High Impact Low Frequency Events in Indian Power System

04 June 2024

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Grid Controller of India Limited

Dimensions of Indian Power System

~442 GW
generation capacity

3.2 million km²
area footprint

250 GW+
peak demand

1.4 Billion+
people served

> 5.46 TWh
daily energy met

4.5 GW+
international exchanges

471817 ckm+
EHV transmission

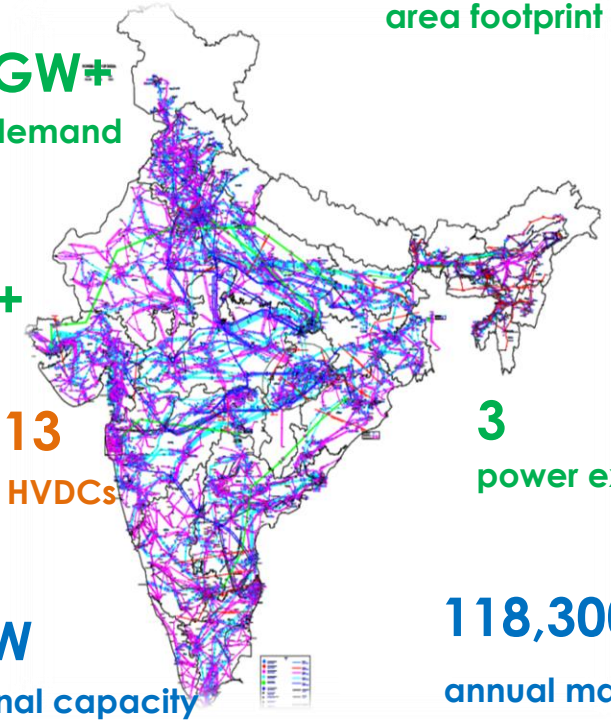
171 TWh+
annual market trades

~192 GW
renewables
(including large Hydro)

13
HVDCs

3
power exchanges

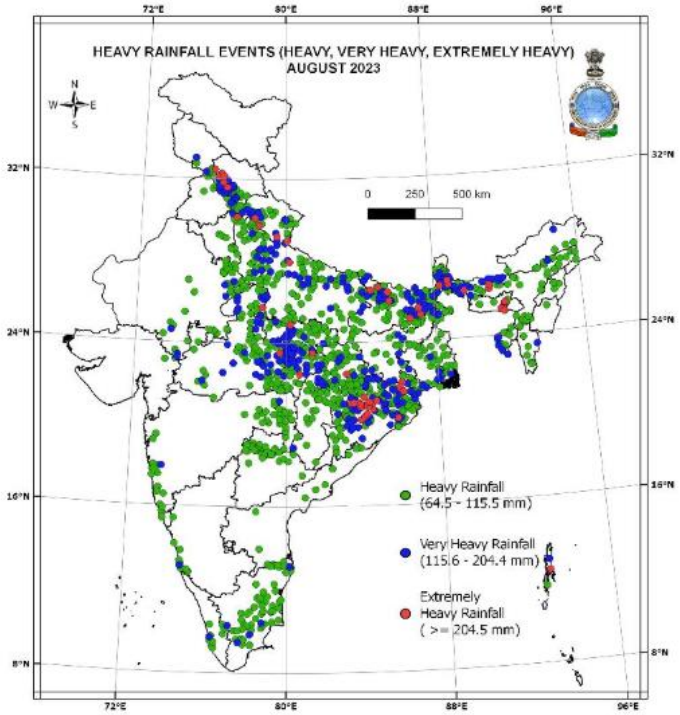
6000+
market participants



~ 112 GW
inter-regional capacity

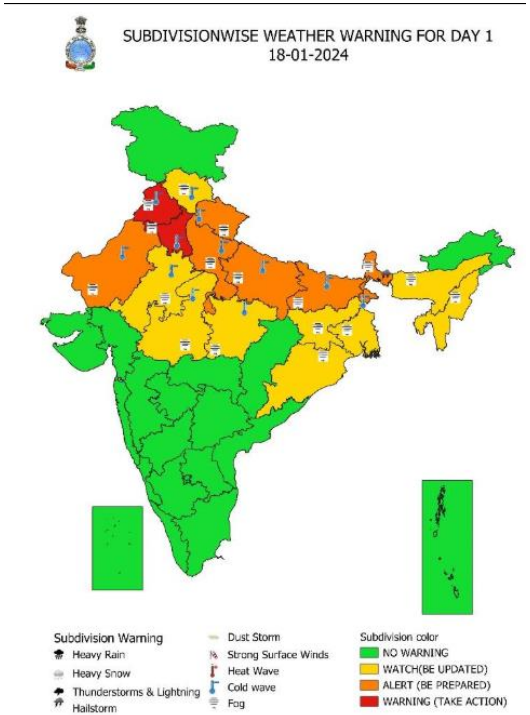
118,300+
annual market transactions

Recent extreme weather events observed in India



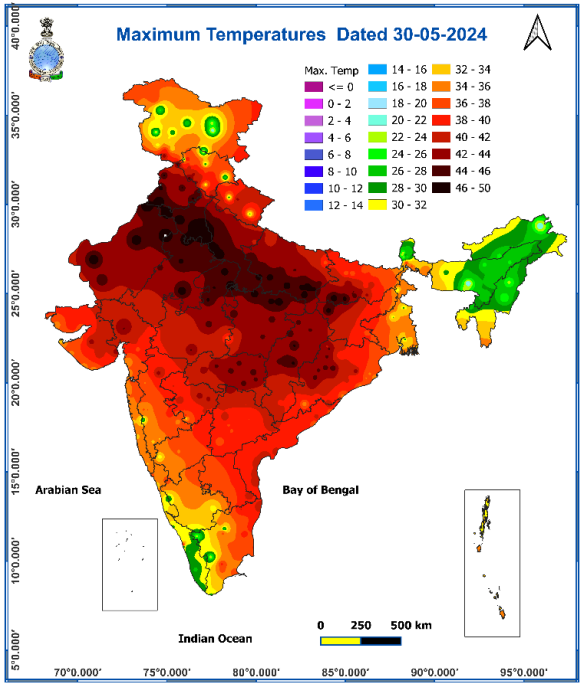
August 2023

Heavy rainfall



Dec 2023-Jan 2024

Cold wave and extended fog



May-June 2024

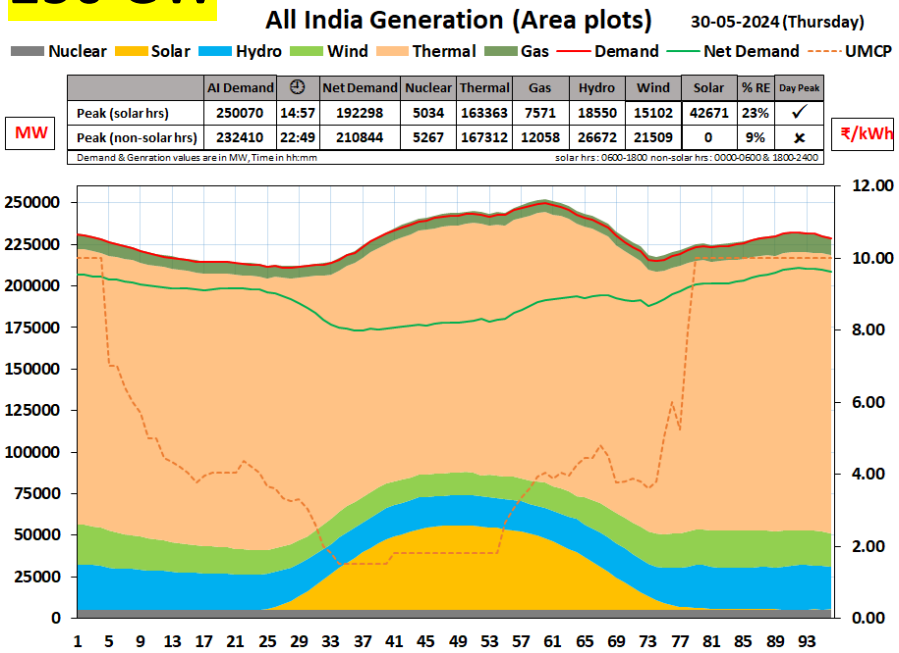
Extended heat wave

Risks

- Extreme weather events
  - Cloudburst, Glacial lake burst Cyclone, Tsunami
- Prolonged adverse weather conditions
  - Heat wave, Wind drought, fog/smog, dry spell, water scarcity
- Celestial, geospatial event
  - Solar storm, Solar eclipse, meteorite, earthquake
- Pandemic
  - Corona, H1N1, Flu

PRESENT

250 GW

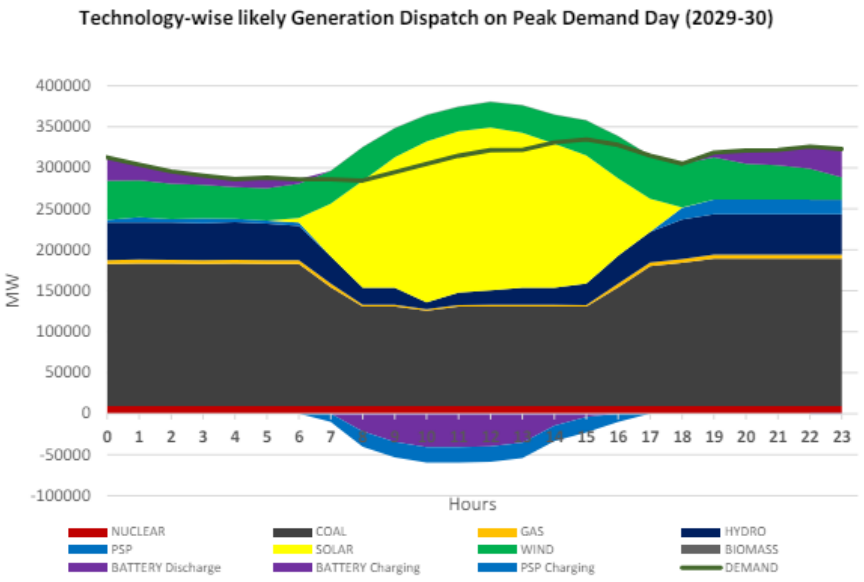


	AI Demand		Net Demand	Nuclear	Thermal	Gas	Hydro	Wind	Solar	% RE	Day Peak
Peak (solar hrs)	250070	14:57	192298	5034	163363	7571	18550	15102	42671	23%	✓
Peak (non-solar hrs)	232410	22:49	210844	5267	167312	12058	26672	21509	0	9%	✗

Total non-fossil installed: ~ 200 GW
Total Solar+Wind VRE installed: 150 GW
Maximum VRE generation achieved: 73 GW
Highest instantaneous penetration: 32 %

