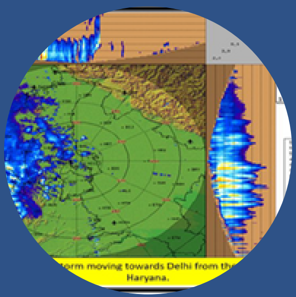
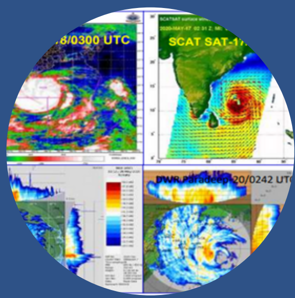
Use of weather information for secure, reliable and economic operation of Indian grid






Prepared by

India Meteorological Department

&

Power System Operation Corporation Ltd.

January 2022

Use of weather information for secure, reliable and economic operation of Indian grid

Contents

List of Figures

Message from Chairman and Managing Director

The partnership forged between India Meteorological Department (IMD) and Power System Operation Corporation Limited (POSOCO) by signing an MOU on 18th May 2015 has come a long way and cemented through various initiatives under the aegis of this partnership like workshops at national and regional level, development of weather portal providing variety of information on weather and publication of Reference document. All these initiatives have proved useful for system operators and has enabled smoother power system operation.

Satellite-based weather warning, live radar imagery helped the states in sending timely requests to RLDCs/ SLDCs for revision of schedule for backing down of generating stations in anticipation of thunderstorms/ rain, which greatly helped in avoiding huge under drawl of power thereby ensuring secure, reliable and economic operation of the Indian grid.

As we are aware, Government of India has set a target of 500 GW of Non-fossil generation by 2030, as part of India's contribution to clean climate. With high penetration of renewable energy resources, which are also highly dependent on weather, the challenges for system operators would further increase. Therefore, it is pertinent to mention that the availability of Weather information and development of new tools would be required to meet the challenges posed by the intermittent & variable generation.

The experience gained over the years has been compiled in the present document. However, with the challenge of integrating large renewable generation in the next several years, more collaborative works with IMD are required. I am sure that the partnership with India Meteorological department would further pave way of excellent developments, which would help in reliable secure and economic operation of the Indian grid.

बाबा

KVS Baba

Chairman & Managing Director, POSOCO

डॉ. मृत्युंजय महापात्र
मौसम विज्ञान विभाग के महानिदेशक,
विश्व मौसम विज्ञान संगठन में भारत के स्थाई प्रतिनिधि
एवं कार्यकारी परिषद के सदस्य

Dr. Mrutyunjay Mohapatra
Director General of Meteorology,
Permanent Representative of India with WMO,
Member of Executive Council, WMO

भारत सरकार
पृथ्वी विज्ञान मंत्रालय
भारत मौसम विज्ञान विभाग
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Message from DG IMD

IMD provides weather information and forecast required for power sector, which is one of the largest users of weather information. The Power system elements are always exposed to changing weather conditions and may experience faults as a result of different meteorological events. Moreover, new Generation technologies such as solar and wind generation are highly influenced by the Weather and thus poses lots of challenges to the power system professionals. In an initiative to support the power sector, IMD has collaborated with Power System Operation Corporation (POSOCO) and equipped the System Operators across the country with real time weather information, adequate weather forecasts and has thus enabled better power system operation. I am very happy to note that a report on the utilisation of weather information in Indian grid has been prepared based on the experiences till date. I am sure that with continuing integration of renewable energy (RE) generators, this partnership would further help the power sector in delivering reliable and cost-effective power to end consumers. I would like to appreciate the commendable efforts by the IMD team including Shri Subash Chander Bhan, Scientist F and Dr Ananda Kumar Das, Scientist E and POSOCO team including Shri Alok Kumar, General Manager, Shri Paresh Khandelwal, Chief Manager and Shri Sunil Kumar Kanaujiya, Manager who have helped in implementation of this joint collaboration through organisations of workshops, development of dedicated weather portal, preparation of Reference document etc. according to the need of power sector.

(Mrutyunjay Mohapatra)

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Message from Director System Operation

I am happy to note that Indian Meteorological Department (IMD) and Power System Operation Corporation Limited (POSOCO) are bringing out a report on the impact of weather on operation of electricity grids. Changes in weather conditions such as heatwave, thunderstorms, snowfall, high humidity etc. are one of the biggest reasons for variations in intraday as well as day to day demand patterns. Meeting this change in demand by utilising the available resources poses challenge to system operators. Over the last few years, IMD and POSOCO have collaborated on number of fronts which have been of great advantage to the system operators of the country.

Over the last several years, the support provided by IMD has helped in handling several cyclones such as Nisarga, Amphan, Yaas, Tauktae etc. as well as annular solar eclipse events. Accurate anticipation of extreme weather conditions such as snowstorms, duststorms, high winds, thunderstorms and cyclones helps in advance operational planning, secure system operation and early restoration.

Accurate weather forecast would help in minimising the renewable generation forecast error as well as demand forecast error. This would help to ensure better load generation balancing and also optimally keep reserves in the system. With the target of 500 GW non-fossil fuel generation integration by 2030, the role of IMD becomes all the more important. Timely and effective forecasting of weather is one of the key issues in enabling renewable generation integration in the Indian grid. More granular information as well as multiple updates in a day would be the key.

I am sure that IMD and POSOCO would continue to collaborate in this area for the benefit of reliable operation of the country's electricity grids even as we navigate the energy transition path.

S R Narasimhan

Director (System Operation)

POSOCO

Core Team

Overall guidance and supervision:

POSOCO:

- Shri KVS Baba, Chairman and Managing Director, POSOCO
- Shri S R Narasimhan, Director (System Operation), POSOCO
- Shri S.S. Barpanda, Director (Market Operation), POSOCO
- Shri N. Nallarasan, Executive Director, NRLDC, POSOCO

IMD:

- Dr. Mrutyunjay Mohapatra, Director General of Meteorology,IMD
- Shri Subhash Chander Bhan, Scientist F, IMD

Report prepared by:

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IMD:

- Dr. Anand Kumar Das, Scientist E, IMD

Other Contributors:

- SLDC's and few Discoms

Reviewed by:

- Shri Surajit Banerjee, Chief General Manager, NRLDC

List of Acronyms

AI: Artificial intelligence

ASCAT: Advanced Scatterometer

BRPL: BSES Rajdhani Power Limited

COP26: Glasgow Climate Change Conference

DAM: Day Ahead Market

DWR: Doppler Weather Radar

DRDO: Defence Research and Development Organisation

DISCOM: Distribution Company

ESSO: Earth System Science Organization

EHV: Extra High Voltage

GDP: Gross domestic product

HVDC: High Voltage Direct Current

ISGS: Inter-State Generating Stations

IMD: India Meteorological Department

IITM: Indian Institute of Tropical Meteorology

INCOIS: Indian National Centre for Ocean Information Services

INSAT: Indian National Satellite

IST: Indian Standard Time (UTC+05:30Hrs)

MOES: Ministry of Earth Sciences

MoU: Memorandum of understanding

NLDC: National Load Dispatch Centre

NRLDC: Northern Regional Load Dispatch Centre

NR: Northern Region

NER: North Eastern Region

NERLDC: North Eastern Regional Load Dispatch Centre

NCMRWF: National Centre for Medium Range Weather Forecasting

POSOCO: Power System Operation Corporation Ltd.

RE: Renewable Energy

RSD: Reserve Shutdown

RLDC: Regional Load Dispatch Centre

RVMO: Reduced Voltage Mode Operation

RRAS: Reserves Regulation Ancillary Services

RTM: Real Time Market

SLDC: State Load Dispatch Centre

STOA: Short Term Open Access

SCADA: Supervisory Control and Data Acquisition

SCATSAT: Scatterometer Satellite

Executive Summary

Global average temperature has risen by around 1°C since pre-industrial times[1] (1880–1900). One of the most visible consequences of a warming world is an increase in the intensity and frequency of extreme weather events. A report published by Ministry of Earth Sciences (MoES), Government of India on Assessment of Climate Change over the Indian Region[2] finds that India has witnessed a rise in average temperature by 0.7°C during 1901-2018; a decrease in monsoon precipitation by 6%; a rise in extreme temperature and rainfall events, droughts, and sea levels during 1951-2015 and an increase in the intensity of severe cyclones during 2000-2018, alongside other changes in the monsoon system.

Temperature and humidity are essential meteorological variables which directly affect the electricity demand. In general, electricity demand in summer/monsoon season is very high compared to winter season. Electricity is one of the key drivers for the economic growth of any country and India is no exception to it.

India has voluntarily committed to reducing greenhouse gas emission intensity of its GDP by 33-35 per cent below 2005 levels by 2030[3].As part of its climate mitigation efforts, the Indian government set a target of 500 GW[4] of renewable energy capacity by 2030 as mentioned by Hon'ble Prime Minister of India in COP-26 Summit held in Glasgow. As renewable energy resources are highly influenced by weather conditions its large integration into grid further poses challenge to power system operators to operate the grid in secure and reliable manner. Extreme Weather conditions can affect both power system elements and operation of the system as a whole to a large extent. Several states of Northern and Eastern India experience a spate of severe thunderstorms and dust storms with strong winds and lightning. The inclement weather conditions coupled with frequent thunderstorms lead to sudden load crash in pockets due to sudden drop in temperatures and tripping/opening of distribution

[1] https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature

[2] https://cerca.iitd.ac.in/uploads/Reports/15941862512020_Book_AssessmentOfClimateChangeOverT.pdf

[3] https://pib.gov.in/newsite/printrelease.aspx?relid=128403

[4] As part of its climate mitigation efforts, the Indian government set a target of 500 GW of renewable energy capacity by 2030 as mentioned by Hon'ble Prime Minister of India in COP-26 Summit held in Glasgow

feeders leading to high voltages in the Northern Grid. However, the load again returns to its normal level within a few hours after short and temporary effects of thunderstorm.

In winter season the cold weather conditions bring down the ambient temperature to low value. Western disturbances in winter season bring moderate to heavy rain in the plains and snow fall in mountainous areas of the Northern Region.

Cyclones affect thousands of Indians living in coastal regions. This is particularly common in the northern reaches of the Indian Ocean along the Bay of Bengal and Arabian Sea coasts. Cyclones cause heavy rains, large storm surges, and strong winds that often damage power elements in the distribution and transmission systems causing wide spread interruption of power supply to the affected areas.

As increase in the intensity and frequency of extreme weather events poses challenge to secure and reliable power system operations, prior information of weather conditions facilitates power system utilities to advance operation planning, secure system operation and early restoration of the affected area which in turn reduce expenditures also. Accurate Weather forecast information further improves the accuracy of forecast for electricity demand and Renewable generation thus enabling power system utilities to make appropriate operational decisions in power system.

Weather forecast issued by IMD has helped RLDCs, SLDCs and DISCOMs in improving their demand forecast which has aided in planning and ensuring load generation balance in advance including demand ramp requirements. By observing movement of thunderstorm/dust storm through RADAR system, RLDCs and SLDCs are able to reduce their control area generation as per the predicted demand variations. Along with satellite-based weather warning, live radar imagery helped the states in sending timely requests to SLDC / RLDC for revision of schedule for backing down of generating stations in anticipation of thunderstorms/ rain, which greatly helped in avoiding huge under drawl of power thereby ensuring grid economic and secure operation of the grid.

Warnings and forecast issued by IMD for major cyclonic events such as Amphaan, Nisarga, Tauktae, Yaas etc. helped in identifying the transmission and distribution elements at risk. Advance actions such as deploying additional manpower at critical substations, mobilising ERS in case of requirement, outage/revival of generating units have helped to ensure smooth grid operation during such events. Awareness of Cyclone path and assessment of its intensity in advance from weather power portal, enable system operators to take corrective actions for maintaining the system reliability and security of the Indian grid.

1. Introduction

Indian electricity grid is one of the largest synchronously operating grids in the world. As on 30-11-21, the Indian electricity grid has total installed generating capacity of around 392.01 GW[5] comprising of 23.46GW of Thermal, 46.51 GW of Hydro, 104.03 GW of Renewable and 6.7GW of Nuclear Generation. India has the fourth[6] -largest installed wind power generation capacity in the world and ranks 5th [7] globally in terms of solar and hydro electricity generation. The details of all India fuel wise installed capacity are given below:

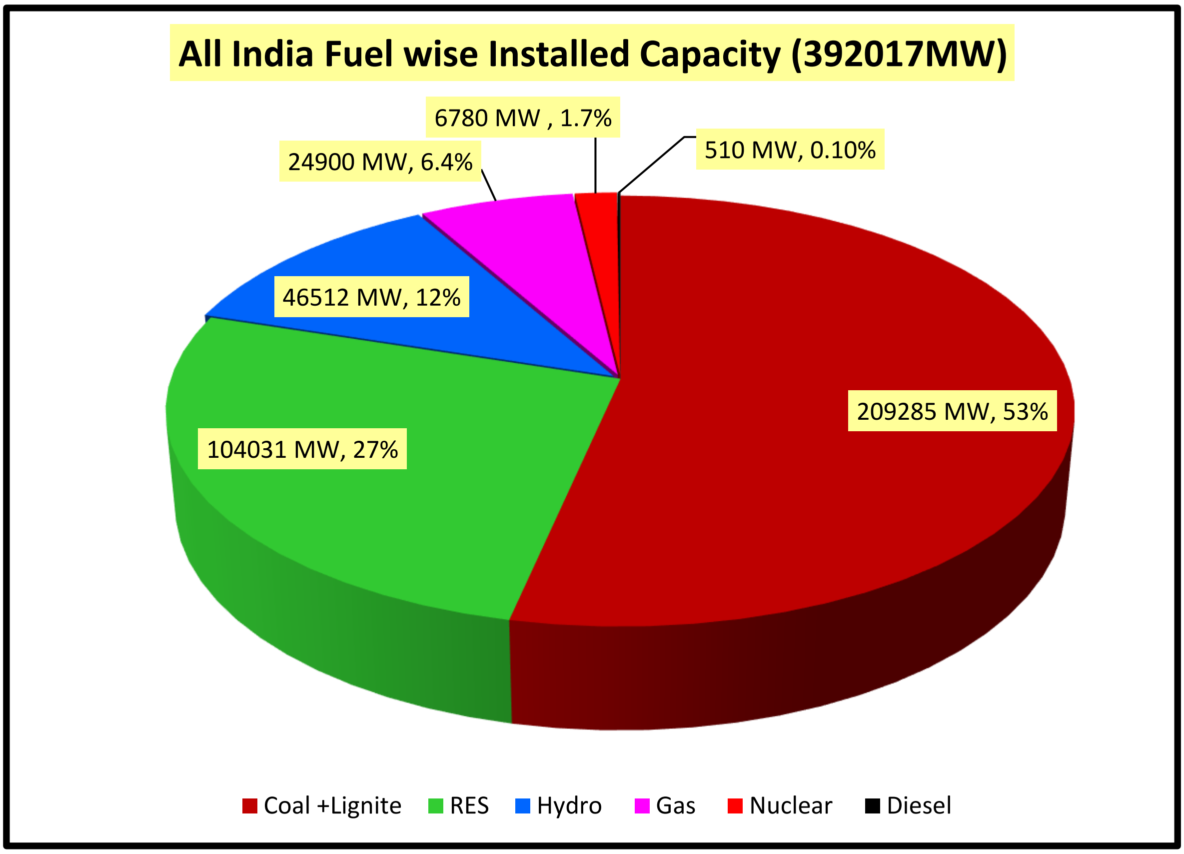


Figure 1:All India fuel wise installed capacity

2. Objective of the Study

The climate of India comprises a wide range of weather conditions across a vast geographic scale and varied topography, making it difficult to generalize. Climate in North India is generally hotter than that in South India whereas the South India gets more rainfall. Most

[5] https://cea.nic.in/installed-capacity-report/?lang=en
[6] https://mnre.gov.in/wind/current-status/
[7] https://mnre.gov.in/solar/current-status/

parts of the country, outside the hills and adjoining plains in northern parts of the country, don't experience temperatures below 10 °C in winter; and the temperature usually tends to exceed 40 °C during summer. Many regions have starkly different microclimates, making it one of the most climatically diverse countries in the world. The India meteorological department (IMD) has categorized meteorological seasons over India in four parts[8]: winter (January and February), summer (March, April and May), monsoon/rainy season (June to September), and post-monsoon season (October to December). Weather plays a very crucial role for electrical power system. As already stated, the changes in weather condition lead to changes in electricity supply and demand. Prior information of weather conditions to the Grid Operators enables them to effectively manage grid security and economy. The objective of this report is to find out the advantages of prior weather information for reliable, secure and economic operation of Indian Power System.

3. Impact of Weather on Indian power system:

Following weather variable and extreme weather events pose challenge to the power system.

1. Temperatures& Humidity
2. Solar Radiation& Wind Speed
3. Thunder storm
4. Fog
5. Snowfall
6. Rainfall
7. Cyclone

3.1. Impact of Temperature and Humidity on Power demand

Summer in Northwestern India starts from April and ends in July, and in rest of the country from March to June[9]. The temperatures in the north rise as the vertical rays of the Sun reach the Tropic of Cancer. The hottest month for the western and southern regions of the country is April; for most of North India, it is May. Temperatures of 50 °C and higher have been recorded in many parts of India during this season. Another striking feature of summer is the Loo (hot wind). These are strong, gusty, hot, dry winds that blow during the day in India. In cooler regions of North India, immense pre-monsoon squall-line thunderstorms,

[8] https://www.imdpune.gov.in/Weather/Reports/glossary.pdf
[9] https://mausam.imd.gov.in/imd_latest/contents/seasonal_forecast.php

known locally as "Nor'westers", commonly result in strong winds and large hailstones. In hilly states of Northern India, summer lasts from mid-April till the end of June and most parts become very hot with the average temperature ranging from 28 °C to 32 °C. Winter lasts from late November till mid-March. Snowfall is generally common in hilly tracts that are above 2,200 metres (7,218 ft), especially those in the higher- and trans-Himalayan regions. Near the coast, the temperature hovers around 36 °C, and the proximity of the sea increases the level of humidity. In southern India, the temperatures are higher on the east coast by a few degrees compared to the west coast.

By May, most of the Indian interior experiences mean temperatures over 32 °C, while maximum temperatures often exceed 40 °C. In the hot months of April and May, western disturbances, with their cooling influence, still arrive, but rapidly diminish in frequency as summer progresses.

Temperature and humidity are the principal meteorological variables which directly affects the electricity demand. Electricity demand in summer season is very high compared to winter season. The Typical load curve of summer and winters in Northern Region is given in Figure2, Load curve provides an insight into the consumption pattern. It can be observed that the demand in winter nights is 30-40 % lower compared to summer nights. Further, sharp rise in demand is observed due to heating load during morning hours in winter.

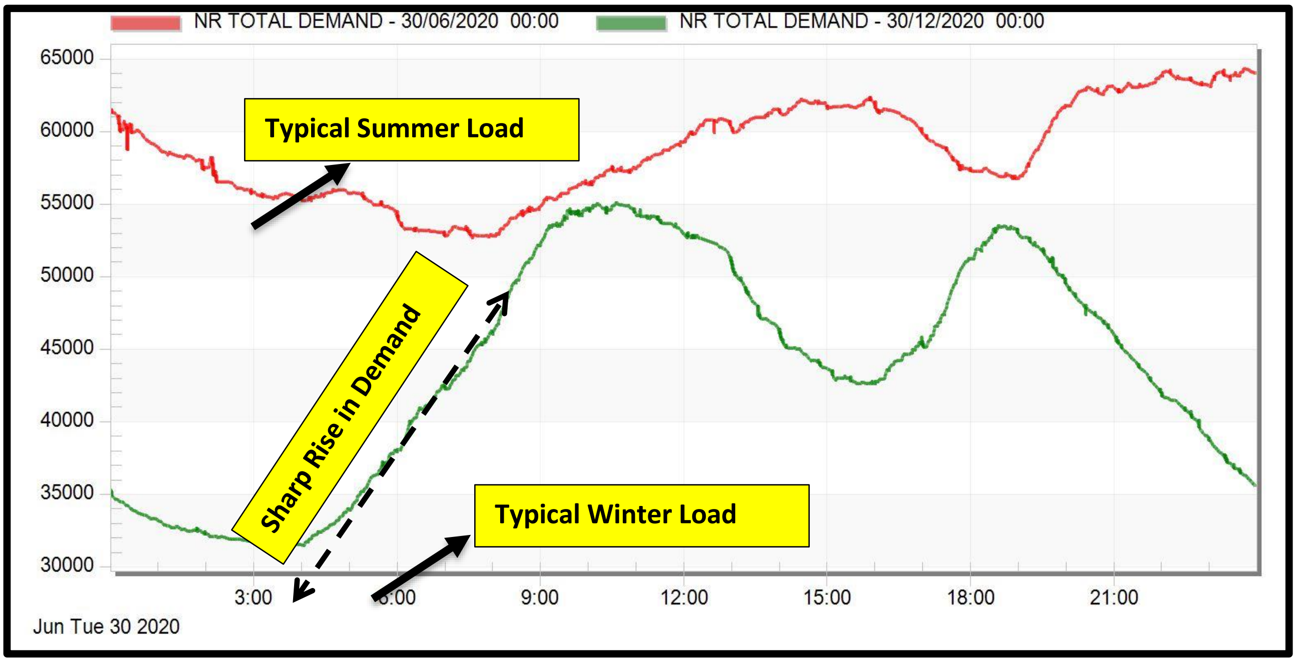


Figure 2:Typical load curve of summer and winters in Northern Region

3.2. Impact of Weather on Solar power generation and Wind power generation

Renewable energy sources are highly dependent on weather parameters such as wind speed and solar irradiance for their output. The installed capacity of RE generation in India has reached more than 104.03 GW (Solar 48.55GW, Wind 40.03 GW, small Hydro 4.80 GW and Bio Power 10.61 GW as on 30-11-21). Cloudy weather condition and variation in wind speed has the potential to cause a large variation in solar and wind generation. Sudden variation in wind speed can increase or decrease the output power of wind turbine in very short span of time, thus, posing a major challenge for system operators to operate the grid in secure and reliable manner (Figure 3). Similarly, sudden cloud cover over the solar plants can cause solar power to decrease with a very high ramp rate and later increase quickly as the cloud drifts away. (Figure 4).

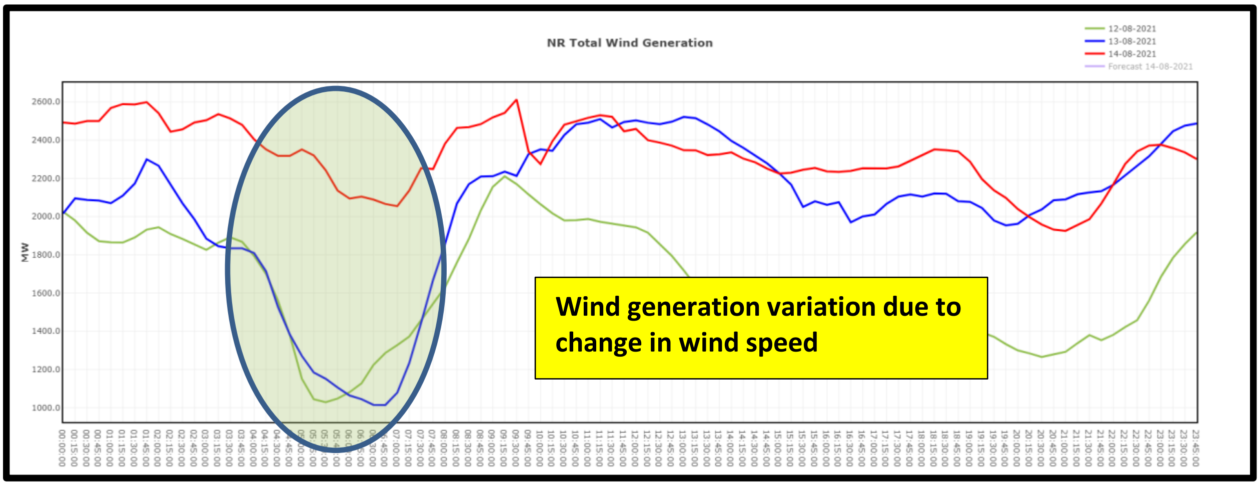


Figure 3: Northern Region Wind Generation Profile

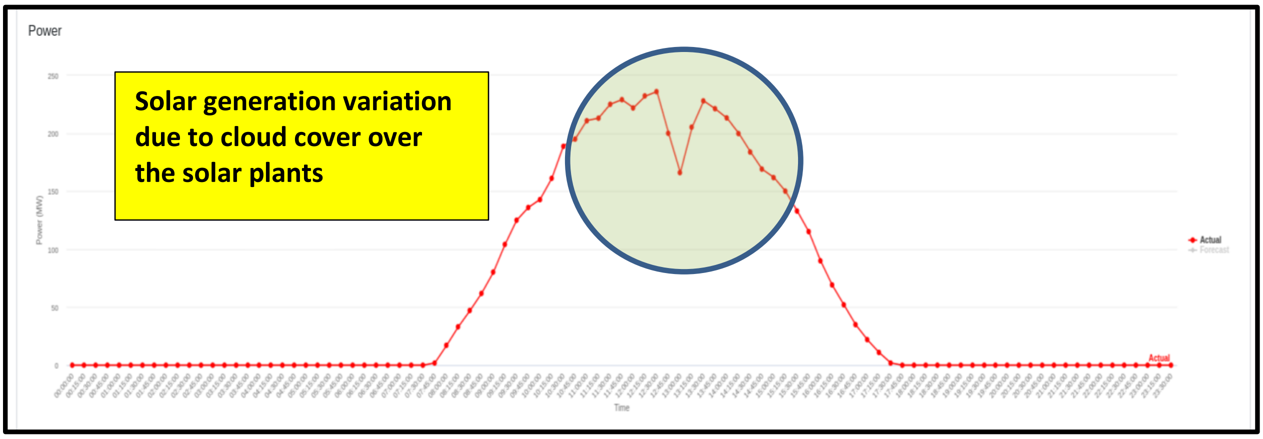


Figure 4: Solar generation variation due to cloud cover

3.3. Impact of Thunderstorm on the Indian grid

Extreme Weather conditions can affect both power system elements and operation of the system itself to a large extent. During summer period, massive convective thunderstorms dominate Northern India's weather. The rise in temperatures in the North India is accompanied with strong, gusty, hot and dry winds. In summer months, with increase in temperature, power demand increases sharply. These weather conditions coupled with frequent thunderstorms lead to sudden load crash in pockets due to sudden drop in temperatures and tripping/opening of distribution feeders leading to high voltages in the Northern Grid. The load returns within few hours after short and temporary effects of thunderstorm (Figure 5).

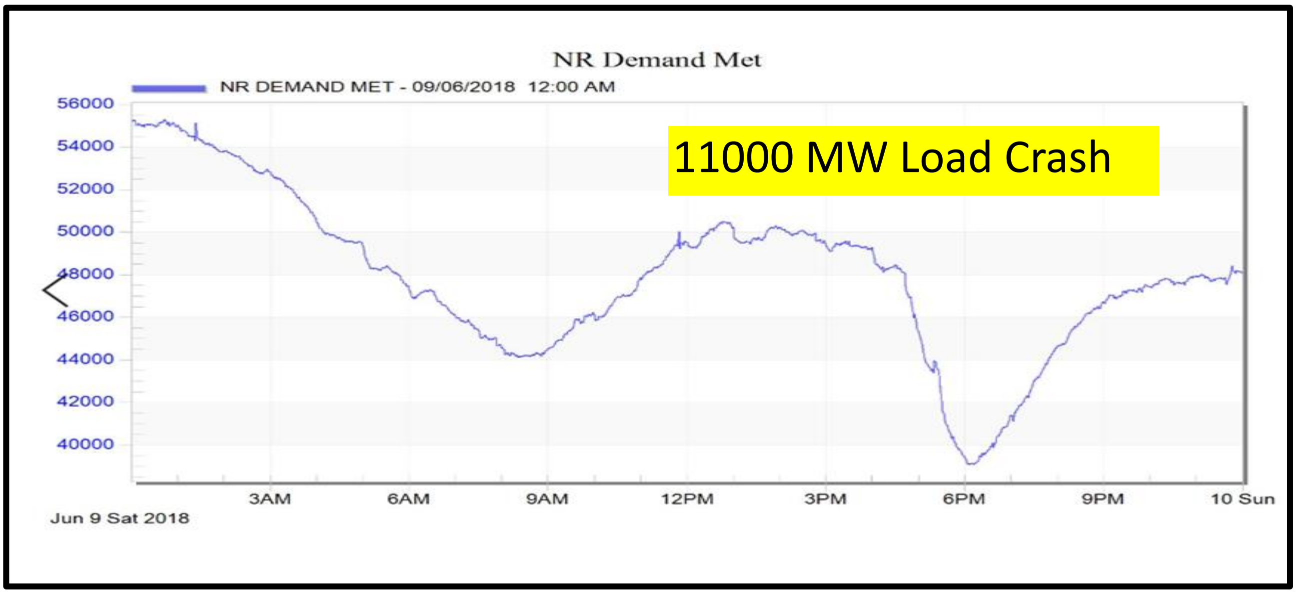


Figure 5:Northern Region Load Crash during Thunderstorm

3.4. Impact of Fog on Power System Elements

Northern and Eastern Regions of the power system in India face foggy conditions during night and early morning hours of winter months. Fog coupled with pollution leads to tripping of EHV lines and frequently tripping of these EHV lines (which is falling in fog zone) poses challenge to grid operators to operate the grid in secure and reliable manner.

3.5. Impact of Snowfall on Power System Elements

Himalayan Region of Northern India comprising of Jammu & Kashmir (UT), Ladakh (UT), Himachal Pradesh and Uttarakhand experience heavy snowfall during winter season. During heavy snowfall, many EHV transmission as well as distribution lines trip resulting in massive power outages in the region. J&K (UT) and Ladakh (UT) load crash due to heavy snowfall from 1st November 2018 to 5th November 2018 is shown in Figure 6 below: The figure 7 below show serious damage to EHV power transmission lines due to heavy snowfall in Jammu and Kashmir, which threw normal life out of gear in the state and people suffered due to long power outage.

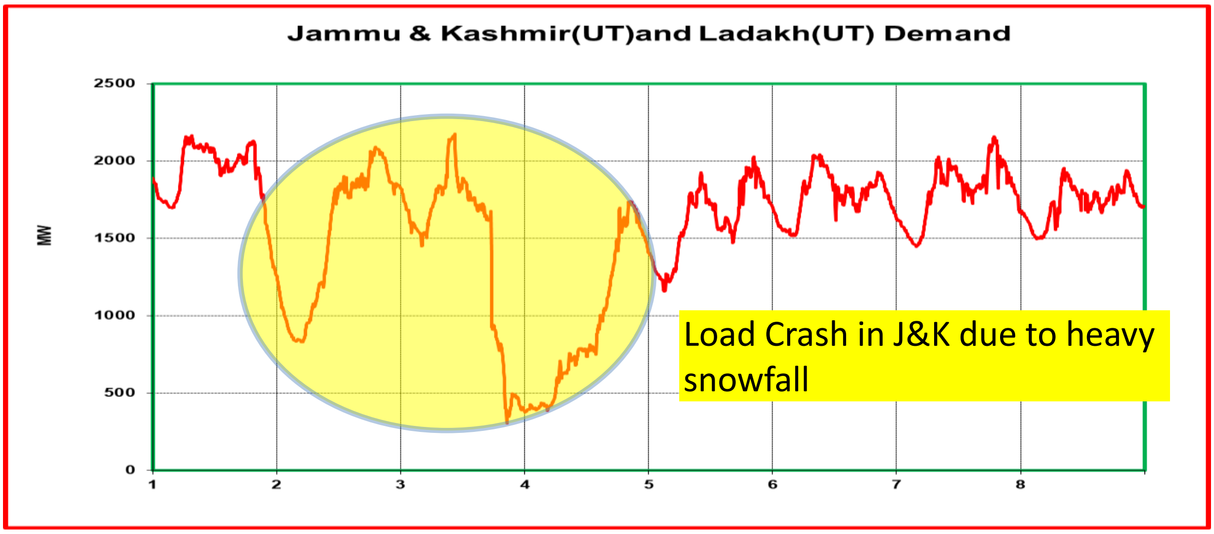


Figure 6: J&K (UT) and Ladakh (UT) Load Crash due to heavy Snowfall

Figure 7: Impact of snowfall on Transmission lines

3.6. Impact of Rainfall on Power demand and Hydro generation.

The industrial, domestic and agricultural constitute major categories of consumers of electricity. Agriculture sector is third highest sector in terms of electricity consumption and sudden or continuous precipitation leads to decrease the demand of electricity due to reduction in agriculture load (Pumping load), domestic and Industrial load (mainly cooling load). Further, many a time heavy rainfall leads to increase the voltage of lines above the specified safe limit due to decrease in demand. This cause tripping of transmission line or opening the lines manually on over voltage.

Hydropower generation has a close relationship to rainfall. The increase in precipitation in catchment area of the plant leads to higher water inflow with consequent increase in power generation, and vice-versa. However, very high rainfall in catchment area of hydro plants situated in Himalayan region increases the chances of outage of hydro stations due to sudden increase of silt in inflow.

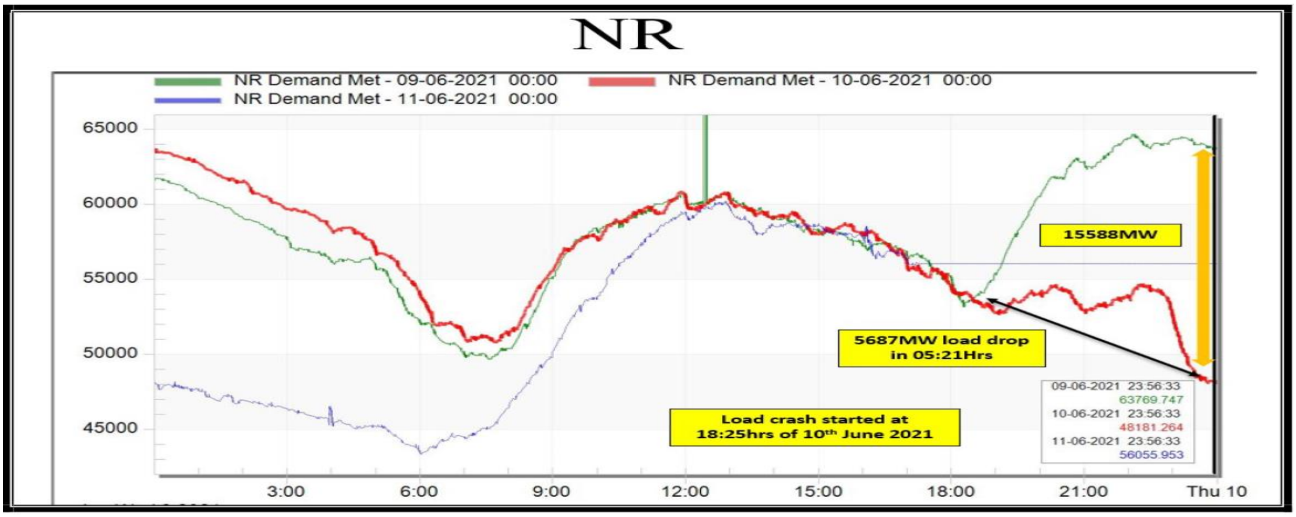


Figure 8: Impact of Rainfall on Northern Region Demand

3.7. Impact of cyclone on Power System infrastructure.

A tropical cyclone (TC) is a rotational low-pressure system in tropics when the central pressure falls by 5 to 6 hPa from the surrounding and maximum sustained wind speed reaches 34 knots (about 62 kmph)[10]. It is a vast violent whirl of 150 to 800 km, spiralling

[10] http://www.imdsikkim.gov.in/cyclonefaq.pdf

around a centre and progressing along the surface of the sea at a rate of 300 to 500 km a day. Tropical cyclones have great socio-economic concern for the Indian subcontinent being the only region in the world having two cyclone seasons within a year[11]. Due to the varying coastal bathymetry of the Indian coast, the severity of the storm surge created by the cyclones vary from place to place for the same intensity of the cyclone. Further, during cyclone many EHV transmission as well as distribution transmission lines trip and result into massive power outage in the cyclone affected area.

