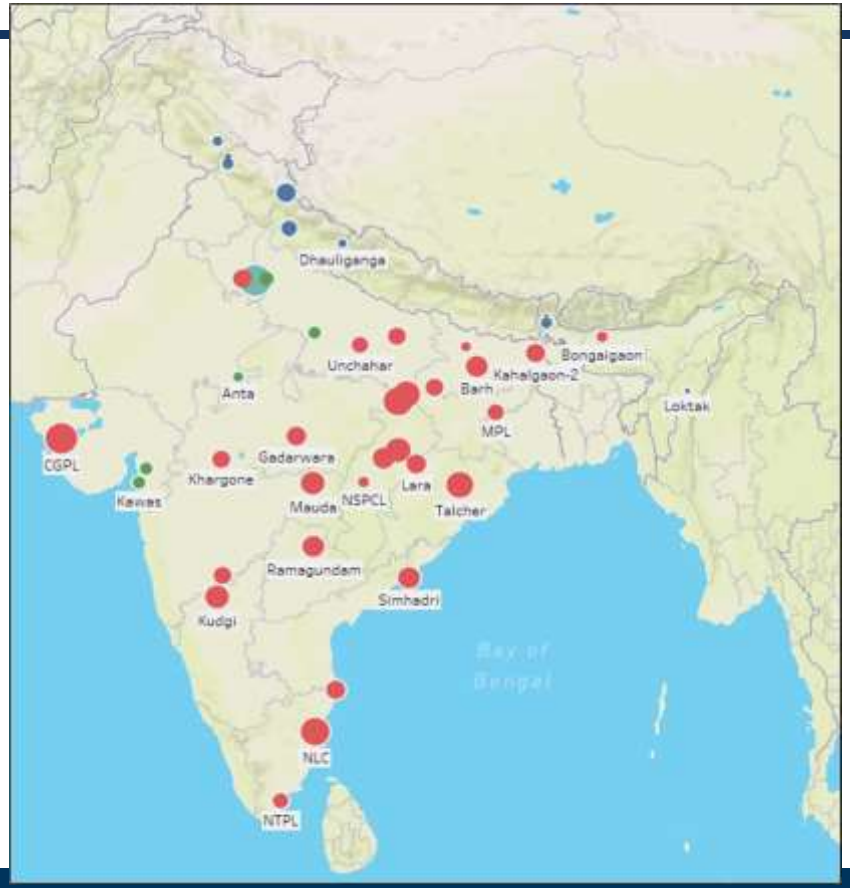
Detailed Procedure for Tertiary Reserve Ancillary Services (TRAS) – April 2023 – Link

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

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

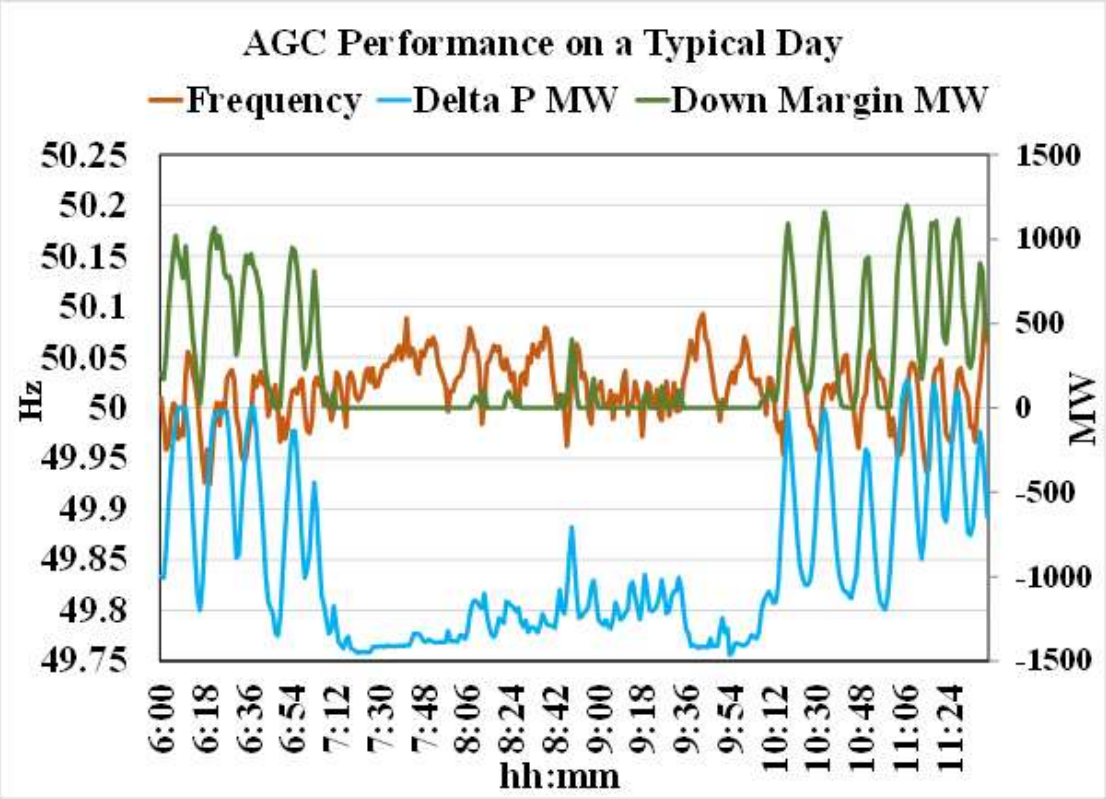
Procedure for Performance Assessment of TRAS and SRAS Providers – IEGC 2023 - LINK

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

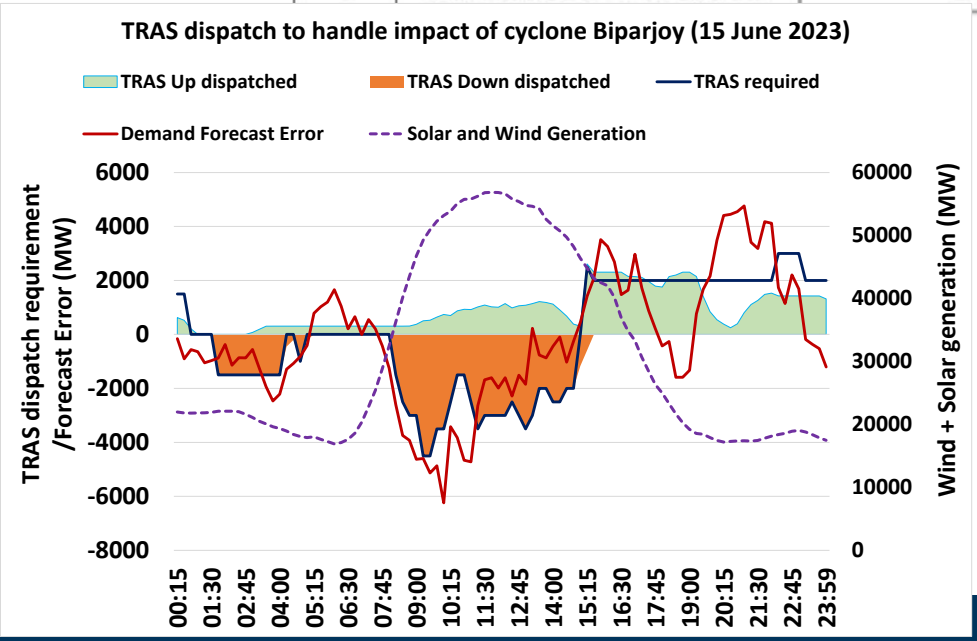


- Up and down regulation of around +/-1300 MW in response to frequency changes
- Down reserve fully utilised
- AGC helps in controlling high frequency during such solar pickup periods.