FUTURE

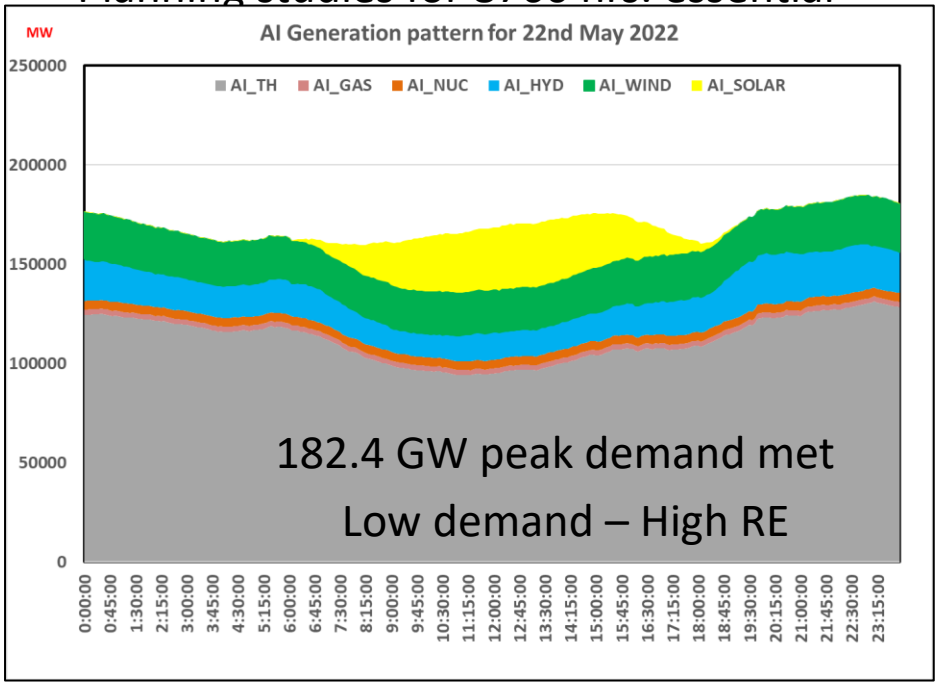
335 GW

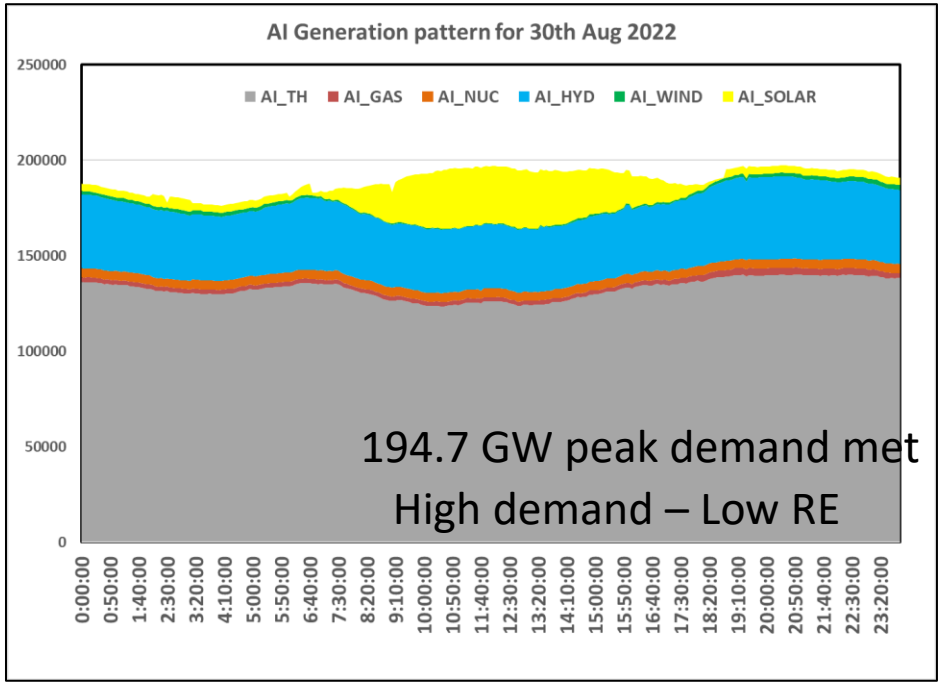


Total non-fossil installed: 500 GW
Total VRE installed: 400 GW

Resource Adequacy need for 8760 hours

- Challenges in resource adequacy due to variability of RE
- Reserve requirement and system constraints would vary
- Planning studies for 8760 hrs. essential

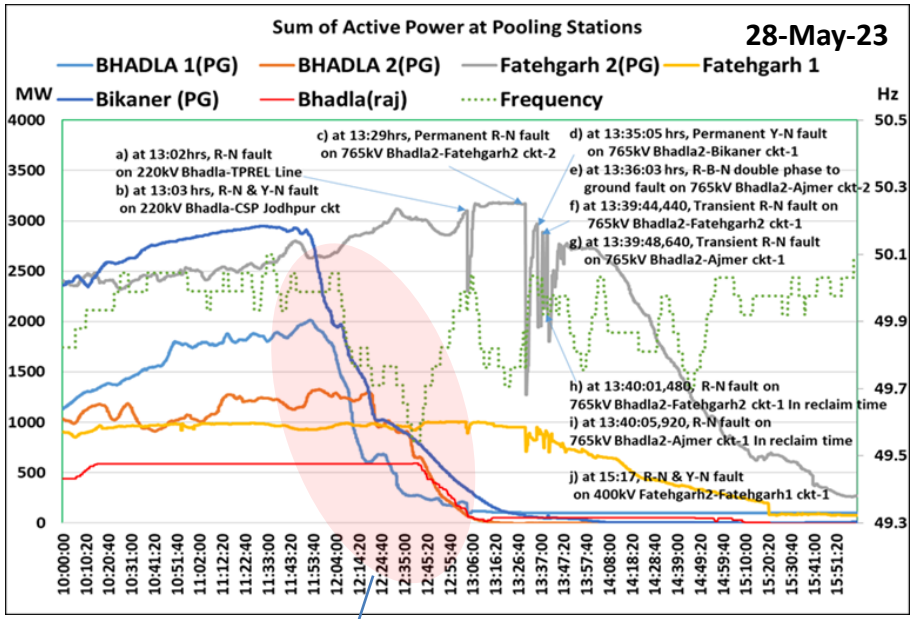


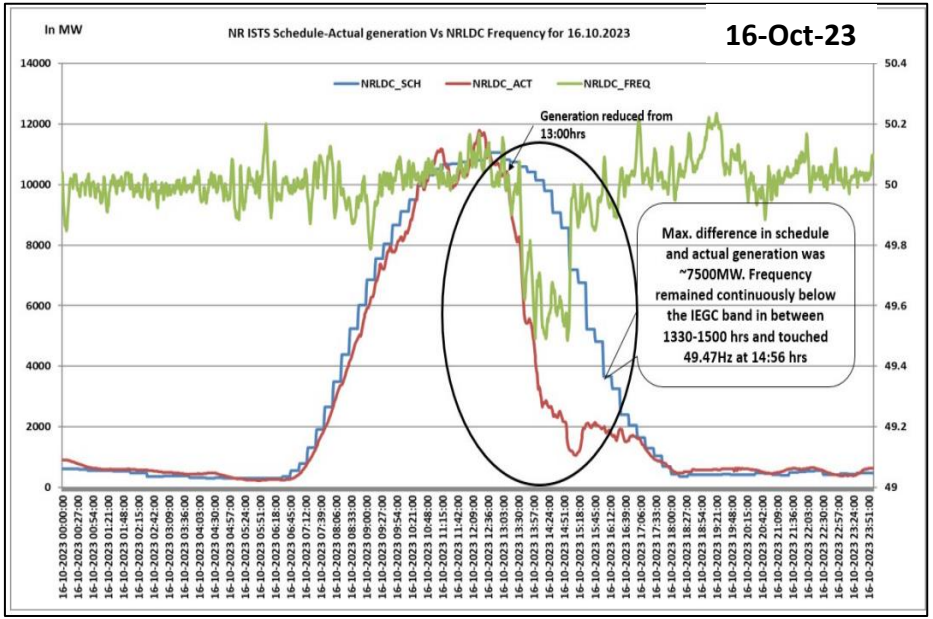


Highest Instantaneous RE penetration (in Q1 FY 2022-23) of ~31.8 % was recorded on 22nd May 2022 (Sunday)