Figure 9: Impact of Cyclone on Power System

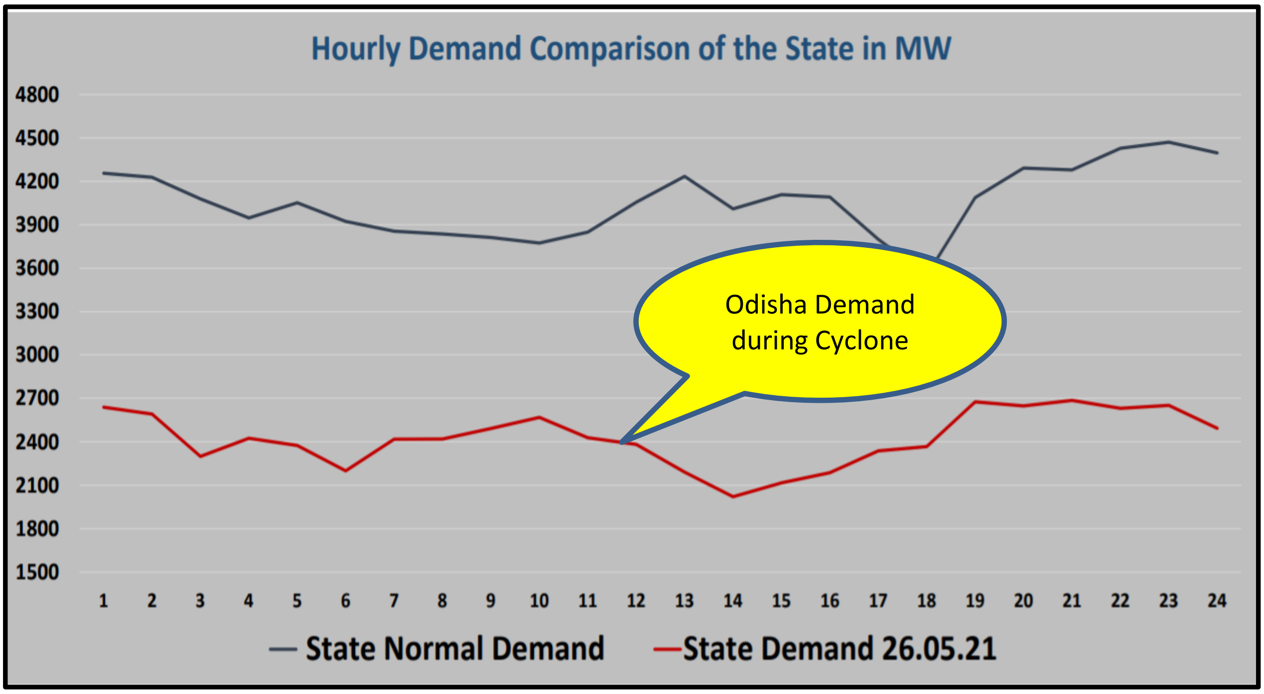


Figure 10:Demand of Odisha during cyclone.

[11] https://www.nrsc.gov.in/sites/default/files/pdf/ebooks/Chap_11_Cyclones.pdf

4. POSOCO-IMD collaboration for Utilization of weather information in power sector:

4.1. Background:

Earth System Science Organization, India Meteorological Department (ESSO-IMD), Under the Ministry of Earth Sciences and Power System Operation Corporation Ltd. (POSOCO), signed a Memorandum of Understanding for optimum use of weather information / forecast in the power sector.

Salient features of the MoU signed in the presence of senior officers from the Ministry of Power and the Ministry of Earth Sciences include:

- All weather information provided by ESSO-IMD shall be used by the Power System Operators across India for better management of Indian Power System and for the purpose of analysis.
- ESSO-IMD shall make available current weather information for the identified stations; and forecasts at different time scales (Nowcast to medium range scales) of temperature, humidity, wind speed, wind direction, rainfall and other meteorological parameters of the identified stations/sectors.
- ESSO-IMD shall provide weather warnings about likely occurrences of thunderstorm, heat wave, cold wave, rainfall, fog etc. over various states up to next 72 hours.
- ESSO-IMD shall provide state / region wise Monthly /Seasonal outlooks of weather conditions.
- Both the parties agreed to provide expert opinion and knowledge support in areas of Weather information and its effect on power distribution system.
- Data & Inputs shall be exchanged to encourage further study and research work.
- POSOCO shall endeavour for economic assessment of impact of weather & climate information. Regular feed mechanism shall be put in place for continued up-gradation of the services.

The MoU essentially brings out the fact that energy sector is among the most pivotal spheres of human activity which is highly dependent on weather conditions. To increase the efficiency of power sector and to make it weather resilient, it is not sufficient to act after the weather-related event have taken place. Proactive steps are required to minimise the possible adverse impacts.

Weather information on different time scales is essential both in day-to-day energy management and for the generation and distribution infrastructures. Day to day weather variations have an impact on load demand, renewable power production, transmission and distribution management. Extreme events such as heat waves or cold waves, wind storms or floods can of course have dramatic consequences on the electrical grid of a country including physical damage to the infrastructure. In addition to short & medium-term management processes, the long-term production and supply planning to require climate data and future climate scenarios. In order to manage the risks associated with weather and climate conditions on all time scales from a few minutes to days, reliable weather forecasts and climate information — past, present and future (for minimizing uncertainty, forecast should be as accurate as possible; for which valid weather data of past and present are essential.) are crucial to reduce the uncertainty in supply and demand forecasts, as well as market dynamics.

5. Development of Weather Power Portal and its Utilization:

In pursuance to this MOU, a dedicated weather portal for the power sector has been developed jointly by POSOCO and IMD. The weather portal contains information related to weather forecast, real time weather scenario and past data of various locations across the country.

Weather Portal for Power System has been developed using readily available products of IMD (Such as Weather forecast, Weather warning, Radar Images, Meteogram, Satellite Image). Weather information provided on the Portal is being used by the Power System Operators across India for better management of Indian Power System.

Regional Weather portals for all the five regions of India were made operational as per the details given below:

- **Northern Region** : with effect from 14.03.2017
- **North Eastern Region** : with effect from 29.04.2017
- **Southern Region** : with effect from 01.05.2017
- **Eastern Region** : with effect from 05.05.2017
- **Western Region** : with effect from 01.06.2017

5.1. Salient Features of Weather Power Portal

The weather power portal (http://14.139.247.5/power/NRLDC/)provides following information:

- Regional based weather information
- All India Weather Forecast (for the next 5 days)
- All India Weather Warning (for the next 5 days?)
- All India Weather Meteogram
- Nowcast Warning
- Images recorded by Indian Satellites for every 30 minutes
- Fog Monitoring
- Cyclone Monitoring
- Near real time weather information using Radar

5.2. Utilization of Weather Portal

All the RLDCs, NLDC and constituents (SLDCs) are using the products / features available on the weather portal on regular basis. The forecast available at the portal helps constituents to take pro-active steps such as demand estimation, decisions on STOA (Short Term Open Access), reviewing their short-term power sale/purchase portfolio etc. Real time information available from Radar and Satellite help system operators to take real time decisions related to grid operation.

Usage of Weather Power Portal by RLDCs, NLDC and constituents are mentioned below:

5.2.1. Operating procedure for use of weather information

- A mail is triggered on daily basis by NRLDC to all the constituents of the concerned region regarding weather conditions expected to prevail in the region for the next 5 days.
- Weather warnings as issued by Indian Meteorological Department regarding rainfall, foggy conditions etc. are informed to the SLDCs and ISGSs and are requested to be vigilant. The warnings are used for real time grid management also by RLDC's/SLDC's system operators.

5.2.2. Fog monitoring during Winter Season

Northern and Eastern (and North-Eastern) regions are more prone to foggy conditions during winter season (Night hours and early morning) compared to the other regions. During foggy conditions many extra high voltages transmission lines trip which pose challenge to grid operator to operate the grid in a secure and reliable manner. Weather power portal provides the fog forecast issued from five airports of the Northern Region. It gives the outlook of fog for the first 6 hours and also for the subsequent12 hours (Figure 11). Based on the fog forecast, Northern and Eastern region constituents elevate the vigilance level to transmission lines which are located in the fog zone and take preparatory and precautionary actions accordingly.

INDIA METEOROLOGICAL DEPARTMENT
METEOROLOGICAL OFFICE I.G.I. AIRPORT
NEW DELHI

FOG FORECAST OF DELHI REGION

HOME

DATE : 02-01-2018. TIME OF ISSUE 02/0000 UTC.

VALIDITY	VALID FROM DATE/TIME 02/0030 UTC. VALID UPTO DATE/TIME 02/0630 UTC.	FROM DATE/TIME 02/0630 UTC. TO 02/1830 UTC.
STATION	FORECAST	OUTLOOK FOR NEXT SUBSEQUENT 12 HOURS
(VIDP) I.G.I. AIRPORT, DELHI	VISIBILITY MAY REMAIN 0200M IN FOG TILL 02/0400 UTC IT MAY IMPROVE TO 0800M IN SHALLOW FOG FROM 02/0600 UTC.	VISIBILITY LIKELY IMPROVE TO 1000M AND ABOVE IN SMOKE FROM 02/0700UTC.
(VILK) LUCKNOW AIRPORT	VISIBILITY LIKELY REDUCZE TO 0500M IN SHALLOW FOG FROM 02/0130 UTC.I T MAY IMPROVE TO 1000M IN MIST FROM 02/0600 UTC.	NO DENSE FOG DURING THE PERIOD.
(VIJP) JAIPUR AIRPORT	NO FOG DURING THE PERIOD.	NO FOG DURING THE PERIOD.
(VIAR) AMRITSAR AIRPORT	VISIBILITY LIKELY REMAIN BELOW 0050M IN VERY DENSE FOG(CAT -III VERY DENSE FOG) TILL 02/0400 UTC IT MAY IMPROVE TO 0500M IN FOG FROM 02/0600 UTC.	VISIBILITY LIKELY IMPROVE TO 1000M AND ABOVE IN MIST FROM 02/0700 UTC. IT MAY RECUDR TP 0200M IN DENSE FOG FROM 02/1800 UTC.
(VEBN) BABATPUR AIRPORT	VISIBILITY LIKELY REDUCE TO 0300M IN FOG FROM 02/0100 UTC.I T MAY IMPROVE TO 1000M IN MIST FROM 02/0630 UTC.	NO DENSE FOG DURING THE PERIOD.

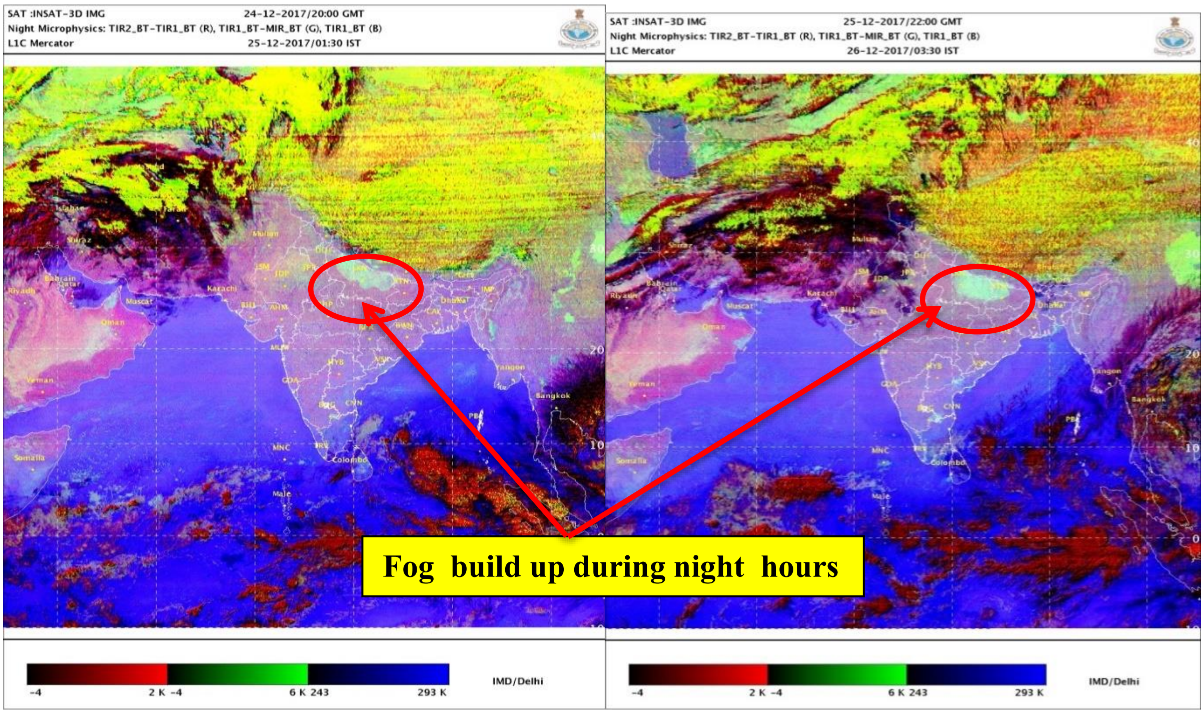
Figure 11: Fog Forecast of Delhi

Near real time colour composite images of fog from Satellite image have enabled grid operators to take prudent decisions to mitigate the adverse effect of tripping on power system. Two such cases are explained below:

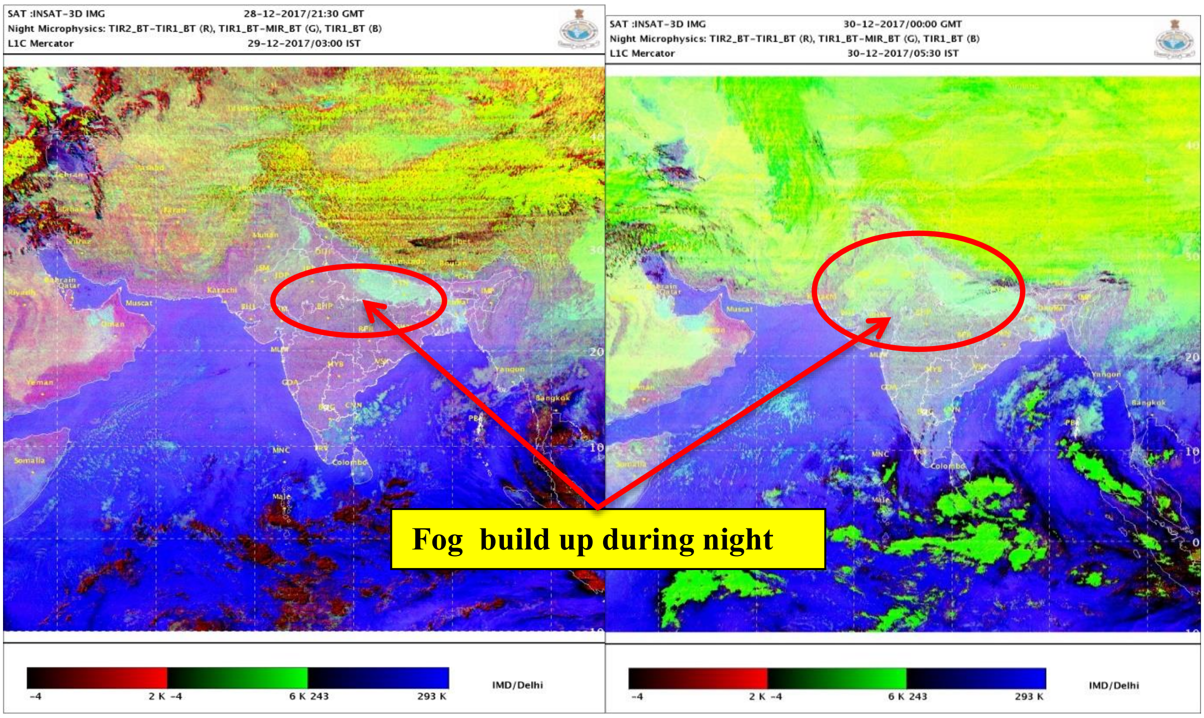
(a) Tripping of 765kV AnparaC-Unnao.

Frequent tripping of 765kV Anpara C-Unnao line attributed to fog during winter nights (25.12.17- 01.01.18)

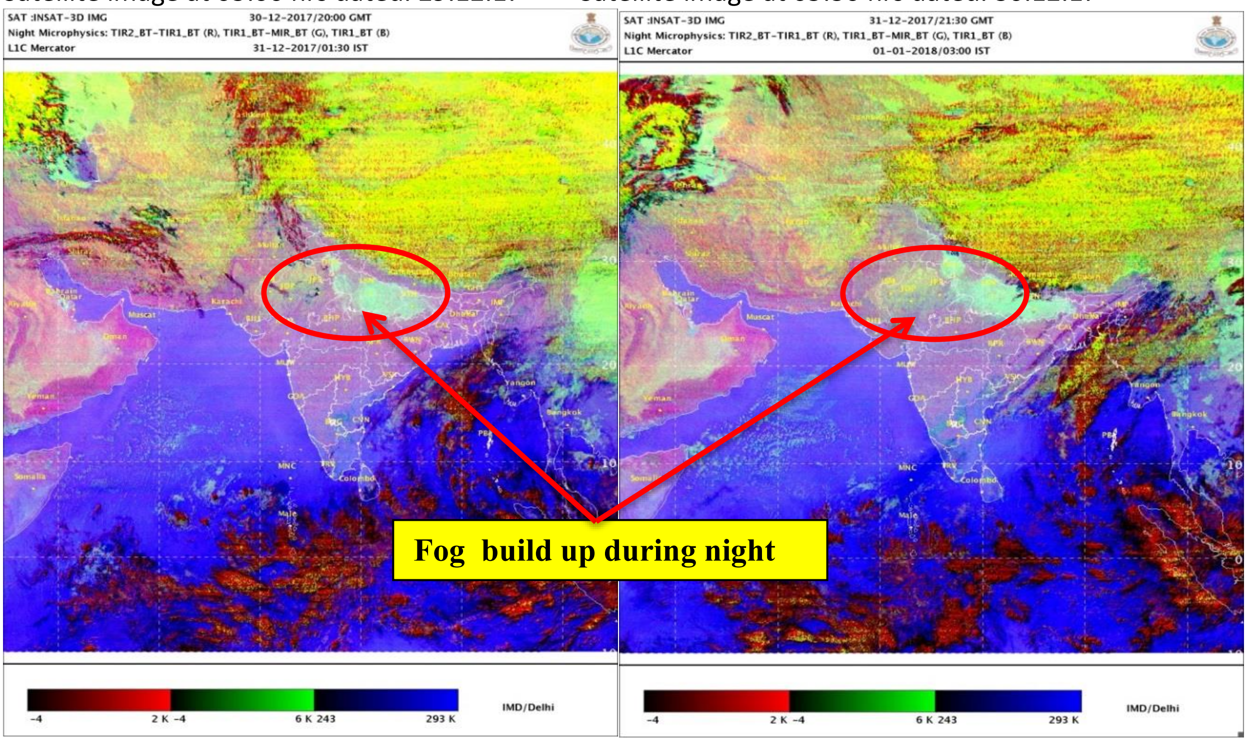
Date	Time of Tripping	Time of Revival
25.12.17	01:38 hrs	16:31hrs
26.12.17	03:49 hrs	10:06hrs.
29.12.17	03:30 hrs	10:48 hrs.
30.12.17	06:24 hrs	10:53 hrs.
31.12.17	01:55 hrs	18:45 hrs.
01.01.18	03:18 hrs	10:59 hrs.



Satellite image at 01:30 hrs dated. 25.12.17   Satellite image at 03:30 hrs dated. 26.12.17



Satellite image at 03:00 hrs dated. 29.12.17 Satellite image at 05:30 hrs dated. 30.12.17



Satellite image at 01:30 hrs dated. 31.12.17 Satellite image at 03:00 hrs dated. 01.01.18

It was observed that due to tripping of 765kV Anpara C – Unnao line, line loadings of other 400kV lines especially 400kV Anpara - Sarnath D/C increased beyond permissible limits (>700MW per ckt). Operating these lines on such high loading posed a threat to grid security.

Action taken: From the inputs of weather portal regarding spread of fog, UP SLDC was advised to back down generation in Anpara complex and increase generation in other plants to meet its load, in the interest of grid security. Low generation in Anpara complex ensured that in the event of tripping of 765kV Anpara C-Unnao line or any other 400kV line in Anpara complex due to fog, the loading of other lines didnot exceed operating limits. This provided theoperator an increased time window for corrective action.

(b) Transients in HVDC Rihand-Dadri during foggy winter nights

Transients in HVDC Rihand-Dadri line were observed during night hours in the period 25.12.17 to 01.01.18. To prevent the occurrence of insulator flash over and consequent outage of the HVDC link, RVMO (Reduced Voltage Mode Operation) mode of HVDC was utilized

Action taken: Visualization of fog from Satellite image at the weather portal was used to ascertain the requirement of putting the HVDC in RVMO mode.

5.2.3. Usage of Weather Portal for Real Time Grid Operation

- In real time, the "Nowcast" feature and RADAR Image of weather portal are extensively used for monitoring and alerting the constituents.
- The SLDCs are made aware of any disturbance in weather conditions and they are advised to manage their load accordingly.
- The weather portal also allows the real-time grid operator to remain more vigilant as in case of heavy wind, cyclone, or heavy lightning which may lead to increased equipment tripping.

5.2.4. Usage of Weather Portal for Scheduling:

- The warnings of inclement weather help in anticipating sudden unprecedented decrease in demand.
- In such cases where demand is anticipated to be low due to inclement weather, generation schedule of hydro machines is revised in such a way that only optimal numbers of hydro units operate to meet the reduced demand.
- The states are advised to monitor the weather conditions at various locations in their respective states and revise their power requisition, if needed

5.2.5. Thunderstorm Monitoring:

During summer period, massive convective thunderstorms dominate Northern India's weather. Temperature rise in North India is accompanied with strong, gusty, hot and dry winds. These weather conditions coupled with frequent thunderstorms lead to sudden load crash in pockets due to sudden drop in temperatures and tripping/opening of distribution feeders leading to high voltages in the Northern Grid. The load however, recovers to its normal value within a few hours after short and temporary effects of thunderstorm.

Northern Region experienced many instances of thunderstorm during summer 2021and the Weather Power Portal helped power system operators to operate the grid in secure and reliable manner. A case study for the impact of thunderstorm on power system and utilization of weather portal is given below:

The Northern Region (NR) experienced a demand crash during evening hours of 16th April,2021 on account of rain with thunderstorm/dust storm.

The event details are summarized below:

- The load of NR started reducing after 14:00hours of 16.04.2021 and dropped by 5.4GW in the span of 4hrs. At 17:58 hours, load of NR reached its minimum; and the load started picking up after 04 hours from the start of load crash.
- Average demand crash of 4500 MW was observed during inclement weather conditions (14:00hrs to 18:00hrs of 16th Apr 2021) as compared to the previous day.
- Punjab, Haryana, Rajasthan, Uttar Pradesh, Uttarakhand & Delhi were the major affected state control areas during load crash. Demand crash in Rajasthan started first at 13:53hours itself followed by Punjab at 14:00hours, Uttar Pradesh at 14:25hours and in Haryana at 15:07hours. Delhi demand started decreasing at 15:28hours, Uttarakhand at 17:42hours and in Chandigarh at 16:18hours. Maximum demand crash of Northern Region was 7481MW at 17:58hrs of 16th April, 2021 as compared to previous day.

  The table below shows the comparison of demand met of all the NR state from previous day, at 17:58hrs (time of maximum crash in total NR demand).

State Control Area	Demand Met (MW) at 17:58hrs of 15th April'21	Demand Met (MW) at 17:58hrs of 16th April'21	Demand Reduction (in MW)	Minimum Demand Met (in MW)	Load Crash Amount (in MW) and duration
Punjab	5007	4119	888	2869 (15:54hrs)	1439MW in 01:54hrs (Started at 14:00hrs of 16th April)
Haryana	5281	2240	3041	2217 (17:55hrs)	2421MW in 02:50hrs (Started at 15:07hrs of 16th April)
Rajasthan	8756	7553	1203	7347(18:03hrs)	2080MW in 04:00hrs (Started at 13:53hrs of 16th April)
Uttar Pradesh	14164	12537	1627	10270(16:36hrs)	1790MW in 02:10hrs (Started at 14:25hrs of 16th April)
Delhi	4038	3289	749	3334(18:00hrs)	975 MW in 02:30hrs (Started at 15:28hrs of 16th April)
Chandigarh	195	190	5	182(16:51hrs)	18 MW in 00:30hrs (Started at 16:18hrs of 16th April)
Jammu &Kashmir	2303	2375	-72		
Uttarakhand	1768	1678	90	1453 (18:44hrs)	430 MW in 01:00hrs (started at 17:42hrs of 16th April)
Himachal Pradesh	999	1234	-235	1132(16:24hrs)	160 MW in 00:10hrs (started at 16:12hrs of 16th April)
Northern Region	**42611**	**35130**	**7481**	**35130(17:58hrs)**	**5450MW in 04:00hrs (started at 14:00hrs of 16th April)**

- The demand pattern of Northern Region and its states are attached as **Annex-I.** During the thunderstorm/dust storm, there was heavy under drawl by Punjab, Haryana, Rajasthan, Uttarakhand and Delhi. State Schedule & Actual Plots and State Deviation plots are attached at **Annex-II**. The Schedule & Actual IR exchange of NR is given at **Annex-III.**
- State demand vs state thermal generation pattern is also plotted and attached as **Annex-IV.**
- Total 25 numbers of 400kV and above voltage level elements (lines and ICTs) tripped/hand tripped including one event of multiple element tripping (Grid Disturbance-1 category) during dust storm on 16th April 2021. The list of tripped elements is attached as **Annex-V.**
- The graph below makes it very evident that during the thunderstorm/dust storm frequency was slightly on the upper side due to heavy under drawal by several state control areas. Maximum System frequency reached up to 50.20Hz at 18:01hrs during load crash. Frequency plot is given below:

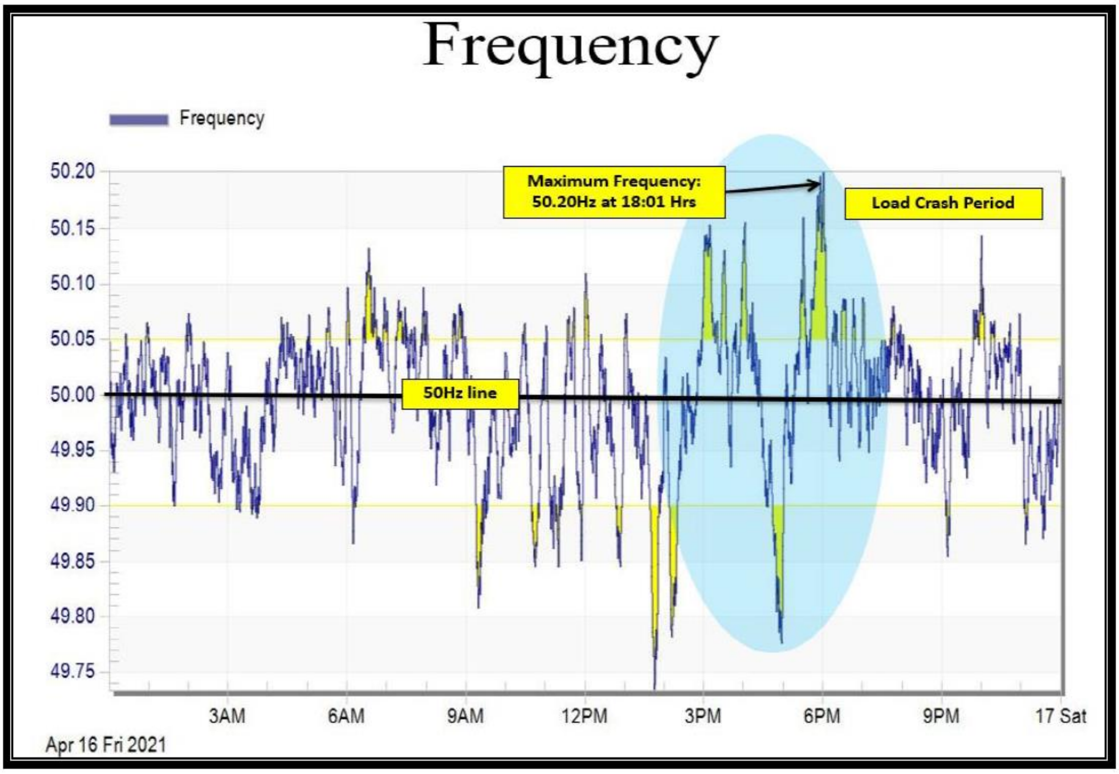


Figure 12: Frequency Profile on 16th April 2021

Actions taken by NRLDC/SLDC Control Centre:

- Warning about inclement weather condition was given to all the states in advance over telephone and through mail.
- Alerts were issued to all concerned to reduce under-drawl and for backing down of their generation in order to control high frequency operation besides containing over-voltages.
- Immediate actions were taken to ensure that states surrender their share of power from ISGS/CGS generating stations; and that generation is reduced at regional level. Subsequently the same was incorporated by NRLDC Scheduling.
- The generation of ISGS thermal stations was backed down.
- Instructions were issued for backing down of generation in state generating stations of Punjab, Haryana, UP, Rajasthan, Uttarakhand and Delhi in order to maintain the frequency within the allowable band.
- Total 500MW Northern Region Central Sector Generation was backed down due to load crash in the region. SCADA plot is attached as **Annex-VI.**
- RRAS down schedule was given by NLDC of 500MW for the period of 16:00Hrs - 16:30Hrs, 1000MW for the period of 16:45Hrs -18:00Hrs and 800MW for the period of 18:45Hrs -21:45Hrs.
- SLDCs assessed the movement of thunderstorm/dust storm through RADAR system and reduced their state control area generation. UP reduced its thermal generation by 1000MW, Punjab and Haryana reduced their thermal generation by 700MW & 450MW, Delhi and Rajasthan also reduced their generation by 400MW & 1200MW, respectively.

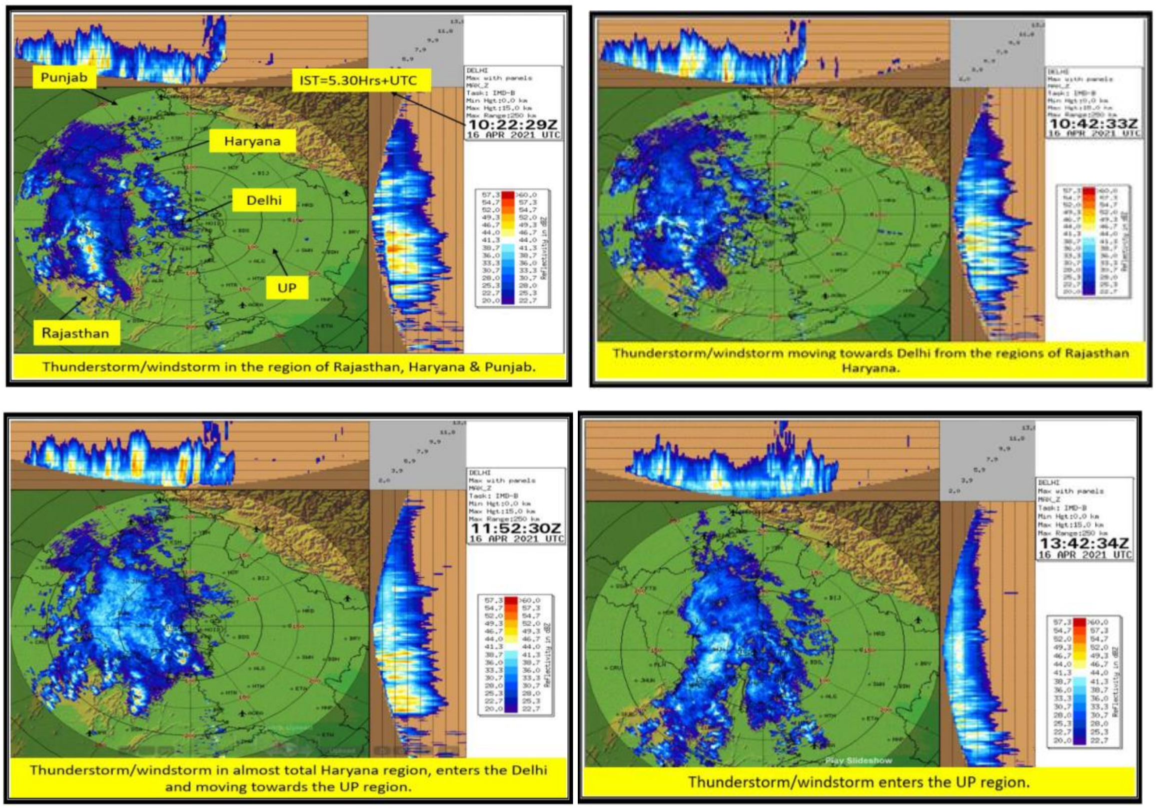


Figure 13:Radar Images on 16th April 2021

- It is also observed that during such event of thunderstorm/dust storm, wind generation rises significantly due to high wind speed. So, system operators at SLDC Rajasthan considered this factor also while estimating generation reduction required to avoid deviations or unscheduled interchange of its control area during such events.

5.2.6. Usage of Weather Portal for Cyclone Monitoring:

India generally witnesses 2-3 cyclones on an average every year over Arabian sea and Bay of Bengal. Cyclonic storm causes large scale damage to Transmission and Distribution infrastructures of coastal states of India leading to long outage of power supply to affected areas. Cyclones result in heavy rains, high storm surges and strong winds that often-cut power supply to affected areas. Awareness of Cyclone path and assessment of its intensity in advance from weather power portal, enable system operators to take corrective actions for maintaining the system reliability and security of the Indian grid.

Cyclone “MORA”:

Warning regarding cyclonic storm "MORA" over east central Bay of Bengal was issued by Indian Meteorological Department vide bulletin number12, dated 29.05.17. The same was also available in cyclone warning tab in weather portal of North Eastern Region. Heavy rainfall warning was issued for Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura.

NERLDC immediately informed all the SLDCs and ISGSs of NE region about the upcoming cyclonic storm “MORA”. NERLDC also informed all the SLDCs and ISGSs that due to effect of the cyclone, there could be extensive load crash as well as generation loss in the North Eastern Region. To tackle the emergency situations, the generators were requested to either maintain generation at the technical minimum or units may back down as much as possible for security of the power system. All the SLDCs and ISGSs responded to the Cyclone “MORA” warning and reported their preparedness for taking care of the situation. Time to time update about the path of Cyclone “MORA” as received from IMD were monitored by real time operators at RLDC and all SLDCs and ISGSs were also informed about the same.

Load crash due to adverse weather conditions was also reported by Assam, Manipur, Mizoram and Meghalaya during cyclone “MORA”. The brief details of total amount of load and generation loss is given below:

Date	States Affected	Total Load Loss	Total Generation Loss
30.05.17	Assam, Manipur, Mizoram, Meghalaya	558	Nil
31.05.17	Assam	194	Nil

Cyclone “Gaja” Monitoring using Radar Image

In southern region Cyclonic Gaja made landfall in Nagapattinam district of Tamil Nadu around 1:40 AM (IST) on 16th November 2018. All the Control Centres started the closed monitoring of the RADAR images from 15.11.2019 (Figure14) available on the Weather Portal for Power Sector. Close monitoring of cyclone helped in controlling the System parameters and early restoration of power supply in the affected area.

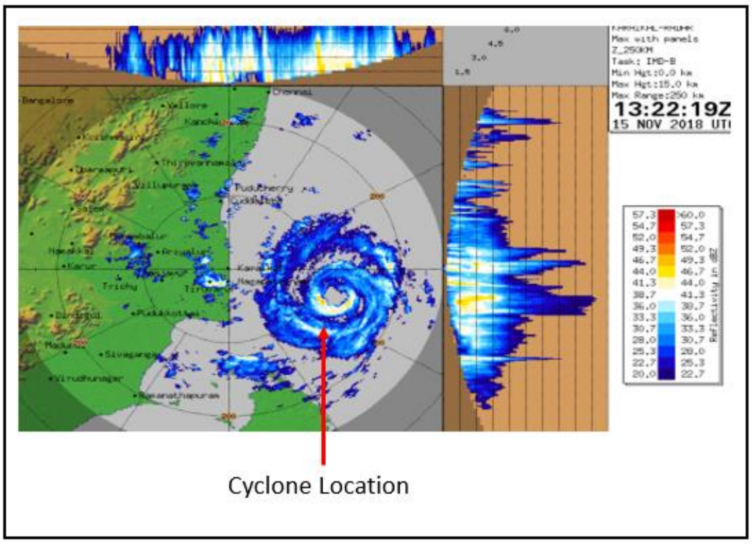


Figure 14: Gaja Cyclone Monitoring using Radar Image

During the Cyclone, based on the radar images the system parameters of 08 Numbers of substations (Figure 15) falling in the path of Cyclone after landfall were closely monitored. In addition to this, reactors in the transmission network were made available to control voltages and all the outages were deferred in the affected region. Generating unit of Generating Station A -210 MW, Generating Station B – 600 MW & Generating Station C – 250MW were shut downed in anticipation of reduction in demand.

Close monitoring of cyclone path, intensity of wind speed and rainfall based on real time radar images helped in controlling the System parameters.