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

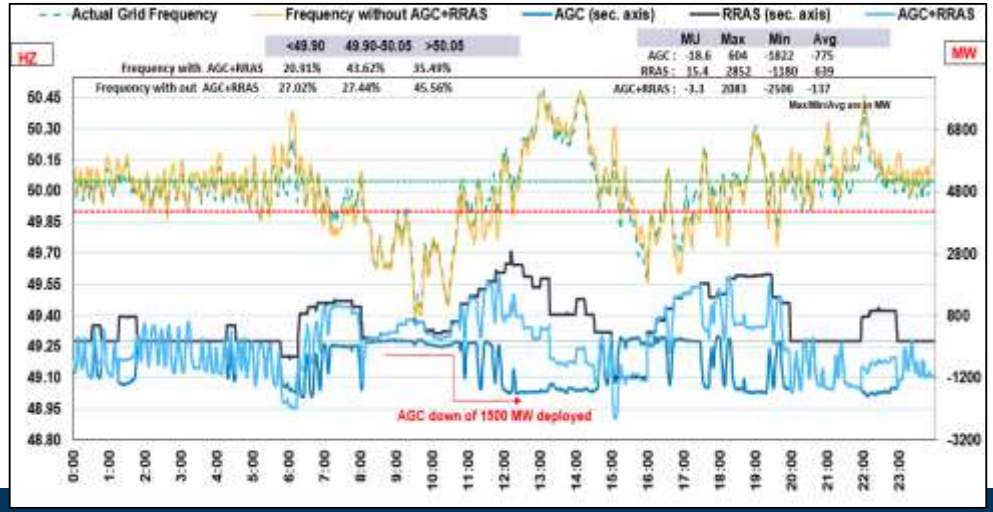
Insufficient Secondary Reserve

Automatic generation control (AGC)

Type of Reserve	Within State (MW)	ISGS (MW)	All India Total (MW)
Secondary	**3211**	**3788**	**7000**
Tertiary	8887	3788	12676
Primary	Solar Hours	Non-Solar Hours	
	7000 MW	4500 MW	

CERC in Its order 01/SM/2023 also stated System operators need to take all possible measures to enlarge the canvas of SRAS and RRAS/TRAS providers by enabling participation of State entities through necessary procedures.

Desired

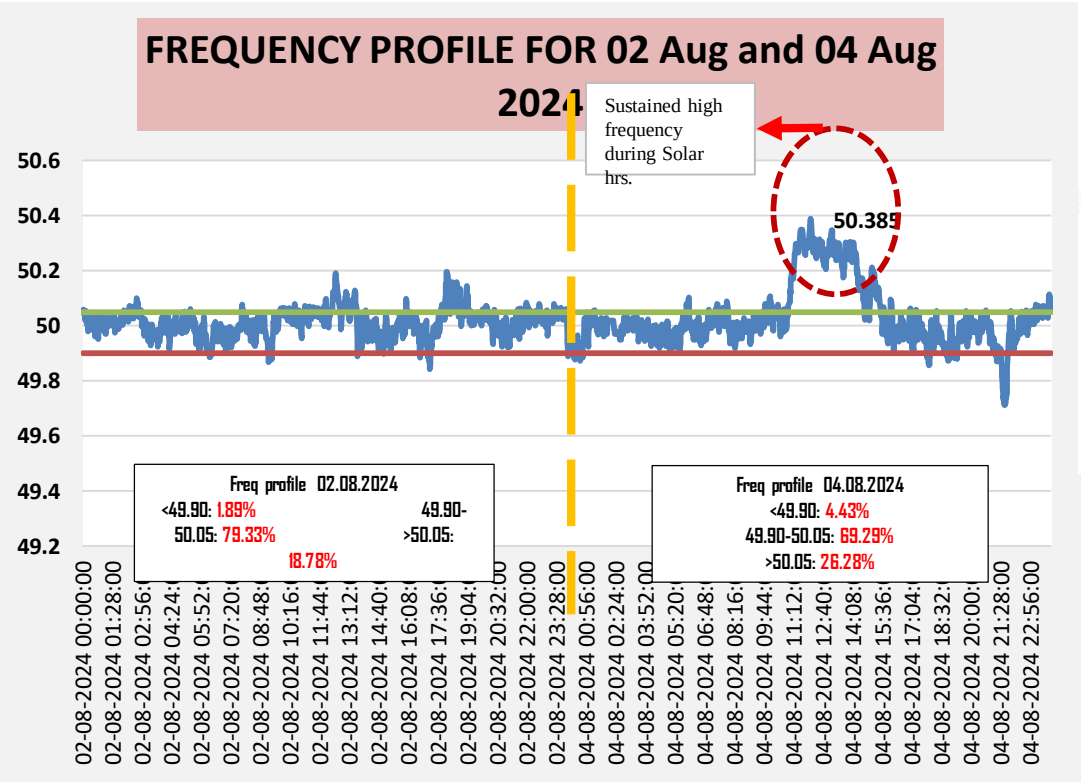


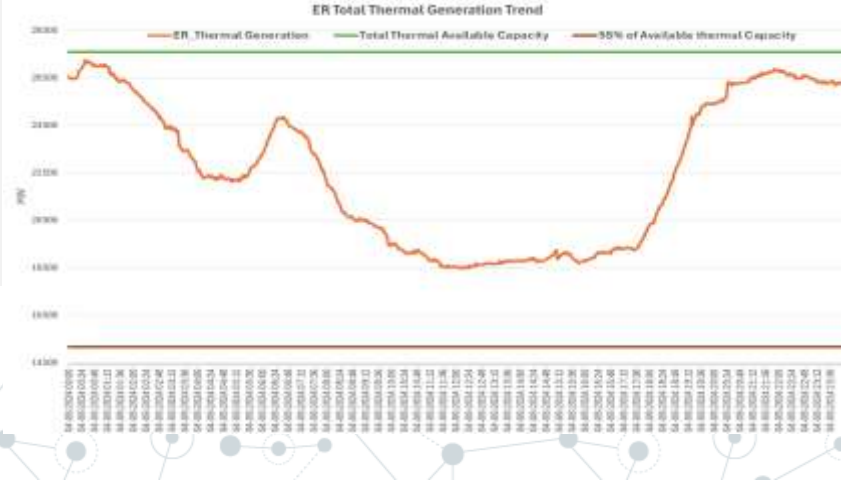
Status of Ancillary service Regulation at State level

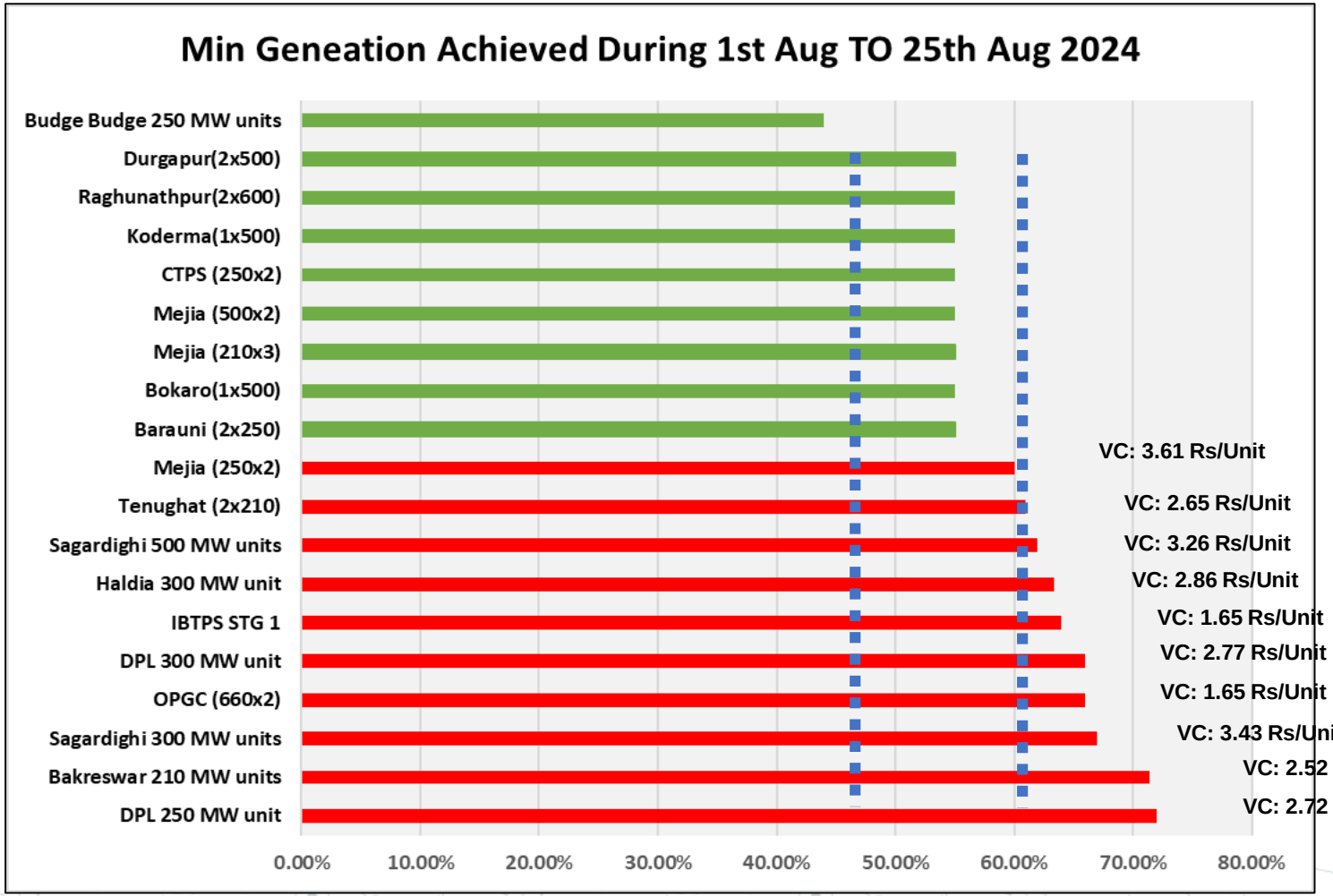
- **West Bengal** has notified **Final A**ncillary service regulation.
- MP has issued **Draft** Ancillary service regulation .