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

Impact of Cloud cover on Power System

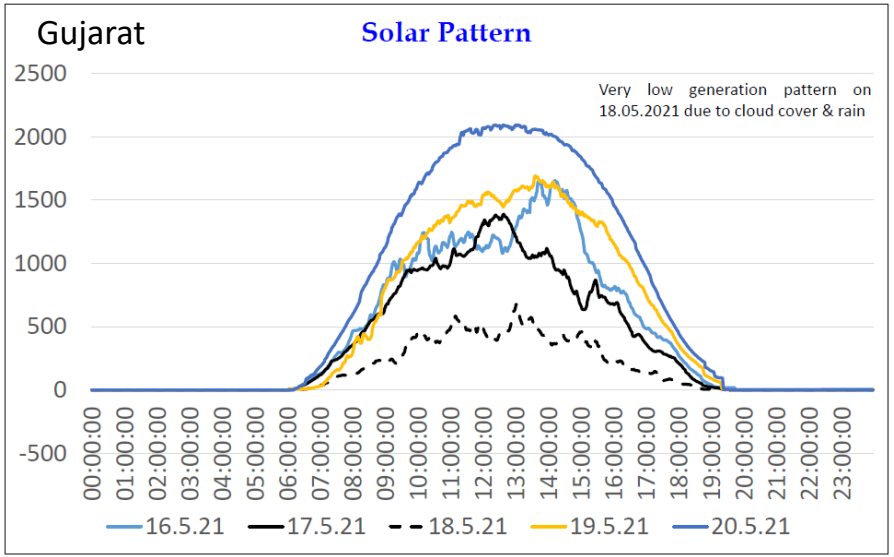


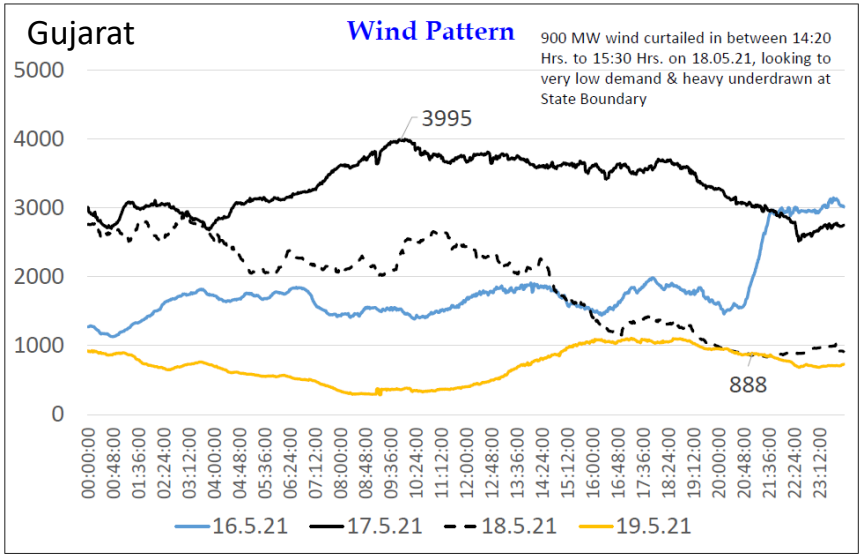


Approx. 8000 MW reduction in solar generation in 1 hour due to Cloud Cover

Approx. 7500 MW reduction in solar generation in 1 hour due to Cloud Cover

Impact On Renewable Generation

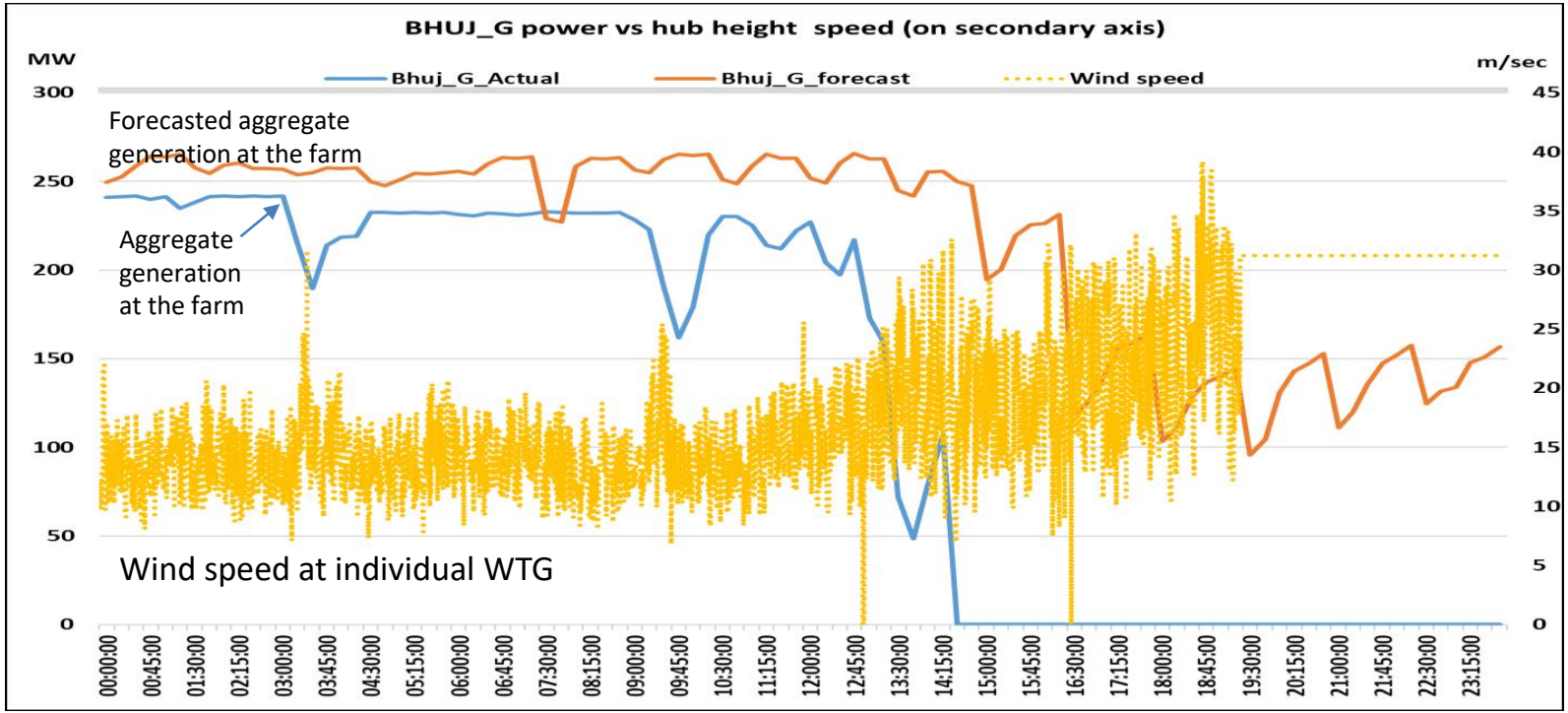




- High intermittency
- Low generation

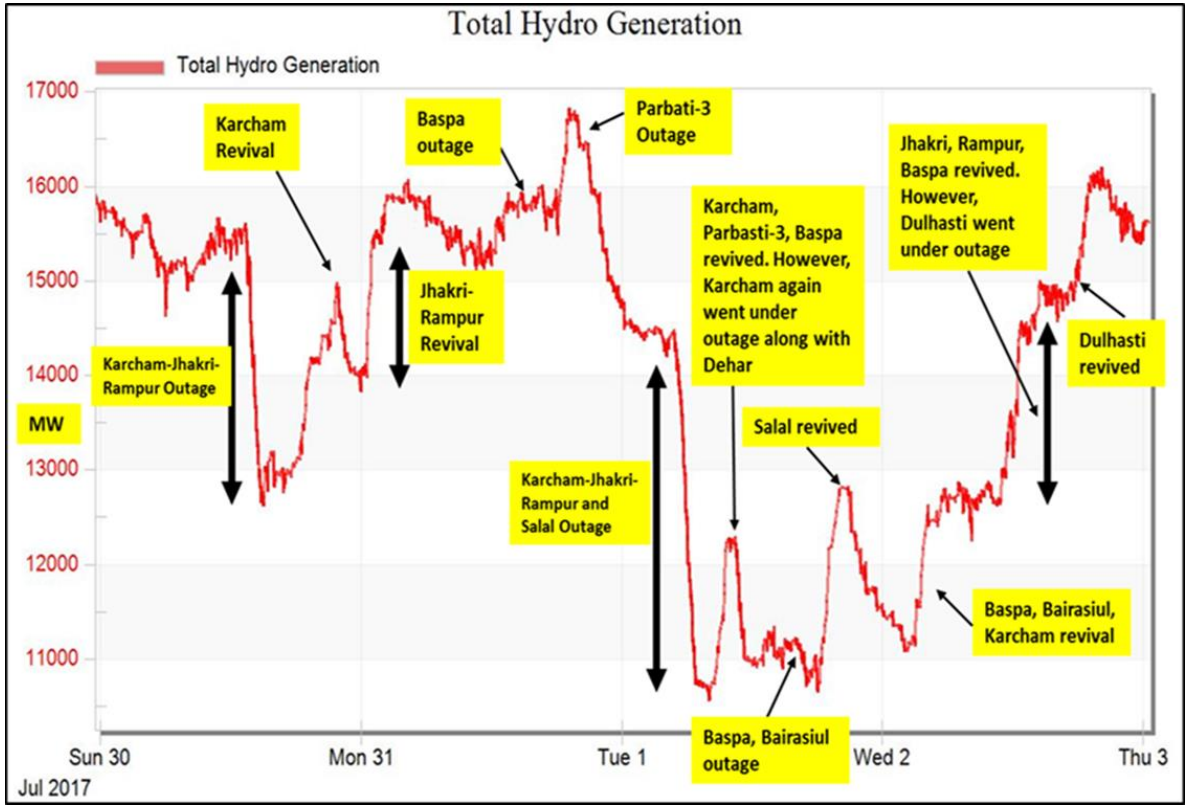
- Wind generation blocked out due to wind gust exceeding cut off speed.
- Wind Generation curtailed on 18th May to maintain ACE within limits.

Measured wind speed and power output from an individual Wind Turbine Generator in Bhuj on 15.06.2023

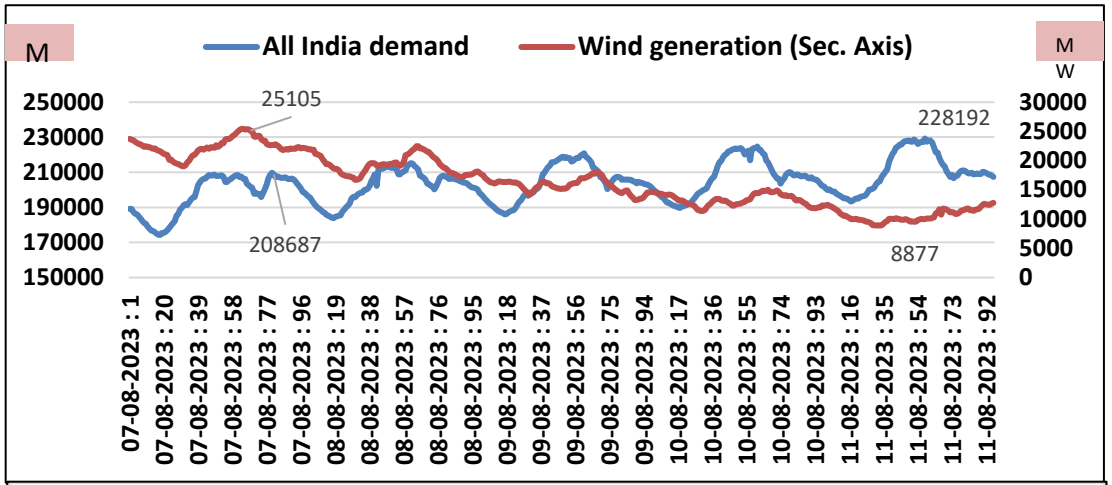


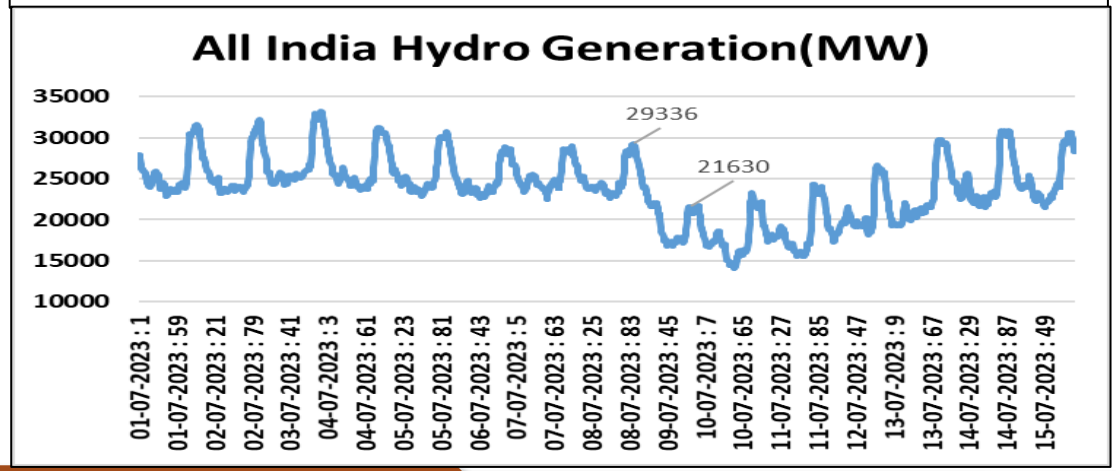
- On 15th June 2023, due to high cyclonic wind speed over Coastal areas of Gujrat, led to generation reduction of 217MW at a generating station pooled at Bhuj from 12:45 hrs to 14:15hrs.
- Maximum speed recorded was 39m/sec at 18:30hrs.
- Cut out speed is 25m/sec for WTG.