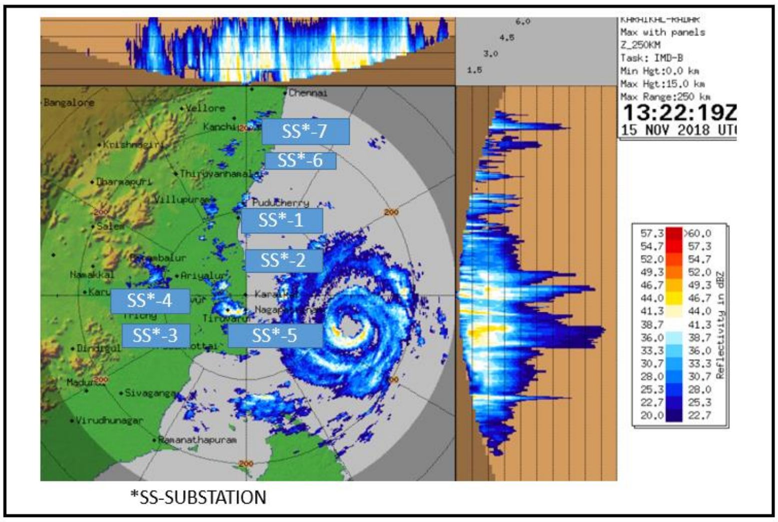


Figure 15: Substations Location on radar image

Cyclone ''OCKHI'':

Weather portal for Southern Region helped the system operator and the system reliability team to take precautionary measures in issuing warning notes to the southern states to prepare for a bad weather and a probable cyclone. Weather portal gave timely warning on the depression formed over southwest Bay of Bengal near southeast Sri Lanka coast in the morning of 29th November, 2017. It was predicted that this depression would develop into a cyclonic storm during the next 12 hours.

System reliability and study group of SRLDC prepared an alert report explaining the anticipated intensity of the approaching cyclone and various precautions to be taken during the cyclone period by all concerned states. The following aspects were of utmost importance for safe system operation.

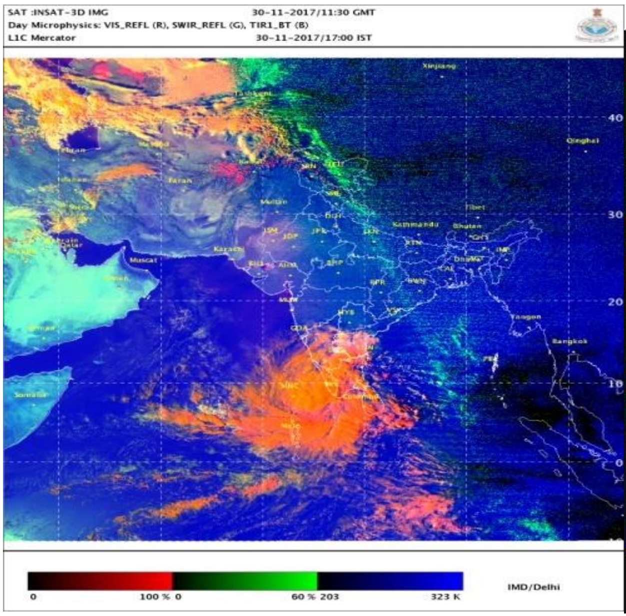
1. **Rainfall Information and Wind Warning:** It was informed that there would be widespread rainfall in parts of southern Tamilnadu and Kerala.
    - Tamilnadu was advised to be prepared for a demand reduction of approximately 1000 MW due to this and, therefore, be ready to reduce their internal Generation.
    - Kerala also witnessed a 350 MW reduction in demand; internal generation was regulated by 200 MW.
    - Totally, internal generation of Southern Region was reduced by 2500 MW.
2. **Precautions Taken**
    - It was expected that a voltage rise would occur in the Southern Grid due to load loss.
    - All the Bus-Reactors were made ready to be taken into service to combat over-voltages.
    - Thermal generators already in operation were instructed for maximizing reactive power absorption
    - All the planned transmission line outages were deferred during the cyclone period.
3. **Kudankulam Nuclear Power Station (2 x 1000 MW)**

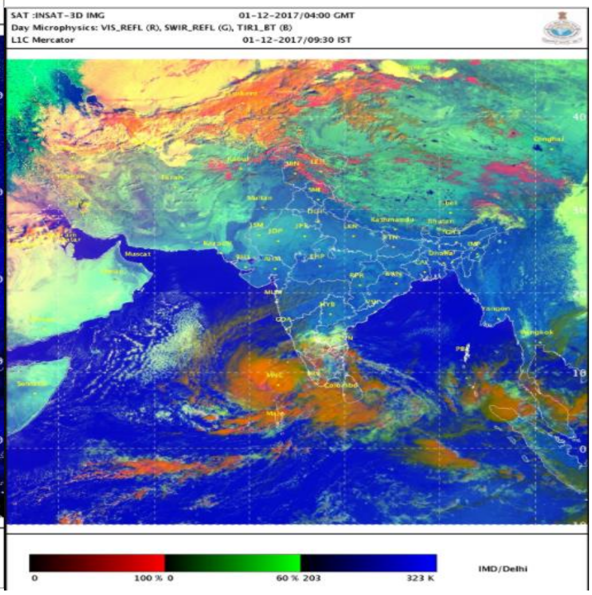
    Since the cyclone was passing close by to this nuclear station, a plan was prepared for restoration of supply in-case of any emergency.

4. Traction Supply

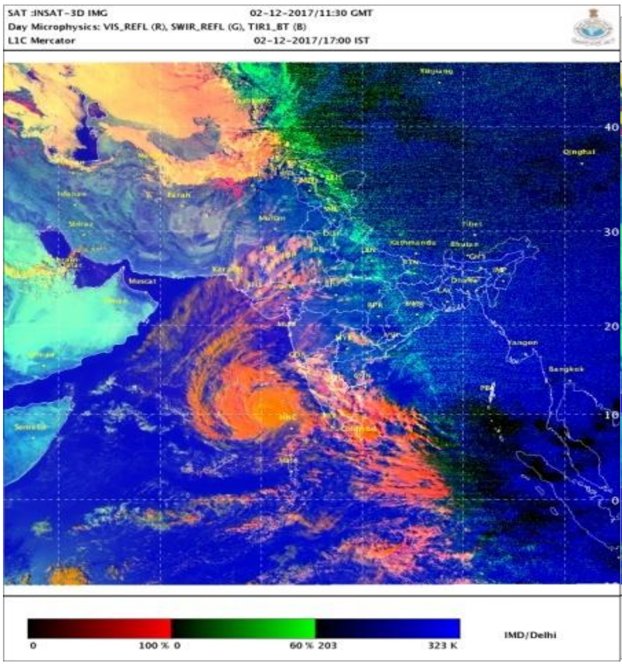
All the important traction feeding points were identified for South Western Railways for immediate extension of supply from the grid, in case of disruption of traction power. There was no loss of traction supply in Tamilnadu and Kerala.

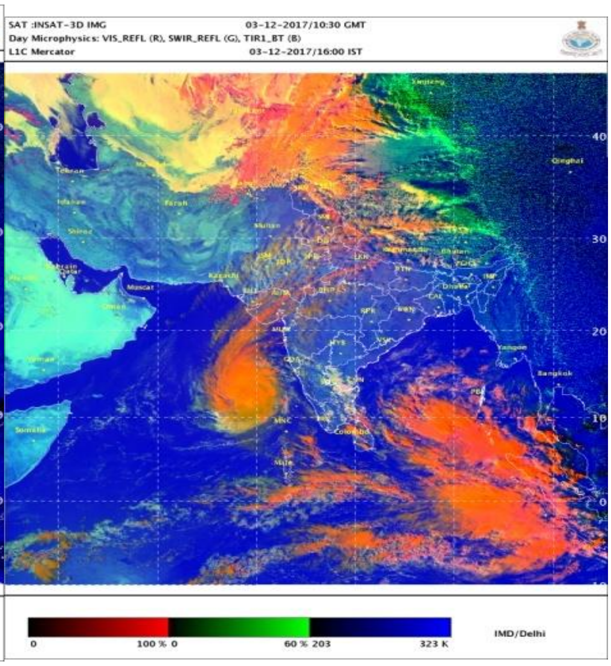
Monitoring of Cyclone OCKHI



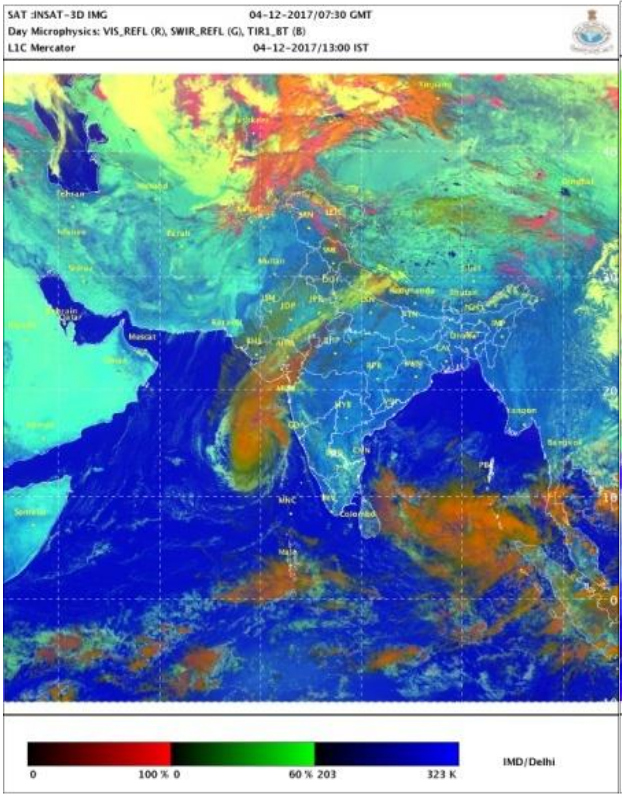


30ThNovember 2017 1stDecember 2017

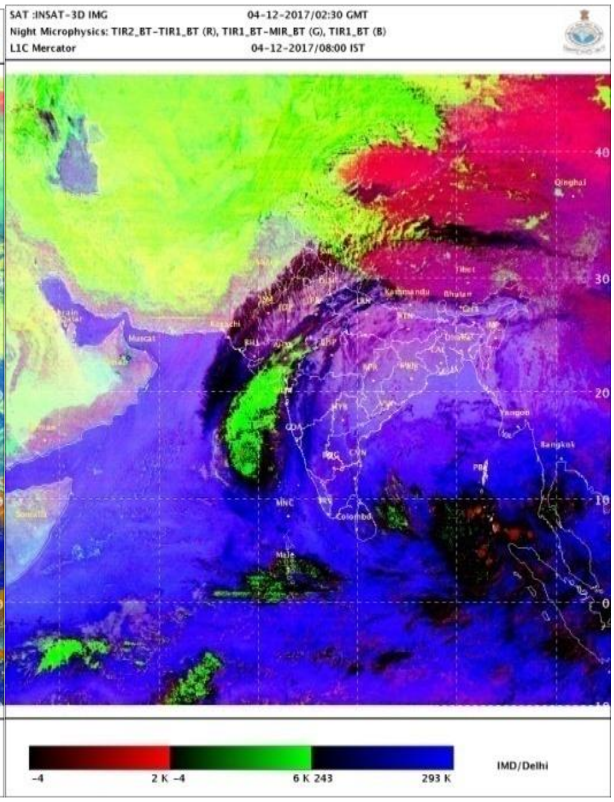




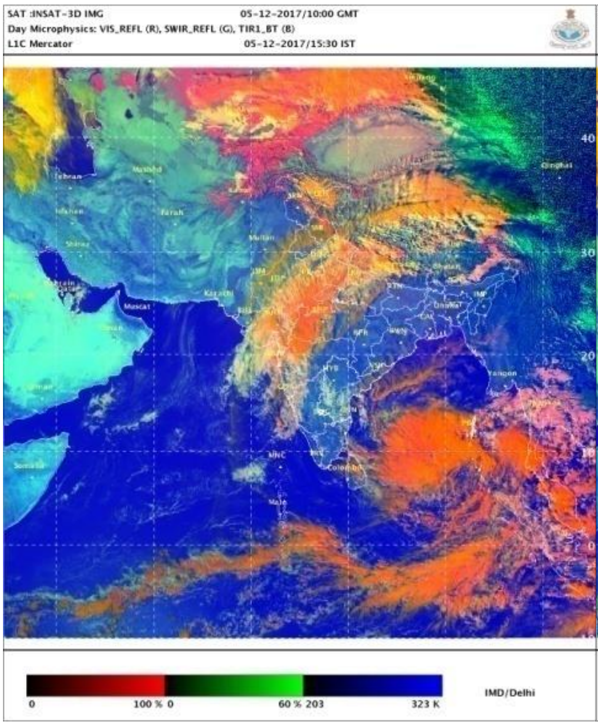
2ndDecember 2017 3rdDecember 2017



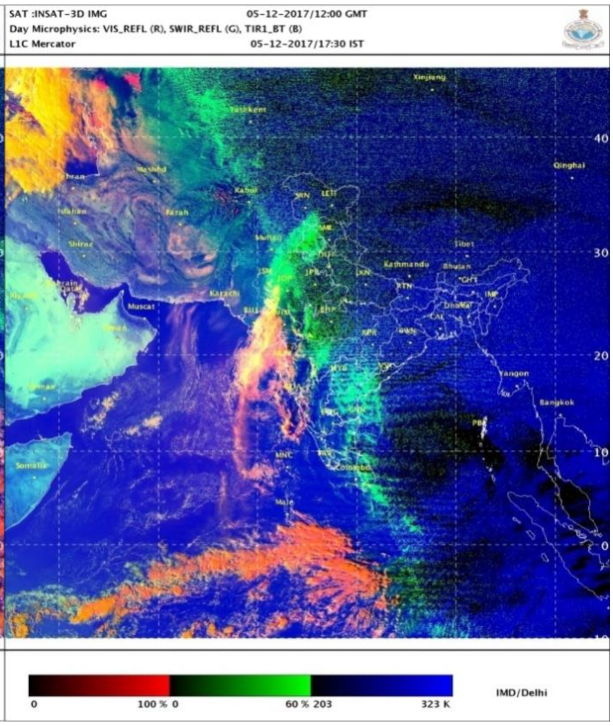
4thDecember 2017



4thDecember 2017 (night hours)



5thDecember 2017



5thDecember 2017 (night hours)

Cyclonic Storms on Eastern and Western Coast

The vast and diverse geographical landscape of Indian sub-continent makes it prone to natural calamities viz. earthquake, cyclone, flood, landslides etc[12]. Two severe cyclonic storms hit the eastern and western coasts of India during the COVID-19 pandemic period. Cyclonic storm named 'Amphan' hit the eastern coastal states of West Bengal and Odisha on 20thMay, 2020[13].India Meteorological Department (IMD) maintained round the clock watch over the north Indian Ocean and the system was monitored since 23rd April about three weeks prior to the formation of the Low-Pressure Area on 13th May. In the extended range outlook issued on 7th May, IMD indicated possible cyclogenesis during the second week over south Andaman Sea and adjoining southeast Bay of Bengal. On 9th May, it was indicated that a Low-Pressure Area would form over the region on 13th May (96 hours prior to formation of the system) under the influence of the remnant cyclonic circulation persisting over the region during 6th-12th. On 11th, it was indicated that cyclogenesis (formation of depression) would occur around 16th May (48 hours prior to formation of the Low-Pressure Area and 120 hours prior to formation of depression) over the Bay of Bengal.

The cyclone was monitored with the help of available satellite observations from INSAT 3D and 3DR, polar orbiting satellites including SCATSAT, ASCAT etc. and available ships & buoy observations in the region. From 18th May midnight (1800 UTC) onwards till 20th May, the system was tracked gradually by IMD Doppler Weather Radars (DWRs) at Visakhapatnam, Gopalpur, Paradip, Kolkata and Agartala as it moved from south to north. IMD also utilised DWR products from 'DRDO Integrated Test Range', Chandipur, Balasore for tracking the system. Various numerical weather prediction models run by Ministry of Earth Sciences (MoES) institutions (viz.,IMD, IITM, NCMRWF & INCOIS), various global models and IMD's dynamical-statistical models developed in-house were utilized to predict the genesis, track, landfall and intensity of the cyclone. A digitized forecasting system of IMD was utilized for

[12] S. K. Soonee et al., "Grid Resilience in Indian Power System," 2018IEEE 8th Power India International Conference (PIICON), Kurukshetra, India, 2018, pp. 1-6
https://ieeexplore.ieee.org/document/8704397
[13] PIB, Press Information Bureau, Ministry of Power Press Release, PIB,Delhi
https://pib.gov.in/PressReleasePage.aspx?PRID=1625165

analysis and comparison of guidance from various models, decision making process and warning product generation.

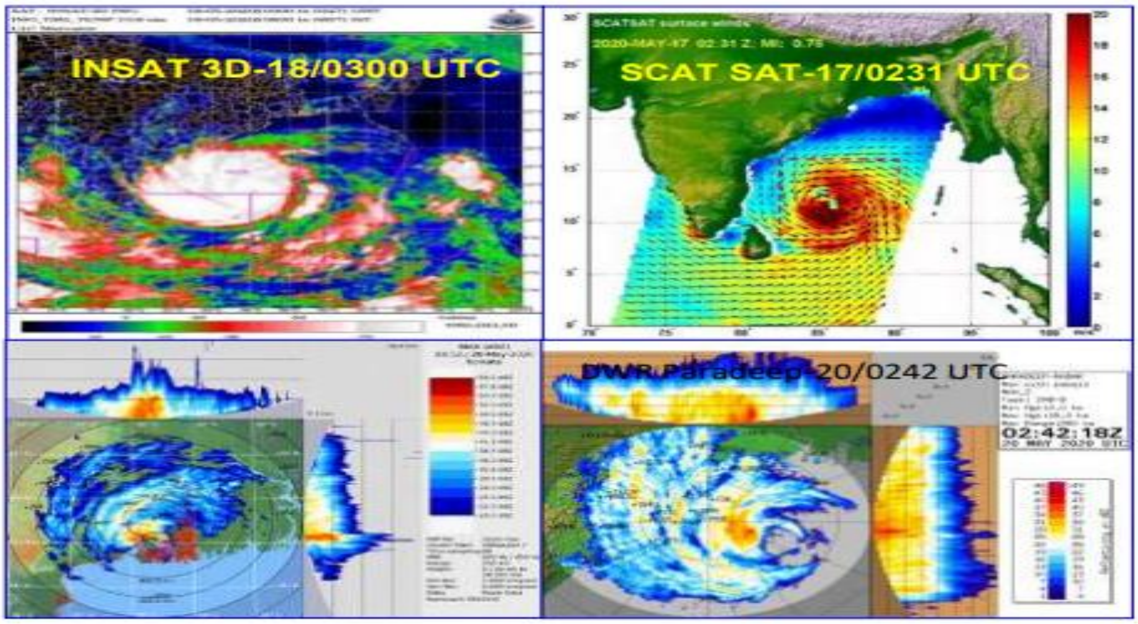


Figure 16:Typical satellite imageries for SuCS Amphan over the Bay of Bengal and Radar imageries from DWR Kolkata & Paradip

Based on the periodic bulletins, Satellite images and Radar imagery from IMD, Power sector utilities of affected region started preparing towards handling the event. During the event, there was total demand reduction of around 5000 MW in West Bengal & 750 MW in Odisha. There was also 260 MW loss on supply side.

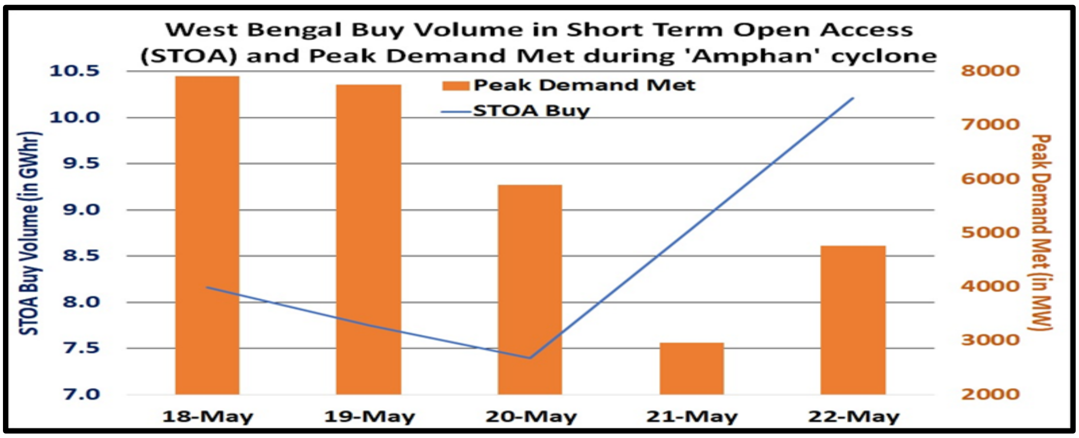


Figure 17:West Bengal STOA Buy Volume and Peak Demand

As depicted in Fig. 17, the West Bengal state peak demand crashed from around 8000 MW pre-cyclone to 3000 MW post-cyclone. Similarly, there was marginal reduction in the procurement from Short Term Open Access (STOA) market i.e., both through OTC and power exchanges due to tapering of demand. However, the prolonged time for revival of internal generation due to loss of evacuation path led to increased procurement from STOA post-cyclone.

Severe Cyclonic Storm ‘NISARGA

Another cyclonic storm named ‘Nisarga’ hit the western coastal states of Maharashtra and Gujarat on 03rd June, 2020. Again ,India Meteorological Department (IMD) maintained round the clock watch over the north Indian Ocean and the cyclone was monitored since 21st May, about 10 days prior to the formation of low-pressure area over the southeast & adjoining east central Arabian Sea and Lakshadweep on 31st May. The cyclone was monitored with the help of available satellite observations and available ships & buoy observations in the region. The system was also monitored by Doppler Weather radar (DWR) Goa and Mumbai. Various numerical weather prediction models and dynamical-statistical models were utilized to predict the genesis, track, landfall and intensity of the cyclone. A digitized forecasting system of IMD was utilized for analysis and comparison of various models’ guidance, decision making process and warning products generation.

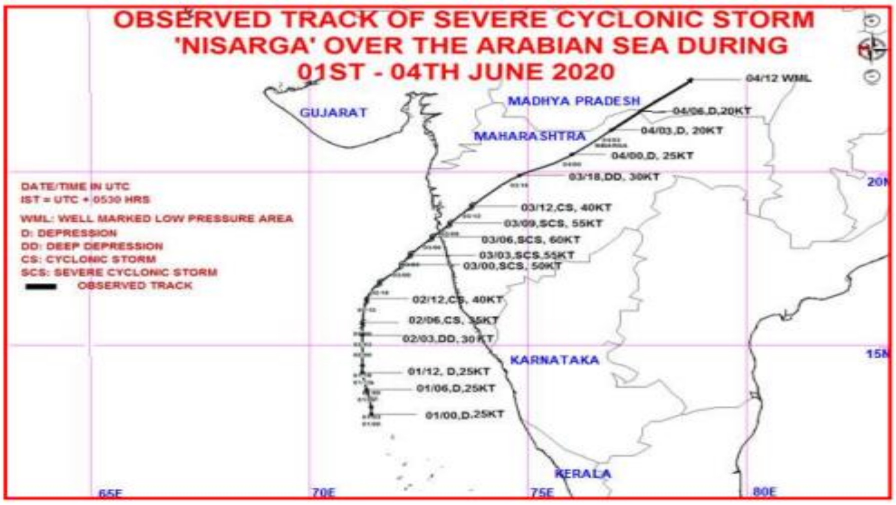


Figure 18: Observed track of SCS „NISARGA‟ over the eastcentral and adjoining southeast Arabian Sea

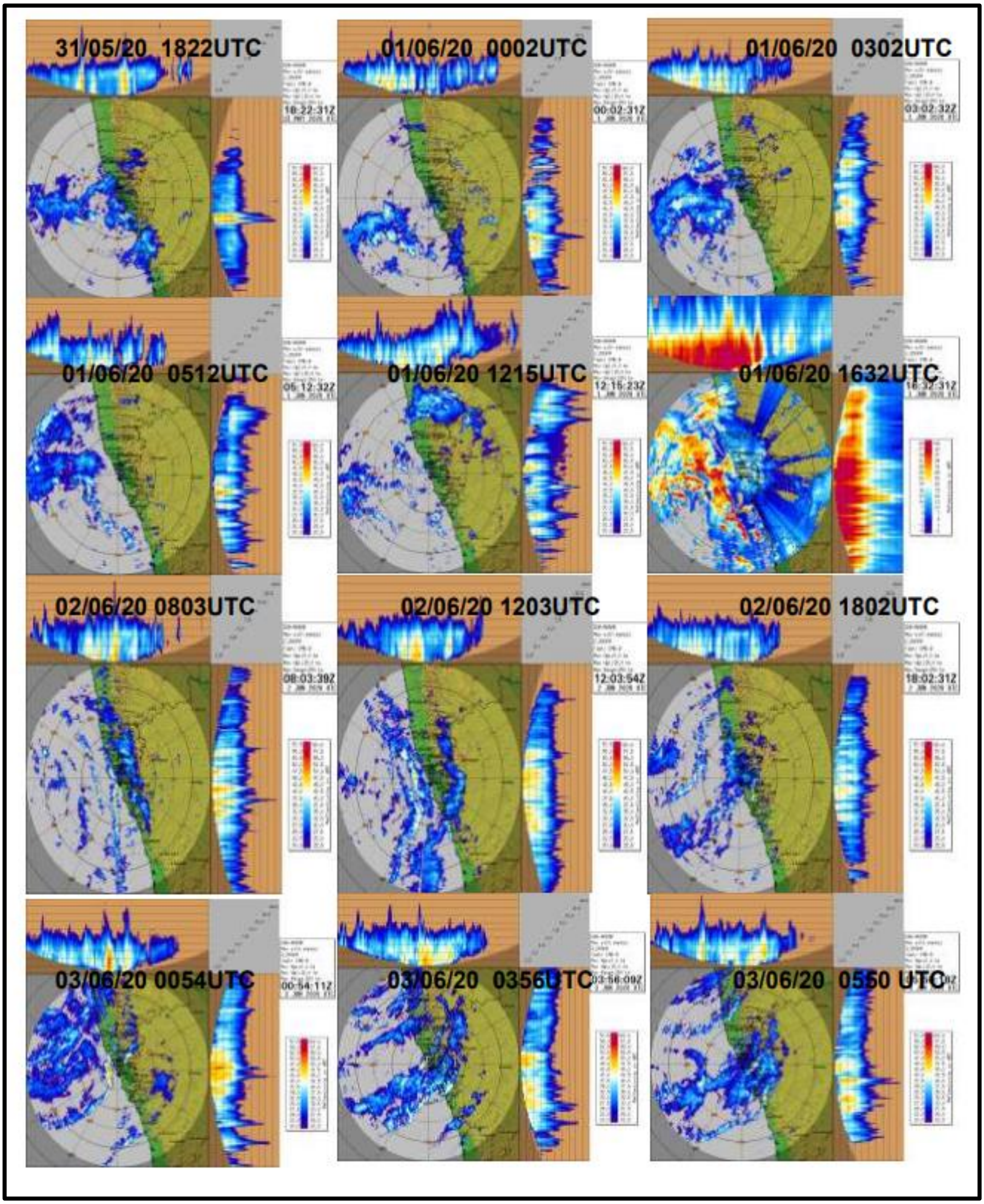


Figure 19:Typical Radar imagery from DWR GOA during 31May- 03 June of SCS NISARGA

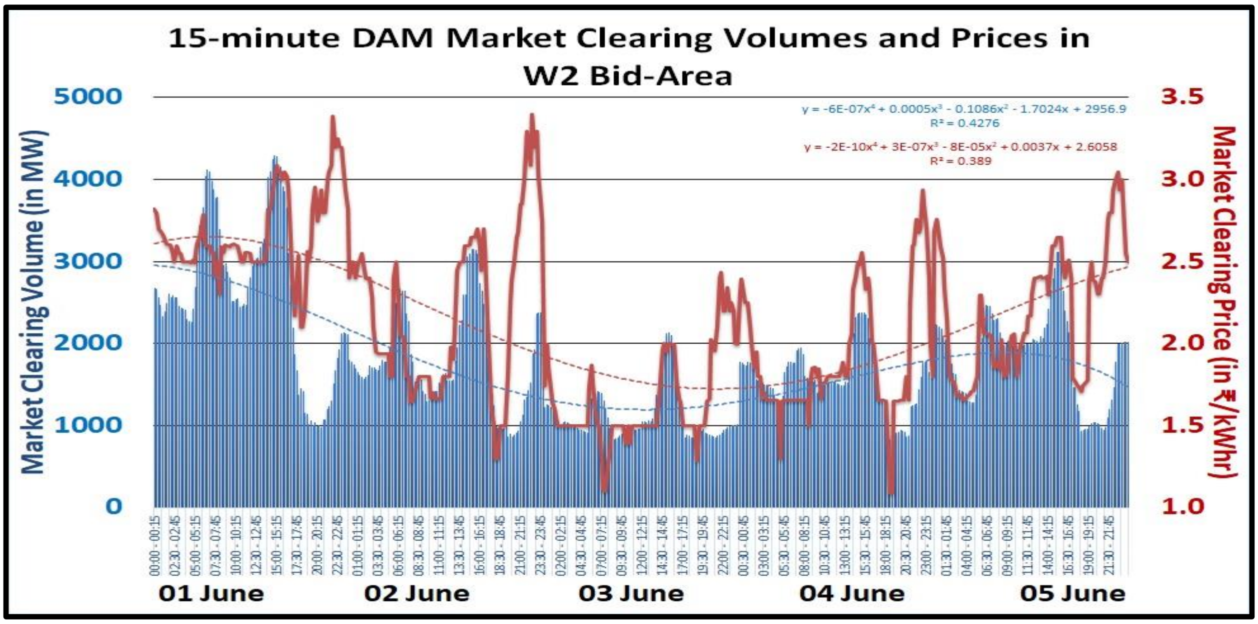


Figure 20:W2 Market Clearing Volumes and Prices for 01-05 June, 2020

Due to this cyclone, there was a total demand reduction of around 2000 MW in Gujarat and 200 MW in Mumbai area. There are 13 bid areas demarcated for congestion management in power exchanges. One of the bid-areas is W2 bid area comprising of states of Maharashtra, Gujarat, Daman and Diu, Dadar and Nagar Haveli and North Goa. As depicted in Fig. 20, the DAM market clearing volumes in W2 plummeted to around 1000 MW on 03rd June, 2020. Similarly, the market clearing prices also fell below ₹ 2/kWh on 03rd June, 2020 which is about 30 – 35 % lower than prices on other days.

Cyclone Tauktae"

1. IMD bulletin issued at 12:45 IST of 14th May 2021 provided the following information.

- "*The well-markedlow-pressure area over Lakshadweep area & adjoining southeast Arabian Sea moved east-northeastwards, concentrated into a Depression and lay centred at 0830 hours IST of today, the 14thMay, 2021 over Lakshadweep area near latitude 10.5°N and longitude 72.3°E, about 80 km south-southwest of Amini Divi, 360 km west-southwest of Kannur (Kerala), 1170 km south-southeast of Veraval (Gujarat). It is very likely to intensify into a Deep Depression during next 12 hours and into a Cyclonic Storm during subsequent 12 hours. It is very likely to intensify further. It is very likely to move initially north-*

northeastwards till today evening. It would then move northwestwards and reach near Gujarat coast by 18th May morning."

2. **Likely impact areas due to the influence of the Depression:** In aforesaid IMD bulletin, it was reported that under the influence of cyclone and further intensification, rainfall may occur on following locations:
   - **Kerala:** Light to moderate rainfall at most places with heavy to very heavy falls at a few places and extremely heavy falls (≥ 20 cm) at isolated places on 14th, heavy to very heavy falls at a few places 15th and heavy to very heavy falls at isolated places on 16th and 17th May.
   - **Tamil Nadu (Ghat districts):** Light to moderate rainfall at many places with heavy to very heavy falls & extremely heavy falls at isolated places very likely on 14th and heavy to very heavy falls at isolated places on 15th May.
   - **Karnataka** (coastal & adjoining Ghat districts): Light to moderate rainfall at most places with heavy to very heavy falls at a few paces with extremely heavy falls at isolated places on 14th and15th May and heavy falls at isolated places on 16th May.
   - **Konkan & Goa:** Light to moderate rainfall at a few places with heavy falls at isolated places very likely over Goa on 14th May, at most places with heavy to very heavy falls at a few places over south Konkan & Goa and heavy to very heavy falls at isolated places over north Konkan on 15th May and heavy falls at isolated places on 16th May.
   - **Gujarat:** Light to moderate rainfall at many places with heavy falls at isolated places very likely over coastal districts of Suarashtra on 16th May, at most places with heavy to very heavy falls at a few places on 17th May and with heavy to very heavy falls at a few places extremely heavy falls (≥ 20 cm) at isolated places over Saurashtra & Kutch on 18th May.
   - **Southwest Rajasthan:** Light to moderate rainfall at many places with heavy falls at isolated places very likely on 17th and18thMay.
3. **Track of Cyclone:** The cyclone was expected to reach Gujarat coast in intervening night hours of 17thand18th May 2021. The forecast track of cyclone was as given below (Figure 21):

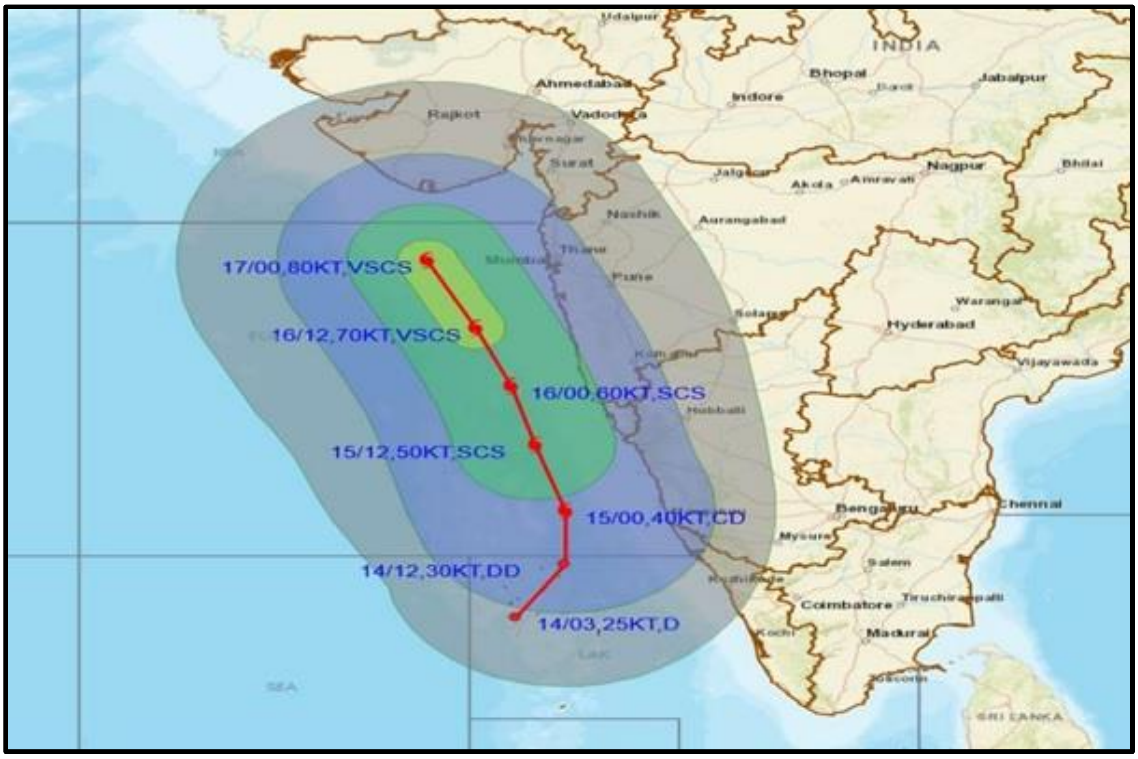


Figure 21: Source of coordinates is IMD

4. **Impact on System:** The likely affected area from infrastructure point of view is highlighted in power map of western region as per forecast track of cyclone (Figure 22).