DVC work order placed AGC will be implemented within 3 months

MINIMUM TURN DOWN LEVEL OF THERMAL GENERATORS(55% - 40%)







Variable charges data source: meritindia.in and respective SERC websites

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

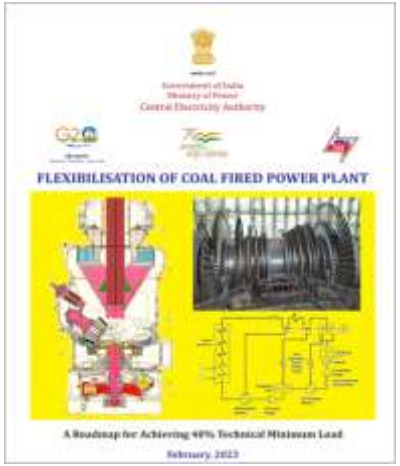
Flexibility Initiatives

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,

- 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%



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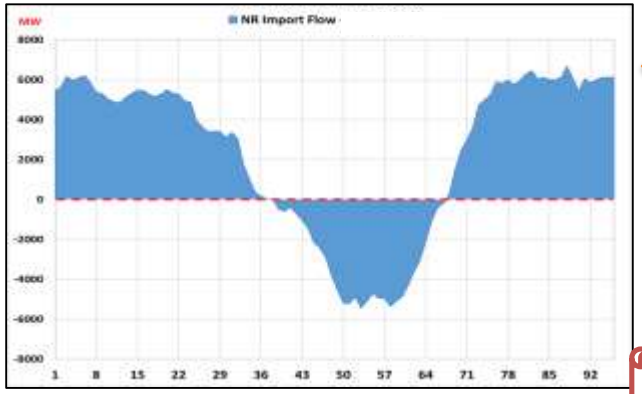
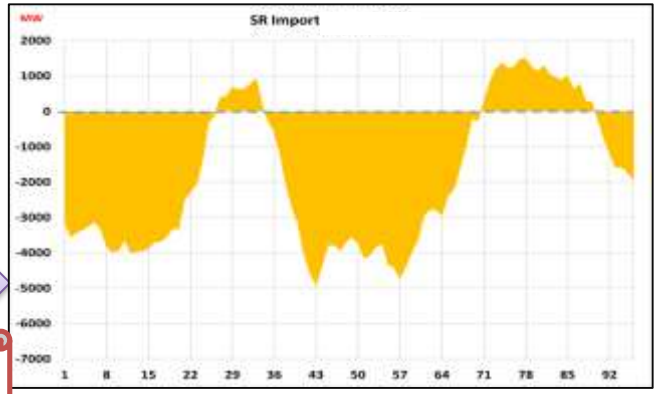
Central Electricity Authority – Phasing Plan for Implementation of 40% Technical Minimum Level

Other Operational and Planning Challenges with High RE Integration

Transmission Planning – Behavioral Change in Flow Patterns

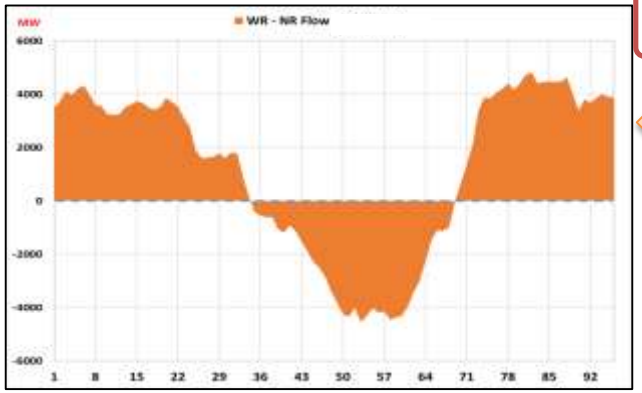


NR Import

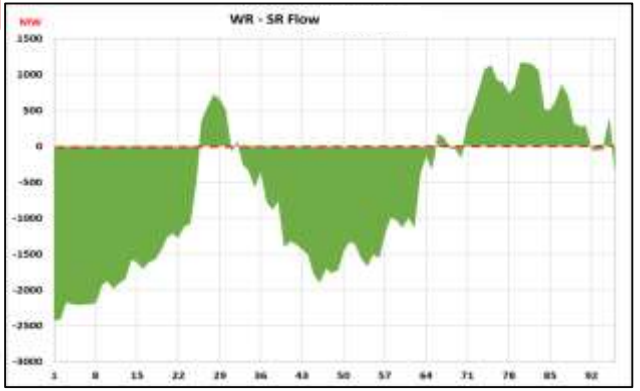


SR Import

Bi-directional Flows
The New Normal !!