Hydro generation affected dur to silt



Resource Adequacy challenges





Long duration storage, quick starting thermal vital to sail through resource droughts

Minimum: 358 MW(30.08.22)	Low wind generation during high wind season
~30% less hydro In 2023	Low hydro generation due to drought/weak monsoon

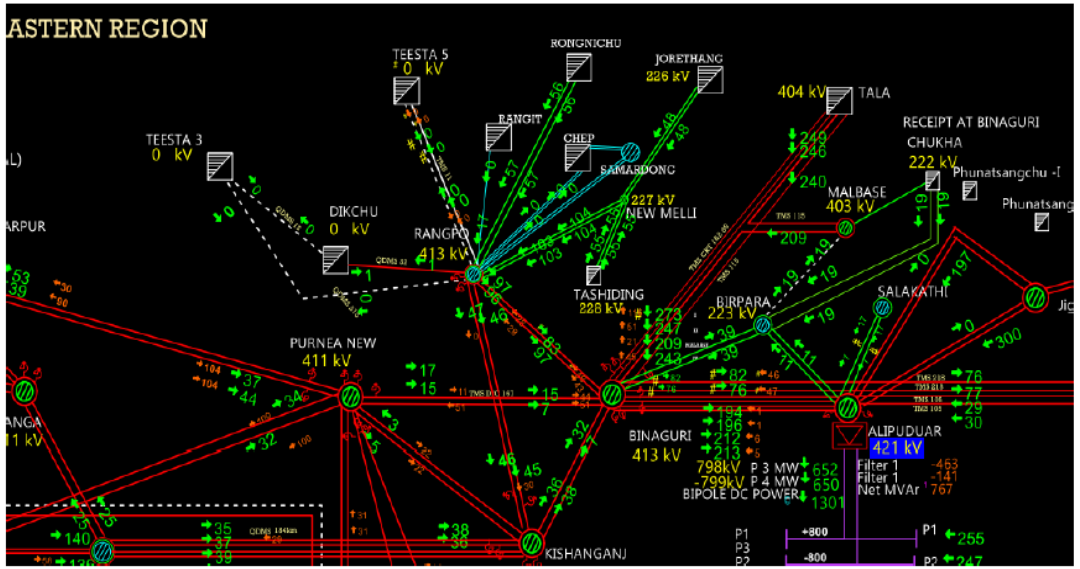
Adequacy of reserves vital to handle contingencies

Max affected: 8000 MW (28.05.23)	Cloud cover, sandstorm
Max affected: 7100 MW (15.05.23)	RE generation loss due to fault ride through issues

Cloudburst and Damage of Teesta Dam
04th October 2023

High impact Low frequency event in Teesta Valley

- Due to continuous high silt and rise in inflow due to cloud burst in the upstream area of the reservoir, **Teesta-III all units (6*200 MW)** (On bar gen around 1300 MW) taken out of bar at 00:50 Hrs on 04-10-2023.
- **Dikchu both units (2*48 MW)** taken out of bar at 01:49 hrs due to flash flood
- All 3 units of **Teesta V (3*170 MW)** (generating around 504 MW) taken out of bar at 02:37 hrs due continuous high silt
- **Entire ~1900 MW** of Hydro Generation is yet to be revived



Lines Under Forced Outage	Remarks
400KV-RANGPO-TEESTA-V-1	Tower collapsed at loc. 1
400KV-RANGPO-TEESTA-V-2	
400KV-TEESTA-III-RANGPO-1	Hand-tripped as a precautionary measure
400KV-TEESTA-III-DIKCHU-1	
400KV-RANGPO-DIKCHU-1	

India – Susceptible to Natural Disasters

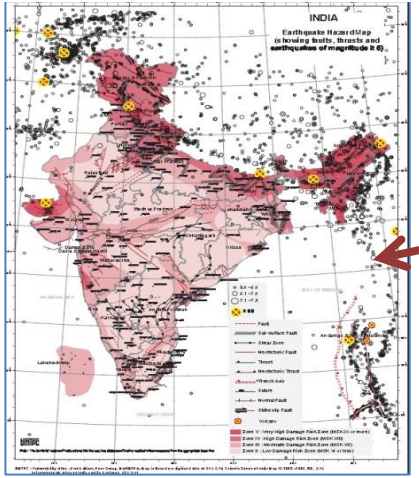
Unique Climatic Regime

Two monsoon seasons (southwest & northeast monsoons)

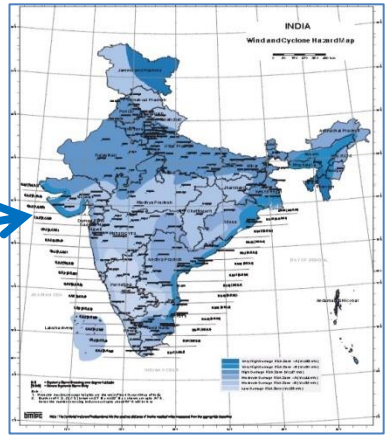
Two cyclone seasons (pre & post monsoon cyclone seasons)

Hot weather season characterised by violent convective precipitation

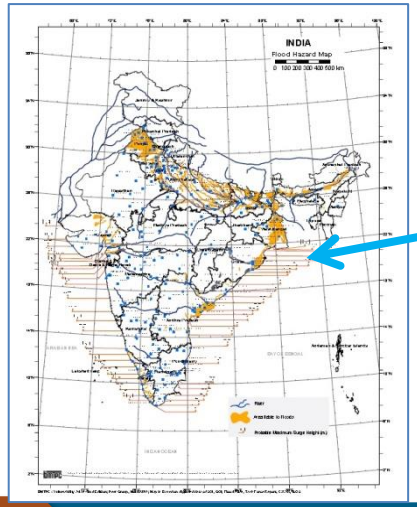
Cold weather season characterised by violent snow storms in the mountains



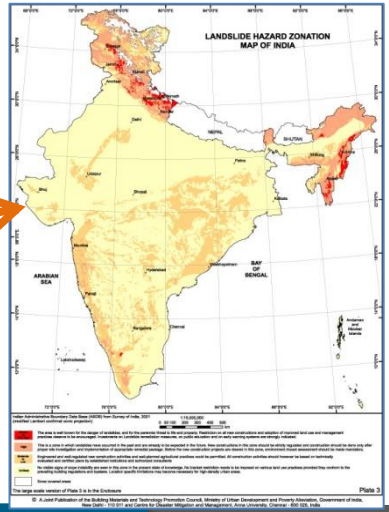
58 % of landmass prone to earthquake of moderate to very high intensity



8 % of landmass prone to cyclone and tsunami



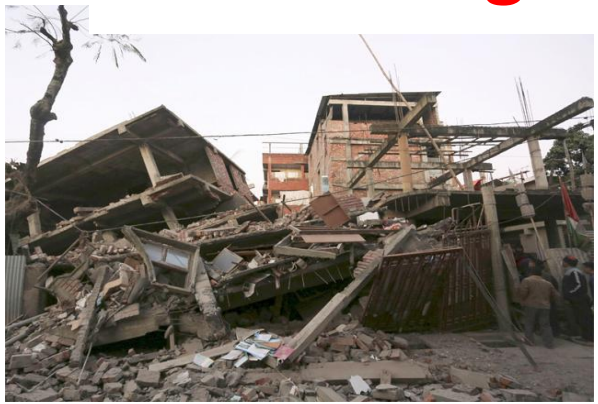
12 % of landmass prone to flood and river erosion.



15 % of land mass is prone to land-slides and avalanches

Source: www.portal.gsi.gov.in

Damage to Power Infrastructure



Natural Disasters in Recent History which impacted Electricity Grid in India

Cyclones

- **2024:** Remal
- **2023:** Biparjoy, Michaung
- **2022:** Asani , Mandous
- **2021:** Tauktae **,** Yass
- **2020:** Amphan, Nivar
- **2019:** Fani, Bulbul
- **2018:** Titli, Gaja
- **2016:** Vardah
- **2014:** Hud-Hud
- **2013:** Phailin

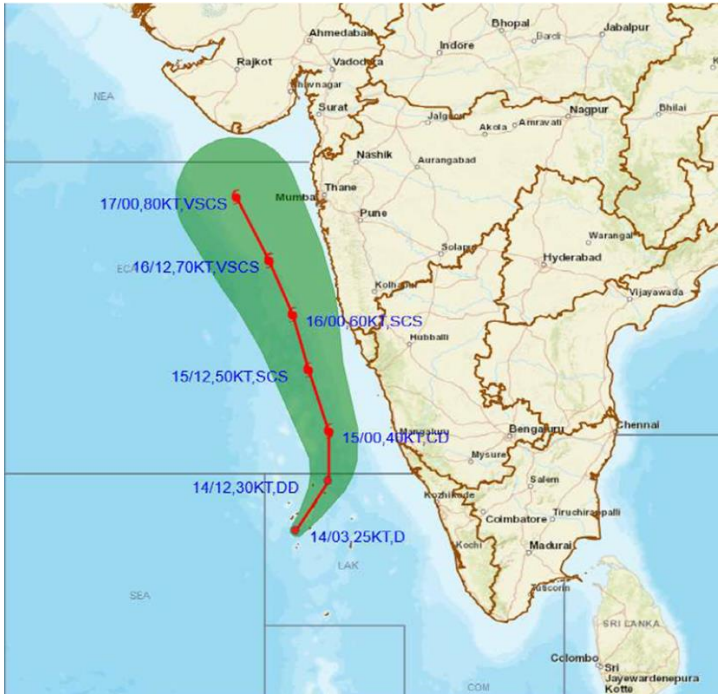
Floods

- **2023:** Chennai
- **2022:** Assam
- **2021:** Uttarakhand, Maharashtra
- **2020:** Assam, Telangana
- **2019:** Karnataka, Kerala
- **2018:** Kerala
- **2017:** Tamil Nadu
- **2016:** Assam
- **2015:** Tamil Nadu
- **2013:** Uttarakhand