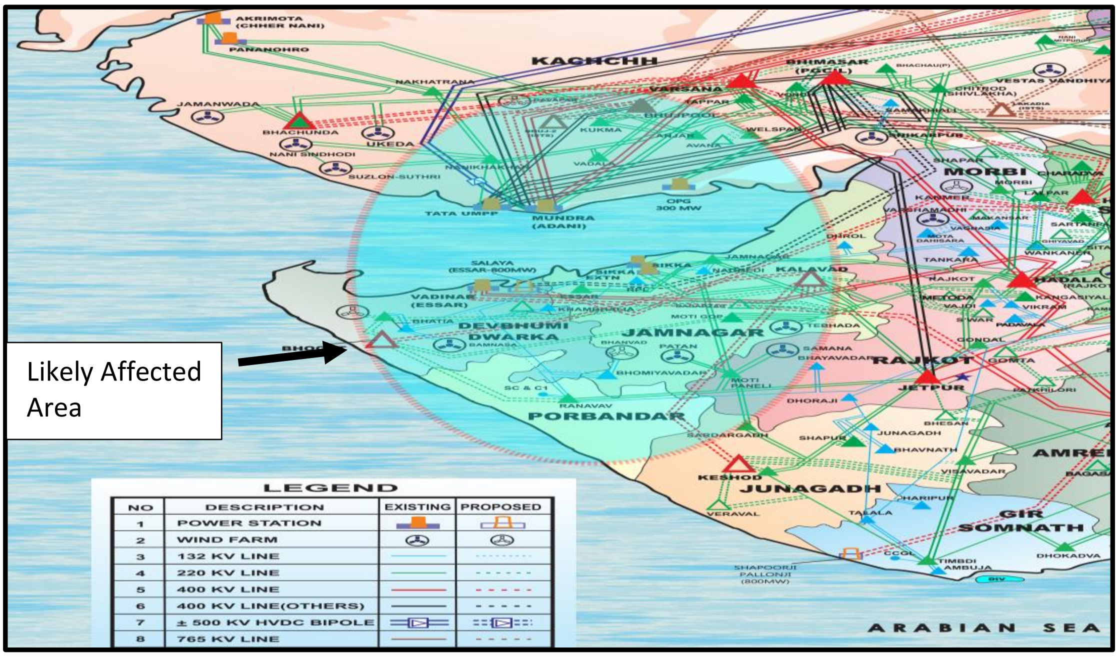


Figure 22:Likely Affected Area during cyclone Tauktae

Demand crash was expected to occur in Kerala, Tamil Nadu, Karnataka, Goa and Gujarat due to heavy rainfall and high speed of wind.

5. Generating stations, substations and transmission lines which were likely to come in affected area are given below:

- 765kV and 400kV Substations:
  - 765kv Bhuj, 400kv APLMundra, 400kv CGPL Mundra, 400 kV Jetpur
- 220kV Substations:
  - Nanikhakhar, Hadala, Kukma, Anjar, Jamnagar, Essar, Moti GOP, MOT Paneli, Ranavav, Shahpur
- Generating stations:
  - Thermal Stations: Essar (264 MW),SikkaTPS(190MW), KLTPS (80MW), Akrimota(60MW), BECL(150MW), APL Mundra(2868 MW) and CGPL Mundra (730 MW).
  - Wind Stations: Jamanwada, Nani Sindhodi, Ukeda, Suzlon Suthri ,Bamnasa, Patan, Samana, Tebhada, Wind stations connected to Bhuj(GIWEL-II, GIWEL-III, INOX, AWEK1, Gadhsisa, Alfanar)
- Important transmission lines
  - HVDC Mundra-MahendergarhBipole
  - 765kV Bhuj-Banaskanta D/C
  - 400 kV CGPL-Jetpur D/C
  - 400 kV CGPL-Bachau Q/C
  - 400 CGPL-Bhuj D/C
  - 400 kV APL Mundra – Sami D/C
  - 400 kV APL Mundra – Varsana D/C
  - 400 kV APL Mundra – Hadala
  - 400 kV APL Mundra – Charnaka

6. Above mentioned generating stations and substations are highlighted in the attached Power Map (Figure22). In case of outage of these stations, power supply was expected to get affected in Gujarat area. Further, power export to northern region by HVDC Mundra-Mahendergarh bipole was also expected to get affected.

In view of above, necessary actions like deployment of ERS (12 tower were set atDehgamand15 tower at Boisar) and related manpower, tools etc. were mobilized and all stakeholders were requested to remain alert for system restoration in case of any contingency.

5.2.7. Annular Solar Eclipse on 26th December 2019 and 21st June, 2020

The celestial phenomenon of annular solar eclipse was witnessed in India on 26th December 2019 and 21 June, 2020. During solar eclipse, the Sun is partially/fully covered by the Moon which results in reduction of irradiance received at ground level and subsequent increase in irradiance after peak of eclipse. This phenomenon directly impacts power generation from solar PV cells. As on date, India has significant penetration of solar capacity in grid and astronomical events such as solar eclipse have an impact on secure and reliable operation in electricity grid due to variations caused by solar eclipse. To understand the behaviour of solar radiation in the event of solar eclipse, solar radiation data for the month of January 2010 (last solar eclipse) of Trivandrum was obtained from India Meteorological Department (IMD). Further, based on various other research and experiments carried out it was concluded that during solar eclipse, reduction in total solar irradiance level is directly proportional to Solar irradiance during solar Eclipse. The data available at Positional Astronomy Centre, Kolkata (IMD) were extensively used to calculate the reduction/increase of solar generation across the country. Based on the Solar generation forecast provided by POSOCO, utilities planned their generation from conventional sources and from the market

The behaviour of market participants on 21st June 2020 solar eclipse is detailed below:

The solar eclipse started at 1056 hours in Gujarat and ended at 1429 hours in Assam. The northern regional states of Rajasthan, Delhi, Punjab, Western Uttar Pradesh and Uttarakhand witnessed the complete annular eclipse while other parts of India witnessed partial solar eclipse[14].The impact of solar eclipse was observed both on demand side (due to cultural factors) and supply side (due to ramp down/up effect on solar generation during eclipse).

[14] POSOCO, Solar Eclipse 21 June, 2020 Indian Power System likely impacts and preparedness, POSOCO, Delhi https://posoco.in/wpcontent/uploads/2020/06/Solar-Eclipse-dated-210620_likely-impactsand-preparedness-A-report.pdf

The all-India demand was less by 12 GW as compared to previous day because of the 'Sunday' effect. The all-India solar generation started reducing at 10:07 hours and touched a minimum value of around 7 GW at 1150 hours. Thereafter, solar generation again revived to around 16 GW by 1330 hours and subsequently followed its normal trend. The total solar generation reduction of around 11 GW was observed as compared to previous day.

The market participants, especially from N2 bid-area comprising of Uttar Pradesh, Uttaranchal, Rajasthan and Delhi factored the ramping down in solar generation from 1000 hrs to 1200 hrs and consequent ramping up till 1330 hrs with corresponding variation in procurement from DAM in power exchanges from around 200 MW to 1400 MW as depicted in Fig. 20. There was also corresponding increase in market clearing prices for the period by almost 200 %. In the RTM, the prices surged to almost 150 % of DAM prices at the start of the eclipse and slumped to almost 20 % of the DAM prices towards the end of eclipse.

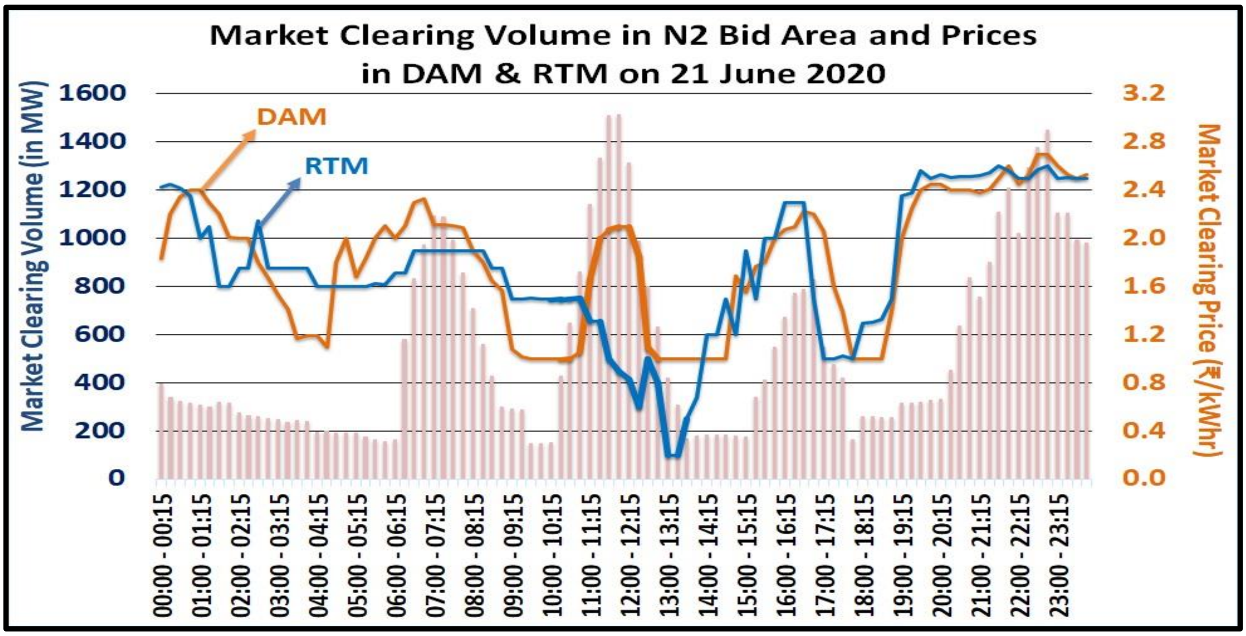


Figure 23: N2 Market Clearing Volumes and Prices on 21 June 2021

5.2.8. Utilization of Weather Warning for Power Purchase/Sell

India meteorological Department issued a weather warning on 28thMay 2021 for 28th May 2021 to 1st June 2021 (Figure 24). The details of the weather warning from 28th May '21 to 01st June '21aregiven below:

28th May (Day 1):

- Thunderstorm with lightning & squall (speed reaching 50-60 kmph) very likely at isolated places over East Uttar Pradesh; with lightning & gusty winds (speed reaching 40-50 kmph) at isolated places over Bihar; with lightning & gusty wind (speed reaching 30-40 kmph) at isolated, places over East Rajasthan, Kerala & Mahe, Telangana, Andaman & Nicobar Islands, Sub-Himalayan West Bengal & Sikkim, Jharkhand, Madhya Maharashtra, Marathwada, Vidharbha and West Madhya Pradesh and with lightning at isolated places over Lakshadweep, Coastal & North Interior Karnataka ,Gangetic West Bengal and Konkan & Goa.
- Thunderstorm/Duststorm (speed reaching 40-50 kmph) likely at isolated places over West Rajasthan.
- Heat Wave conditions very likely at isolated places over West Rajasthan and north Coastal Andhra Pradesh.
- Heavy to Very Heavy Rainfall with Extremely Heavy Falls at isolated places very likely over East Uttar Pradesh, Sub-Himalayan West Bengal & Sikkim and Bihar and Heavy Rainfall at isolated places over Andaman & Nicobar Islands and Jharkhand.
- Squally Weather (wind speed 40-50 kmph) very likely to prevail over Southwest, West central& Northwest Arabian Sea and over Gulf of Mannar and Comorin-Maldives area and south Sri Lanka coasts. Fishermen are advised not to venture into these areas.

29 May (Day 2):

- Thunderstorm with lightning & gusty winds (speed reaching 40-50 kmph) very likely at isolated places over East Rajasthan; with lightning & gusty winds (speed reaching 30-40 kmph) at isolated places over Kerala & Mahe, Telangana, Andaman & Nicobar Islands, Madhya Maharashtra, Marathwada and Vidarbha and with lightning at isolated places over Uttarakhand, Lakshadweep, Coastal Karnataka, Coastal Andhra Pradesh, Jharkhand, Konkan & Goa, Chhattisgarh and Assam & Meghalaya.

- Thunderstorm/Duststorm (speed reaching 40-50 kmph) likely at isolated places over West Rajasthan.
- Heat Wave conditions very likely at isolated places over West Rajasthan and north Coastal Andhra Pradesh.
- Heavy Rainfall at isolated places very likely over Kerala & Mahe, Sub-Himalayan West Bengal & Sikkim and Bihar.
- Squally Weather (wind speed 40-50 kmph) very likely to prevail over Southwest, West central& Northwest Arabian Sea and over Gulf of Mannar and Comorin-Maldives area and south Sri Lanka coasts. Fishermen are advised not to venture into these areas.

30May (Day 3):

- Thunderstorm with lightning & gusty winds (speed reaching 40-50 kmph) very likely at isolated places over East Rajasthan; with lightning & gusty winds (speed reaching 30-40 kmph) at isolated places over Uttarakhand, Punjab, Haryana, Chandigarh & Delhi, Kerala & Mahe,Telangana, Andaman & Nicobar Islands, Sub-Himalayan West Bengal & Sikkim, Odisha, Madhya Maharashtra, Marathwada and Vidarbha and with lightningat isolated places over Tamil Nadu, Puducherry &Karaikal, Lakshadweep, Karnataka, Coastal Andhra Pradesh &Yanam, Rayalaseema, Gangetic West Bengal, Jharkhand, Konkan & Goa, East Madhya Pradesh, Chhattisgarh, Arunachal Pradesh and Assam & Meghalaya.
- Thunderstorm/Duststorm (speed reaching 40-50 kmph) likely at isolated places over West Rajasthan.
- Heavy Rainfall very likely at isolated places over Kerala & Mahe, Coastal Andhra Pradesh &Yanam, Sub-Himalayan West Bengal & Sikkim and Assam &Meghalaya.
- Squally Weather (wind speed 40-50 kmph) very likely to prevail over Southwest, Westcentral& Northwest Arabian Sea. Fishermen are advised not to venture into these areas.

31 May (Day 4):

- Thunderstorm with lightning & gusty wind (speed reaching 40-50 kmph) likely at isolated places over East Rajasthan; with lightning& gusty wind (speed reaching 30-40 kmph) at isolated places over Uttarakhand, Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh, Tamil Nadu,Puducherry &Karaikal, Kerala & Mahe, North Interior Karnataka, Telangana, Andaman & Nicobar Islands, West Bengal & Sikkim, Odisha, Jharkhand,Madhya Maharashtra, Marathwada, Vidarbha and Assam & Meghalaya and with lightning at isolated places over Himachal Pradesh, Jammu & Kashmir,Ladakh, Gilgit-Baltistan & Muzaffarabad, Lakshadweep, Coastal & South Interior Karnataka, Coastal Andhra Pradesh &Yanam, Rayalaseema, Konkan &Goa, East Madhya Pradesh, Chhattisgarh, Arunachal Pradesh and Nagaland, Manipur, Mizoram & Tripura.
- Thunderstorm/Duststorm (speed reaching 40-50 kmph) likely at isolated places over West Rajasthan.
- Heavy to Very Heavy Rainfall at isolated places likely over Assam & Meghalaya and Heavy Rainfall at isolated places over Kerala & Mahe, Sub-Himalayan West Bengal & Sikkim and Arunachal Pradesh.
- Squally Weather (wind speed 40-50 kmph) very likely to prevail over Southwest, Westcentral& Northwest Arabian Sea. Fishermen are advised not to venture into these areas.

01 June (Day 5):

- Thunderstorm with lightning & gusty wind (speed reaching 40-50 kmph) likely at isolated places over East Rajasthan; with lightning& gusty wind (speed reaching 30-40 kmph) at isolated places over Uttarakhand, Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh, Tamil Nadu, Puducherry &Karaikal, Kerala & Mahe, North Interior Karnataka, Telangana, Andaman & Nicobar Islands, Gangetic West Bengal, Odisha, Jharkhand,Madhya Maharashtra, Marathwada, Vidarbha and Assam & Meghalaya and with lightning at isolated places over Himachal Pradesh, Jammu & Kashmir, Ladakh, Gilgit-Baltistan & Muzaffarabad, Lakshadweep, Coastal & South Interior Karnataka, Coastal Andhra Pradesh &Yanam, Rayalaseema, Konkan &Goa, East Madhya Pradesh, Chhattisgarh, Arunachal Pradesh and Nagaland, Manipur, Mizoram & Tripura.

- Thunderstorm/Duststorm (speed reaching 40-50 kmph) likely at isolated places over West Rajasthan.
- Heavy Rainfall likely at isolated places over Assam & Meghalaya.
- Squally Weather (wind speed 40-50 kmph) very likely to prevail over Southwest, Westcentral& Northwest Arabian Sea. Fishermen are advised not to venture into these areas.

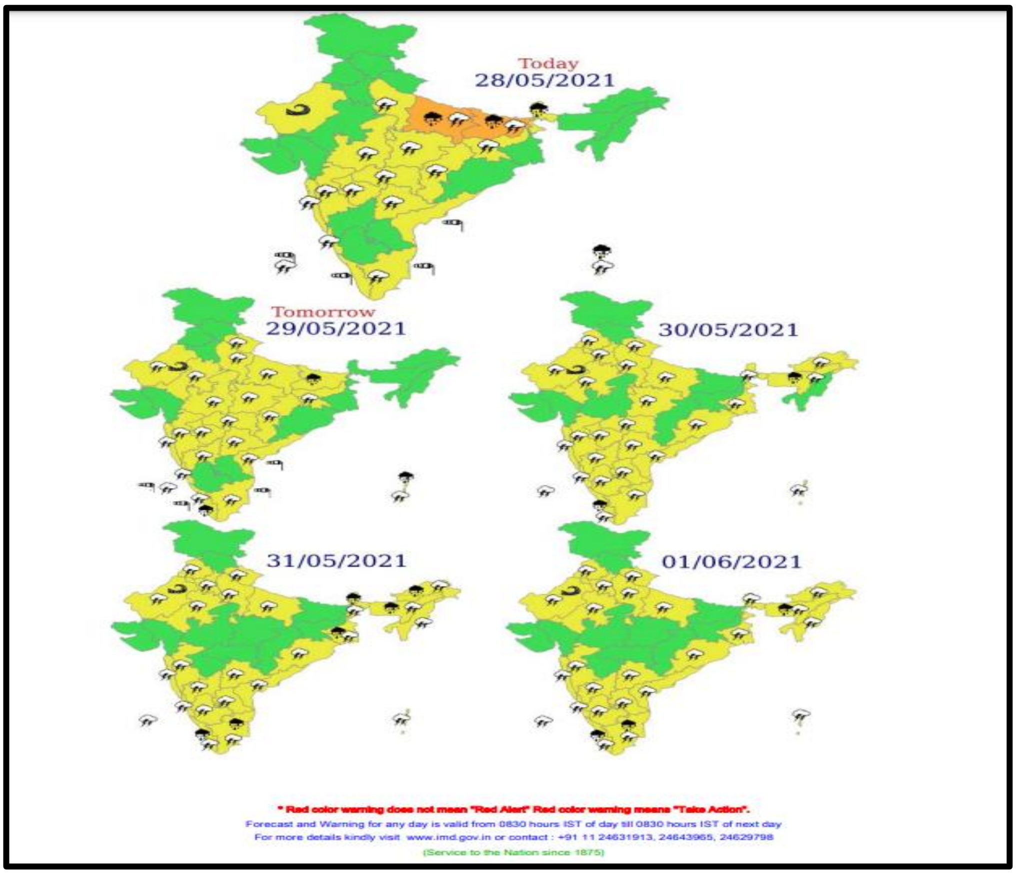


Figure 24: All India Weather Warning

Based on the above warning, it may be observed that there was forecast of thunderstorm, lighting and heavy to very heavy rainfall at Northern, Southern, Eastern and North Eastern regions from 29th May to 01st June 2021.Accordingly, the concerned constituents started reviewing their expected load and generations and other sources of supply that may have to be reduced or sold outside for these periods. In addition to satellite-based weather warning, live radar imagery helped the states in sending timely requests to SLDC / RLDC for revision of schedule for backing down of generating stations in anticipation of thunderstorms/ rain, which greatly helped in avoiding huge under drawl of power thereby also ensuring grid security.

Northern Region:

The Northern Region (NR) experienced a demand crash during 21:45hours on 31stMay, 2021 onwards on account of thunderstorm/lightning accompanied with gusty wind. The event details are summarized below:

The load of NR started reducing after 21:45hours of 31.05.2021and dropped by 18.2GWin as pan of 6hours 33minutes. At 04:18hours of 01.06.2021, load of NR was minimum and thus, load started picking up after 06 hours 33 minutes from the start of load crash.

The details of Power Purchase /Sell from power exchange by states during these periods are given below:

Delhi:

Delhi meets its demand from its ISGS share and own generating stations and any further deficit/surplus of generation is balanced through purchase/sale in power exchange. The Power Purchase/Sell by Delhi state in Day Ahead Market and Real Time Market from 25thMay 2021 to 05th June 2021 are given in Figure 25 below.

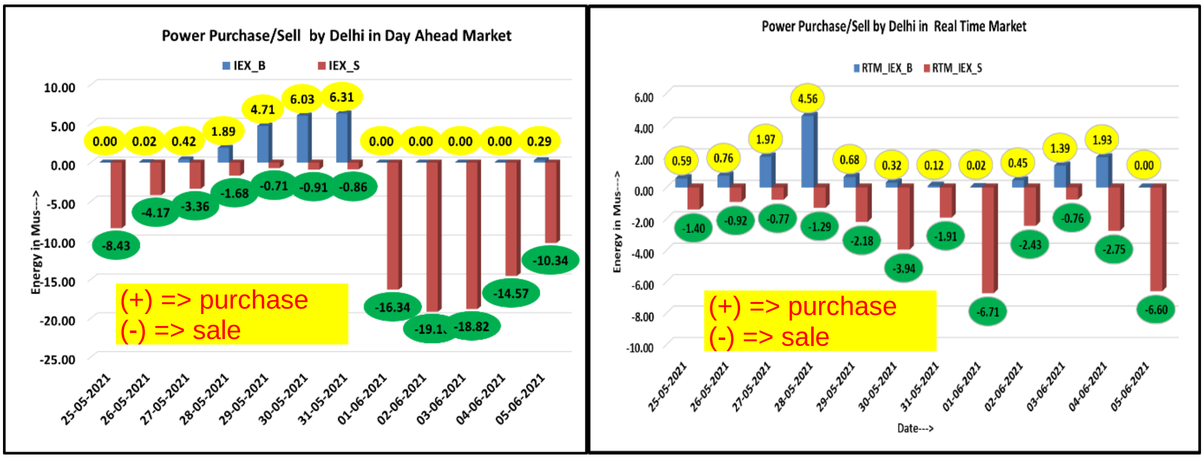


Figure 25:Power Purchase/Sold by Delhi in Power Exchange

As per above graphs of power transactions, it may be observed that during 28th May 2021 to 31st May 2021Delhi purchased power in Day ahead market and RTM on an average of 5 Mus/day and 1.42 Mus/day, respectively and it also sold the power on an average of 1.4 Mus/day and 2.3 Mus/day in DAM and RTM exchange, respectively. There was weather warning of thunderstorm, lighting and heavy to very heavy rainfall in Northern part of India from night of 31st May 2021 onwards. Based on the weather warning, Delhi anticipated that their demand would be on lower side from the night of 31st May 2021 to 4th June 2021 and accordingly they sold the excess available power of around 17Mus per day from 1st June to 4th June 2021 in DAM Power exchange.

In line with anticipated weather conditions., Delhi Demand started reducing after 23:20 hours on 31st May, 2021 and maximum reduction was to the tune of 1600 MW on 1st June,2021 (Figure 26). During the time of maximum load crash, Delhi was under drawing around 500 MW-1000 MW from the grid and it used RTM platform to sell surplus available power i.e., 1.91 Mus on 31st May, 6.71 on 01st June and 2.43 on 2nd June, 2021.

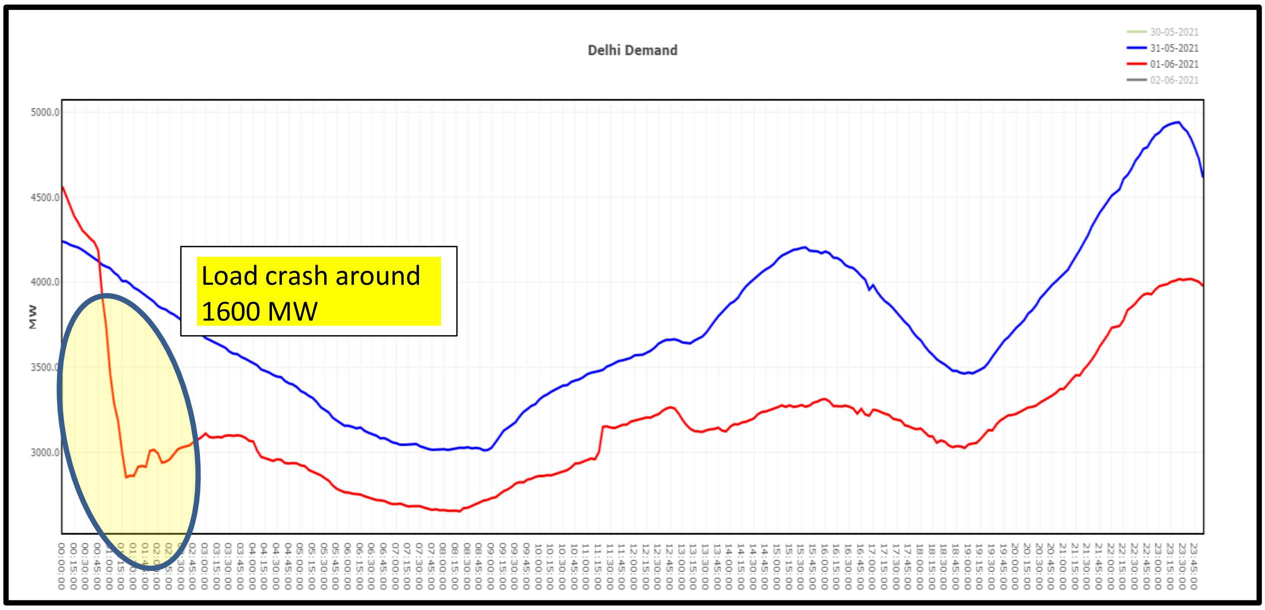


Figure 26: Delhi Load Crash on 31st May and 1st June 2021

Therefore, it is quite evident that using the weather warning, Delhi avoided purchasing any costly power and further sold the surplus generation through power exchange and could thus manage its portfolio in the most optimum manner.

Haryana:

As per weather warning, Haryana anticipated that their demand would be in lower side from 30th May,2021 to 1st June,2021 as compared to normal day, i.e., 29th May, 2021.Load crash in Haryana on 31st May and 1st June 2021 is given in Figure 27 below.

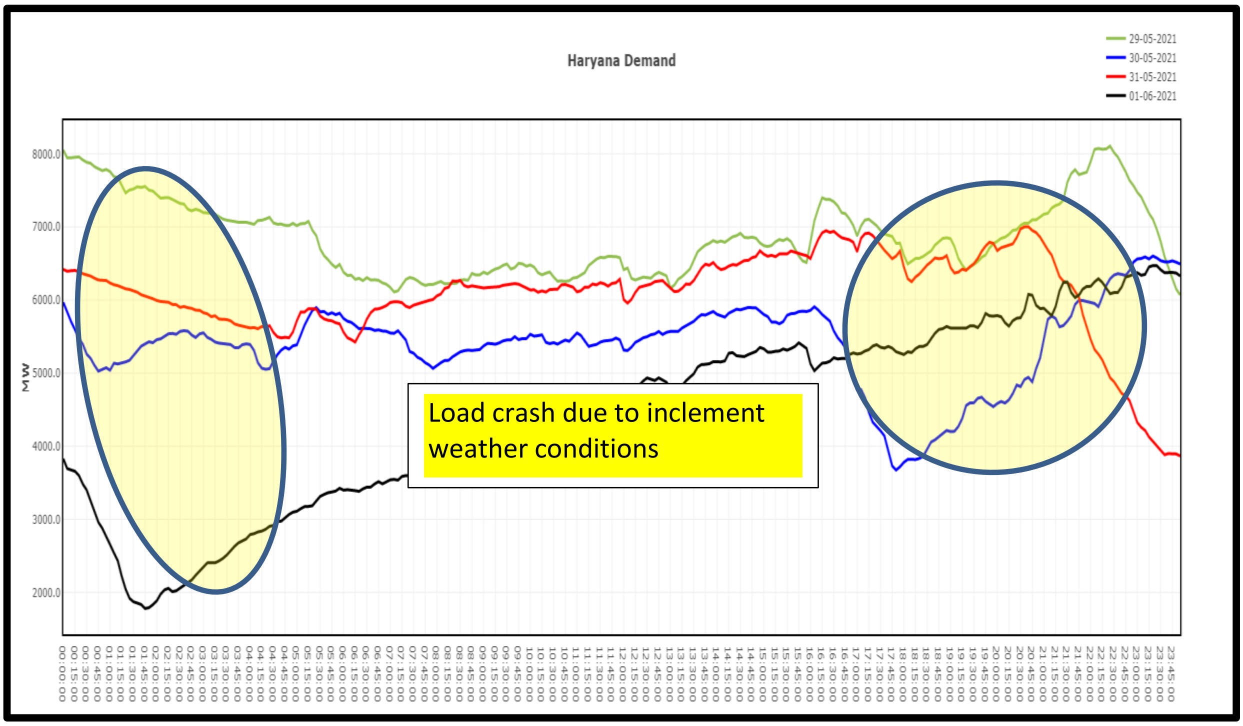


Figure 27:Haryana Load Crash on 31st May and 1st June 2021

The Power Purchase/Sale by Haryana state in Day Ahead Market and Real Time Market from 25thMay 2021 to 05thJune 2021 are given in Figure 28 below:

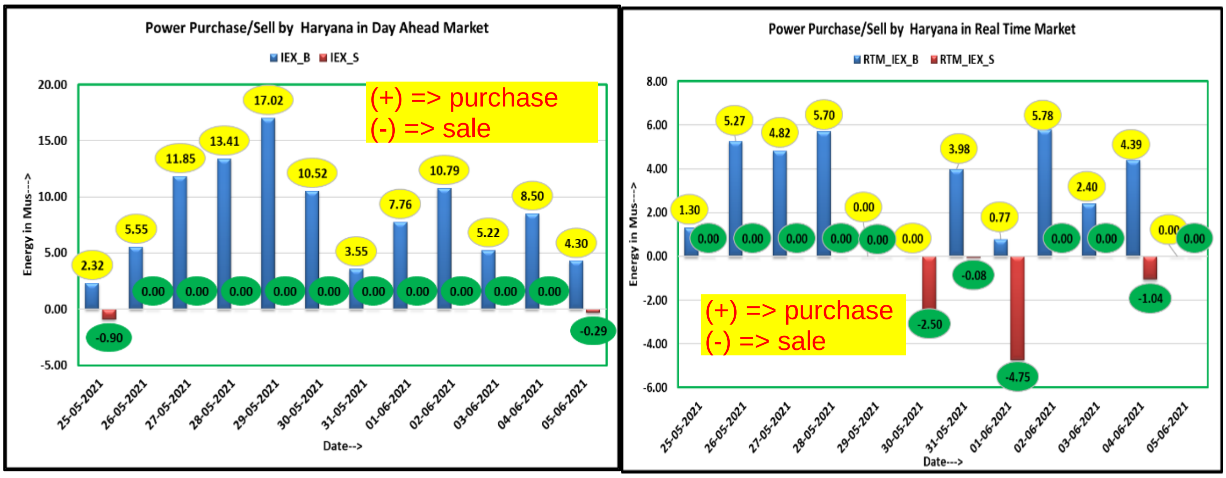


Figure 28:Power Purchase/Sell by Haryana in Power Exchange

As per above graph of power transactions, it may be observed that Haryana reduced their power purchase from power exchanges compared to any normal day. The average power purchased by Haryana state in power exchange during 27thMay 2021 to 29th May 2021(before weather warning) was around 14.00 Mus per day which was reduced by 50%, i.e., around 7 Mus per day. Further it also sold its surplus power of around 2.40 Mus per day in DAM / RTM exchange thus achieving economy in despatch.

Himachal Pradesh:

The Power Purchase/Sell by Himachal Pradesh state in Day Ahead Market and Real Time Market from 25th May 2021 to 05th June 2021 are given in Figure 29 below:

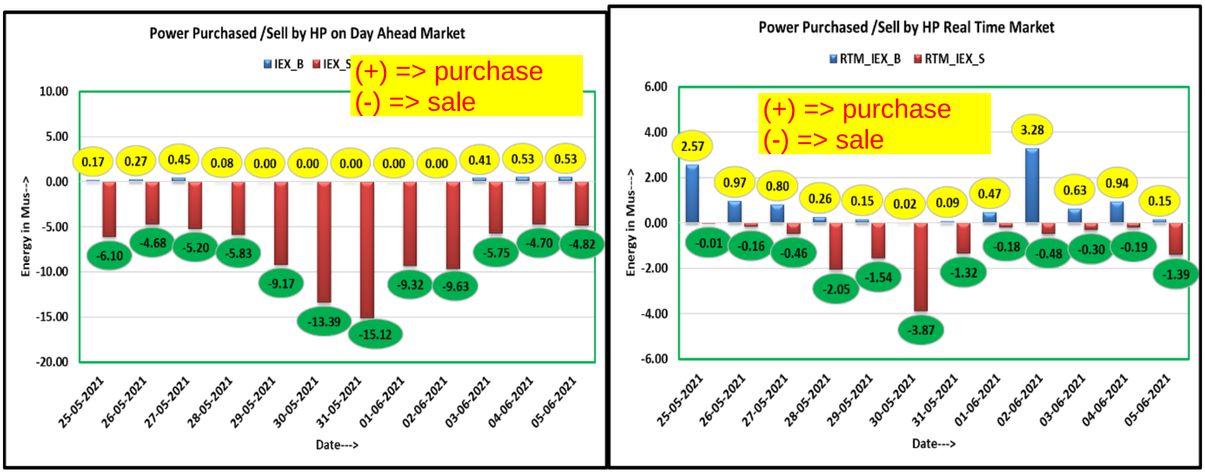


Figure 29:Power Purchase/Sell by Himachal Pradesh in Power Exchange

It may be observed from above graph of power transactions that Himachal Pradesh also utilized weather warning issued by IMD and sold surplus power into power exchange. Before inclement weather conditions (25th May to 28th May 2021),Himachal Pradesh was selling around 5.45 Mus per day in power exchange but during inclement weather conditions, due to further drop in demand, Himachal Pradesh sold surplus power to the tune of 11.75 MU/day in power exchange.

Jammu and Kashmir (UT) and Ladakh (UT):

The Power Purchase/Sale by J&K (UT) in Day Ahead and Real Time Market from 25th May 2021 to 05th June, 2021 are given in Figure 30 below:

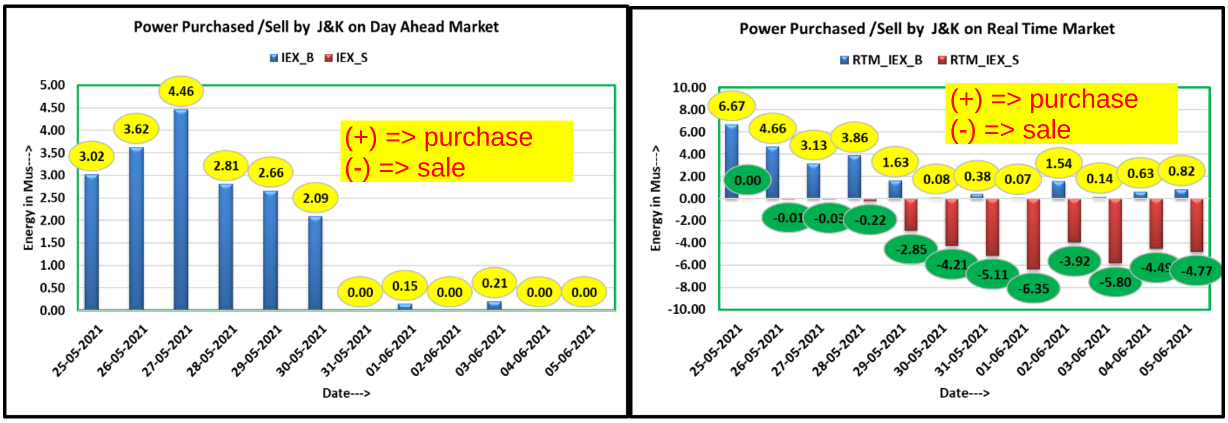


Figure 30:Power Purchase/Sell by J&K(UT) in Power Exchange

J&K(UT) also utilized weather warning issued by IMD and did not purchase power during inclement weather conditions. However, it sold surplus power in power exchange. J&K (UT)was purchasing around 3 Mus in power exchange before inclement weather conditions i.e., 25th May to 28th May, 2021. However, during inclement weather conditions, it sold surplus power of 4 Mus/day in the power exchange.