WR - NR



WR -SR

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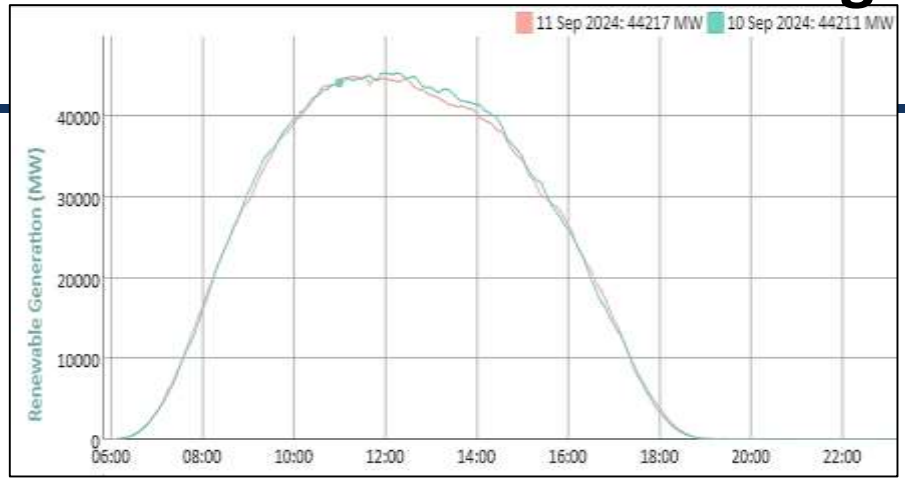
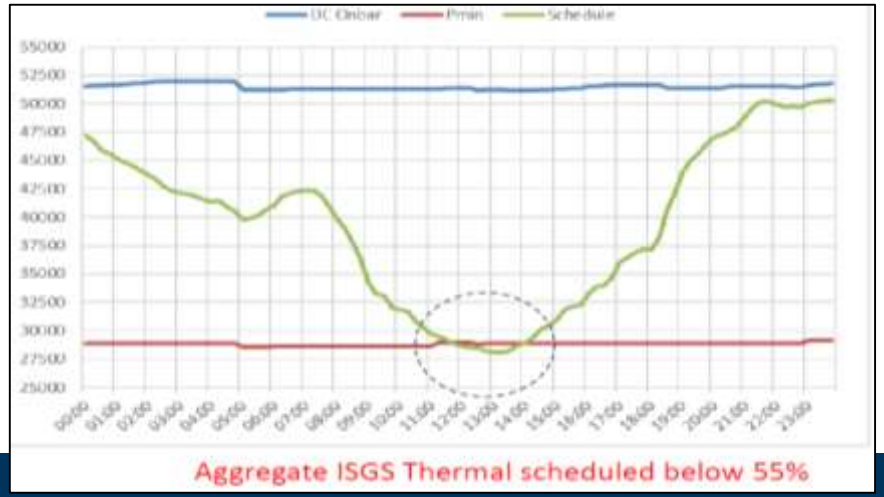
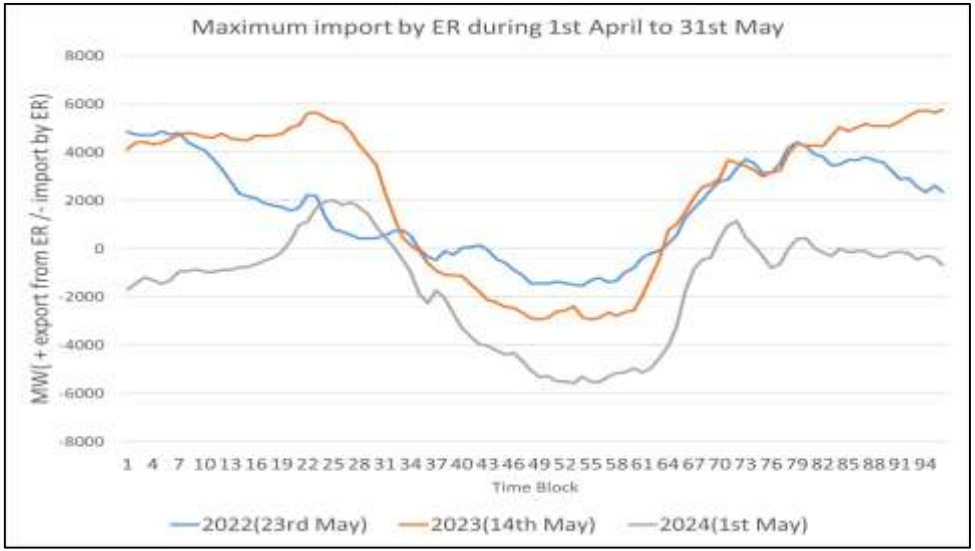
IR Flow changes & Stressed Transmission

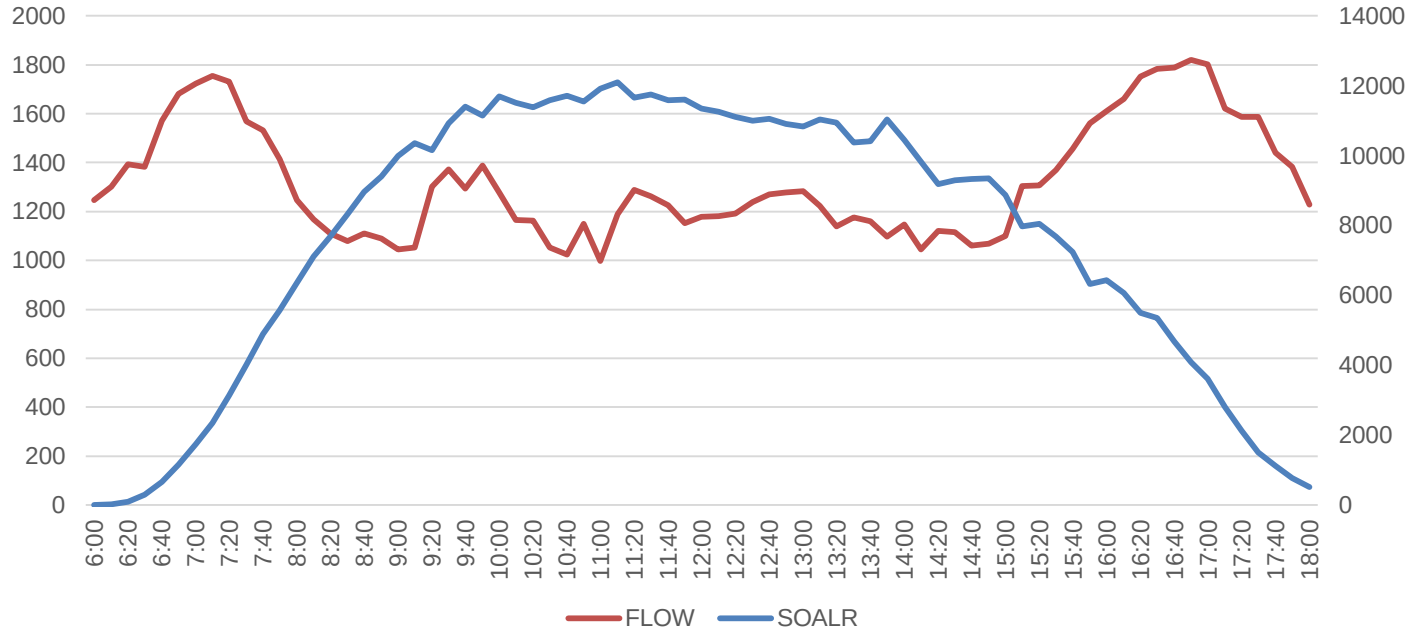




To accommodate RE power ,Backdown of Thermal generations During Solar Hours resulting to High Injection from other regions to ER ,Resulting to high interregional flow changes and posing challenges to manage power flows.