Earthquakes

Date	Affected Area	Intensity
03 Nov 2023	India, Nepal	5.7
28 April 2021	India	6.0
10 April 2018	India	4.6
03 Jan 2017	India, Bangladesh	5.7
04 Jan 2016	India, Myanmar, Bangladesh	6.7
26 Oct 2015	India, Afghanistan, Pakistan	7.7
12 May 2015	India, Nepal	7.3
01 May 2013	India	5.7

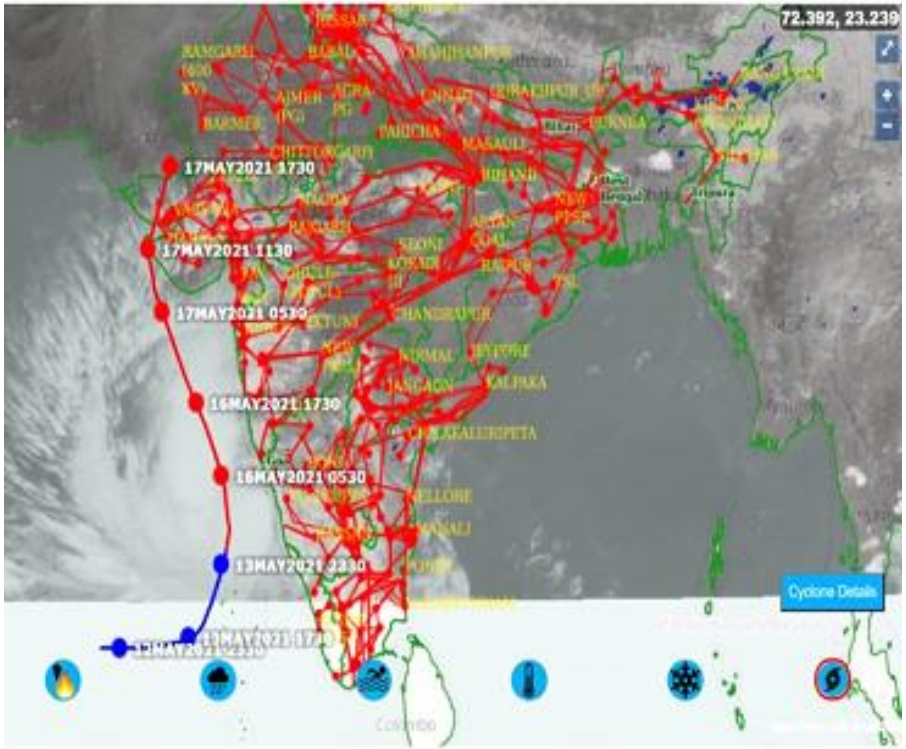
Advance Warning



Predicted Cyclone Track

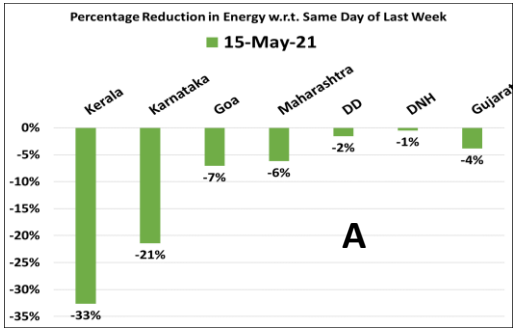
by Indian Meteorological Department on 14th May 2021

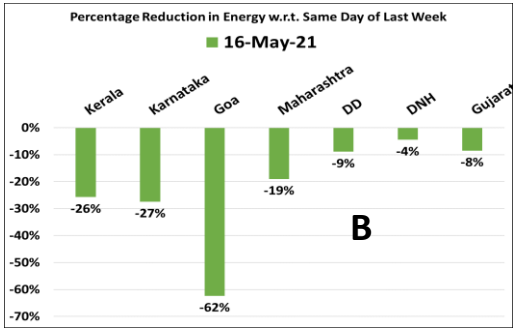
Risk Assessment

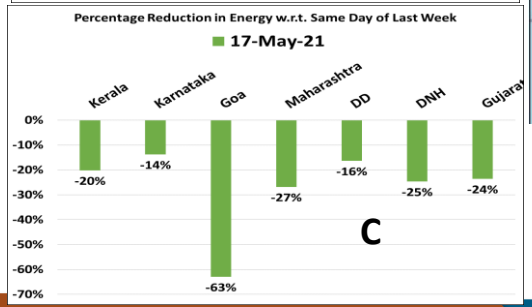


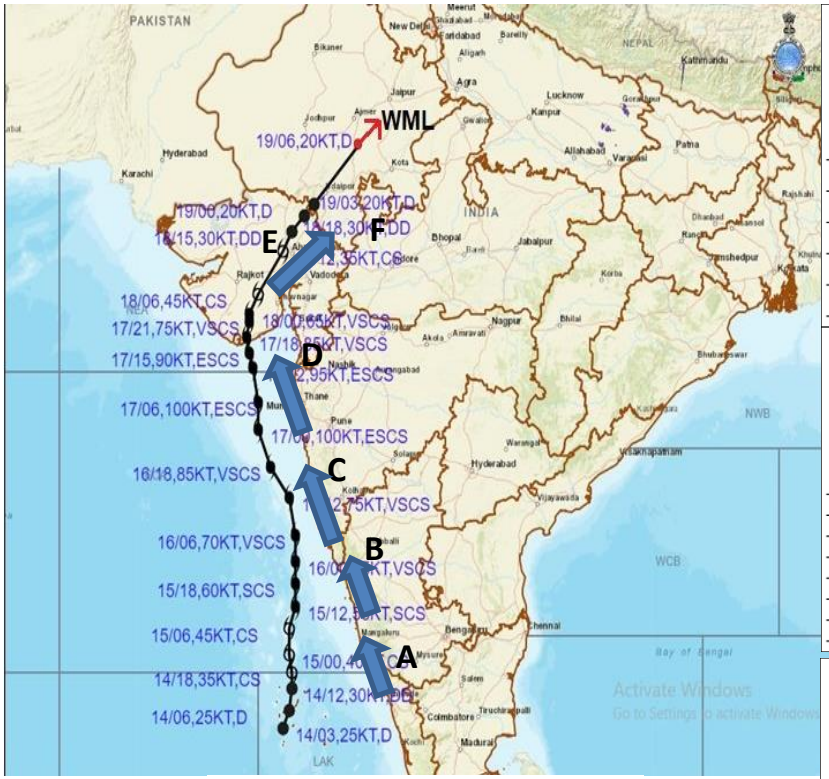
Satellite-based GIS Display from Indian Space Research Organization

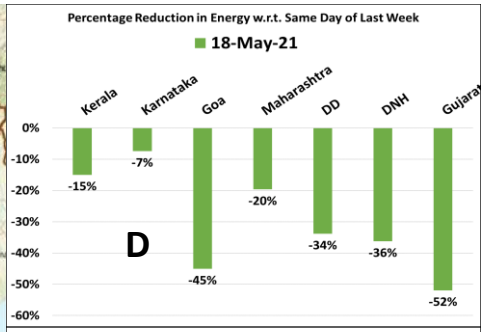
Extremely Severe Cyclonic Storm "Tauktae" May'21

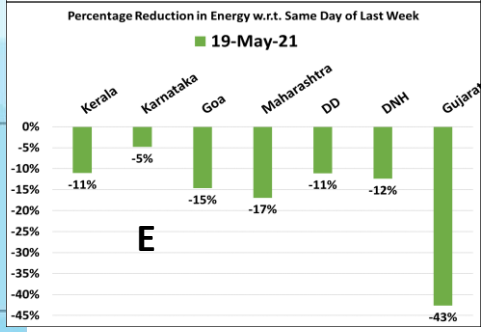


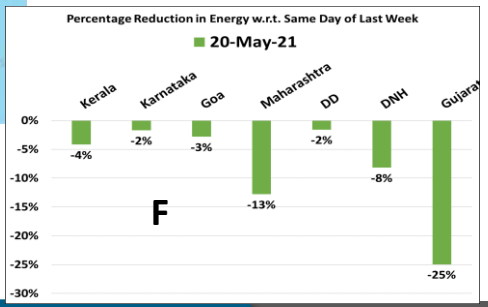








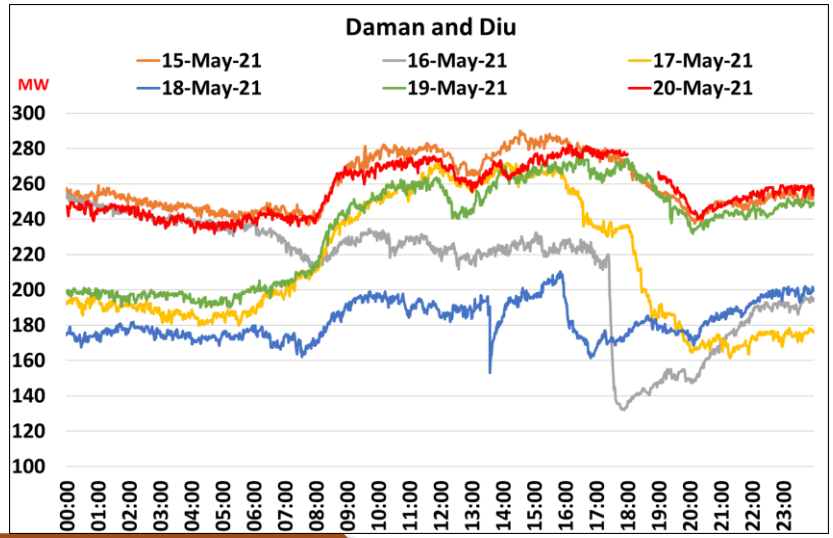




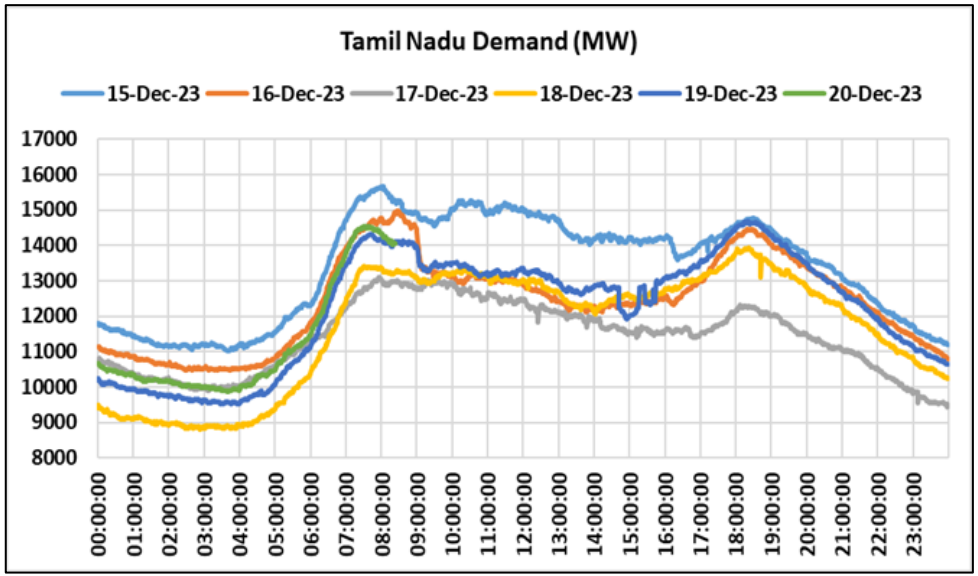
D: Depression
DD: Deep Depression
CS: Cyclonic Storm
SCS: Severe Cyclonic Storm
VSCS: Very Severe Cyclonic Storm
ESCS: Extremely Severe Cyclonic Storm