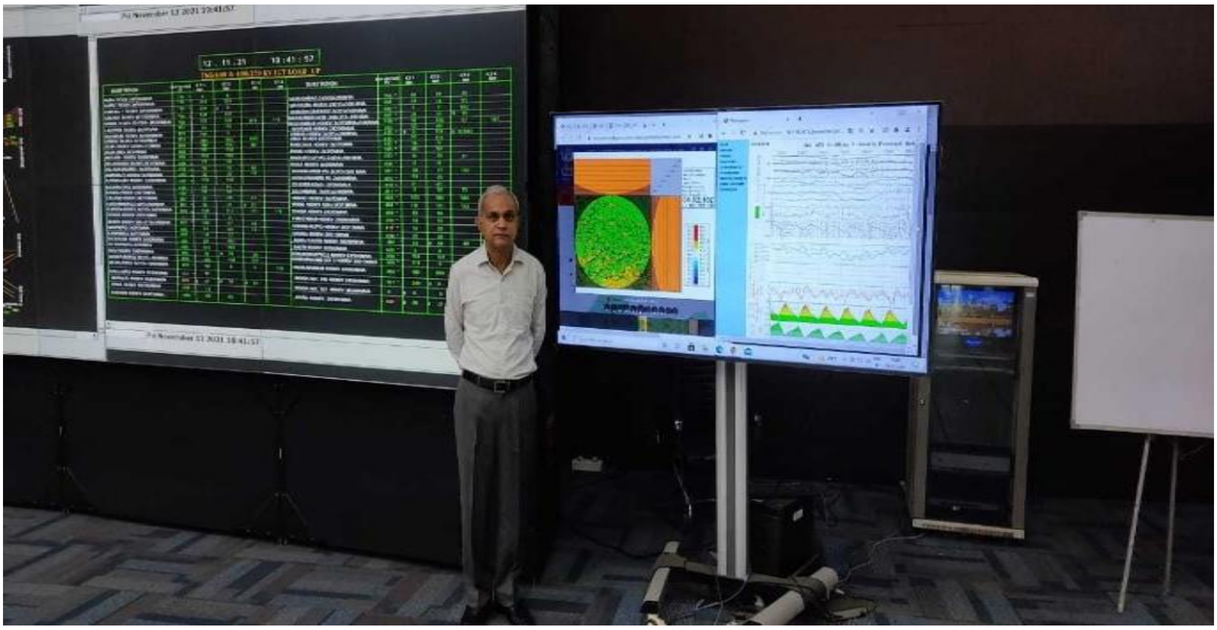


Figure 31:Dedicated screen for weather monitoring at State load despatch Centre, Lucknow

5.2.9. Utilization of weather information by BRPL:

The Delhi's Discom BRPL was able to take proactive action to minimize its drawl from the grid and purchases from power exchange/bilateral contracts, based on the weather information obtained from IMD website. At BRPL, Day Ahead and Intraday demand forecast is done by AI and ML techniques (Artificial Intelligence and Machine Learning) which are data-driven techniques used to model complex relationships between inputs and outputs. The basis of machine learning is mostly statistical. Combinations of ensemble models are used for generating the best output. The input which goes into these forecasting tools are the historical data and historical and current weather parameters.

Meteograms published by IMD helps in Day Ahead demand forecasting which in turn leads to optimal use of available resources (generation) by way of practising Reserve Shut down options (RSD), balanced sale/purchase option in Day ahead Market (DAM)/ Real Time Market (RTM) etc. Further, the 3 hrs ahead weather advisory and live feeds of radar imagery finds its usefulness on volatile days in predicting changes in demand, based upon the intensity and approximate time of weather disturbances such as rainfall and thunderstorm as per radar imagery. The discom made significant savings by utilising weather portal. BRPL used meteogram to predict the increasing temperature and therefore anticipate the increase in demand, based on which requests were made to SLDC Delhi to bring additional generating units on bar. This also helped the Discom in following merit order despatch, by avoiding costly power purchase from power exchange during peak summer. During monsoon season, based upon prediction for thunderstorm/rainfall as per meteogram, decisions were made to reduce purchases from exchange/bilateral contracts while incorporating the above input in the Day Ahead demand forecasting. In addition to meteogram, live radar imagery helped BRPL in predicting reduction in intraday demand based on which timely revisions of its schedule were sent to SLDC for backing down of generating stations in anticipation of thunderstorms/ rain. By this action BRPL avoided under drawl of power, optimised distress sale on RTM and also ensured grid security. Further, it has helped System Operators in BRPL to minimize longer duration outages by way of putting off the feeders with less clearance, which are suspected to get damaged severely due to gusty winds and thunder storm. A few occasions where savings were made by the discom are as follows:

S.no	Date	A=Energy quantum backed down (Mus)	B=Average Market Clearing Price in Power Exchange (RTM) (Rs. /MWh)	Total Saving in Rs. C=A*1000*B
1	10/06/2020	0.93	2392.80	22,23,388
2	20/06/2020	1.51	1906.98	28,78,851
3	29/06/2020	0.87	4151.70	36,07,080
4	05/07/2020	0.91	881.21	8,01,339
5	30/05/2021	0.36	2773.41	10,06,603
6	01/06/2021	0.71	1632.03	11,52,106
7	04/06/2021	0.22	4661.90	10,29,488
8	02/07/2021	0.61	2671.27	16,28,565
			Total Saving in Rs.	1,43,27,420

System Control room of BRPL

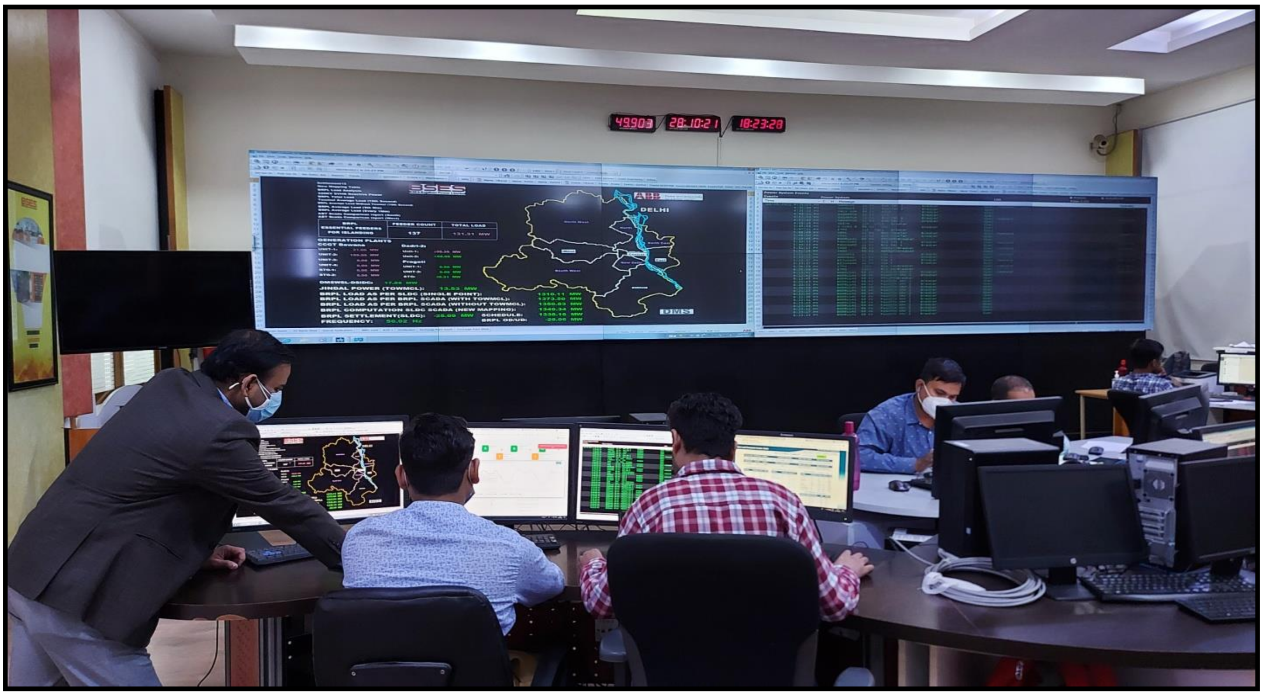


Figure 32:Dedicated weather monitoring at BRPL control Centre, Delhi

The details shared by BRPL is enclosed as **Annexure-VII**

Utilization of Weather Information by **North Eastern Region**

Since inception of the Weather Portal, NERLDC is using the portal of North Eastern Region for Real-Time Grid Management and the same is made available as a separate TAB in NERLDC website for easy reference.

3-HourlyIMD data is used for forecast weather report preparation in line with Load Forecast on a (D+2) basis. The same, report is used in Real-time Grid Management.

Usage of weather portal of North Eastern Region by NERLDC is mentioned below:

- Regional weather forecast report (**Annexure-VIII)** is mailed to all the SLDCs, ISGSs for taking appropriate measures on Daily Basis.
- Nowcast data of 7 (seven) cities are available as of now which are monitored from time to time.
- 3 hours forecast maximum temperature, relative humidity and rainfall data are used by the system operators of NERLDC for hydro dispatch scheduling and as well as mailed to all the SLDCs for computation of load forecast and ISGSs for generation planning on daily basis.

6. Way Forward

- Weather Forecast for integrating Renewable generation: Accurate weather forecasting is crucial for integrating wind and solar power generating resources into the grid, especially at high penetration levels.

  For weather-dependent renewable generators, like solar and wind power plants, the most critical scheduling input comes from weather forecasting data. A power generation forecast is a combination of plant availability and weather forecasts for the location.

  Advanced weather forecasting methods uses, artificial intelligence (AI) and big data, to analyse real time observations and historical weather data and make predictions. In fact, advanced weather forecasting is one of the main applications of AI in facilitating and improving RE integration

  Improving RE generation forecasts on short term and long-term timescales engenders a diverse set of benefits for various stakeholders in the power sector. At short timescales, accurate VRE generation forecasting can help asset owners and market players to better bid in the electricity markets, where applicable. Bids based on more accurate forecasts would reduce the risk of incurring penalties for imbalances (i.e. for not complying with the generation offered in the bid). For power system operators, accurate short-term VRE generation forecasting can improve unit commitment (operation scheduling of the generating units) and operational planning, increase dispatch efficiency, reduce reliability issues and, therefore, minimise the amount of operating reserves needed in the system.

  Over longer timescales (e.g. over days or seasons), improved VRE generation forecasting based on accurate weather forecasting brings significant benefits to system operators, especially when planning for extreme weather events. By contributing to the allocation of appropriate balancing reserves, long-term weather forecasting assists in ensuring safe and reliable system operations. It can also help in better planning the long-term expansion of the system, both generation and network transmission capacity, needed to efficiently meet future demand. Therefore, weather variables forecast and real time observations may be provided to meet the challenges posed by large integration of RE generators.

- Optical fibre of POWERGRID is available at IMD Lodhi Road office and at POSOCO, Katwaria sarai office. Hence, possibility of data sharing from IMD to NRLDC/NLDC control room may be explored for secure sharing of weather data .
- Thunderstorm monitoring system is being used by control centers for real time weather monitoring and is helping system operators for better system operation. The thunderstorm monitoring system has 6 layers at present namely Lightening, Radar reflectivity, wind at 1 km altitude; Satellite derived clouds & district boundaries. The Shape file of transmission network shared by POSOCO may be included as a layer in the Thunderstorm monitoring system and the same may be made as part of Weather Portal for power sector. Layers of Cyclone tracking and real time FOG status may also be included as a layer.
- Customised weather bulletin for power sector may be generated at every 6 hours.
- Availability of snowfall forecast and real time observations of hilly states and along the route of important transmission lines such as Leh-Srinagar transmission system, and 300 kV upcoming HVDC transmission system to evacuate solar generation from Leh. This would be helpful to the system operators for better operational planning and handling contingencies.

7. Testimonials from Himachal Pradesh and Uttar Pradesh

Himachal Pradesh

"This has reference to the trailing email dated 24.08.2021 regarding Sharing of Utilization and Benefit from Weather Portal for Power Sector, in this regard it is submitted that Weather Power Portal is being utilized for ascertaining generation/load based upon weather pattern in different area of HP State. Hence, it is quite beneficial".

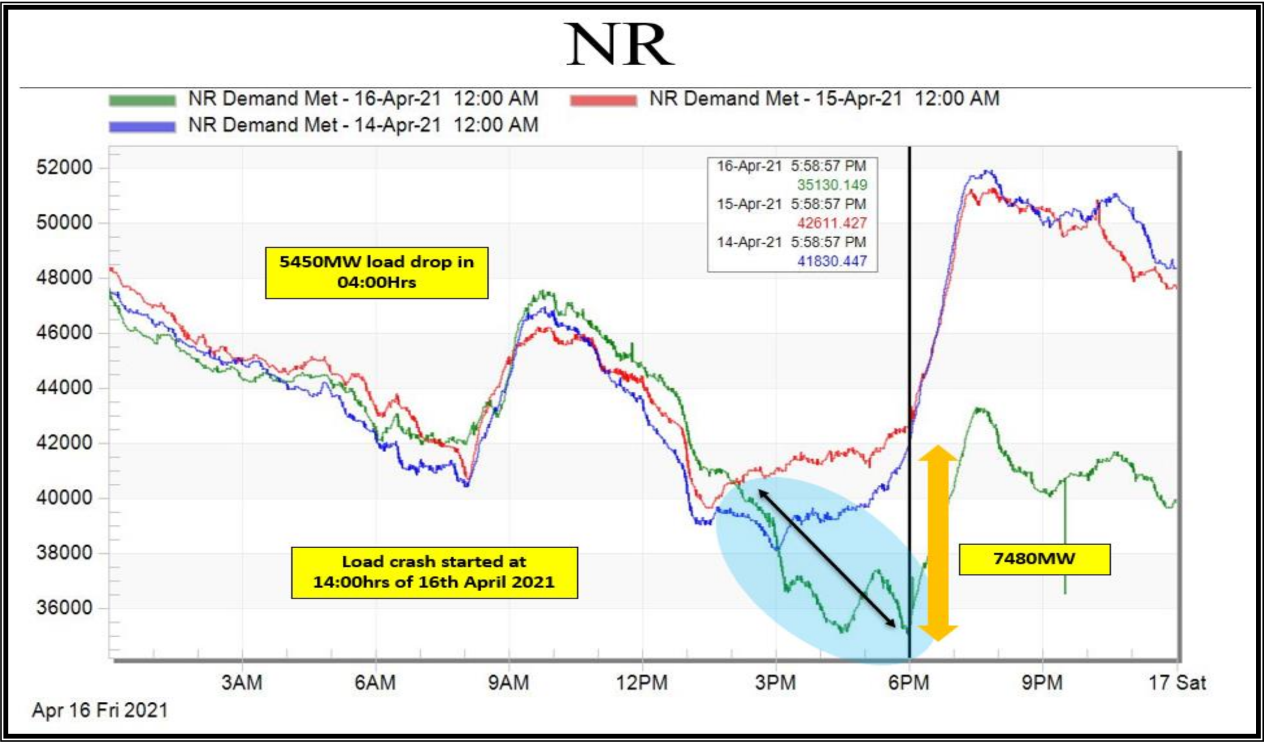
Uttar Pradesh:

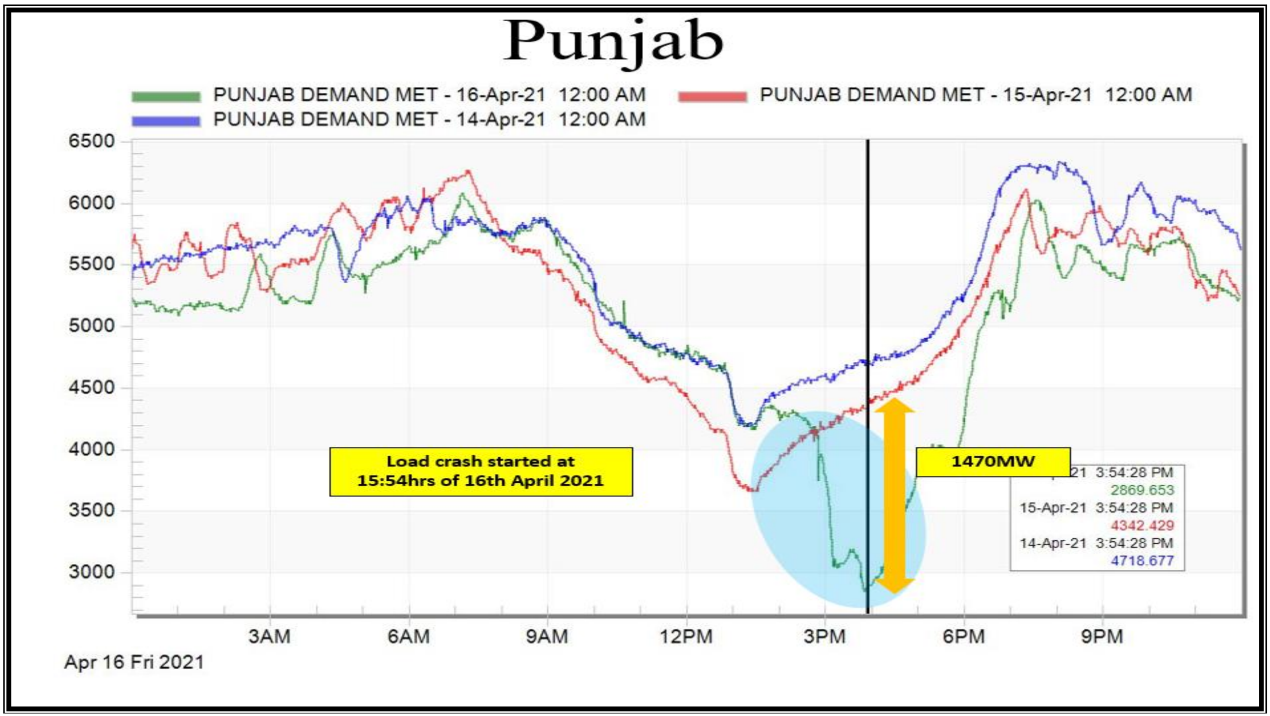
"IMD weather portal is highly useful especially its meteogram, nowcast, Radar visibility and wind speed.

Real time Grid operation, RTM integration and demand is now completely dependent on forecast. At SLDC level decision making is being done on the basis of the IMD portal itself. It is now a need for grid operation."

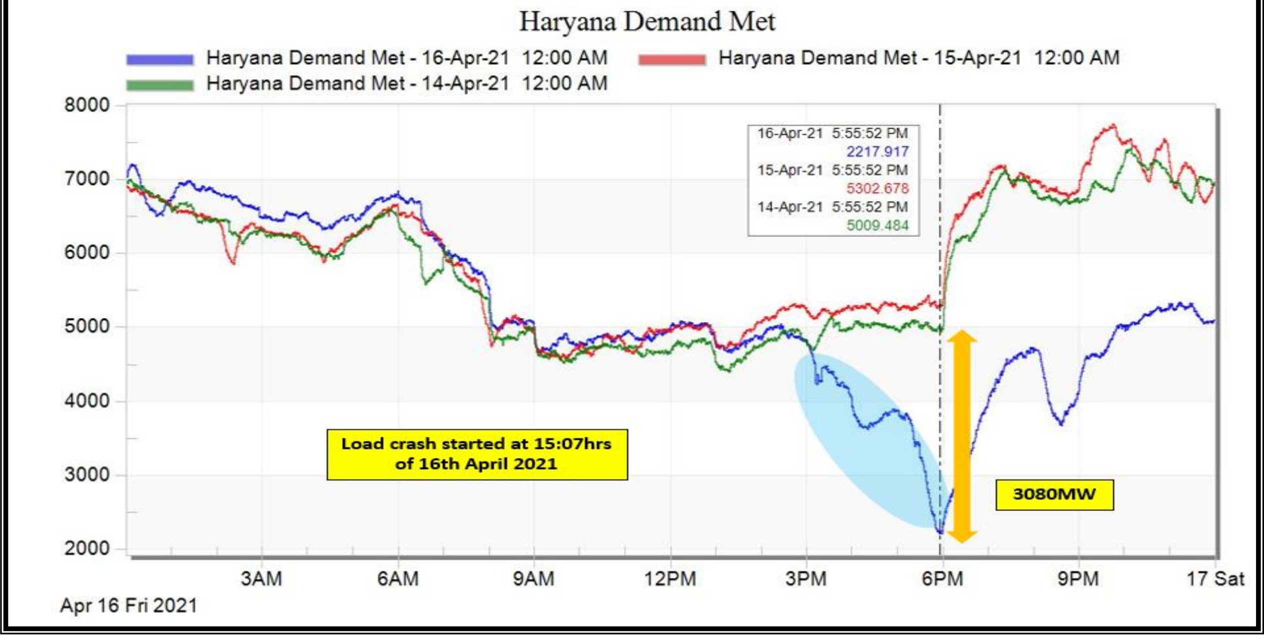
Annexure-I

Northern Region and States Demand Pattern for (14-16 April 2021)