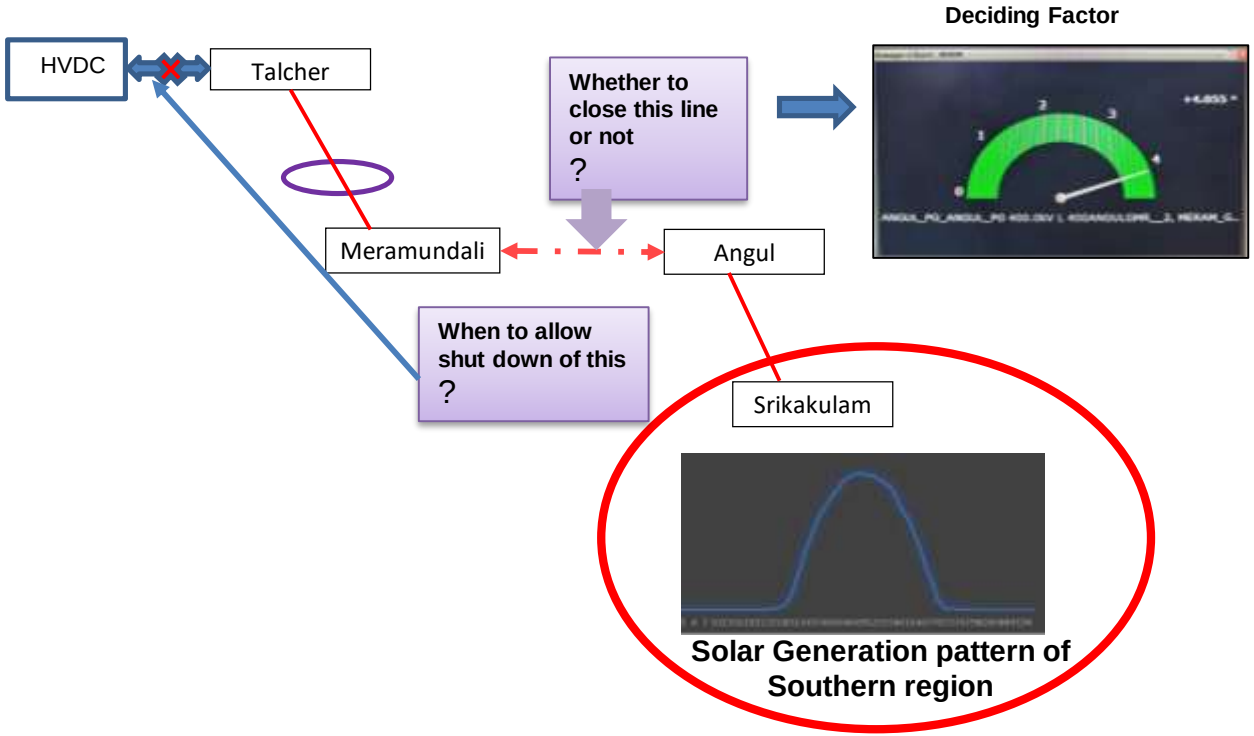


(04) Power flow pattern changes/Outage management

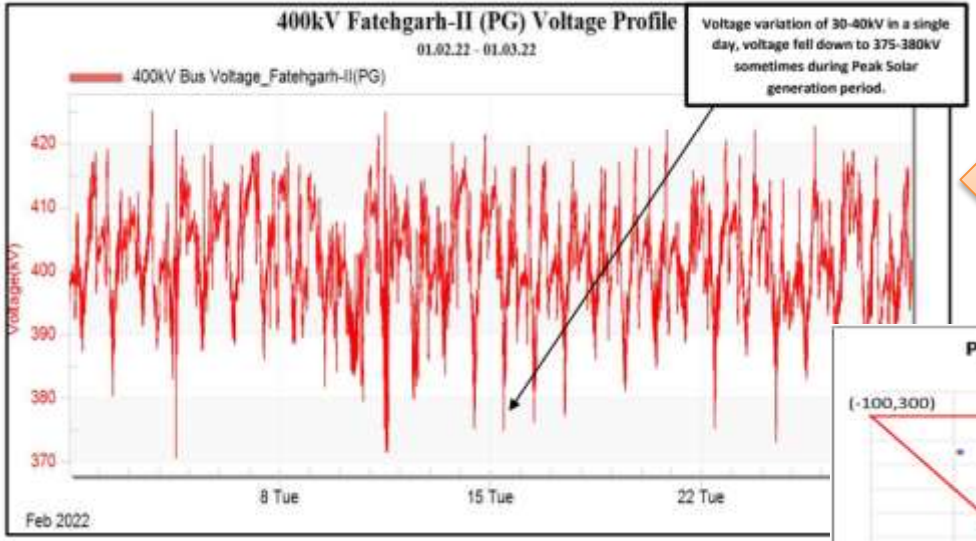


CORRELATION between SR SOLAR GEN & ANGUL SRIKAKULAM FLOW IS -0.7

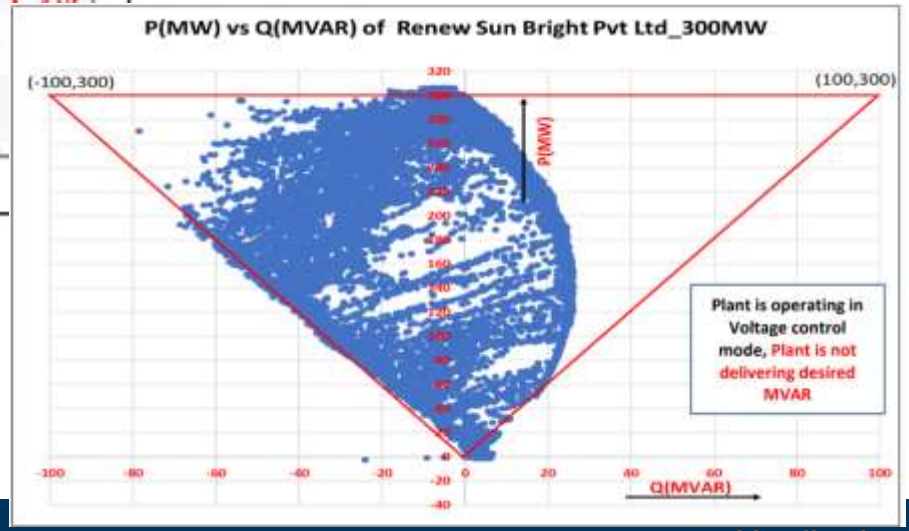
Outage management /Real time Network Re-arrangement



(5)Large Variation in Voltage at RE Pooling Stations



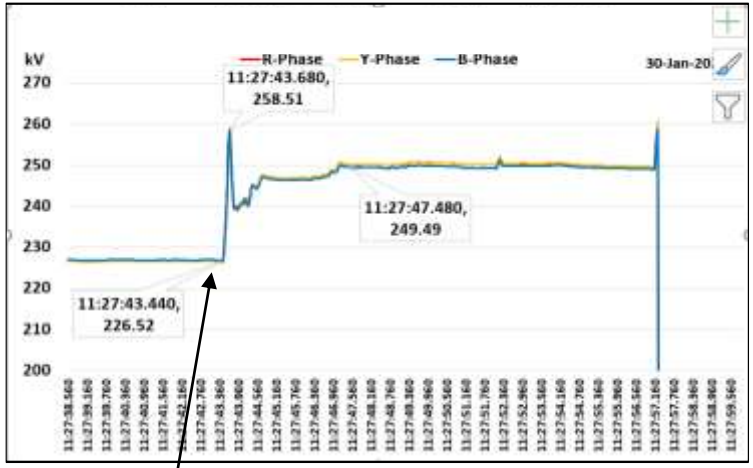
Large Fluctuation in Voltages (High v/s Low RE Period)



Non-Compliance to Specified Technical Standards (Reactive Power Capability)

(6) 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

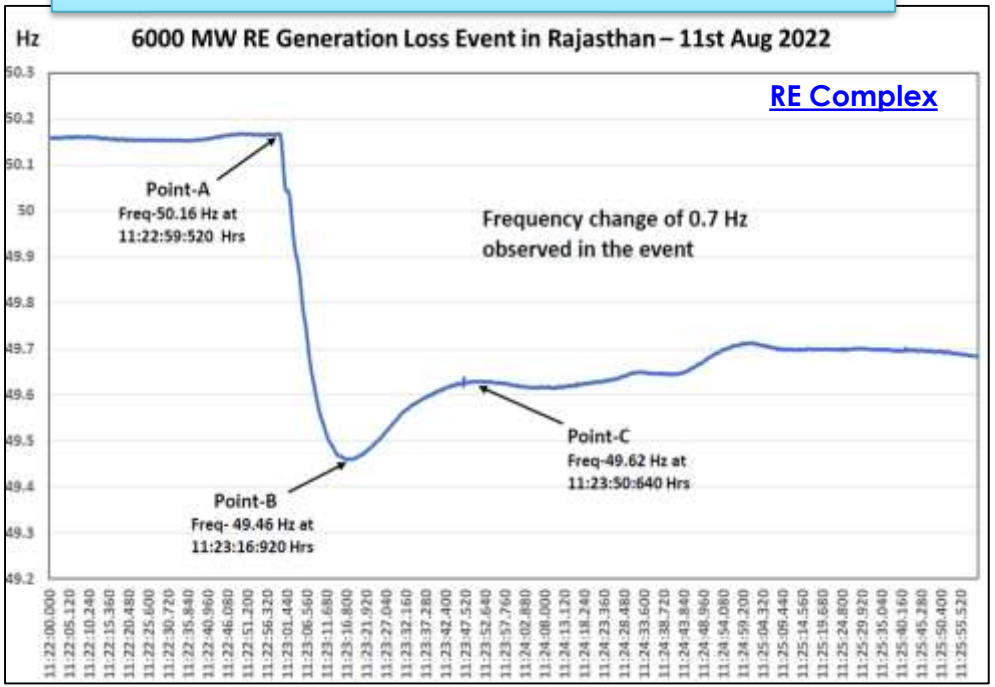
Transient voltage rise leading to tripping of EHV lines and Renewable plants on overvoltage