Impact of Cyclone On Diu Daman & Diu

- **Landfall : Between Diu and Una, ~ 21:00 hrs, 17th May 2021.**
- **Diu (17th May)**
  - Power supply to Diu interrupted due to loss of supply at 66 kV Una S/s and 220 kV Dhokadva s/s consequent to tower collapse at many locations.
  - Power supply was extended to Diu at 20:04 hrs of 22nd May from Gujarat system.



Impact of floods on Power System



Heavy Rainfall Activity Over Tamil Nadu & Kerala, 17th Dec'23

Demand Reduction:

- Tamil Nadu: ~1000 MW
- Kerala: ~400 MW

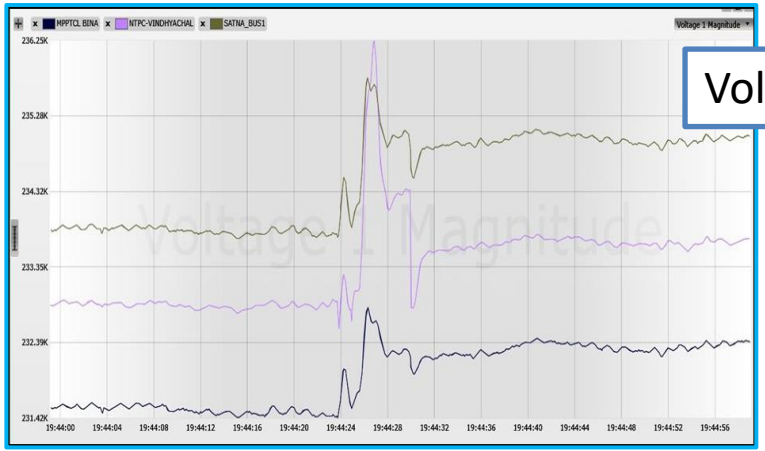
Water logging

- **Thermal Units hand tripped**
  - Coastal Energen unit-2: 600 MW
  - Tuticorin units 1 to 5 : 5x210 (1050 MW)
  - NTPL Unit-1 and Unit-2 : 2x500 (1000 MW)
  - Tuticorin_GRT Jewellers 150 MW solar plant.

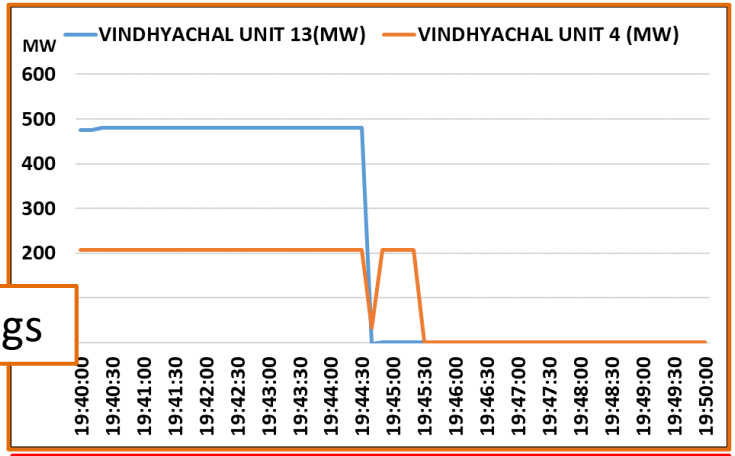
- **Transmission sub stations hand tripped**
  - 400kV Ottapidaram S/s
  - 230kV Tuticorin S/s

Impact due to Earthquake on 10th April, 2018
Richter scale: 4.6

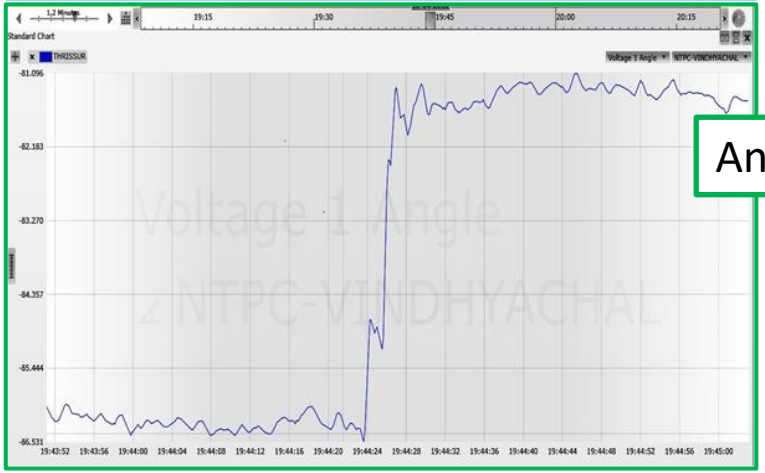
Voltage Transients



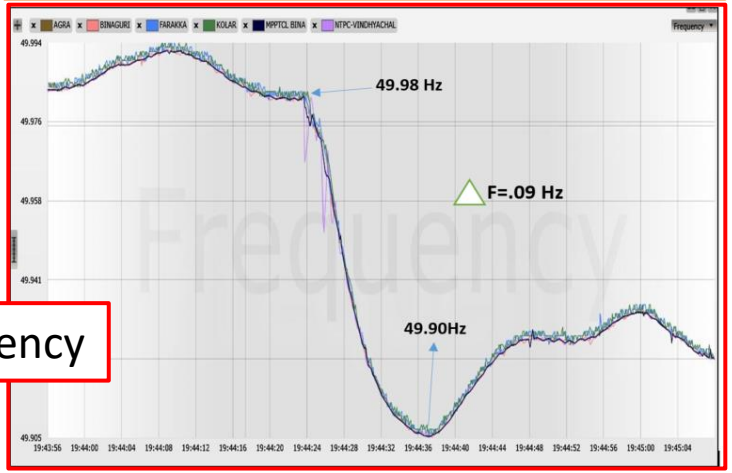
Unit Trippings



Angular Stress



Drop in Frequency



Lessons Learned

Key Success Factors

Early warning	• Early warning of cyclone/floods helped in operational planning and coordinating between multiple control centres and utilities.
Geo-Mapping of transmission assets	• Geo mapping of all available transmission, generation, distribution assets is required for impact assessment and restoration coordination.
System Visibility	• Availability of WAMS enabled facilitated quick response.
Seamless flow of information	• Platforms created for exchange of information between administration, nodal agency and utilities helped in effective crisis management.
Reinforcement of skilled personal on site & control centers	• Challenges in HR mobilisation on account of ongoing pandemic (another HILF) and lockdown affected restoration activities.
Adequacy of Pump for de-watering of substation	• Several substations required dewatering after cyclone induced rain.
Resilience through large synchronous interconnection	• Sequential and extended period of demand crash due to extreme weather events was successfully managed
Backup communication system	• Backup communication system availability and redundancy had helped a lot during the disruption of data in the Diu system while the cyclone impacted the system.

Crisis & Disaster Management Plan (C&DMP) For Power Sector

First formulated in 2004 and updated in 2023 by Central Electricity Authority (CEA)

To act as tool and provide guidelines for assistance to utilities

Inputs provided by experts and stakeholders

Broadly covered activities that enable various agencies to plan for, quick respond to and to recover from unexpected events and situations for ensuring safety of people, protection of environment, protection of installation and restoration of power supply by utilities

National Load Despatch Centre (NLDC) declared Nodal agency for coordination in natural and man made crisis situations in Power Sector

Standard Operating Procedure for Electricity Infrastructure

- Wide dissemination of forecast on cyclones indicating the trajectory and timing of the landfall by the IMD through website and electronic media
- Emergency Response Teams from utilities at all critical sub-stations
- Emergency Response Teams at NLDC / RLDC / SLDC (System Operator)
- Precautionary Interventions/Curtailment in Electricity Market
- Advance plans for restoration of the distribution network
- Planned Shutdown / Backing down of critical Generating Units
- Reduction of the power flow on the transmission lines
- Toggling of Inter-Regional HVDC Links
- Deployment of ERS Towers / additional equipment for quick restoration
- Visualization of faults through Phasor Measurement Units (PMUs)

प्रतिकूलतया: शक्ति:

Strength through adversity

Long Outage of Important Transmission elements due to Tower Collapses

Sl. No.	Line Name	Owner	Outage	Revival	Reason/ Remarks
			Date	Date	
1	220 kV Gazipur(DTL)-Shahibabad(UP) (UP) Ckt-1	NR	30-04-2022	Still out	Tower tilted on one side at tower no 10 from Gazipur (DTL) end.
2	220 kV Gazipur(DTL)-Noida Sec62(UP) (UP) Ckt-2	NR	30-04-2022	Still out	In OCC meeting, UPPTCL representative highlighted funding issues with MCD.
3	220 KV Chamera_3(NH)-Chamba(PG) (PG) Ckt-2	NR	09.07.23	Still out	Line tripped due to tower collapsed at Loc. no. 1 from Chamera-3 end
4	400KV-RANGPO-TEESTA-V-1	ER	04-10-2023	Still out	TEESTA-V is already under long outage
5	400KV-RANGPO-TEESTA-V-2	ER	04-10-2023	Still out	
6	220kV Manubolu-Sullurpet -2	SR	04-12-2023	21-12-2023	17
7	220kV Manubolu-Sullurpet -3	SR	04-12-2023	21-12-2023	17
8	220kV Tondiarpet-ETPS S/C	SR	04-12-2023	Still out	-
9	220kV Gummidipundi-Sullurpet S/C	SR	04-12-2023	02-01-2024	29
10	132 kV Panchgram-Srikona line	NER	14-01-2019	Still out	Reliability of the South Assam & Meghalaya power system has reduced.
11	132 kV Roing-Pasighat	NER	charged through ERS	Still out	Reliability of the Arunachal Pradesh power system has reduced.
12	132kV-Lekhi-Nirjuli-1	NER	28-06-2022	Still out	The line has been charged 132kV Pare-Lekhi-Nirjuli transmission line through the old 132kV LILO transmission line between NDTL and Lekhi substation on 11-07-2022. As per 203rd OCCM Tower locations in spate of floods. Works stalled. Expected completion by March 2024.
13	132kV-Pare-Lekhi-1	NER	28-06-2022	Still out	The line has been charged 132kV Pare-Lekhi-Nirjuli transmission line through the old 132kV LILO transmission line between NDTL and Lekhi substation on 11-07-2022. As per 203rd OCCM Tower locations in spate of floods. Works stalled. Expected completion by March 2024.
14	220 kV BTPS-Rangia	NER	21-06-2023	Still out	The 220 kV BTPS-Rangia line I and II has been charged through ERS tower on 29th June and 05th July 23 respectively.
15	132 kV Panyor HEP-PHEP & 132 kV Panyor-Chimpu line	NER	05-04-2023	Still out	Reliability of the Arunachal Pradesh and Assam power system has reduced

***Note: As per regulation 5b of CERC (Standards of Performance of inter-State transmission licensees) Regulations, 2012, any line going under outage due to tower collapse should be restored back on emergency restoration tower within 12 days and on normal tower within 50 days in case of river bed.**

Standard Operating Procedure for Electricity Infrastructure

- Wide dissemination of forecast on cyclones indicating the trajectory and timing of the landfall by the IMD through website and electronic media
- Planned Shutdown / Backing down of critical Generating Units
- Reduction of the power flow on the transmission lines
- Toggling of Inter-Regional HVDC Links
- Deployment of ERS Towers / additional equipment for quick restoration
- Emergency Response Teams from utilities at all critical sub-stations
- Emergency Response Teams at NLDC / RLDC / SLDC (System Operator)
- Precautionary Interventions/Curtailment in Electricity Market
- Advance plans for restoration of the distribution network
- Visualization of faults through Phasor Measurement Units (PMUs)

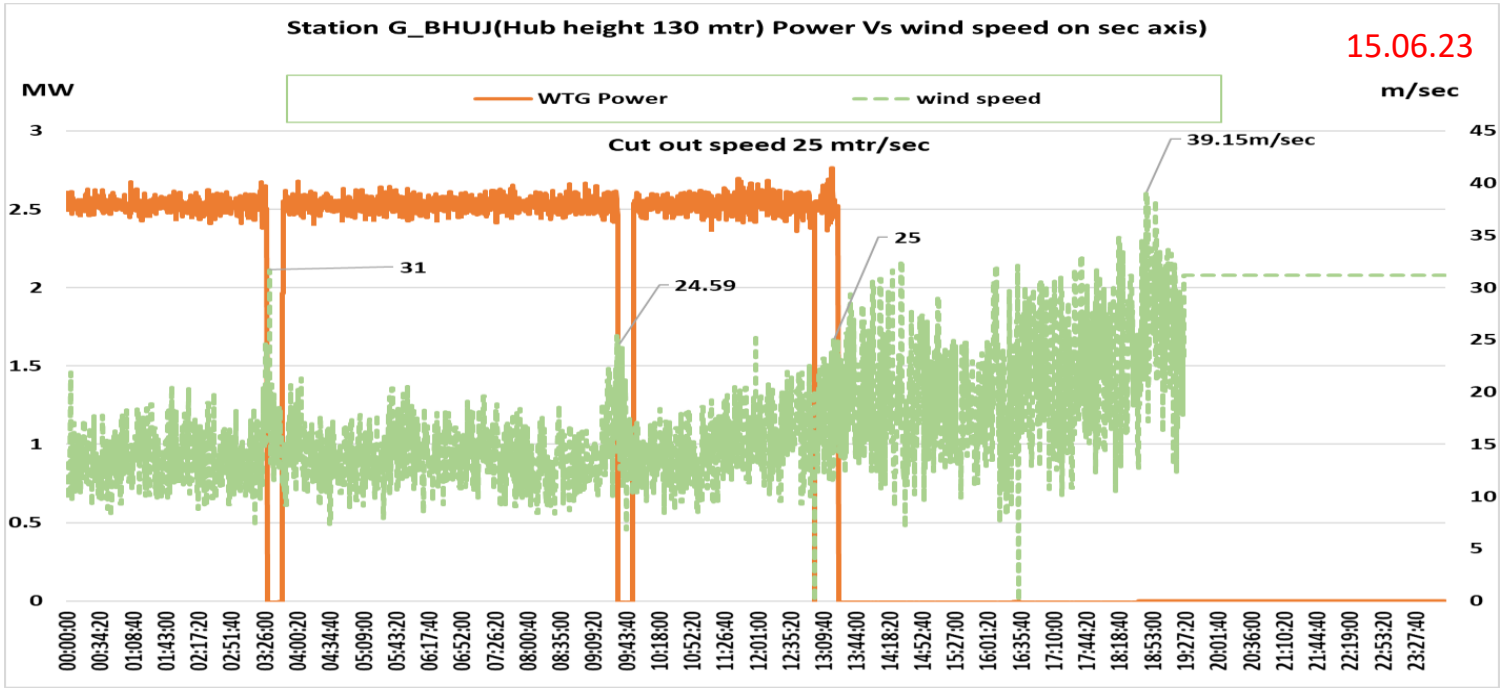
Logistics and Coordination

- Recovery equipment and spares inventory
- Communication facilities
- Transport and Mobility arrangements
- Financial resources
- Black start facilities
- Dewatering pumps
- Mobile Diesel Generator (DG) sets
- Emergency Restoration System (ERS) for transmission
- Regular check up for healthiness and regular drills
- Annual safety audit
- Regular interaction with disaster management groups

Future Initiatives for Grid Resilience

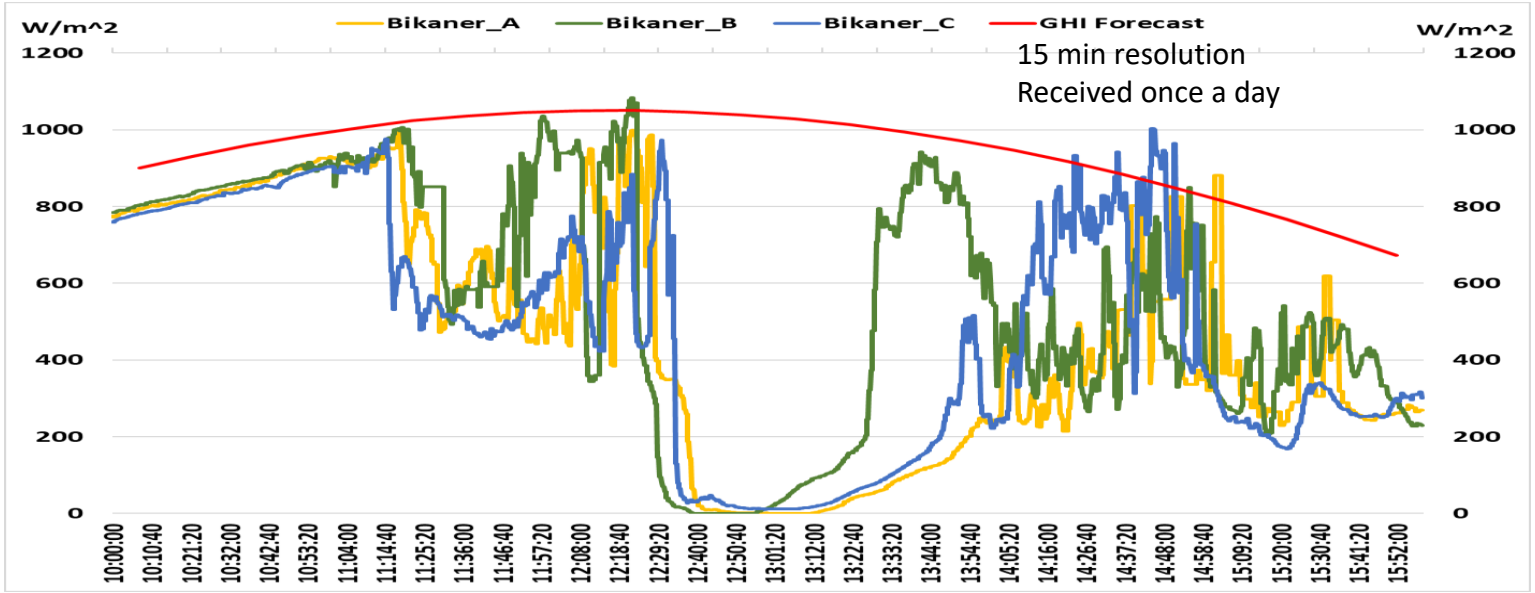
- Regulatory Framework for Reliability and Handling Low Probability High Impact events
- Weather Proofing - Analytics for Climate Information and Forecasting
- Storm Hardy Grid - Risk Assessment and Management for Adaptation Strategy
- Investment in Research and Deployment in upgrades to infrastructure
- Cross-sector collaboration for long-term infrastructure planning and cooperation for crisis response

Measured wind speed and power output from an individual Wind Turbine Generator in Bhuj on 15.06.2023



- Wind speed breached cut out speed around 3:26 hrs and power drop down to zero and cut off speed again observed at around 9:43hrs and 13:30hrs.
- After 13:30 hrs wind speed was continuously above the cut out speed.