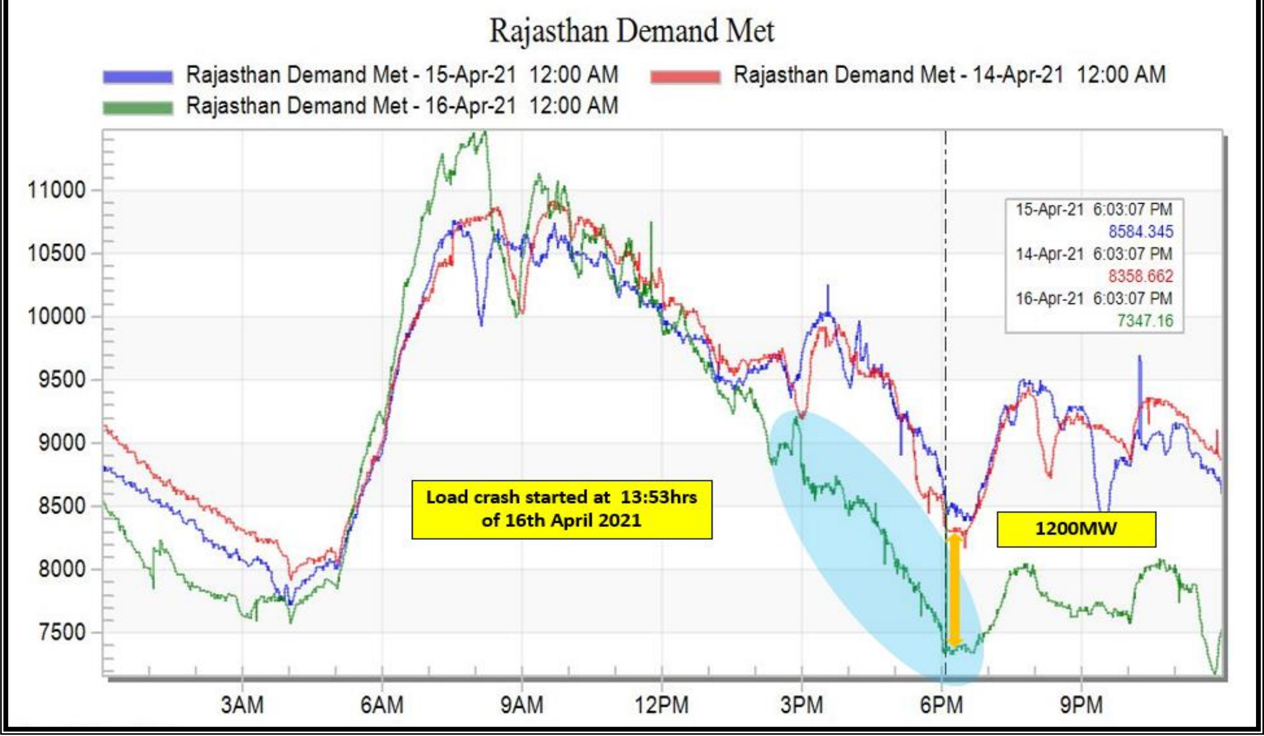




Haryana

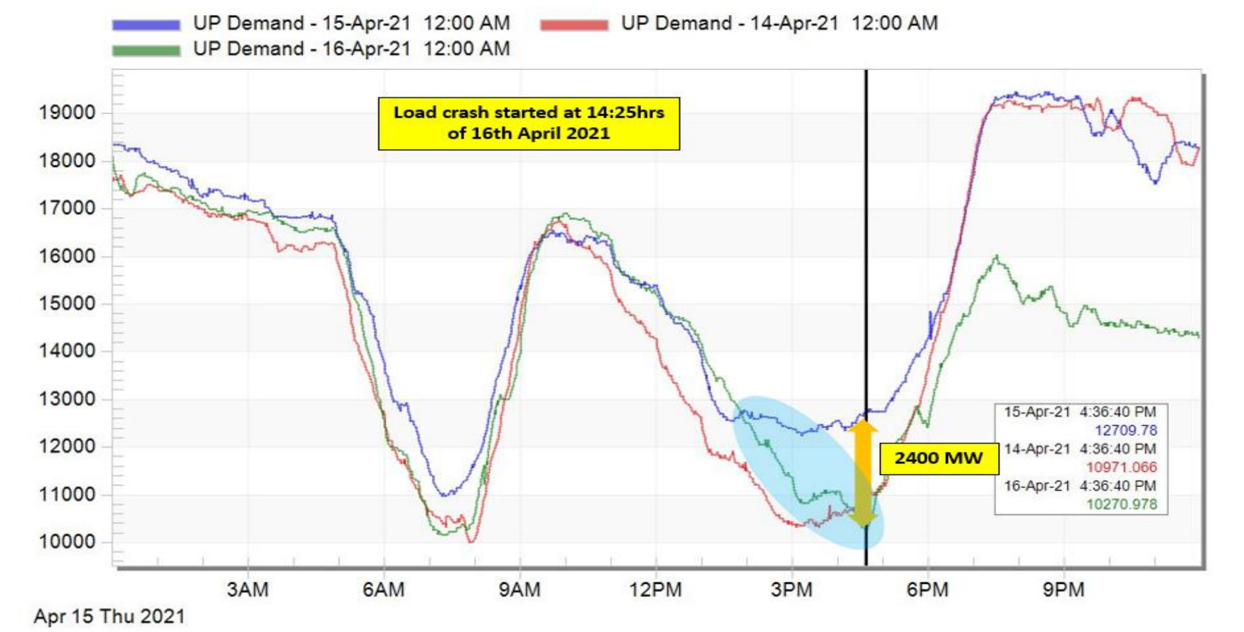


Rajasthan

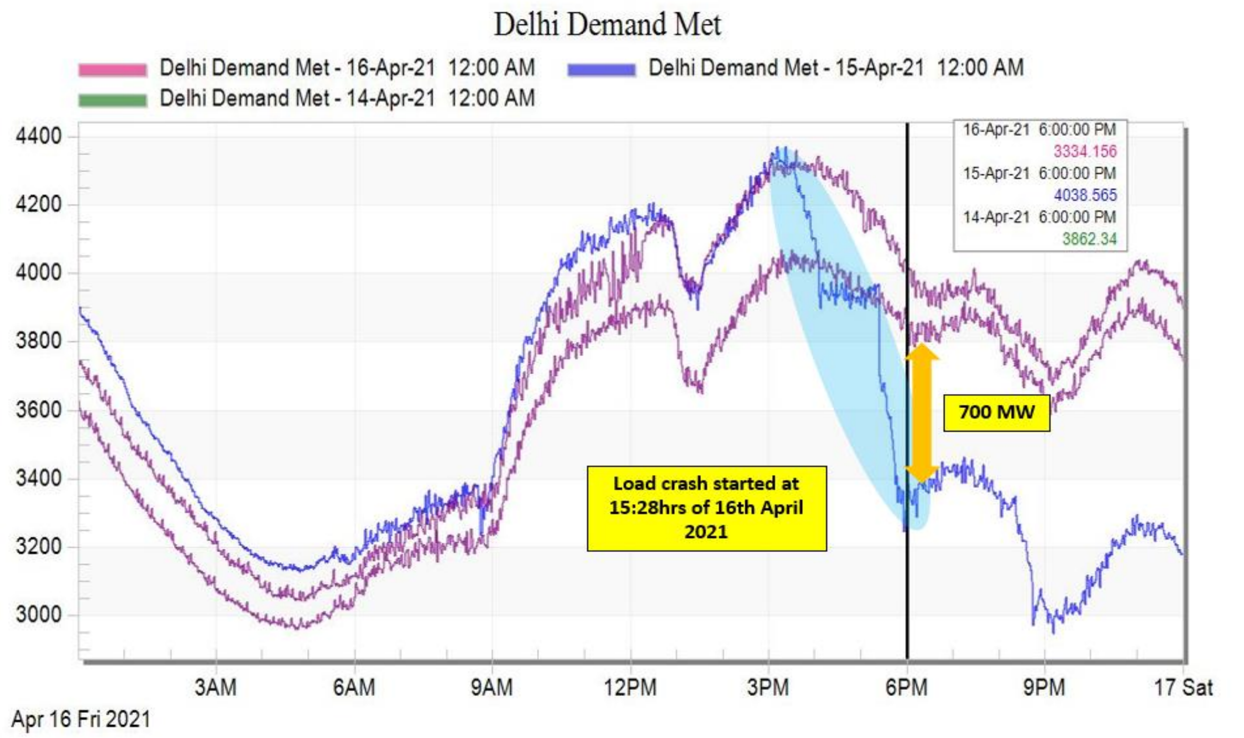


Annexure-II

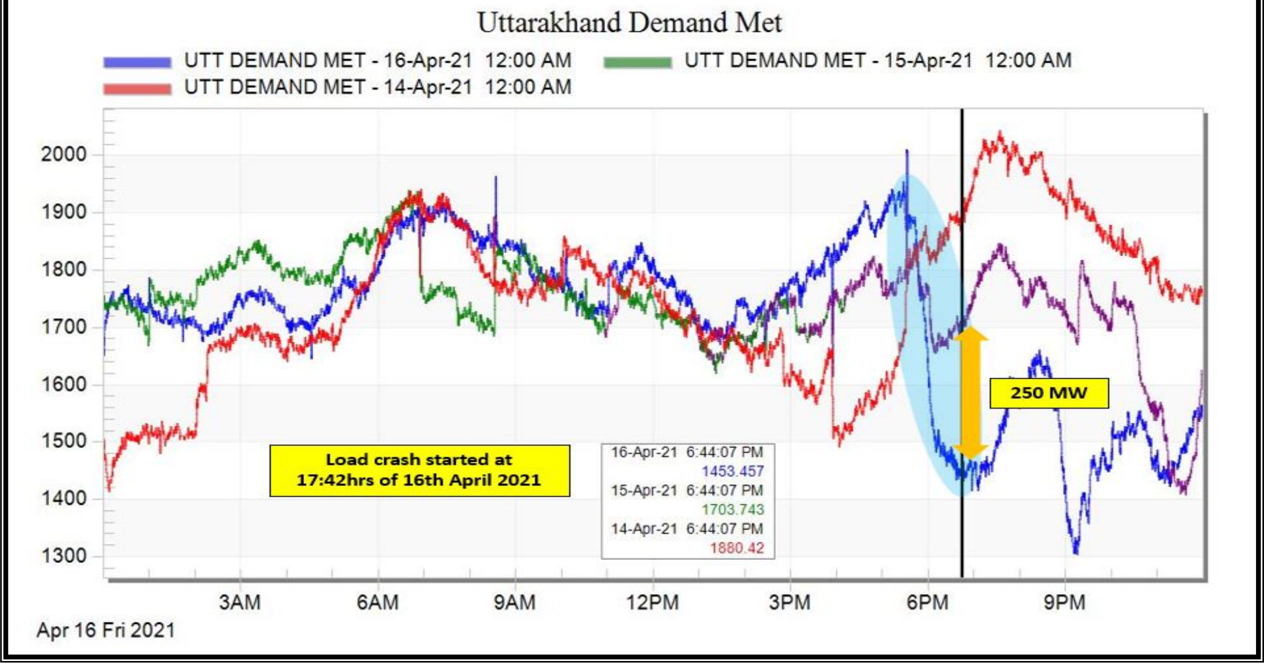
Uttar Pradesh



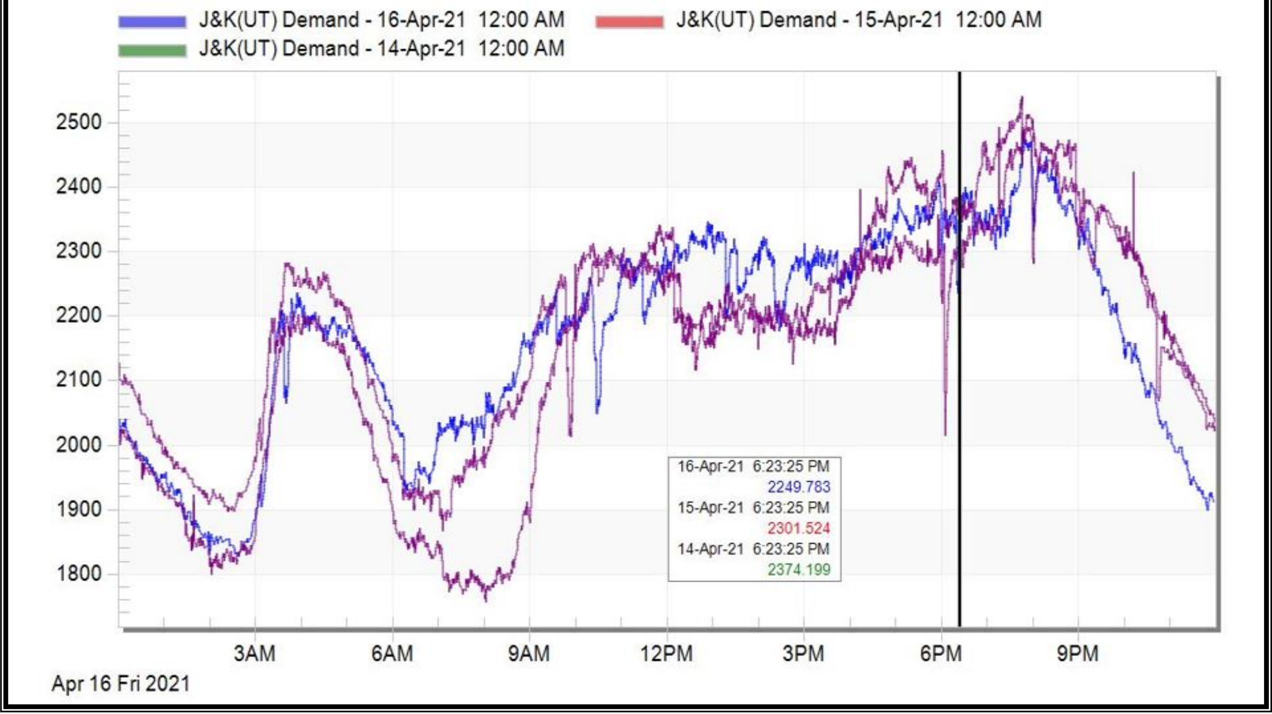
Delhi

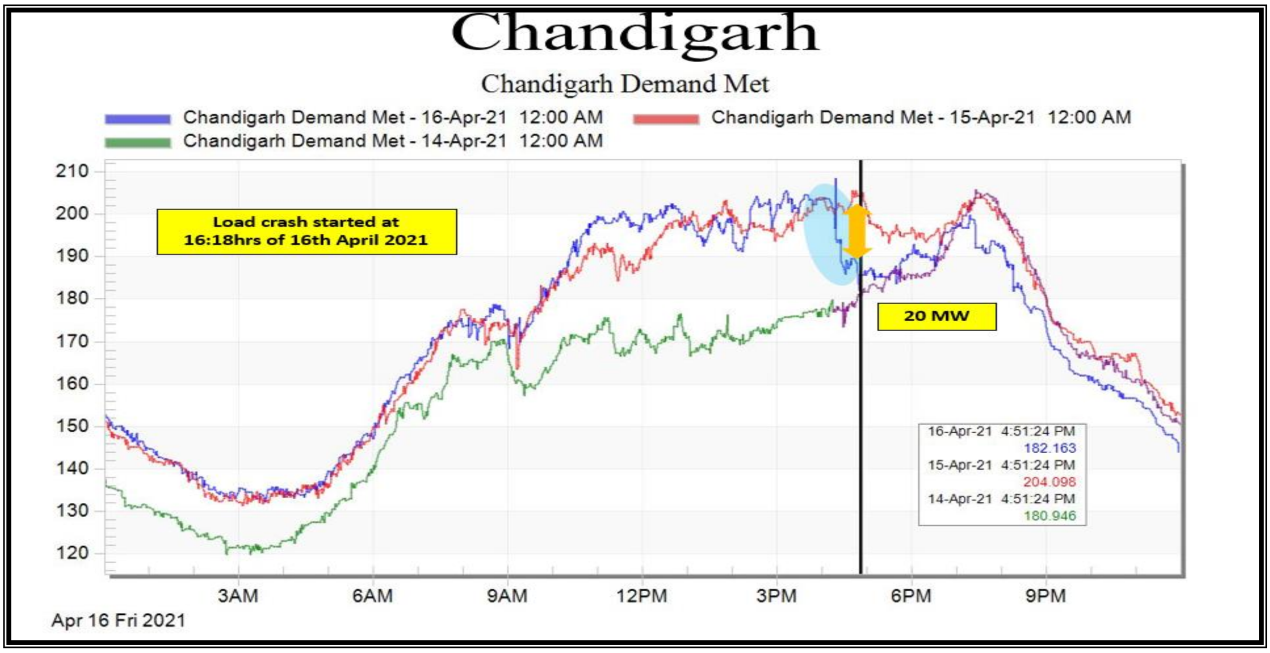


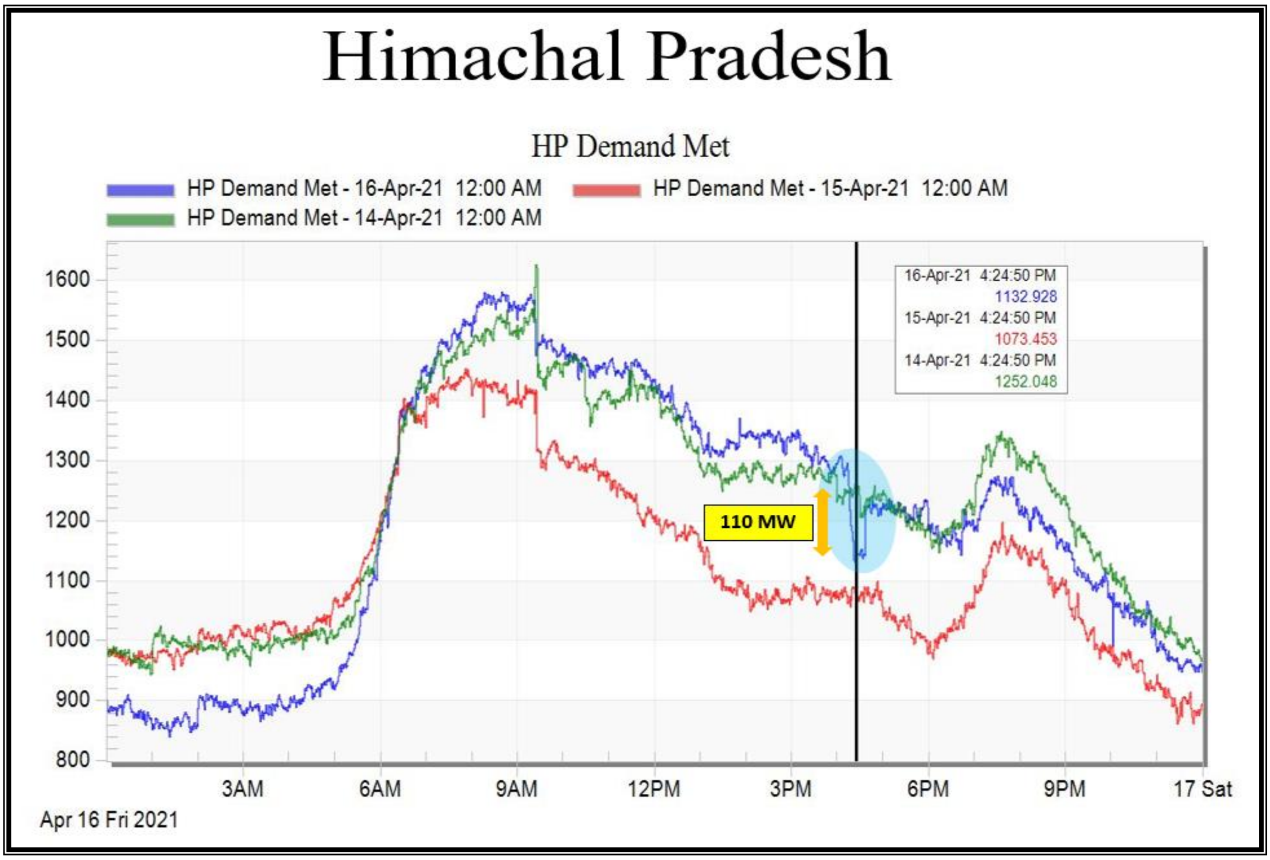
Uttarakhand



Jammu and Kashmir

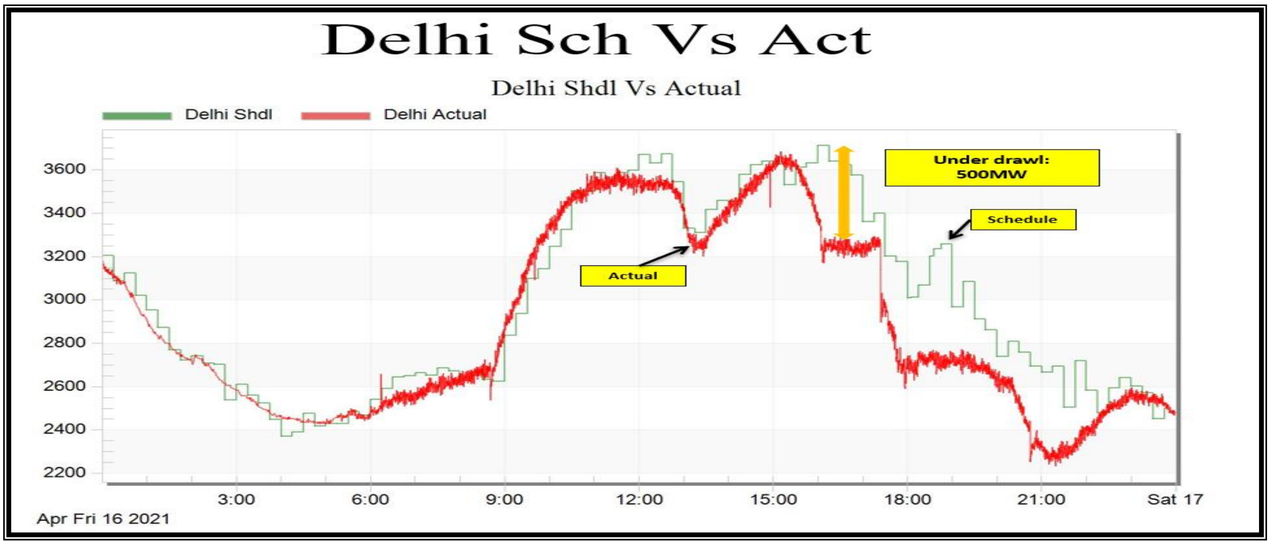


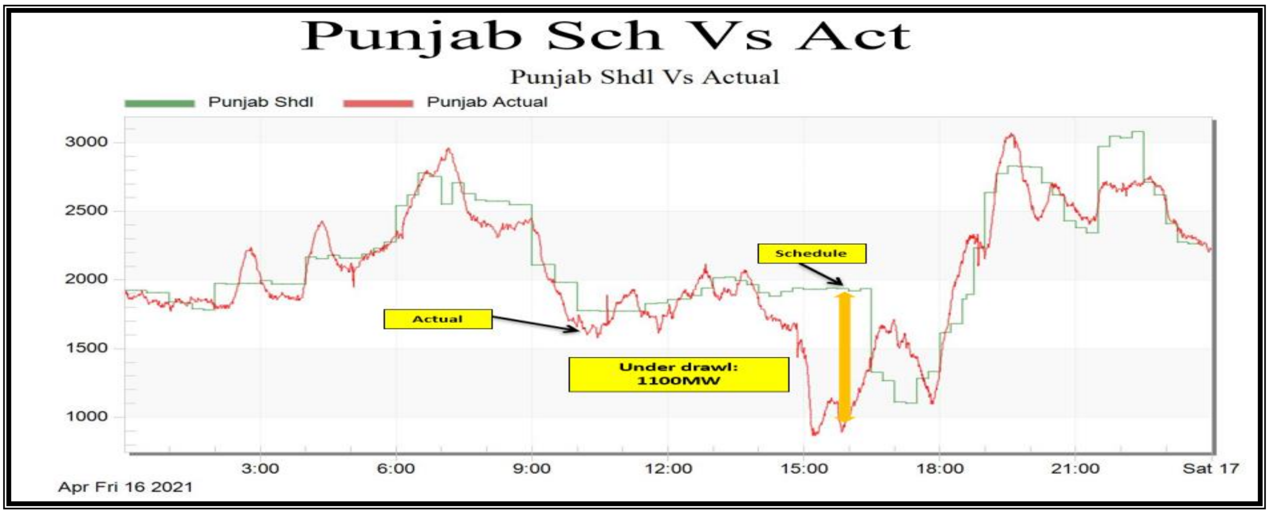

Chandigarh
Chandigarh Demand Met
Chandigarh Demand Met - 16-Apr-21 12:00 AM
Chandigarh Demand Met - 15-Apr-21 12:00 AM
Chandigarh Demand Met - 14-Apr-21 12:00 AM
Load crash started at 16:18hrs of 16th April 2021
20 MW
16-Apr-21 4:51:24 PM 182.163
15-Apr-21 4:51:24 PM 204.098
14-Apr-21 4:51:24 PM 180.946
210
200
190
180
170
160
150
140
130
120
3AM
6AM
9AM
12PM
3PM
6PM
9PM
Apr 16 Fri 2021

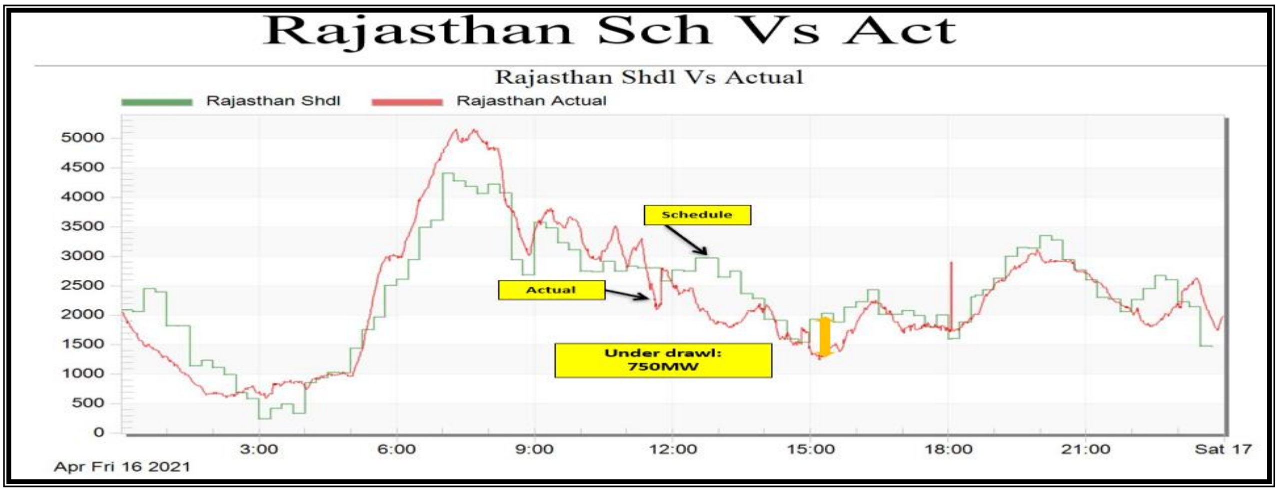

Himachal Pradesh
HP Demand Met
HP Demand Met - 16-Apr-21 12:00 AM
HP Demand Met - 15-Apr-21 12:00 AM
HP Demand Met - 14-Apr-21 12:00 AM
16-Apr-21 4:24:50 PM 1132.928
15-Apr-21 4:24:50 PM 1073.453
14-Apr-21 4:24:50 PM 1252.048
110 MW
1600
1500
1400
1300
1200
1100
1000
900
800
3AM
6AM
9AM
12PM
3PM
6PM
9PM
17 Sat
Apr 16 Fri 2021

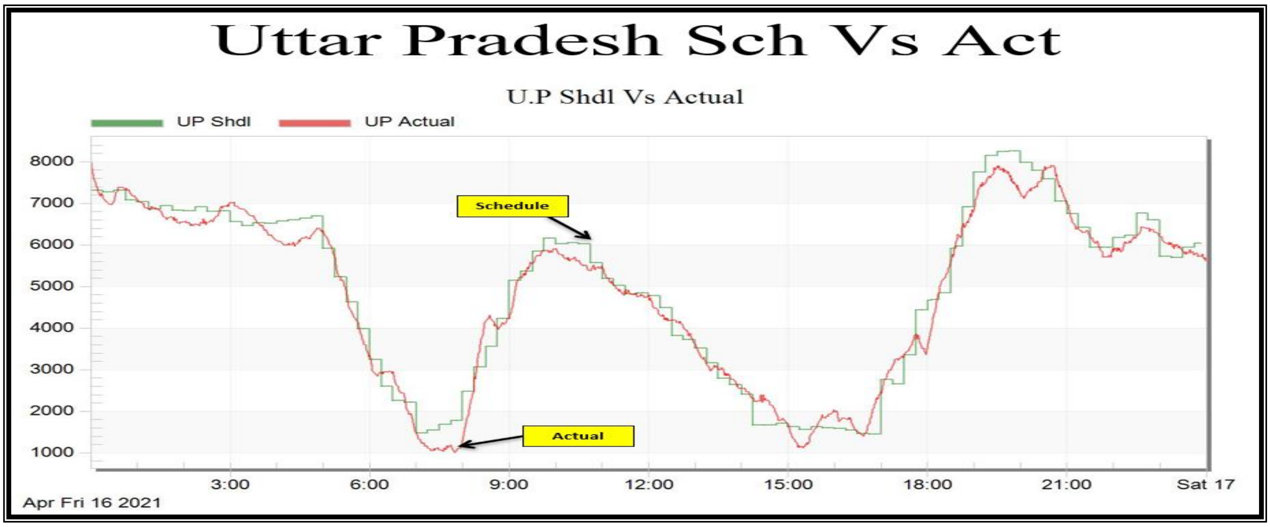
Annexure-II

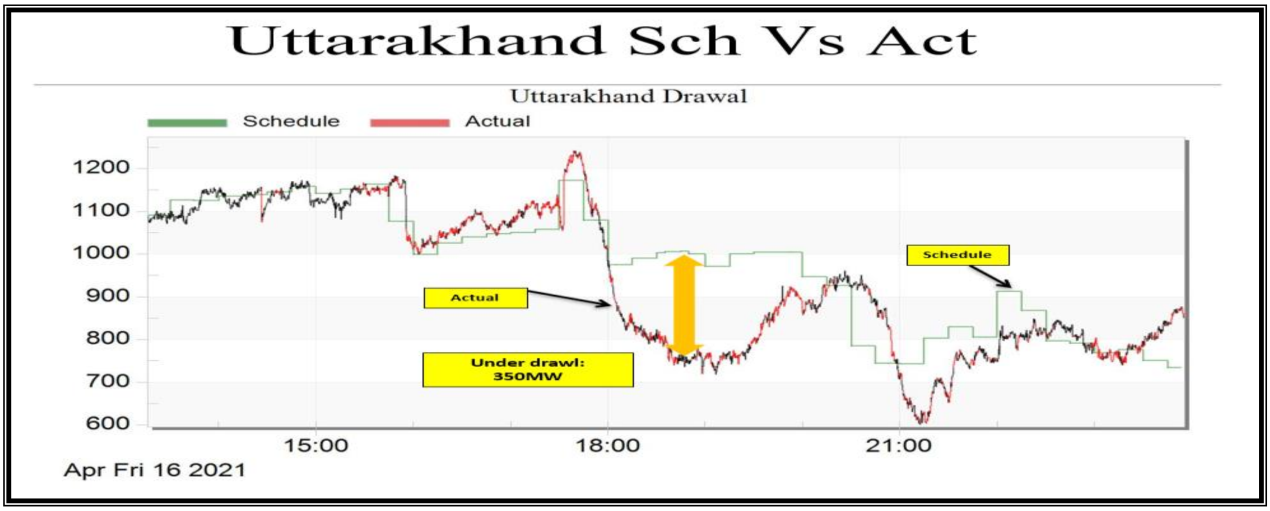
Deviation of state constituents

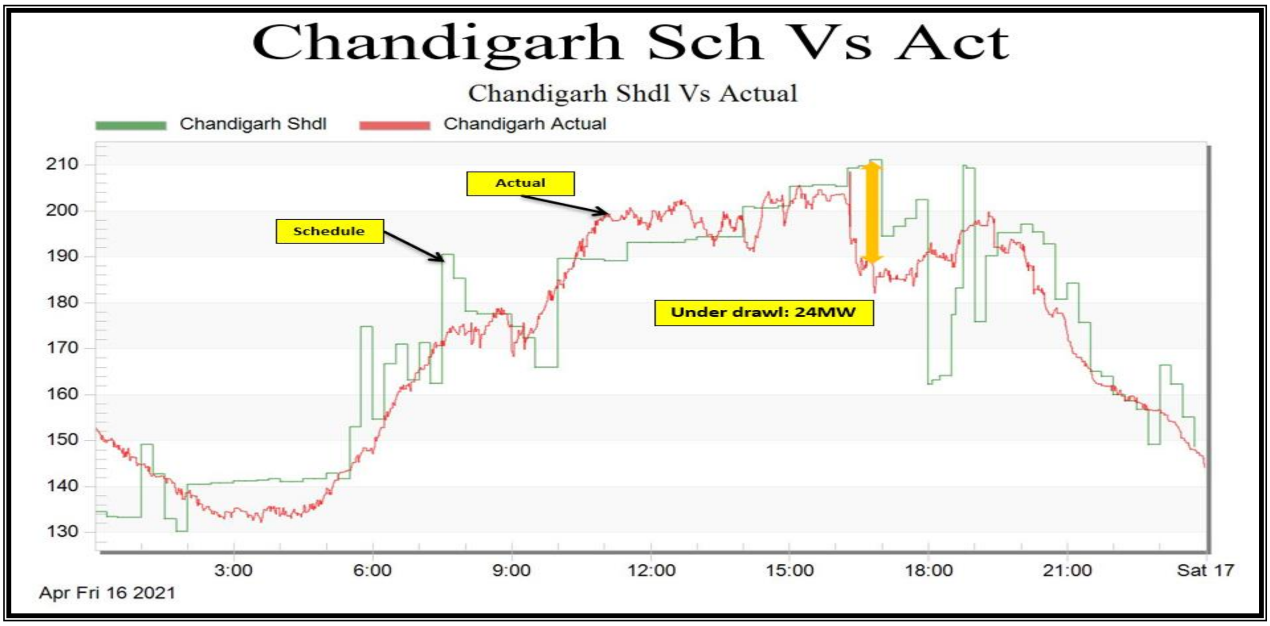






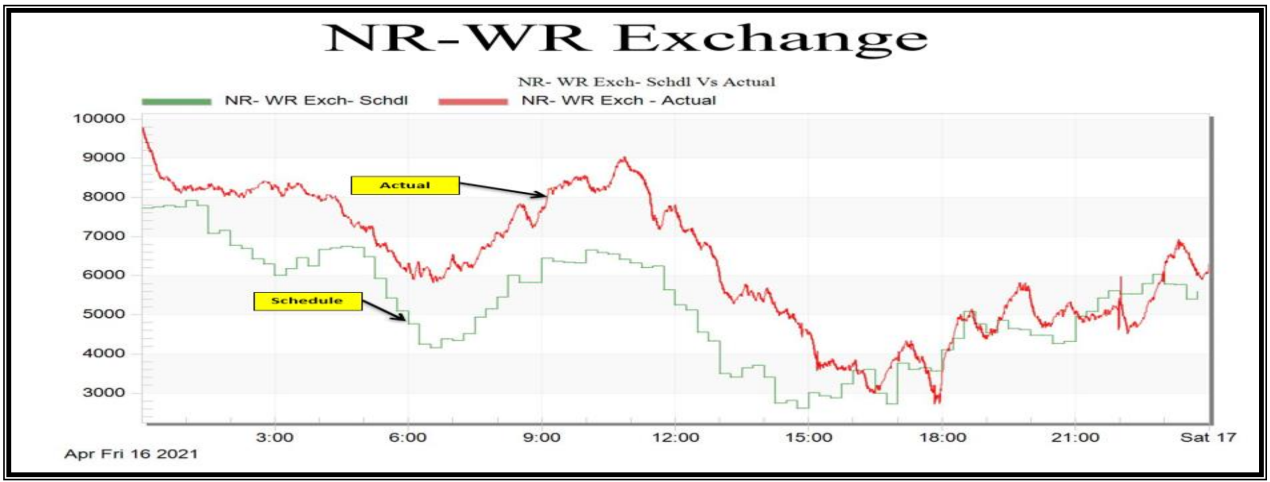

Uttar Pradesh Sch Vs Act
U.P Shdl Vs Actual
UP Shdl
UP Actual
Schedule
Actual
8000
7000
6000
5000
4000
3000
2000
1000
3:00
6:00
9:00
12:00
15:00
18:00
21:00
Sat 17
Apr Fri 16 2021

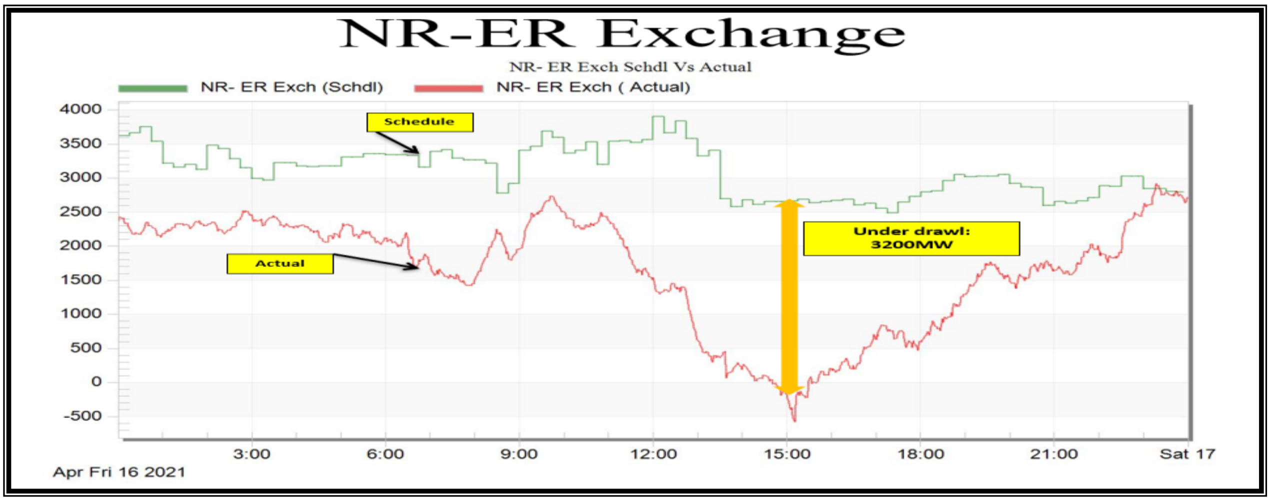

Uttarakhand Sch Vs Act
Uttarakhand Drawal
Schedule
Actual
Actual
Schedule
Under drawl: 350MW
1200
1100
1000
900
800
700
600
15:00
18:00
21:00
Apr Fri 16 2021


Chandigarh Sch Vs Act
Chandigarh Shdl Vs Actual
Chandigarh Shdl
Chandigarh Actual
Actual
Schedule
Under drawl: 24MW
210
200
190
180
170
160
150
140
130
3:00
6:00
9:00
12:00
15:00
18:00
21:00
Sat 17
Apr Fri 16 2021

Annexure-III

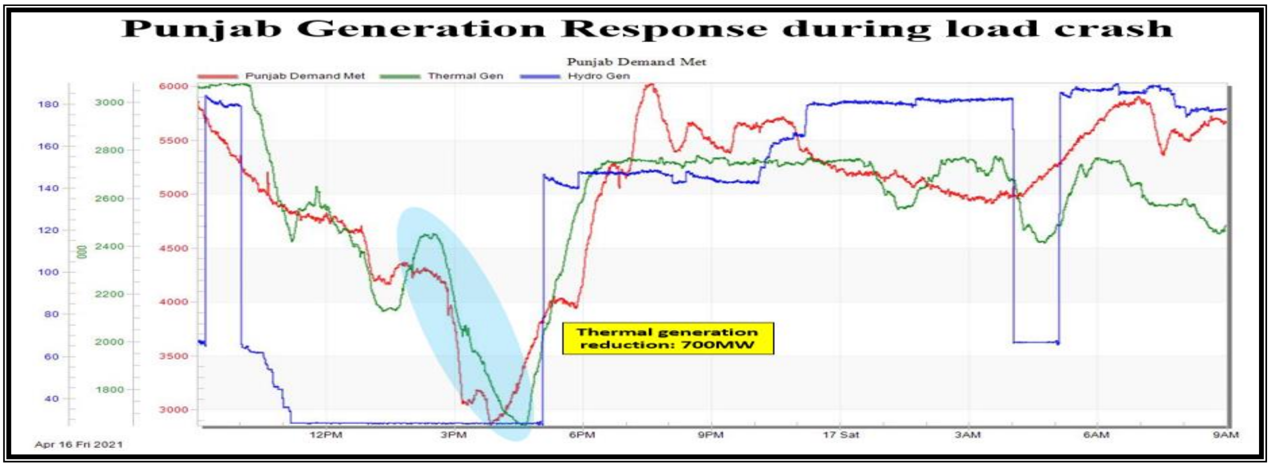
Inter-Regional Exchange (NR-IR)

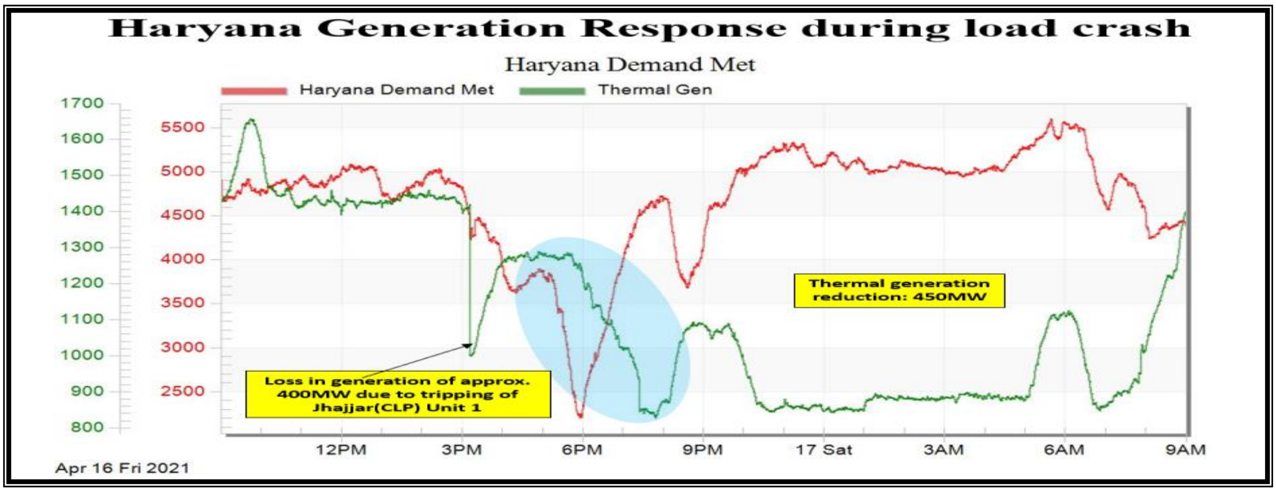


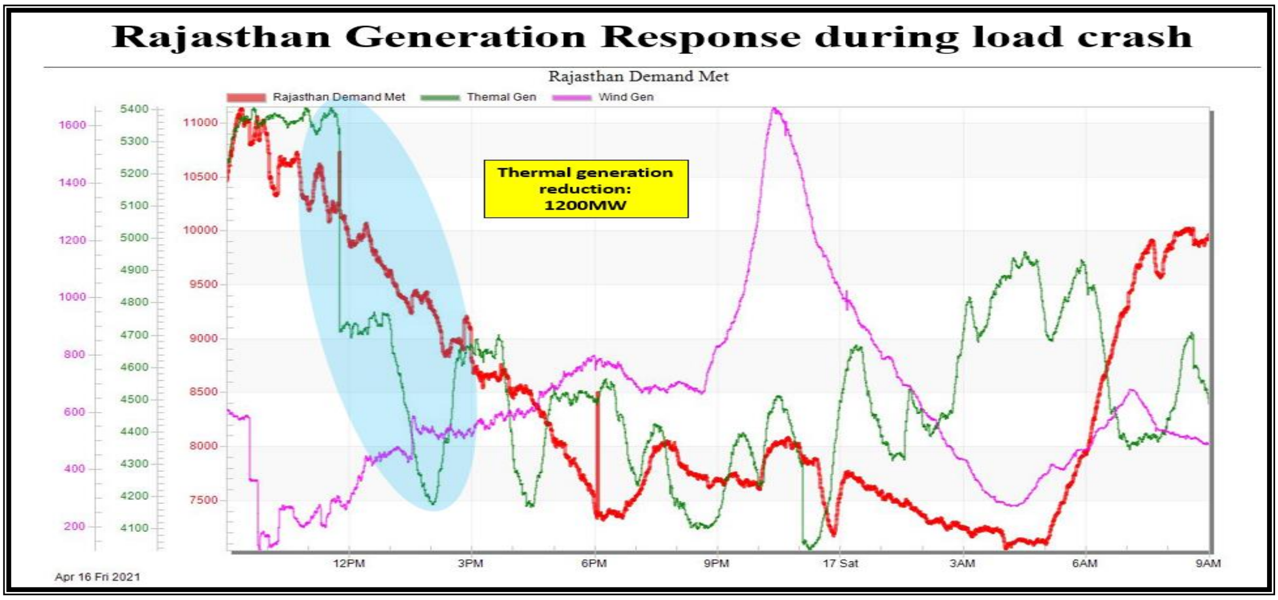


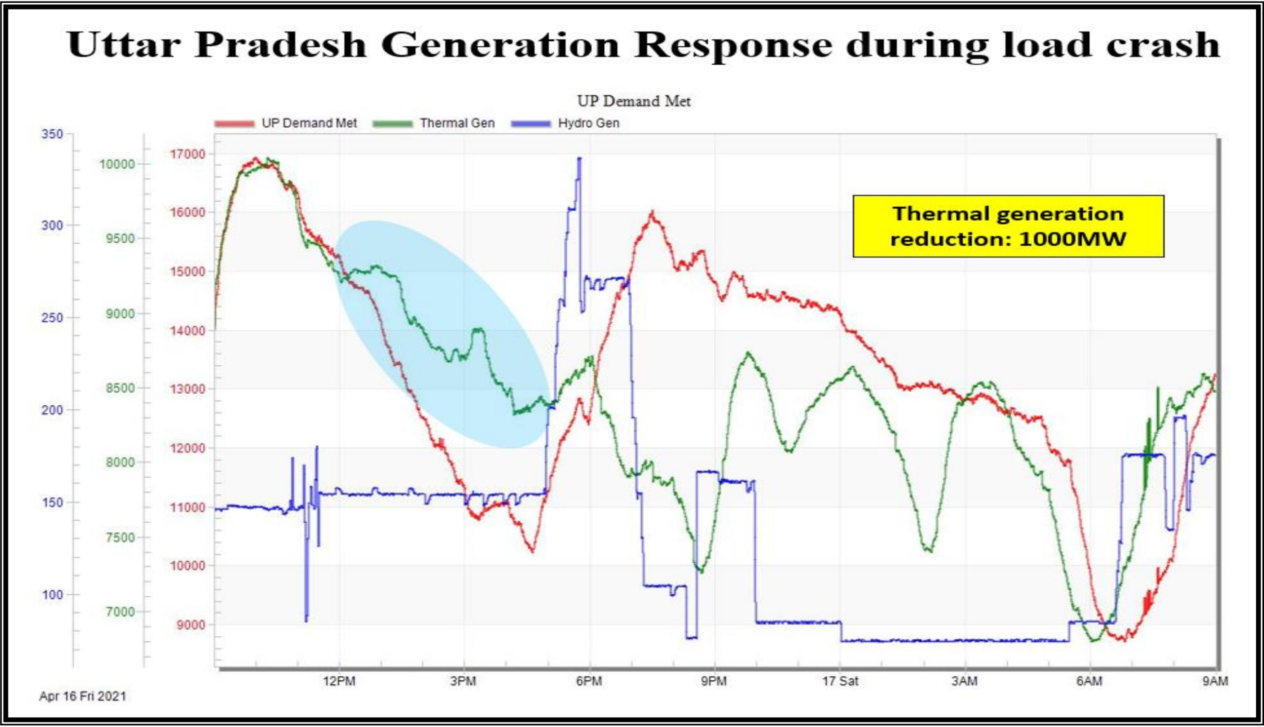
Annexure-IV

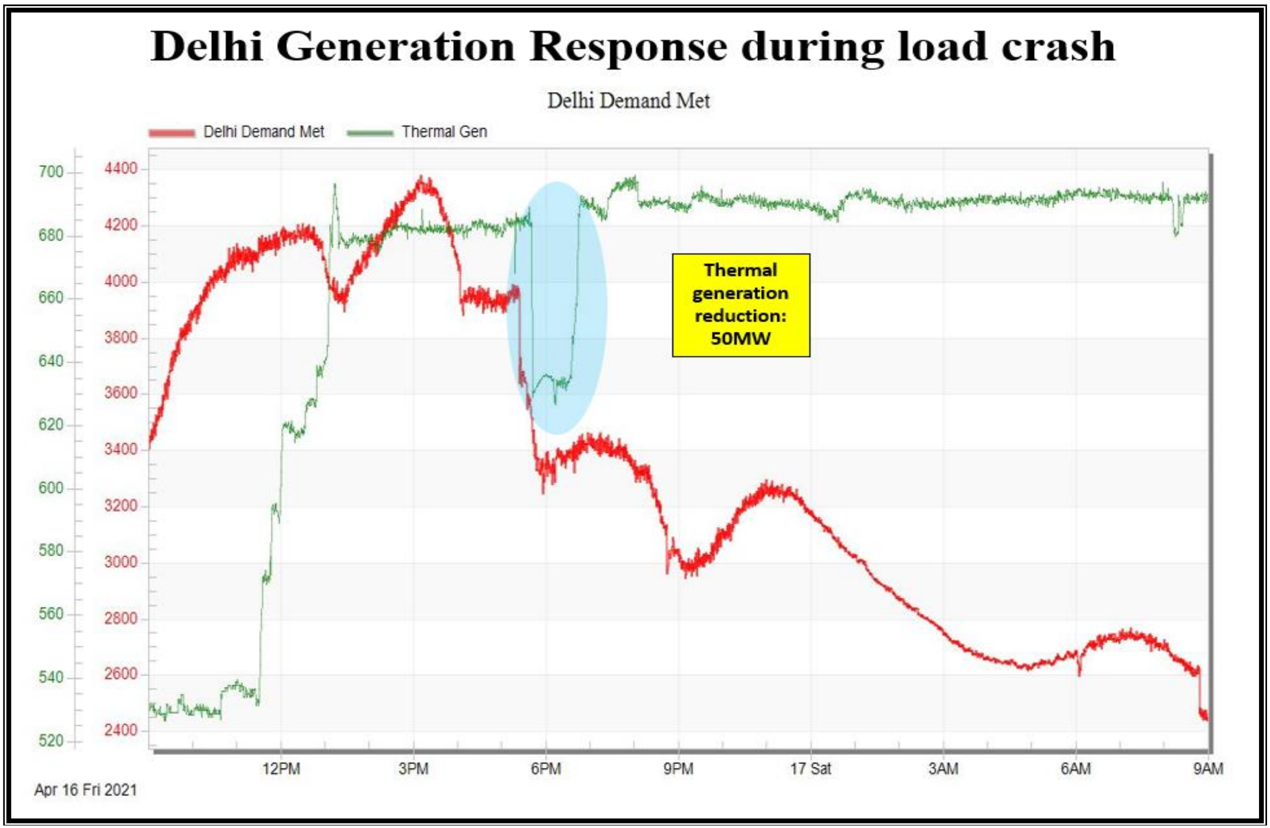
State Generation response during Load Crash








Uttar Pradesh Generation Response during load crash
UP Demand Met
UP Demand Met
Thermal Gen
Hydro Gen
Thermal generation reduction: 1000MW
350
300
250
200
150
100
10000
9500
9000
8500
8000
7500
7000
17000
16000
15000
14000
13000
12000
11000
10000
9000
12PM
3PM
6PM
9PM
17 Sat
3AM
6AM
9AM
Apr 16 Fri 2021


Delhi Generation Response during load crash
Delhi Demand Met
Delhi Demand Met
Thermal Gen
Thermal generation reduction: 50MW
700
680
660
640
620
600
580
560
540
520
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
2400
12PM
3PM
6PM
9PM
17 Sat
3AM
6AM
9AM
Apr 16 Fri 2021