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

Back

(7)Large Generation Loss Events in RE Complexes

Frequency dip due to 6000 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

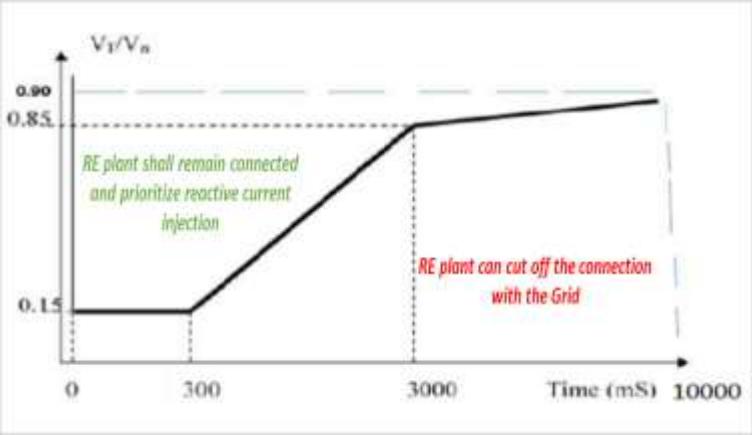
Regulatory Provisions

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

Low Voltage Ride Through (LVRT)

"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."



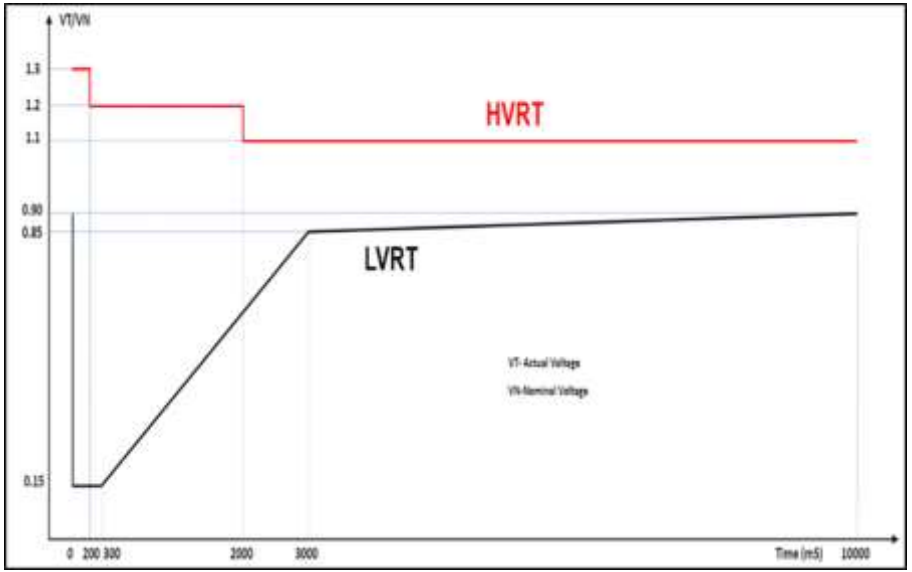
Regulatory Provisions

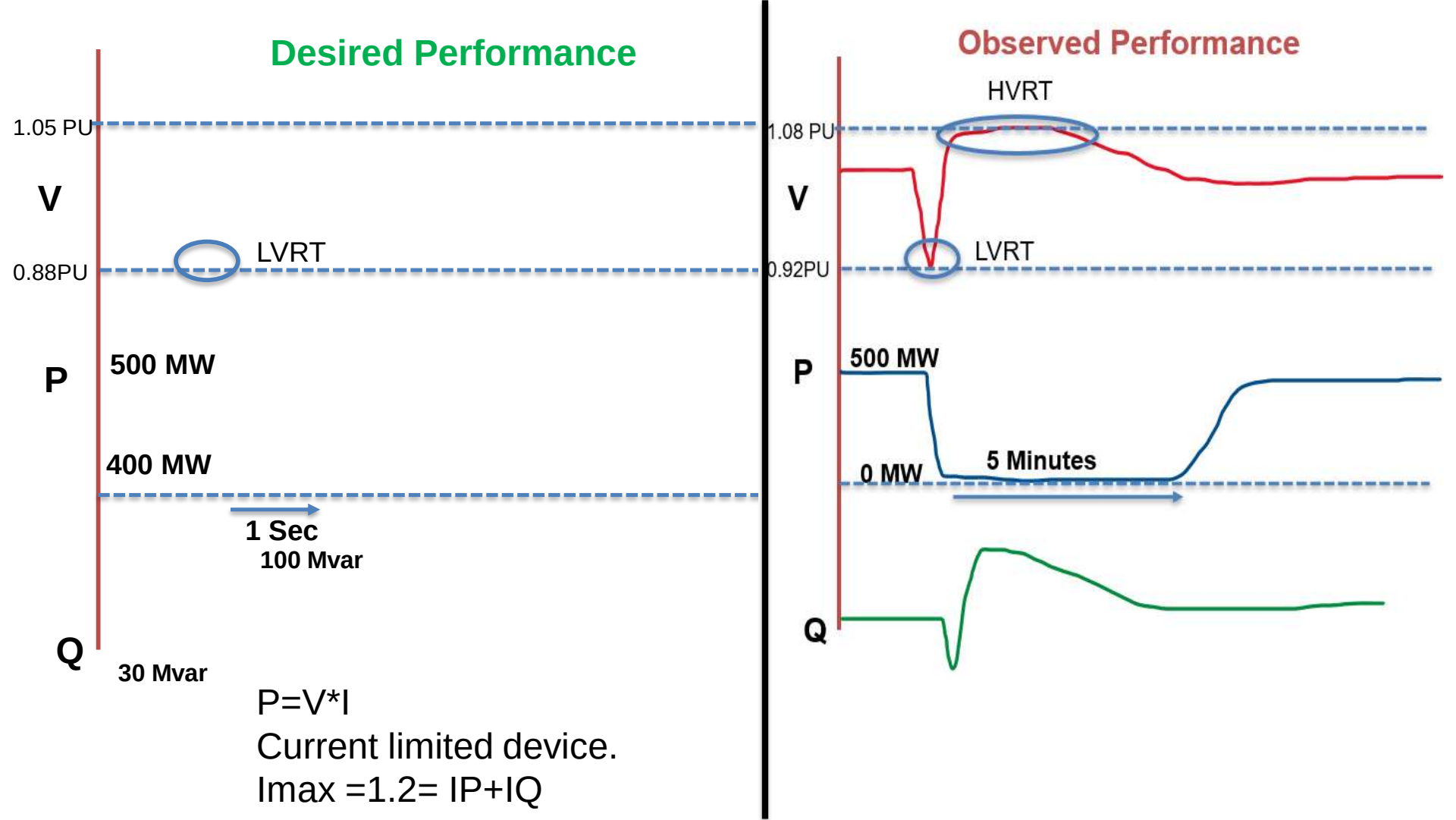
CEA, Technical Standards for Connectivity to the Grid, Regulations 2007

High Voltage Ride Through (HVRT)