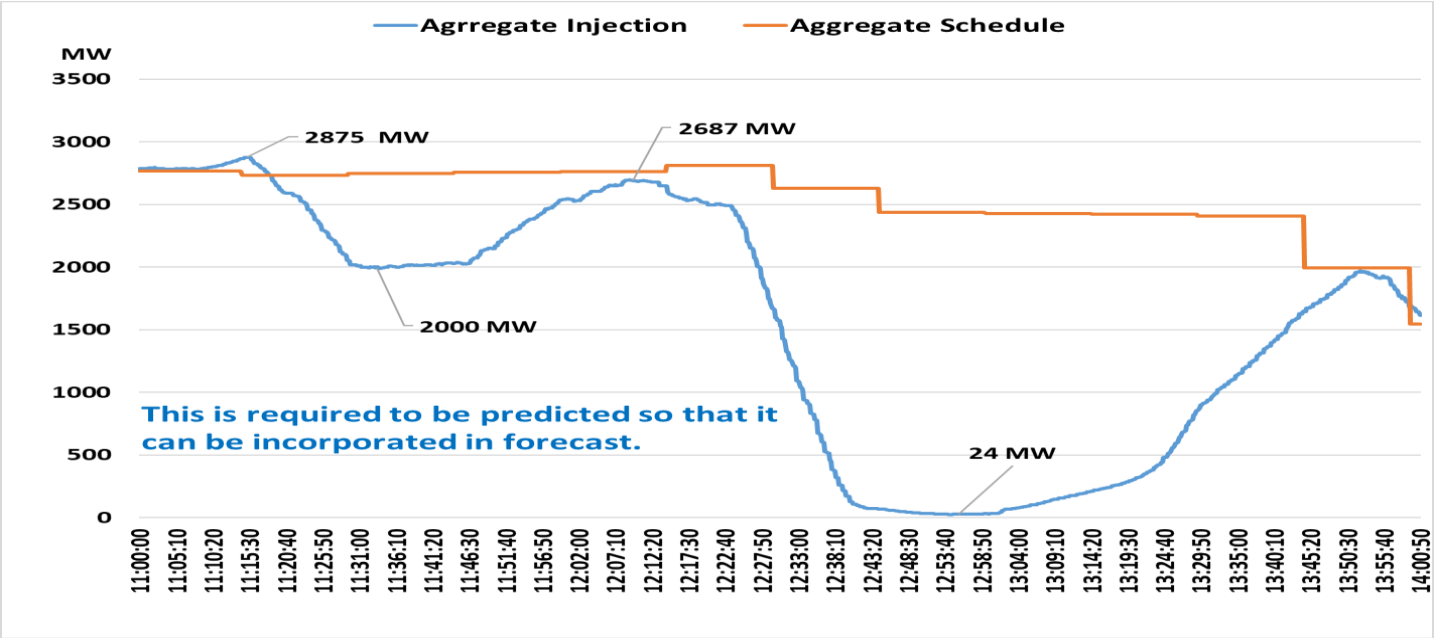
Global Horizontal Irradiance at three locations in Bikaner on 06th June 2023



- Sharp reduction in GHI observed:
  - 1000 W/m^2 at 1115 hrs to almost 500 W/m^2 by 11:30 hrs.

- GHI recovered by 12:00 hrs and then reduced almost to zero by 12:50 hrs.

Bikaner aggregate Solar generation: Actual vs Developer forecast



06.06.23

- Dust storm and cloud cover over Bikaner area during 1115 to 1400 hrs on 06th June 2023
- Before 1115 hrs: Forecast error = Negligible
- 11:15 to 11:30 hrs : Maximum forecast error = - 875 MW
- 12:10 to 12:54 hrs : Maximum forecast error = - 2650 MW

System Resilience

System resilience Vs Reliability:

- The IEEE Technical Report PES-TR65 defines resilience as “The ability to withstand and reduce the magnitude and/or duration of disruptive events, which includes the capability to anticipate, absorb, adapt to, and/or rapidly recover from such an event”. This may also be simply defined as “The ability to protect against and recover from any event that would significantly impact the grid”.

- Similar definition has been adopted in IEGC 2023.

- The IEEE defines Reliability as “The probability that a system will perform its intended functions without failure, within design parameters, under specific operating conditions, and for a specific period of time.”

- Central Electricity Authority has recommended several measures in its “Report of Task Force on Cyclone Resilient Robust Electricity Transmission and Distribution Infrastructure in the Coastal Areas” that accepted by Ministry of Power vide letter dated 10th June, 2021for Creating Resilient Transmission Infrastructure.

https://cea.nic.in/wp-content/uploads/pse___td/2021/11/Task_force.pdf

Electricity Infrastructure Resilience

- Large Grids and Interconnected Control areas introduce a new risk of cascading failures, due to High Impact Low Probability events
- Can lead to breakdown that spread between multiple control areas
- Need for Resilience assessment on a probabilistic risk assessment methodology

  that consider the relations between causes and consequences of destructive events

  - Evaluate the vulnerability of the individual components and their behaviour during stresses

    - Threat modelling with probabilistic models
    - Modelling of vulnerabilities and probability of component failure
    - Definition of a set of single and multiple contingencies
    - Evaluation of the impact on the network and probabilistic power loss calculation

Future Initiatives for Grid Resilience

- Regulatory Framework for Reliability and Handling Low Probability High Impact events
- Weather Proofing - Analytics for Climate Information and Forecasting
- Storm Hardy Grid - Risk Assessment and Management for Adaptation Strategy
- Investment in Research and Deployment in upgrades to infrastructure
- Cross-sector collaboration for long-term infrastructure planning and cooperation for crisis response

System Restoration

- **Immediate system restoration:**

"The isolated, taken out or switched off elements shall be restored as soon as the system conditions permit. The restoration process shall be supervised by the concerned Load Despatch Centre, in coordination with NLDC, concerned RLDC(s) and SLDC(s) in accordance with the system restoration procedures of NLDC and RLDC(s)."

Regulation 29(e) of IEGC

- **System restoration procedure:**

I. System restoration procedure has to prepared by RLDC/SLDC/NLDC that is to be reviewed and updated every year.

"Detailed procedures for restoration post partial and total blackout of each user system within a region shall be prepared by the concerned user in coordination with the concerned SLDC, RLDC or NLDC, as the case may be. The concerned user shall review the procedure every year and update the same".

Regulation 34(3) of IEGC

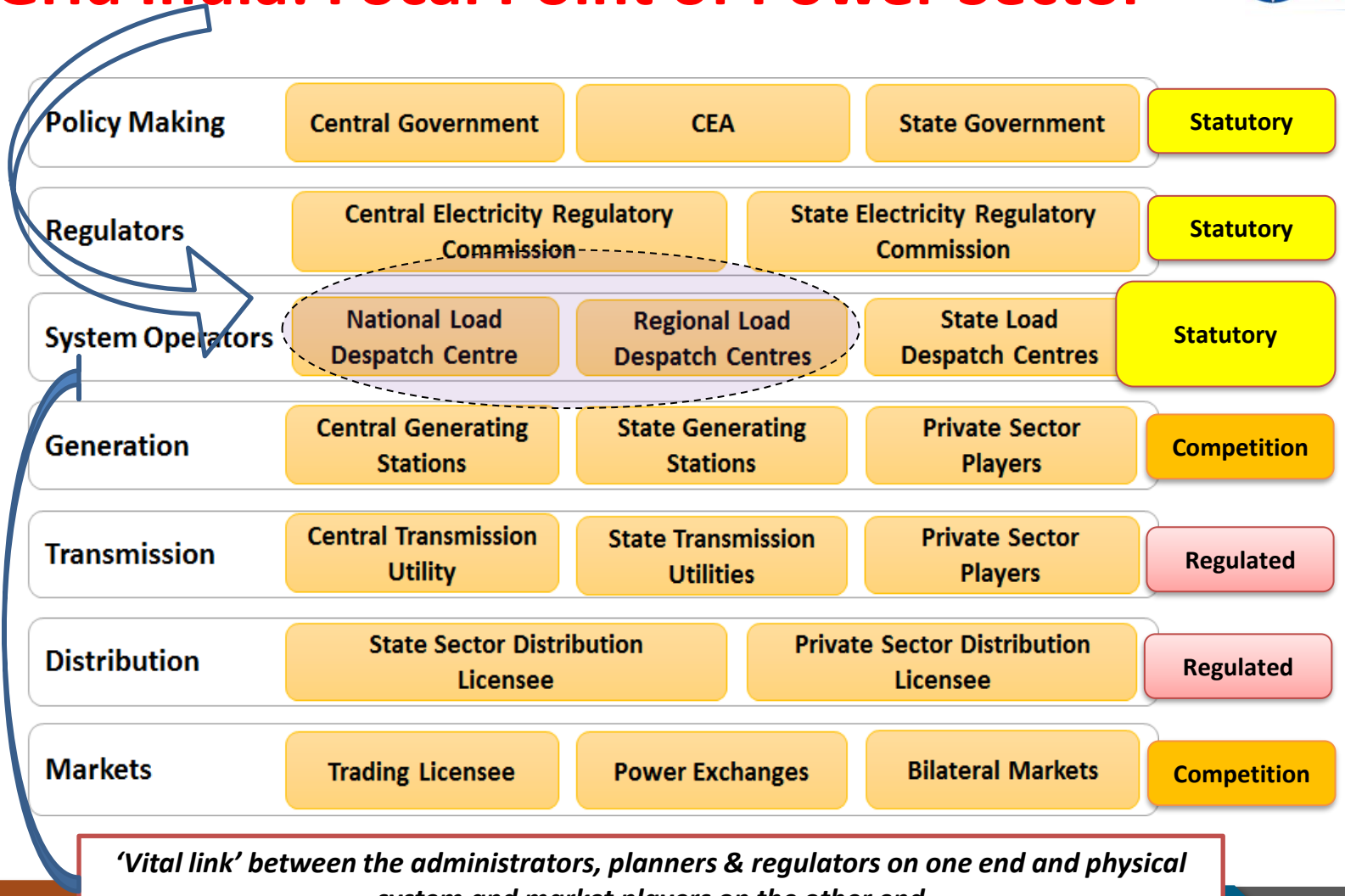
- **Identification of Black start resources:**

"NLDC, RLDC and SLDC shall identify the generating stations with black start facility, grid forming capability of inverter based generating stations, house load operation facility, inter-State or inter-regional ties, synchronizing points and essential loads to be restored on priority."

- During the restoration process following a blackout, SLDC, RLDC and NLDC are authorized to operate with reduced security standards for voltage and frequency.

Regulation 34(6) of IEGC

Grid India: Focal Point of Power Sector



'Vital link' between the administrators, planners & regulators on one end and physical system and market players on the other end

Severe Cyclonic Storm “MICHAUNG” December’23

- Severe Cyclonic Storm “MICHAUNG” made its landfall near
- Transmission Line affected: 94 nos. at 110 kV level & above
- Loss of power supply to Substation: 5 nos. at 132 kV and above
- Bapatla in Andhra Pradesh on 05th Dec 2023.
- Impact on System:
  - **Tamil Nadu**
    - ~4000 MW Demand Reduction
    - 60 :- 110 kV & above lines tripped
    - 840 MW: Capacity taken under RSD
  - **Andhra Pradesh**
    - ~3000 MW Demand Reduction
    - 32 :- 132 kV & above lines tripped
  - **Chennai**
    - Demand reduction from almost 2500 MW to 300 MW
  - Tower Collapse in four lines
- Demand Restored by 07th Dec 23.