Annexure-V

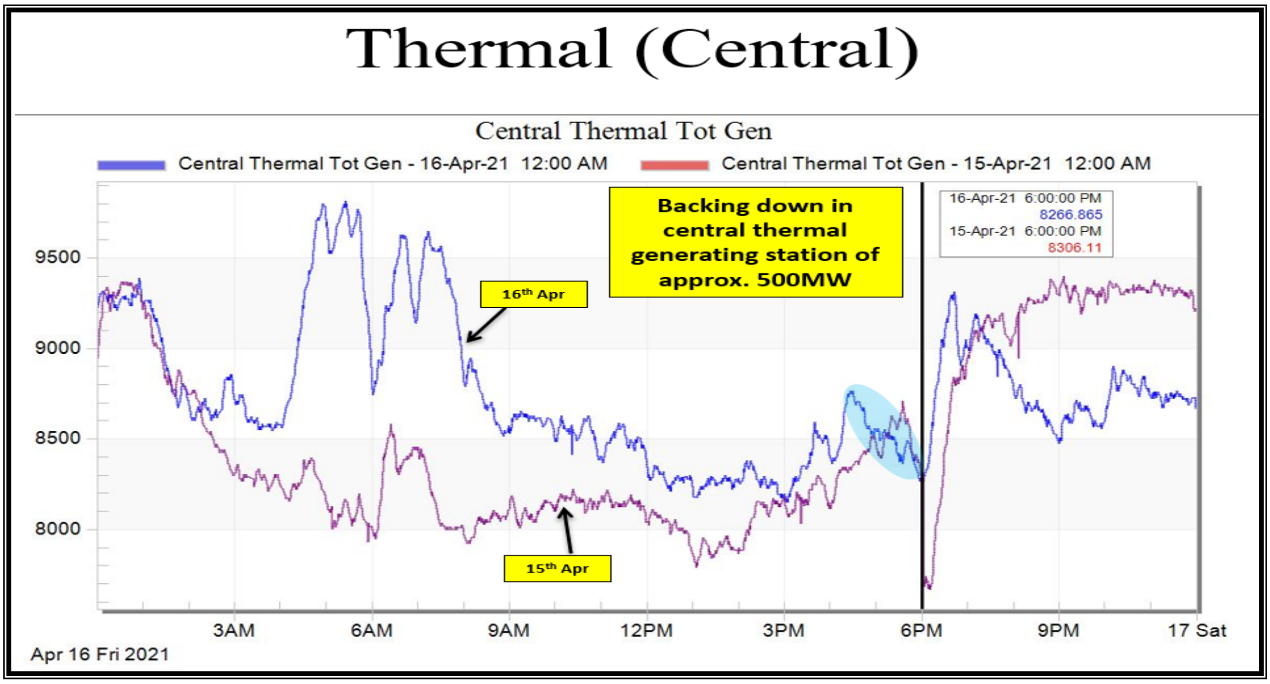
Details of Transmission Elements Tripped

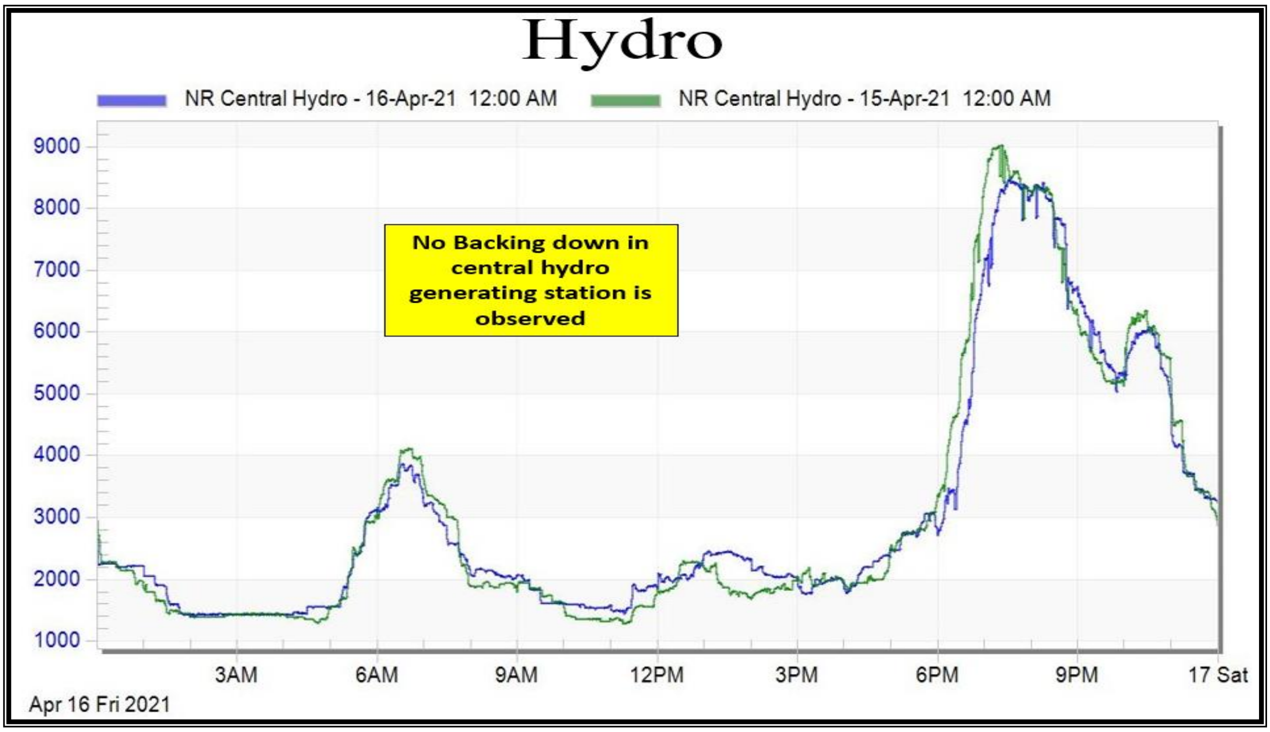
S.No	Element Name	Type	Voltage Level	Owner	Outage		Revival		Reason / Remarks
					Date	Time	Date	Time	
1	765 KV Moga-Bhiwani (PG) Ckt-1	Line	765KV	POWERGRID	16-04-2021	13:59	16-04-2021	19:52	Phase to earth fault Y-N , Dist. 95.5km, Fault current 5.09kA from Moga.
2	400 KV CLP Jhajjar(CLP)-Dhanoda(HV) (HVPNL) Ckt-2	Line	400KV	HVPNL	16-04-2021	14:26	16-04-2021	18:15	Tripped due to failure of DC supply of CB at Dhanonda.
3	400 KV Koldam(NT)-Ludhiana(PG) (PKTCL) Ckt-2	Line	400KV	PKTCL	16-04-2021	14:51	16-04-2021	18:40	Tripped on R-Y fault due to heavy storm, lighting and inclement weather condition. Dist. 0.1km, fault current 19 kA from Ludhiana.
4	125 MVAR Bus Reactor No 2 at 400 KV Banda(UP)	BR	400KV	UPPTCL	16-04-2021	15:07	16-04-2021	18:19	Tripped due Back-up Impedance protection operated.
5	400 KV CLP Jhajjar(CLP)-Dhanoda(HV) (HVPNL) Ckt-1	Line	400KV	HVPNL	16-04-2021	15:11	16-04-2021	18:13	Tripped due to failure of DC supply of CB at Dhanonda.
6	400 KV Deepalpur(JHKT)-Kabulpur(HV) (HVPNL) Ckt-1	Line	400KV	HVPNL	16-04-2021	15:12	16-04-2021	20:32	B-N fault, Dist. 19km from Deepalpur.
7	400 KV Bhiwadi-Gurgaon (PG) Ckt-1	Line	400KV	POWERGRID	16-04-2021	15:15	16-04-2021	20:16	R-N fault. Tripped due to damage of R-phase wave trap during heavy wind storm at Bhiwadi.
8	80 MVAR Bus Reactor No 1 at 400KV Bhiwadi(PG)	BR	400KV	POWERGRID	16-04-2021	15:15	16-04-2021	18:59	REF operated
9	400 KV Alaknanda GVK(UPC)-Vishnuprayag(JP) (UP) Ckt-1	Line	400KV	UPPTCL	16-04-2021	16:43	16-04-2021	18:19	B-N fault, Dist. 16.68 km, Fault current 2.02kA from Vishnuprayag.
10	400 KV Muzaffarnagar(UP)-Vishnuprayag(JP) (UP) Ckt-1	Line	400KV	UPPTCL	16-04-2021	16:43	16-04-2021	18:16	. B-N fault, Dist. 16.68 km from Vishnuprayag.
11	765 KV Jhatikara-Aligarh (PG) Ckt-1	Line	765KV	POWERGRID	16-04-2021	17:02	16-04-2021	19:56	Y-N fault, Dist. 113.7km, Fault current 5.97kA from Aligarh.
12	400 KV Bamnoli(DV)-Tughlakabad(PG) (DTL) Ckt-2	Line	400KV	POWERGRID,DTL	16-04-2021	17:11	16-04-2021	20:08	R-N fault, Dist. 17km, Fault current 8.7kA from Bamnoli end.
13	400 KV Kurukshetra-Jalandhar (PG) Ckt-1	Line	400KV	POWERGRID	16-04-2021	17:18	16-04-2021	18:03	B-N fault, Dist. 249km, Fault current 2.6kA from Jalandhar.
14	400/220 kV 315 MVA ICT 1 at Kotputli(PG)	ICT	400/220KV	POWERGRID	16-04-2021	18:31	16-04-2021	20:42	Over-fluxing.
15	400 KV CLP Jhajjar(CLP)-Dhanoda(HV) (HVPNL) Ckt-2	Line	400KV	HVPNL	16-04-2021	19:31	16-04-2021	21:44	DT received at Dhanonda end due to problem in PLCC at Jhajjar CLP end.
16	765 KV Gr.Noida_2(UPC)-Hapur (UP) Ckt-1	Line	765KV	UPPTCL	16-04-2021	19:47	16-04-2021	21:11	Phase to earth fault R-N , Zone-1, Fault current 11.08kA, Dist. 49.7km from Gr. Noida.
17	400 KV Ballabhgarh(PG)-Tughlakabad(PG) (DTL) Ckt-2	Line	400KV	POWERGRID,DTL	16-04-2021	21:30	16-04-2021	22:17	Phase to earth fault Y-N , Dist. 30.9km, Fault current 7.4kA from Tughlakabad.
18	70252T TIE BAY - 765KV PHAGI(RS)-BHIWANI(PG) (PG) CKT-1 AND 765/400KV 1500 MVA ICT 2 AT PHAGI(RS)	BAY	765KV	RRVPNL	16-04-2021	21:44	16-04-2021	22:13	Main CB AR after Y-N fault but Tie CB tripped.
19	70552B MAIN BAY - 765 KV AJMER(PG)-PHAGI(RS) (PG) CKT-1 (POWERGRID) AT 765KV PHAGI(RS)	BAY	765KV	POWERGRID	16-04-2021	21:48	16-04-2021	23:09	Power swing detected at Phagi end.
20	800 KV HVDC Kurukshetra(PG) Pole-1	HVDC POLE	800KV	POWERGRID	16-04-2021	22:00	16-04-2021	23:58	Pole blocked on DC line fault protection.

Outages of Transmission Element on account of Voltage regulation:

S.No	Element Name	Type	Voltage Level	Owner	Outage		Revival		Reason / Remarks
1	400 KV Talwandi Saboo(PSG)-Muktsar(PS) (PS) Ckt-1	Line	400KV	PSTCL	16-04-2021	15:20	16-04-2021	19:50	Manually opened due to High Voltage
2	400 KV Kurukshetra-Jind (PG) Ckt-2	Line	400KV	POWERGRID	16-04-2021	15:42	*	*	Manually opened due to High Voltage
3	400 KV Suratgarh(RVUN)-Ratangarh(RS) (RS) Ckt-1	Line	400KV	RRVPNL	16-04-2021	17:55	*	*	Manually opened due to High Voltage
4	400 KV Bhiwadi-Hissar (PG) Ckt-1	Line	400KV	POWERGRID	16-04-2021	21:58	*	*	Manually opened due to High Voltage
5	800 KV HVDC Kurukshetra(PG) Pole-2	HVDC POLE	800KV	POWERGRID	16-04-2021	23:19	*	*	Manually opened due to High Voltage

Northern Regional Central Sector Generation





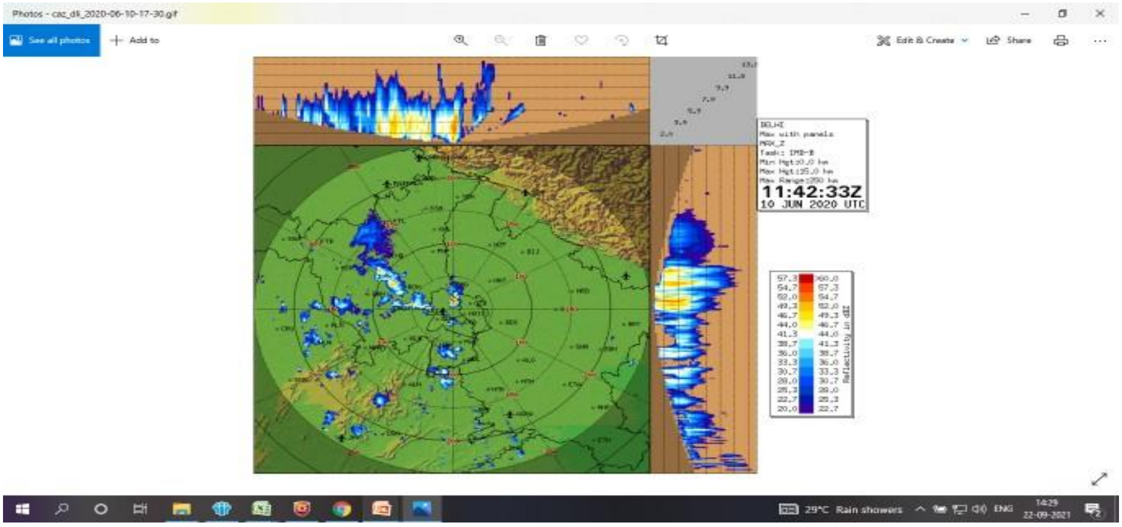
Annexure-VII

Savings due to use of Weather Portal

Savings due to use IMD Portal

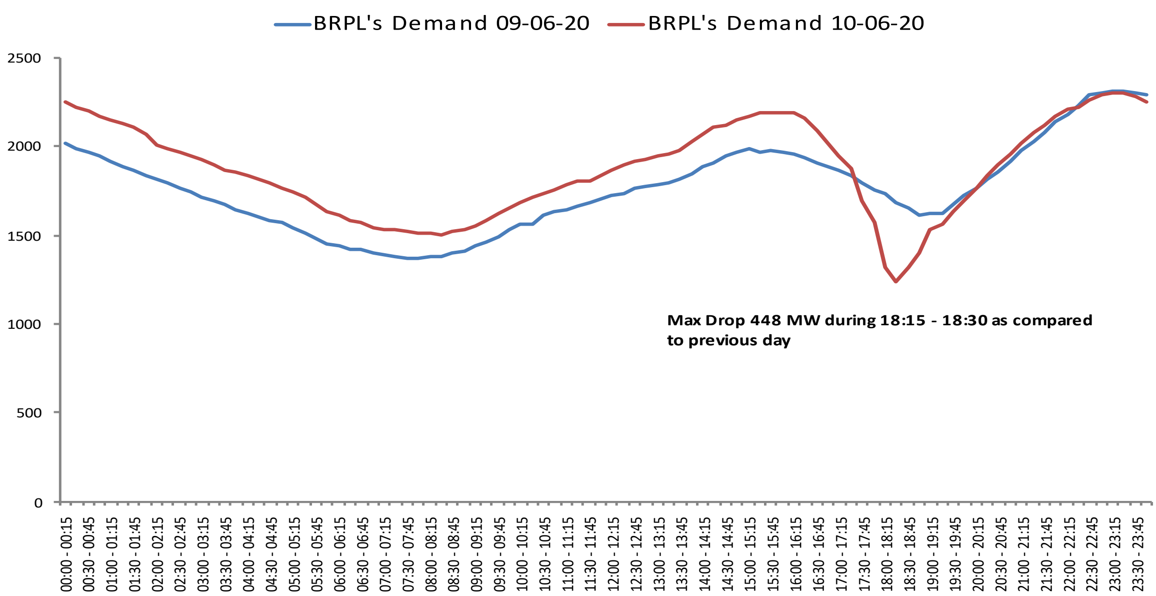
BSES Rajdhani Power Limited 1

10.06.2020



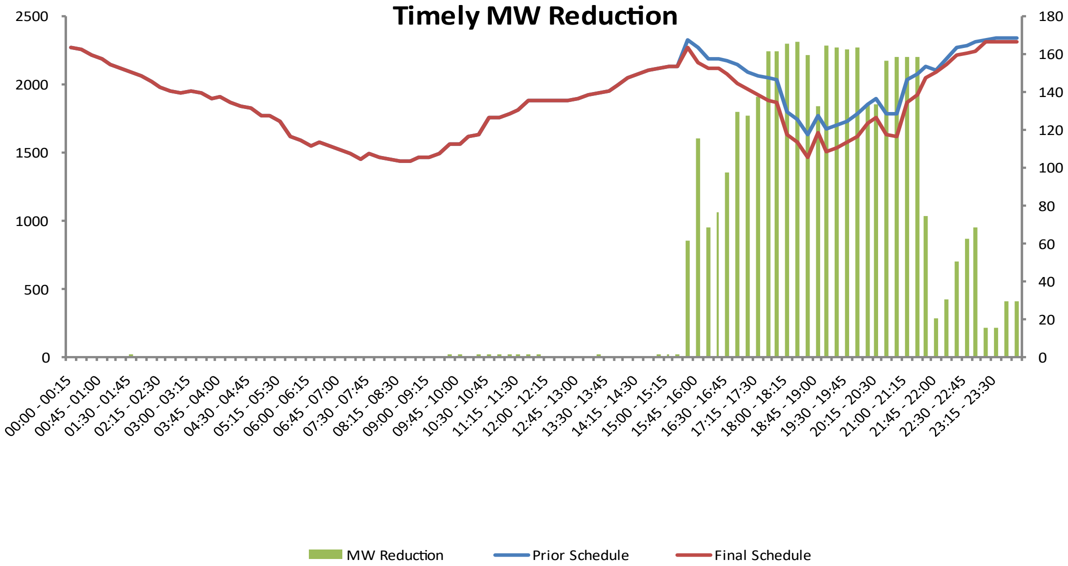
BSES Rajdhani Power Limited 2

10.06.2020



BSES Rajdhani Power Limited 3

10.06.2020



Reduced Mus – 0.93 MUs

BSES

BSES Rajdhani Power Limited

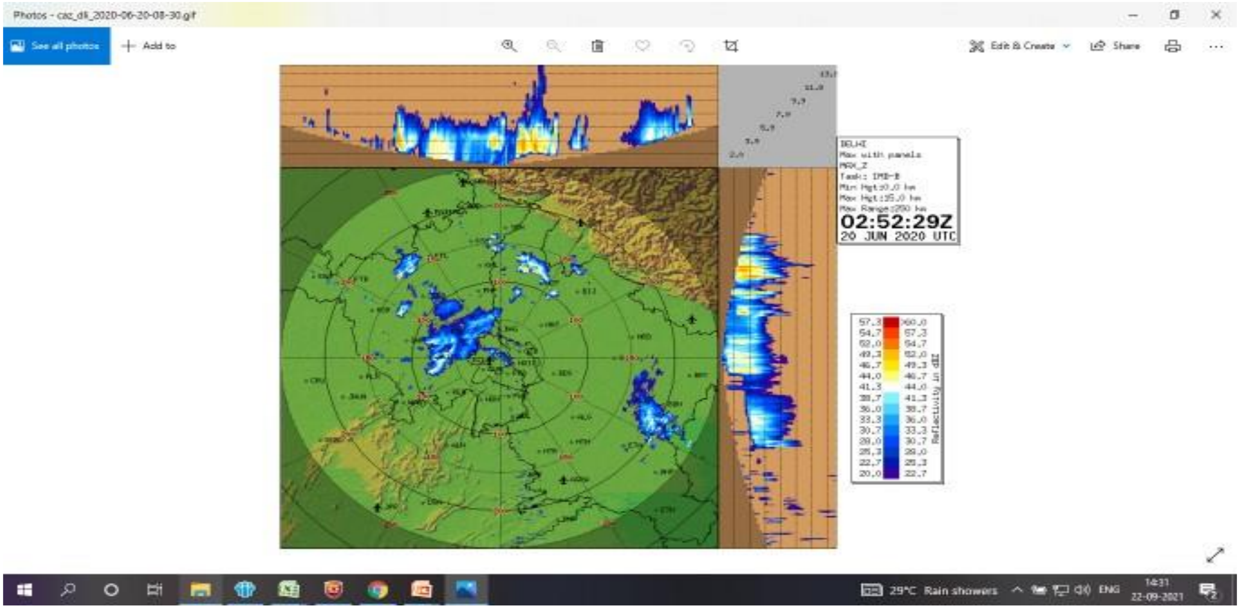
4

Case Study for 20.06.2020

BSES

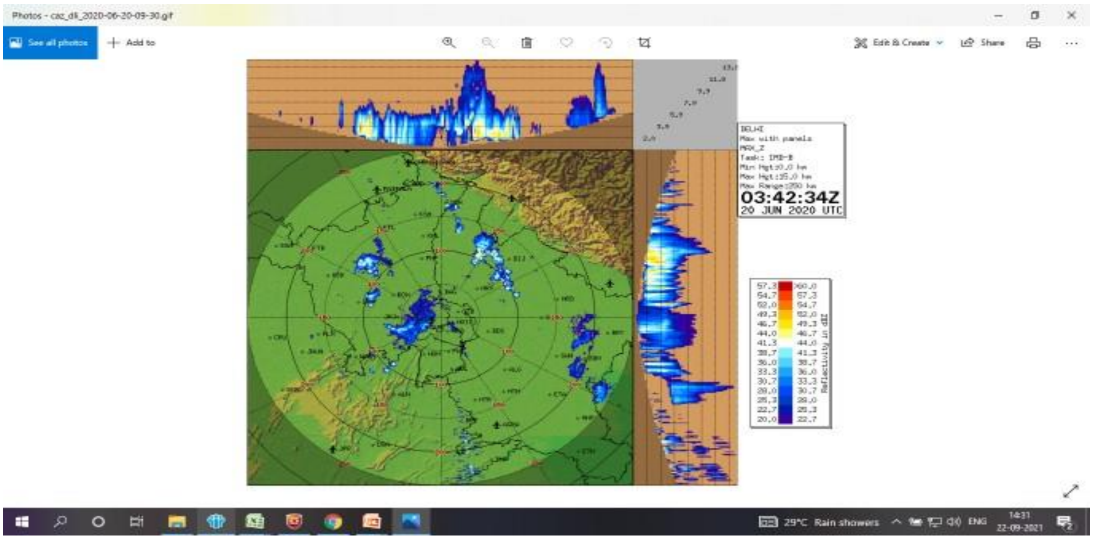
BSES Rajdhani Power Limited

20.06.2020



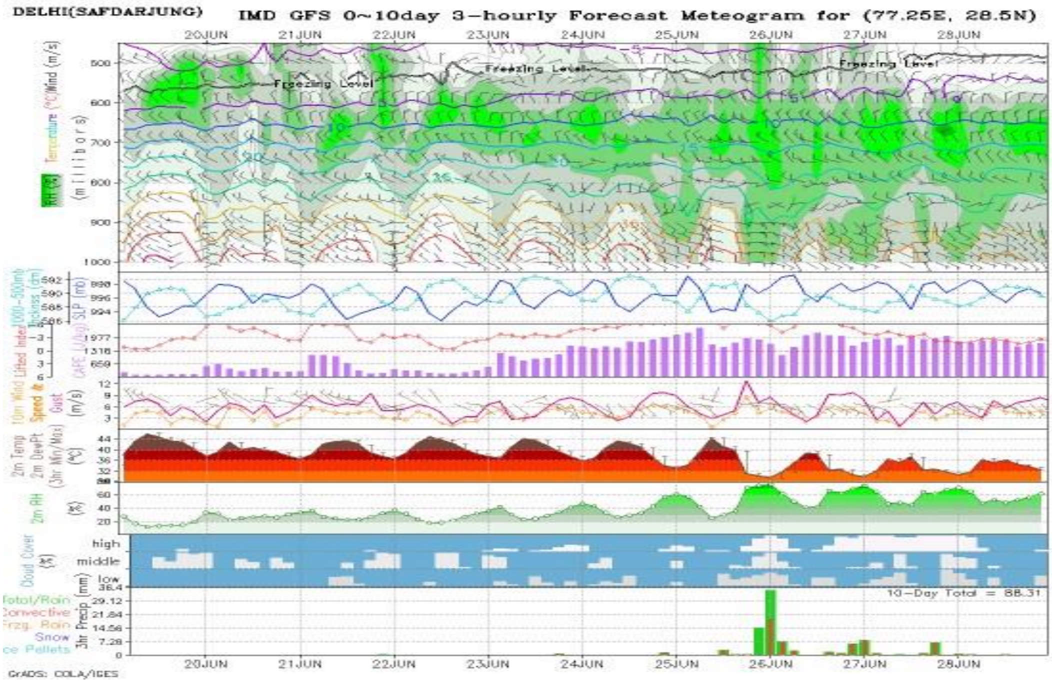
BSES BSES Rajdhani Power Limited

20.06.2020



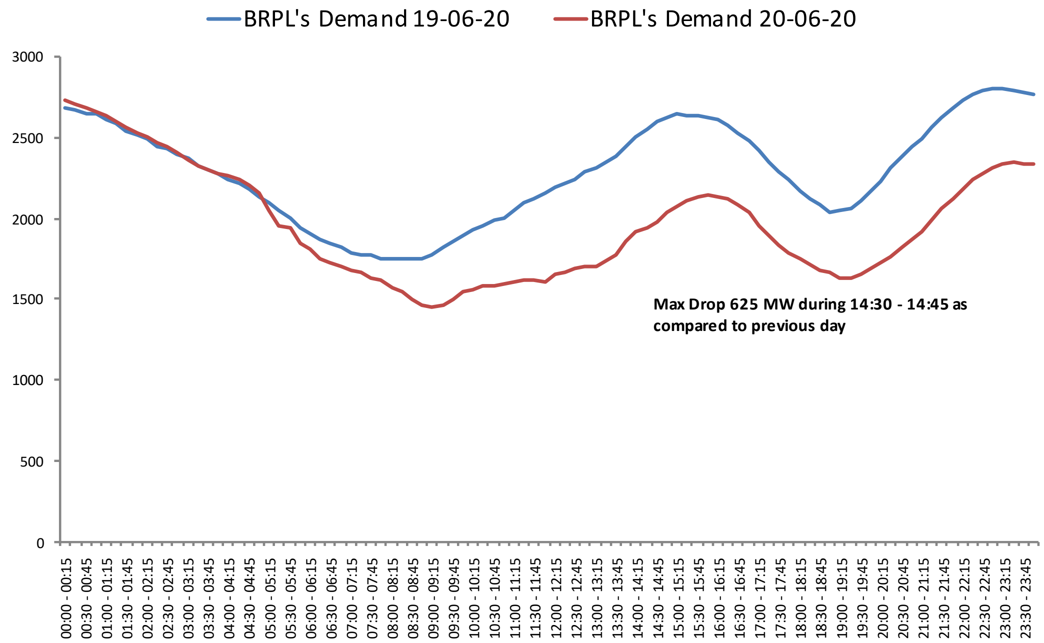
BSES BSES Rajdhani Power Limited

20.06.2020

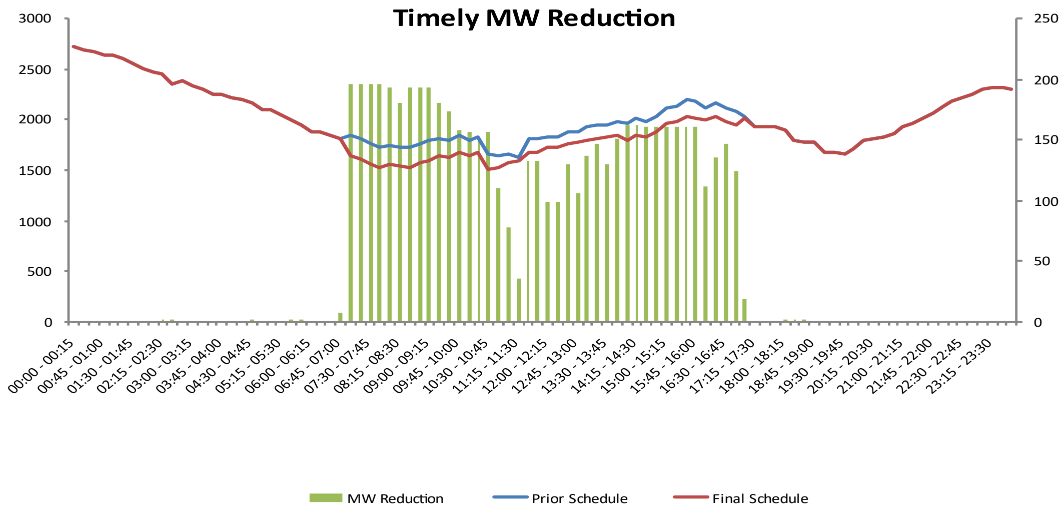


BSES Rajdhani Power Limited

20.06.2020



20.06.2020



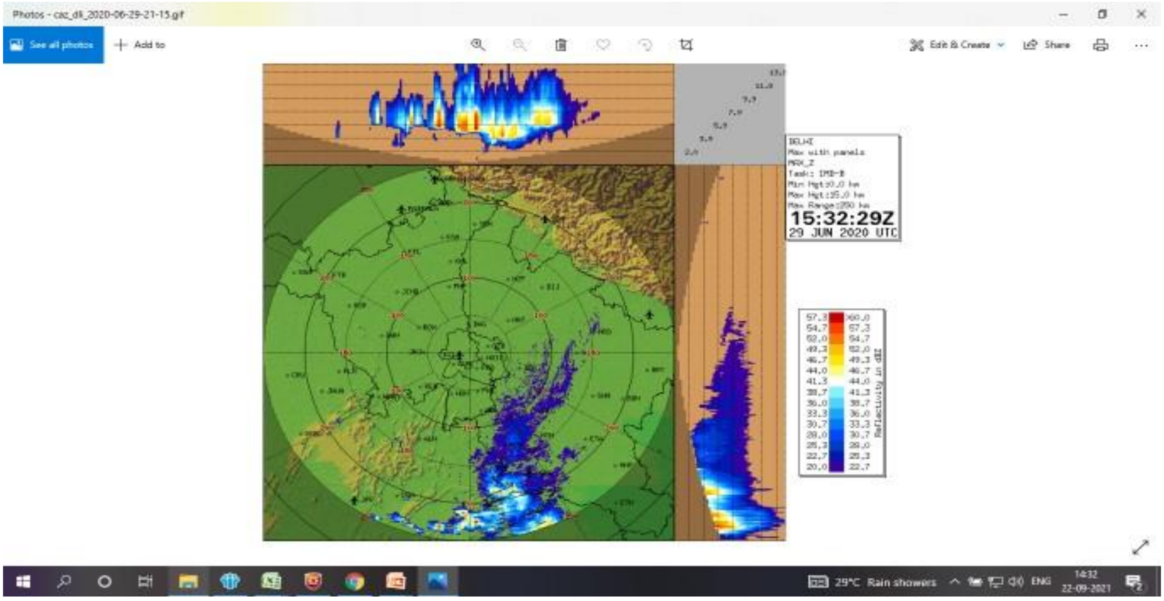
Reduced Mus – 1.51 MUs

BSES BSES Rajdhani Power Limited 10

Case Study for 29.06.2020

BSES BSES Rajdhani Power Limited

29.06.2020



BSES Rajdhani Power Limited

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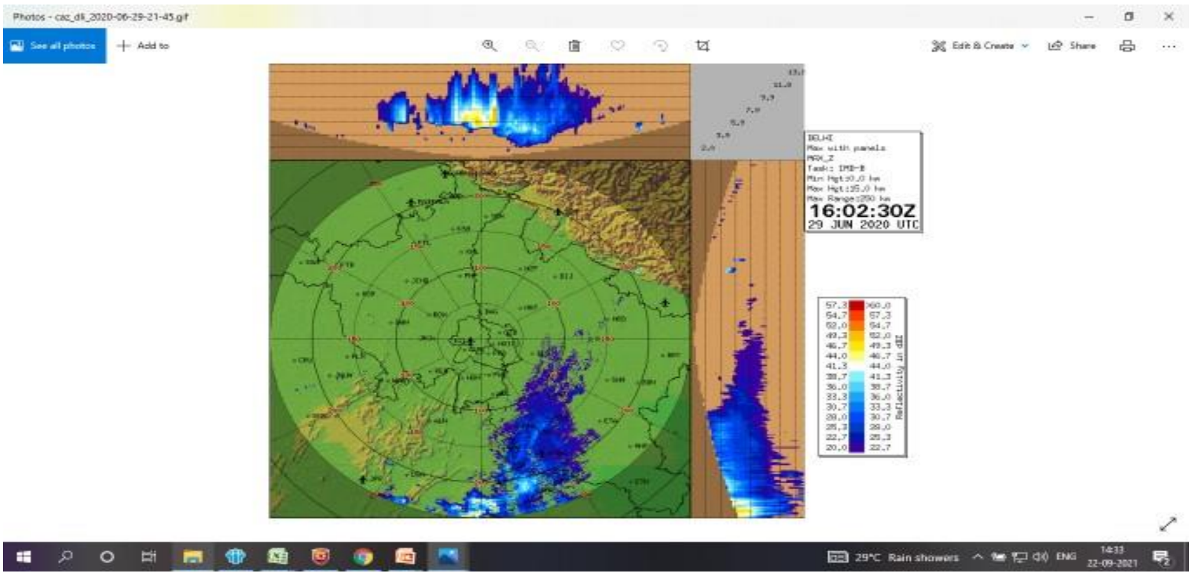
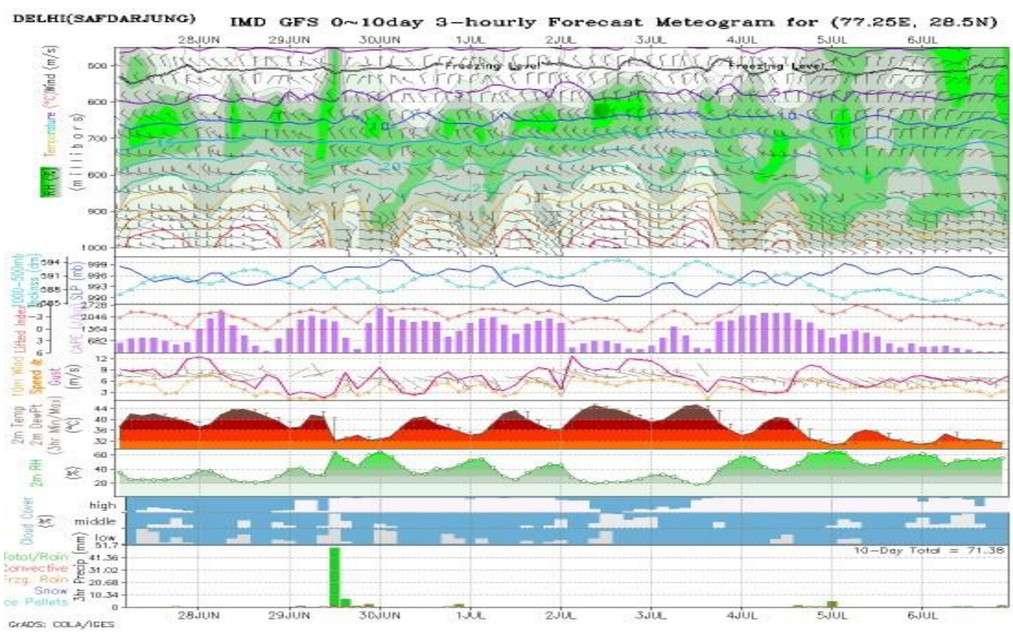