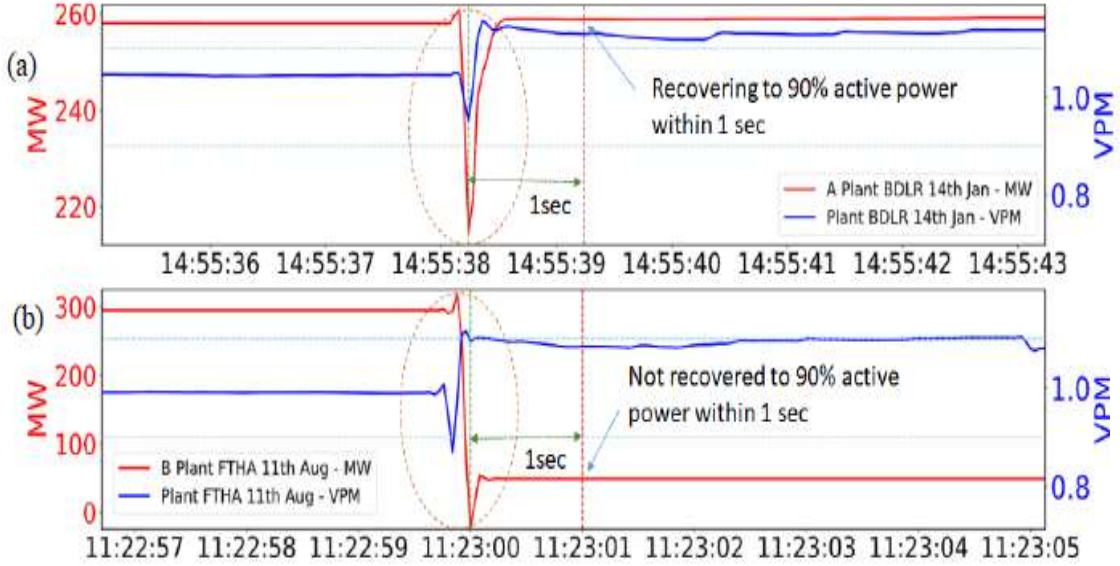
"The generating station connected to the grid, shall remain connected to the grid when the voltage at the interconnection point, on any or all phases (symmetrical or asymmetrical overvoltage conditions) rises above the specified values given below for specified time."

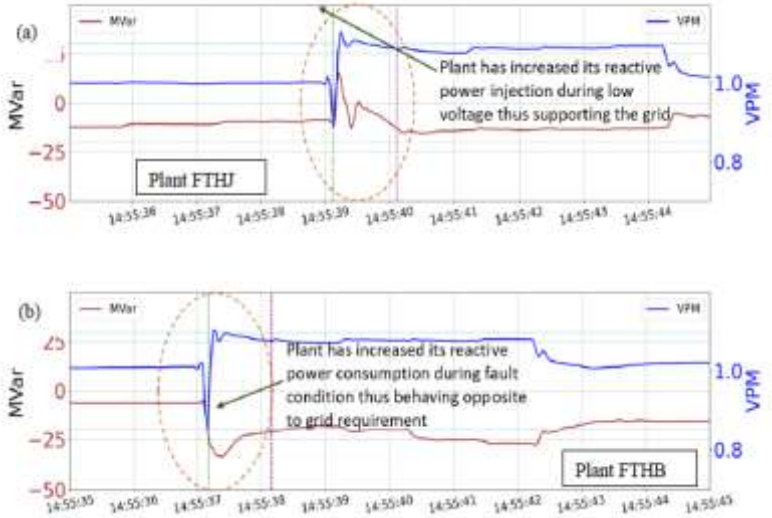
S. No.	Over Voltage (p.u.)	Minimum time to remain Connected (seconds)
1.	1.30 < V	0 (instantaneous trip)
2.	1.30 ≥ V > 1.20	0.2 Sec
3.	1.20 ≥ V > 1.10	2 Sec
4.	V ≤ 1.10	Continuous




Desired Performance
1.05 PU
V
0.88PU
LVRT
P
500 MW
400 MW
1 Sec
100 Mvar
Q
30 Mvar
P=V*I
Current limited device.
Imax =1.2= IP+IQ
Observed Performance
HVRT
1.08 PU
V
0.92PU
LVRT
P
500 MW
0 MW
5 Minutes
Q

Active Power Compliance Vs Non-Compliance

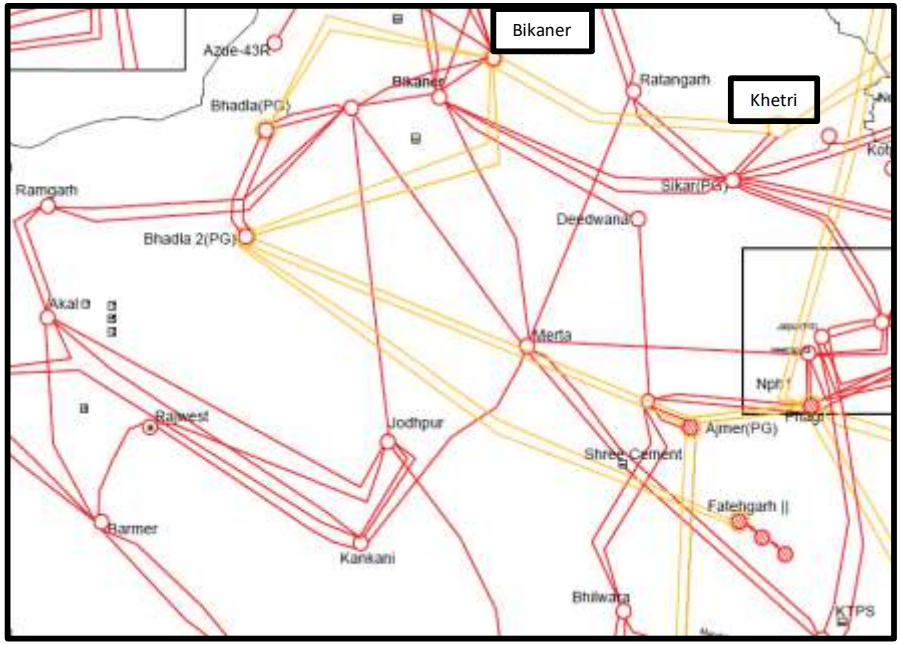




Reactive Power Compliance Vs Non-Compliance

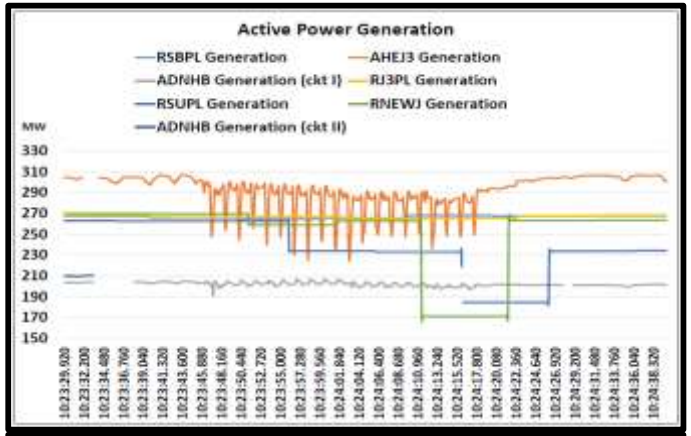
(8)Forced Outage of Critical Transmission Corridor

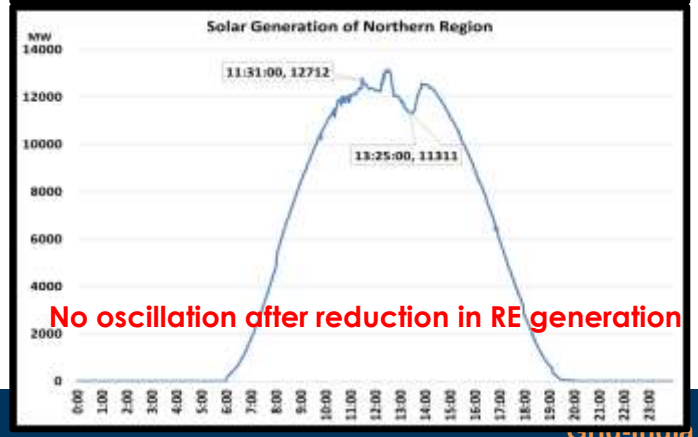
- Tower Collapse in one circuit of the 765 kV D/C line
- Led to further reduction in fault level at RE pooling stations in the vicinity



Oscillations were observed intermittently between 10:20 hrs to 10:50 hrs of 10th June 2022

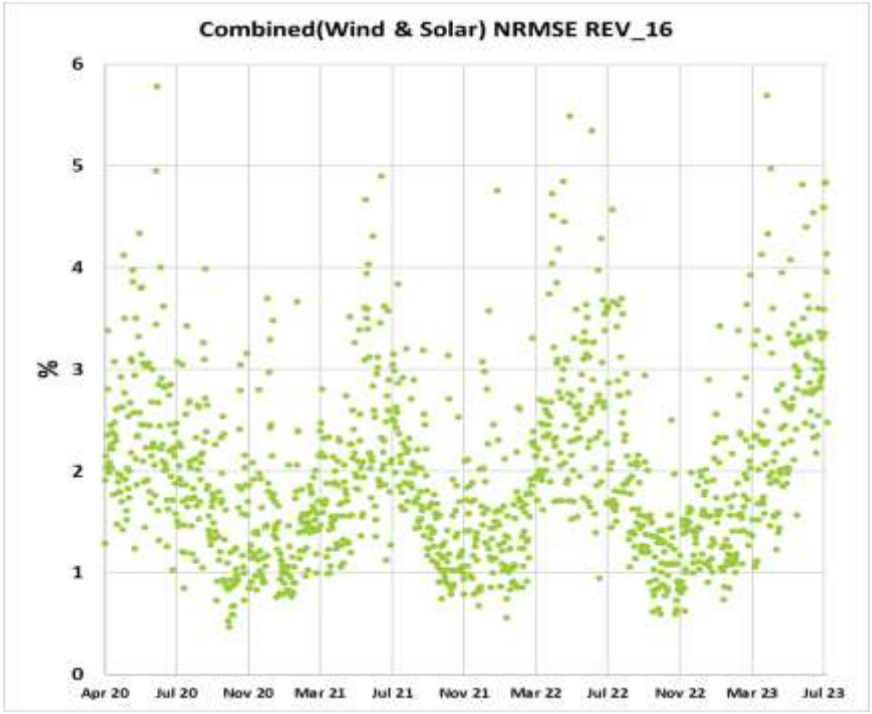
Oscillations in RE plant output during peak solar hours



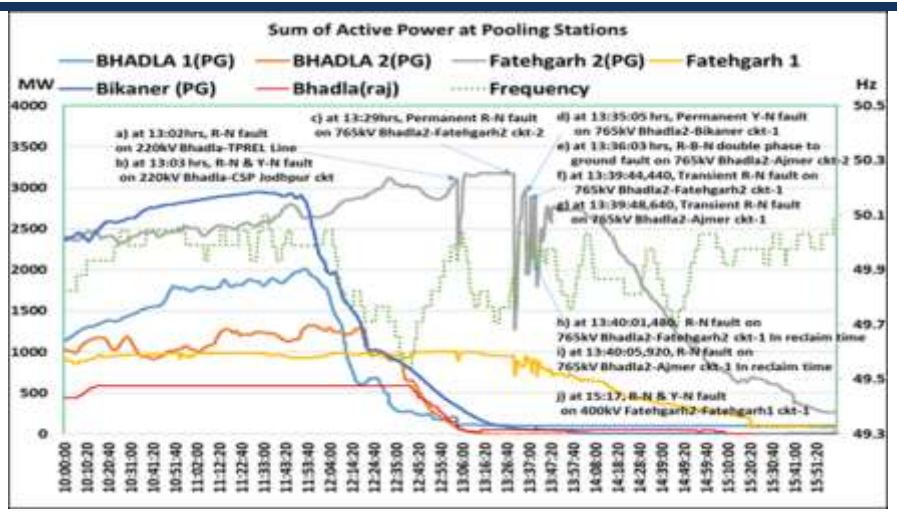


No oscillation after reduction in RE generation

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

Clean Energy Transition – Building Blocks

Standards and Regulatory Framework

- Technical Standards for Connectivity
- Indian Electricity Grid Code
- Compliance Testing
- Strengthening of Standards & Regulations

Resource Adequacy & Flexibility

- Adequate resources in all time frames
- Harnessing flexibility in Conventional Gen.
- Exploring New Avenues for Resource Adequacy and Flexibility

Transmission Planning

- Evolving Transmission Planning Philosophy
- Innovative solutions for Grid Stability

Reserves, Ancillary Services & Markets

- Primary, Secondary and Tertiary Control
- Voltage Control Ancillary Services (VCAS)
- Real-time, Green Day Ahead Market etc.

Real-time Monitoring, Visualization and Situational Awareness

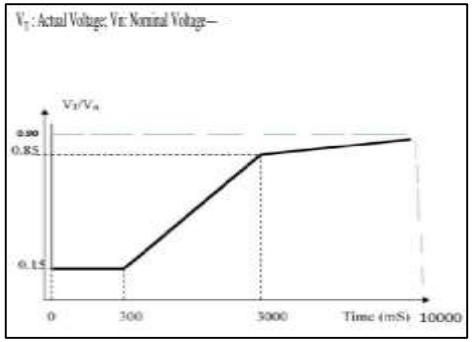
- Renewable Energy Management Centers (REMCs) – 11 nos. at present
- ~93 GW wind and solar capacity being monitored through 11 REMCs
- EMS (State Estimation, Contingency Analysis etc.) and Dynamic Security Assessment (DSA) Tools

Technical Standards

Amendment to CEA's "Technical Standards for Connectivity to the Grid"

Notified on 8th Feb 2019; Effective from 6th Aug 2019

- Frequency Response by RE Generators
- Active Power – Set Point Control
- Voltage Ride Through Applicability
  - Low Voltage - (LVRT)
  - High Voltage (HVRT)
- Provision to vary Active and Reactive Power*
- Short Circuit Ratio – five or above



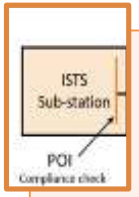
Over voltage (pu)	Minimum time to remain connected (Seconds)
1.30 < V	0 Sec (Instantaneous trip)
1.30 ≥ V > 1.20	0.2 Sec
1.20 ≥ V >1.10	2 Sec
V ≤ 1.10	Continuous

** Based on the signal from the State Load Dispatch Centre or Regional Load Dispatch Center*

Compliance Verification

RE Integration process in India

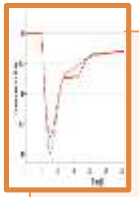
Technical requirements specified for Wind and Solar Generating Stations in CEA Connectivity Standards



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**

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**

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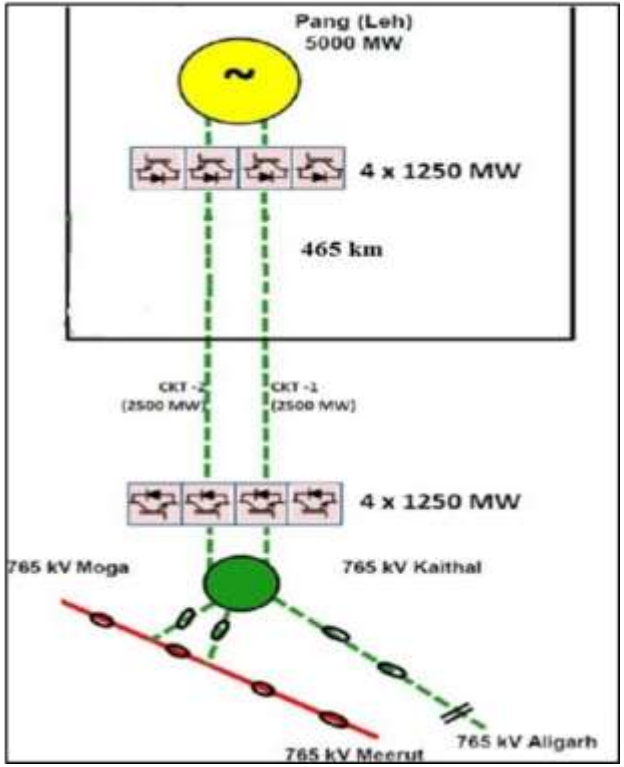
Transmission Planning Initiatives



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

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Thank you !!