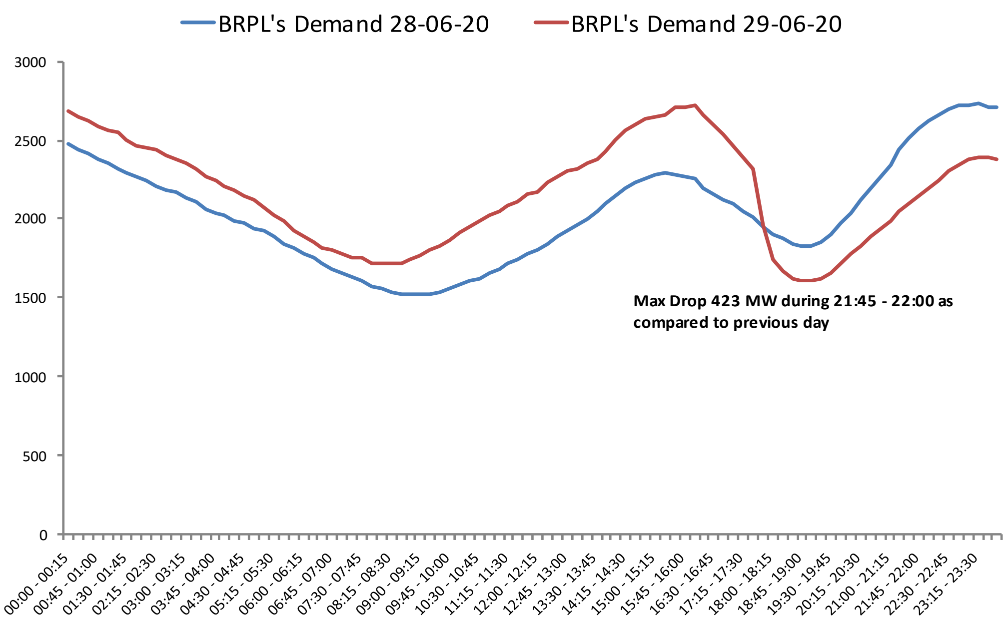
BSES Rajdhani Power Limited

29.06.2020



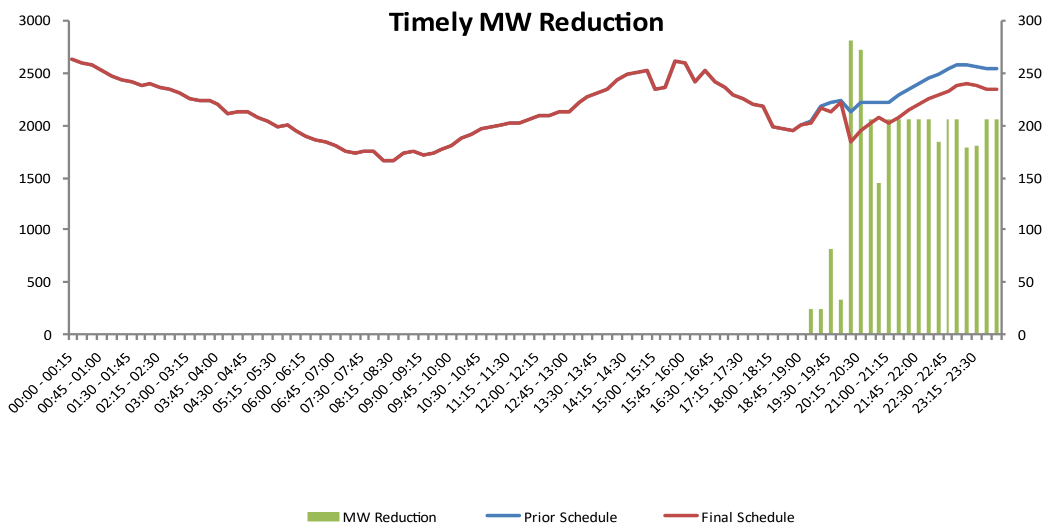
BSES Rajdhani Power Limited

29.06.2020



BSES Rajdhani Power Limited 15

29.06.2020



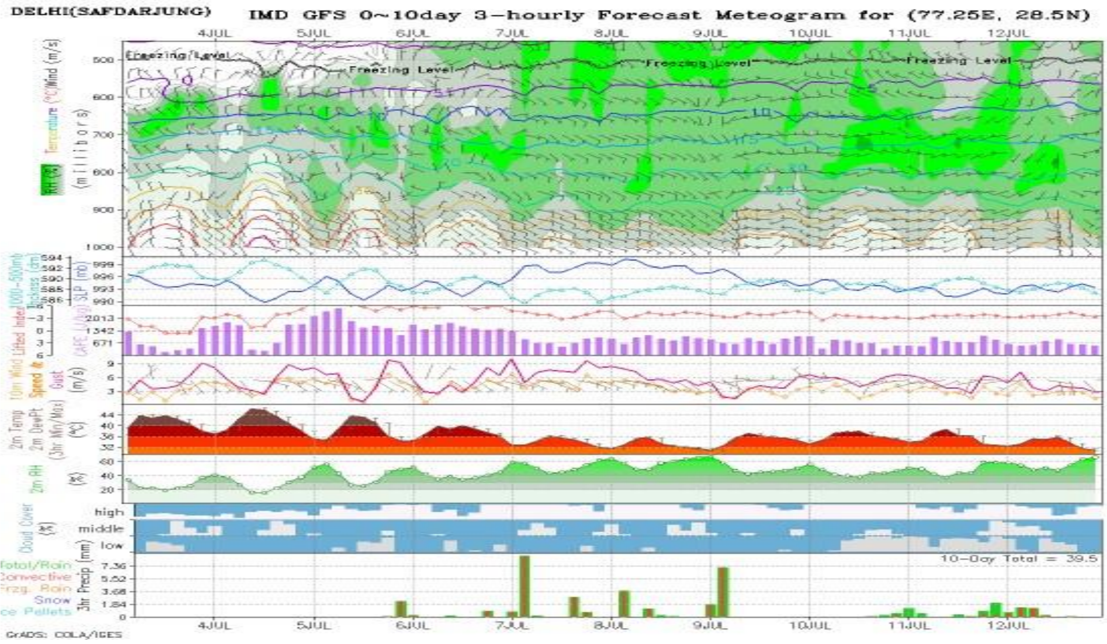
Reduced Mus – 0.87 MUs

BSES Rajdhani Power Limited 16

Case Study for 05.07.2020

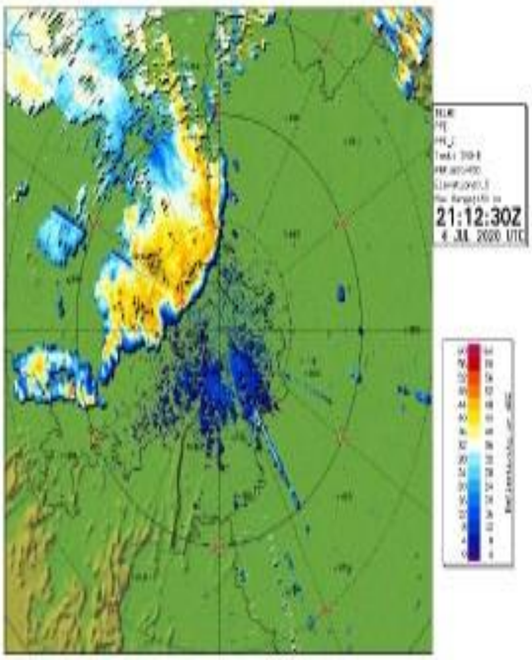
BSES Rajdhani Power Limited

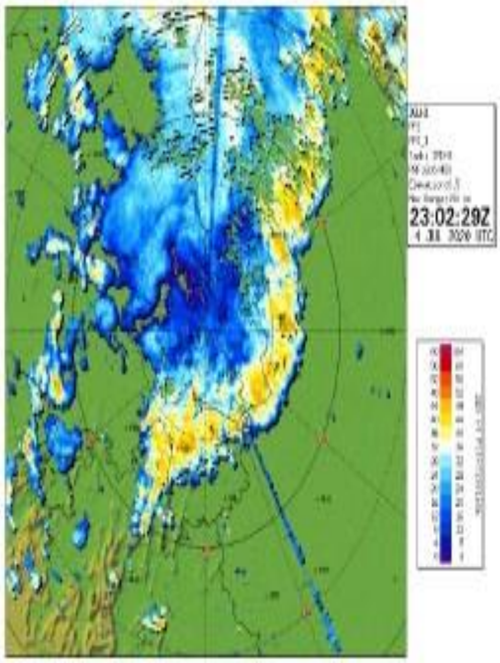
05.07.2020



BSES Rajdhani Power Limited

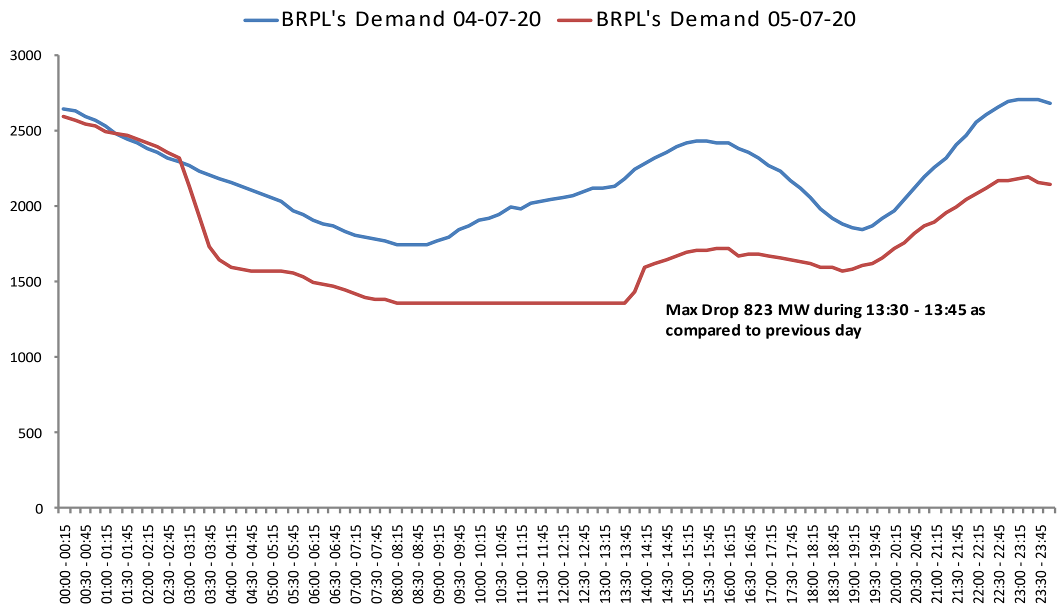
05.07.2020





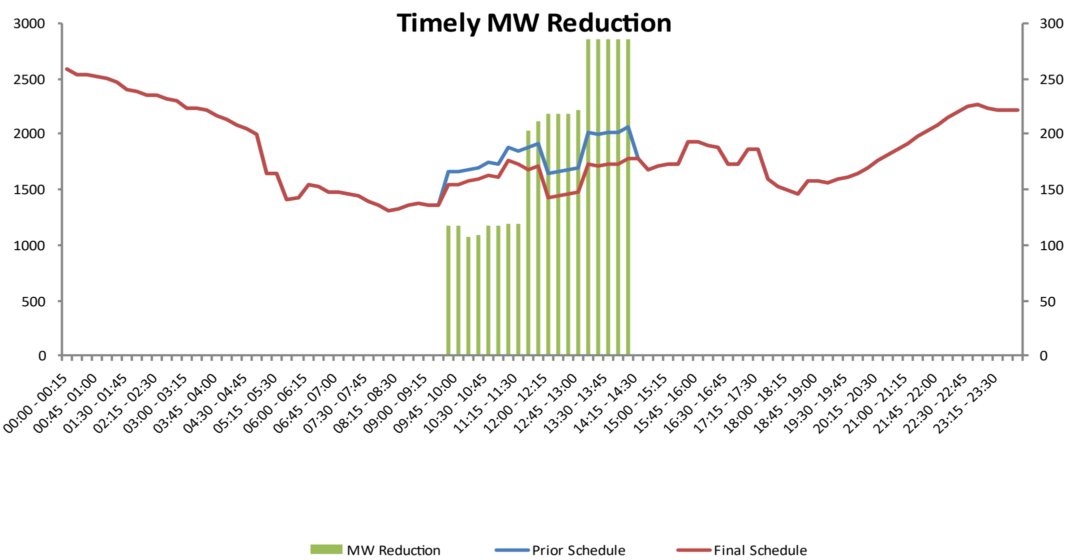
BSES Rajdhani Power Limited

05.07.2020



BSES Rajdhani Power Limited 20

05.07.2020



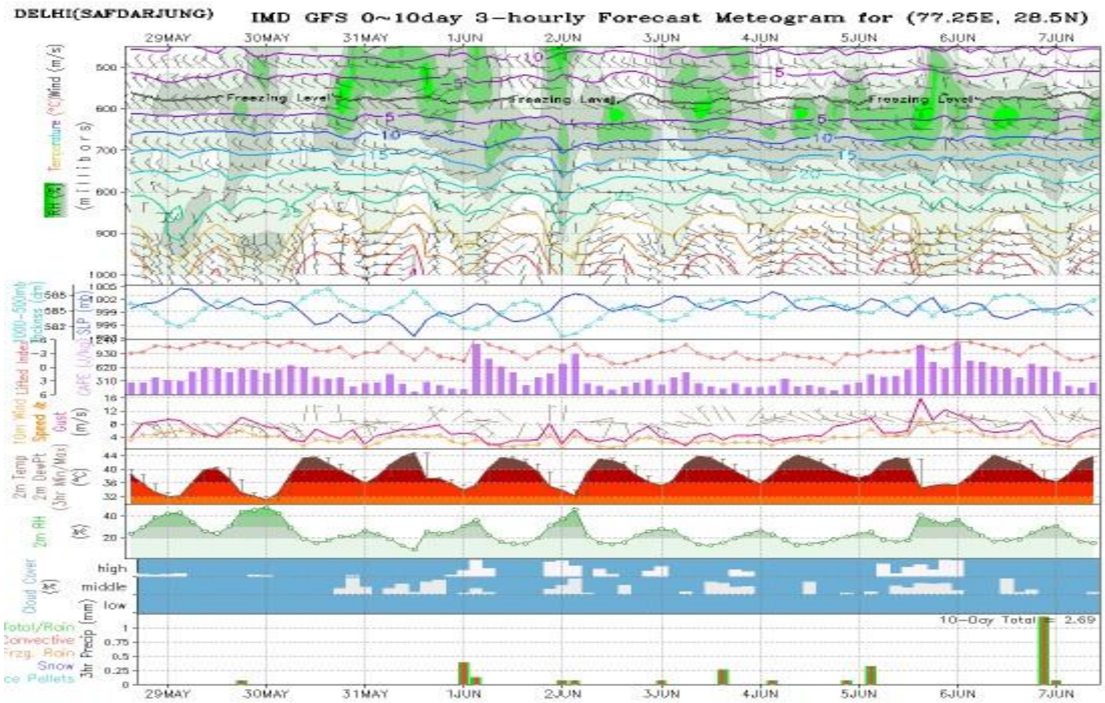
Reduced Mus – 0.91 MUs

BSES Rajdhani Power Limited 21

Case Study for 30.05.2021

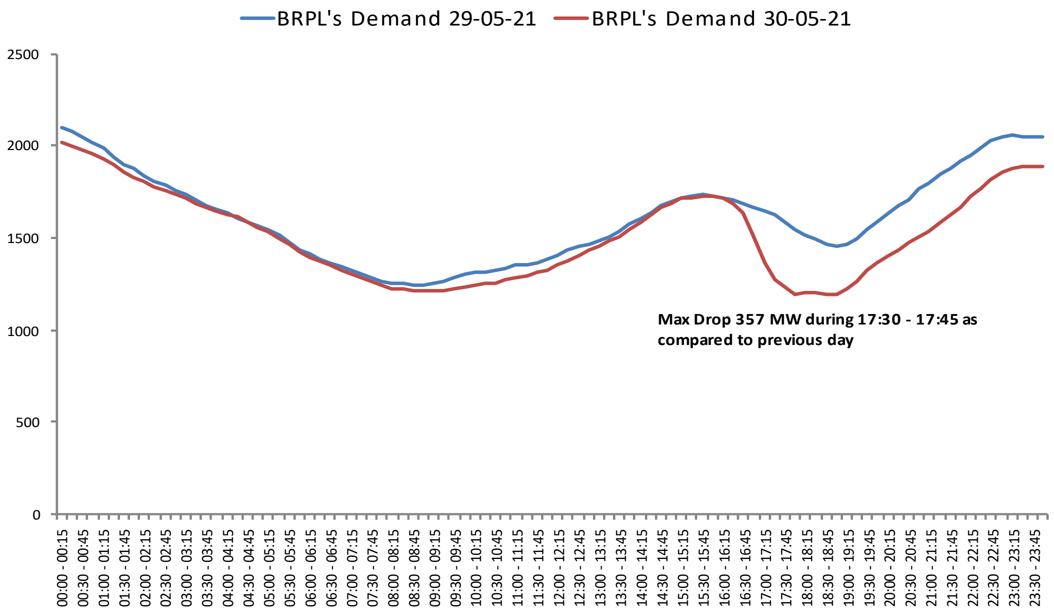
BSES Rajdhani Power Limited

30.05.2021



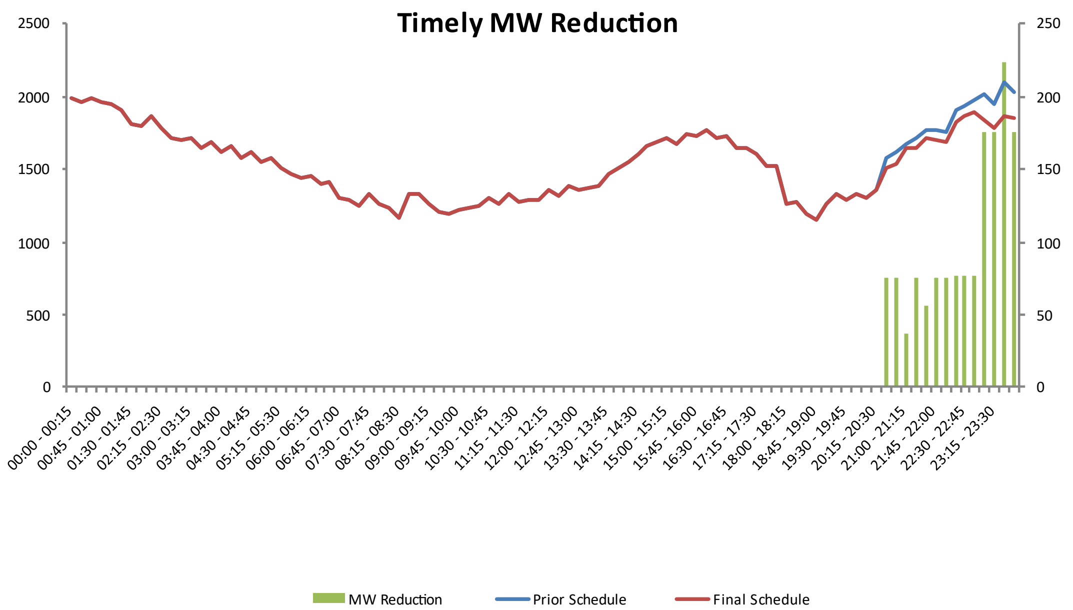
BSES Rajdhani Power Limited

30.05.2021



BSES Rajdhani Power Limited

30.05.2021



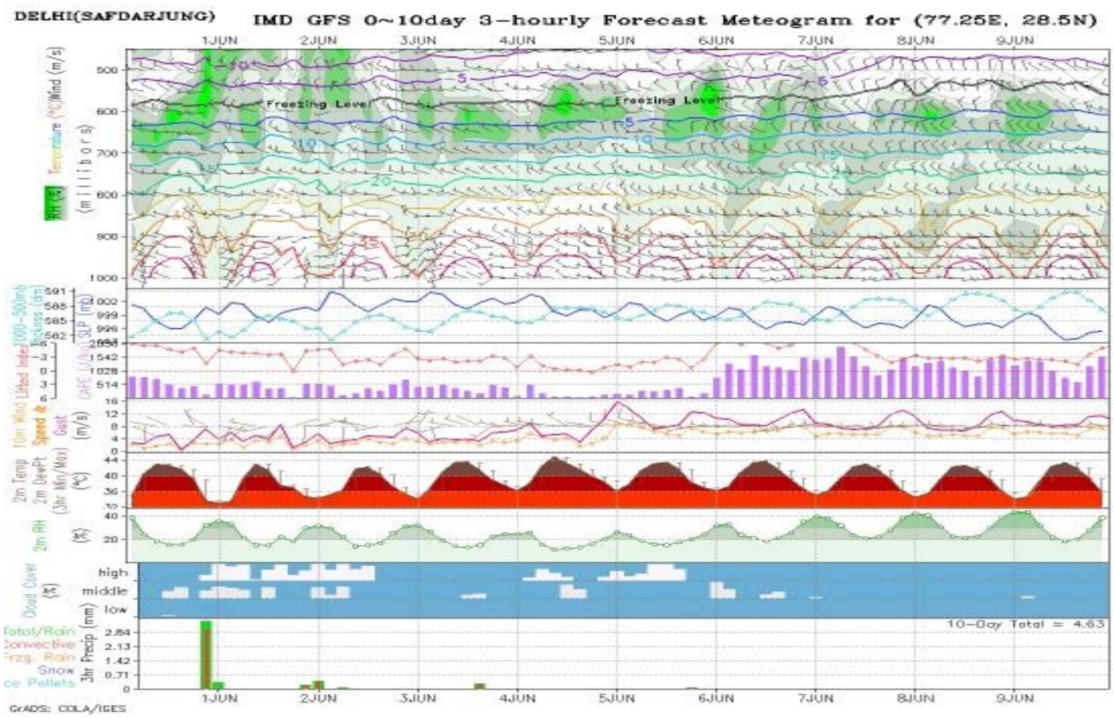
Reduced Mus – 0.36 MUs

BSES Rajdhani Power Limited 34

Case Study for 01.06.2021

BSES Rajdhani Power Limited

01.06.2021



BSES Rajdhani Power Limited

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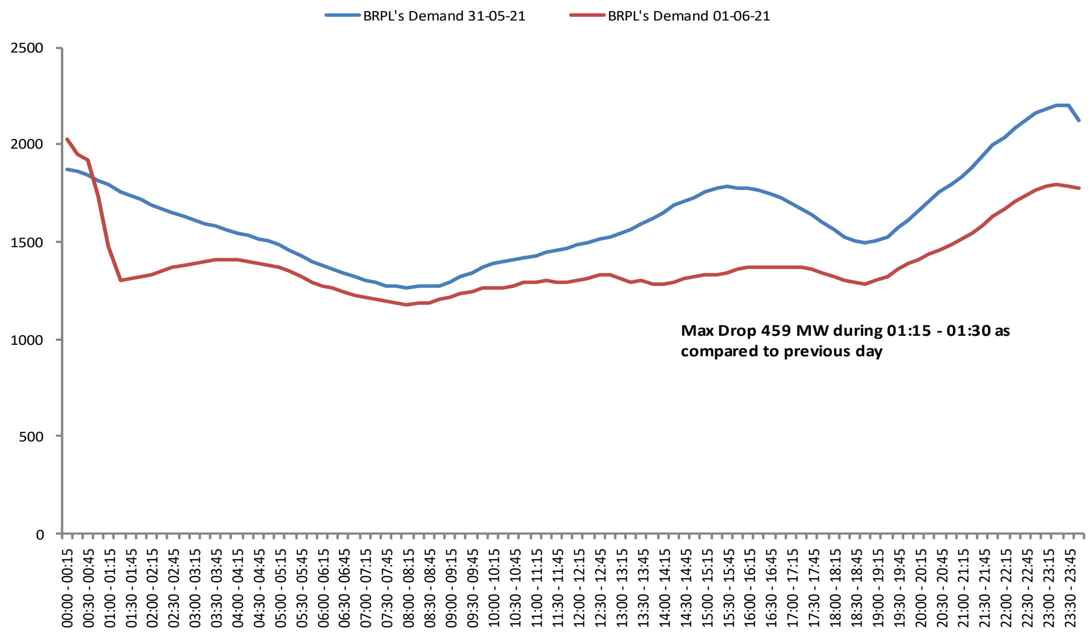

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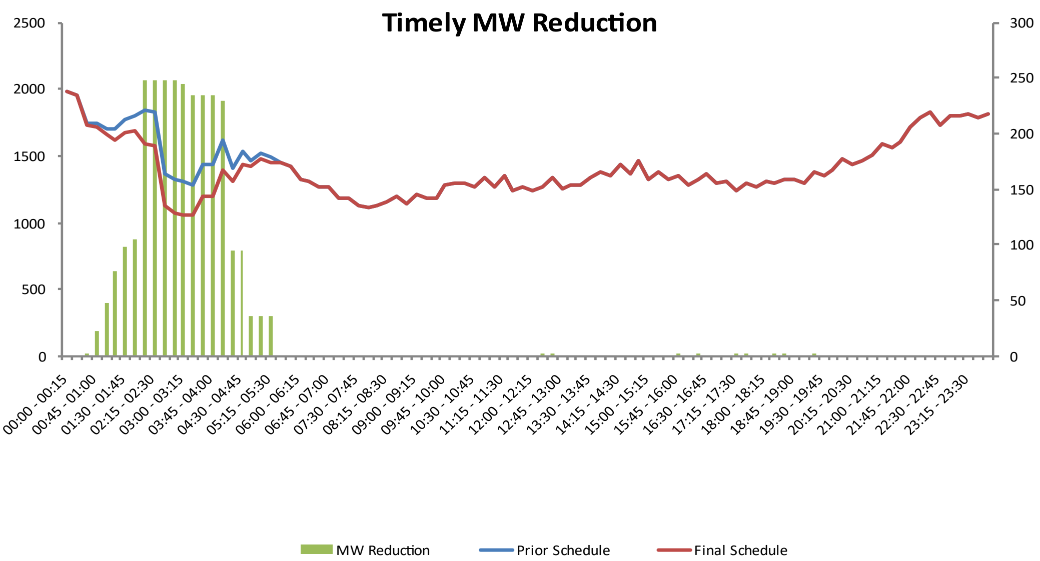
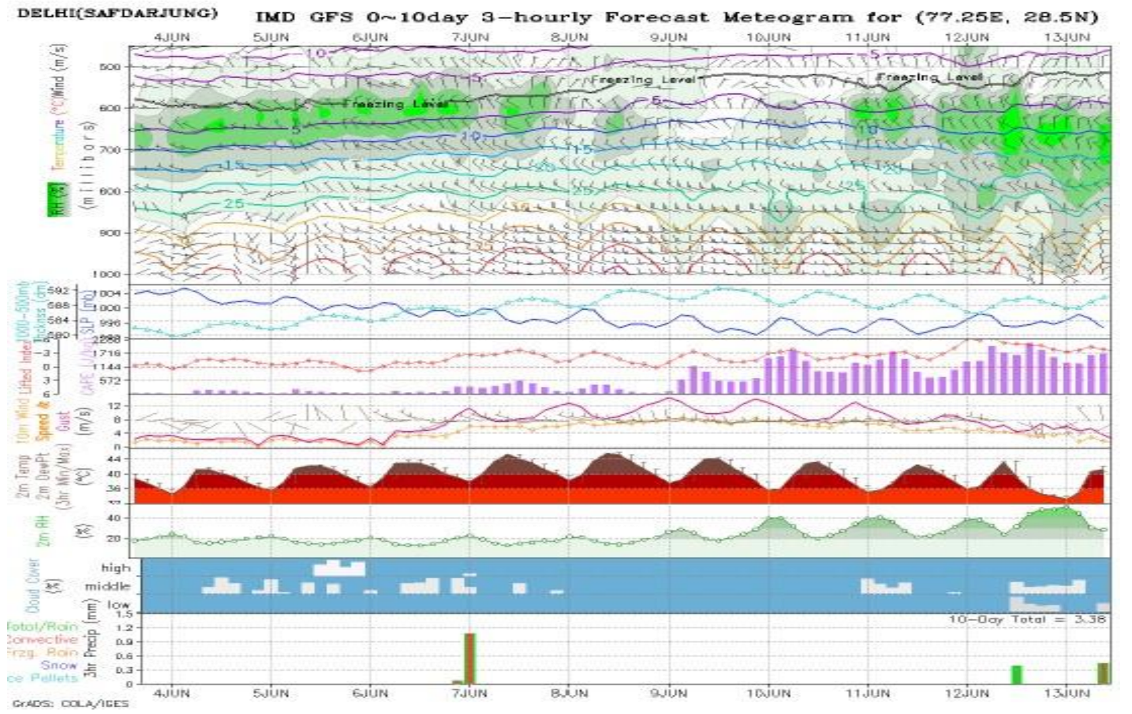


Reduced Mus – 0.71 MUs

Case Study for 04.06.2021

BSES Rajdhani Power Limited

04.06.2021



BSES Rajdhani Power Limited

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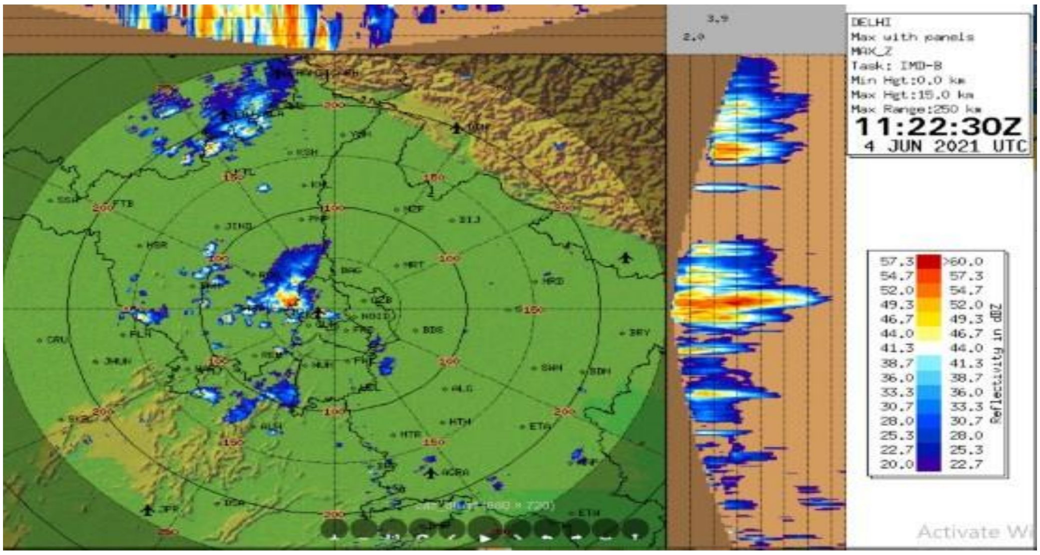

BSES Rajdhani Power Limited

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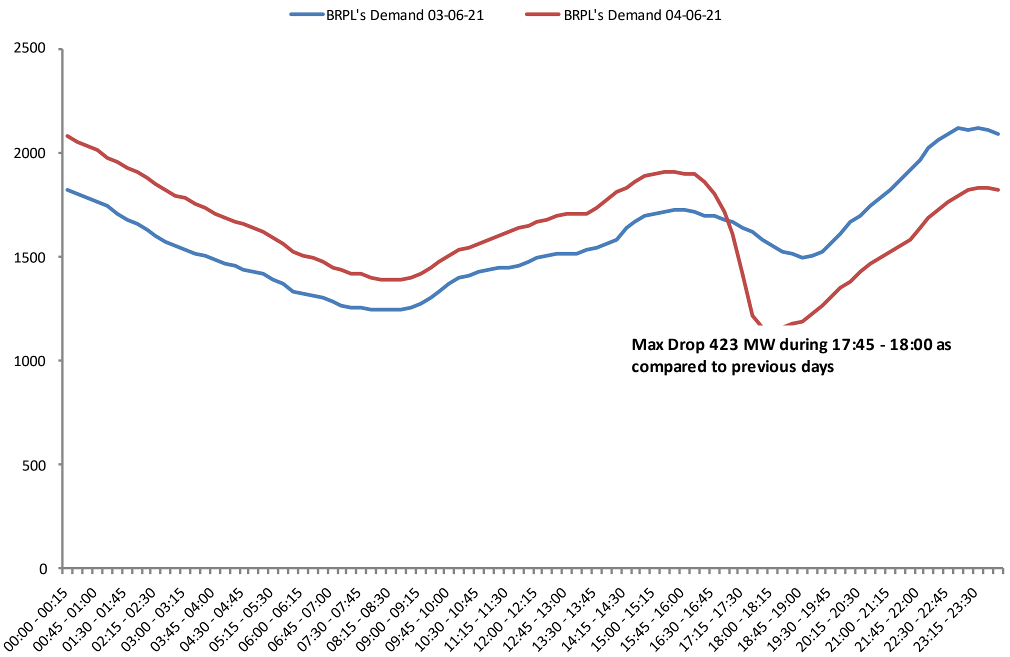
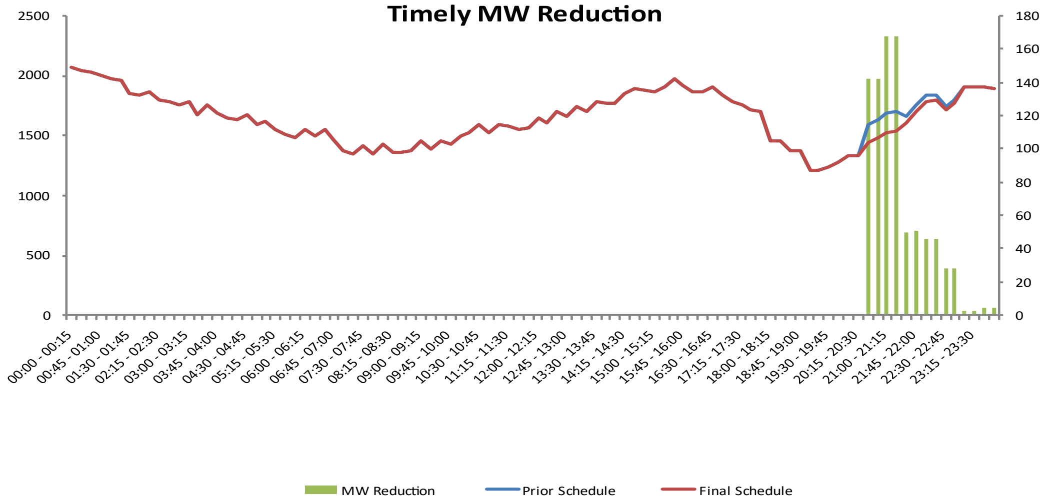


Disclaimer

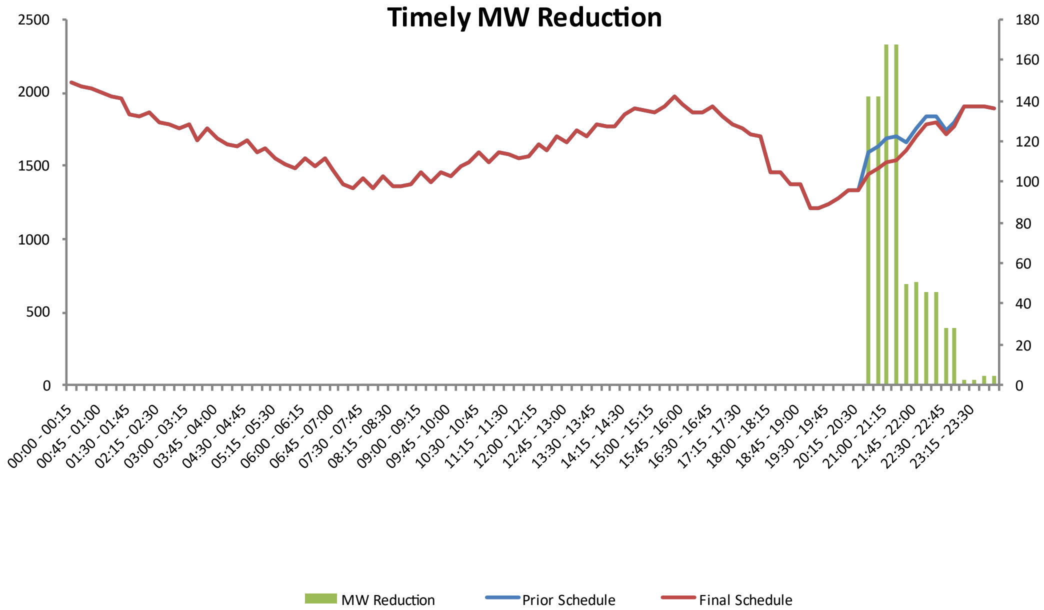
04.06.2021



Reduced Mus – 0.22 MUs

BSES Rajdhani Power Limited 30

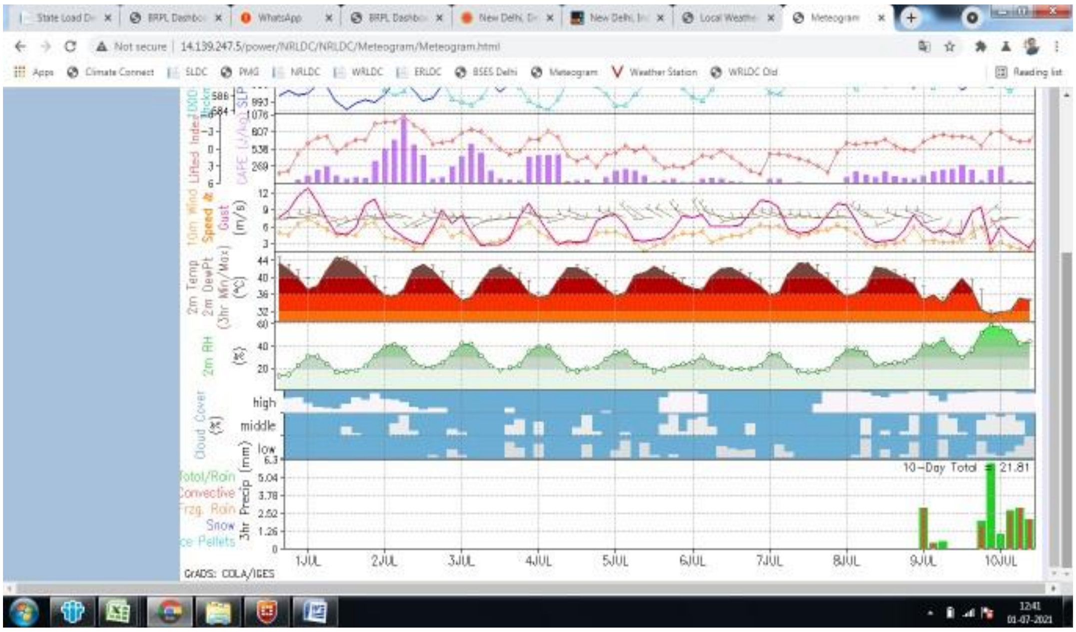
04.06.2021



Reduced Mus – 0.22 MUs

BSES Rajdhani Power Limited 30

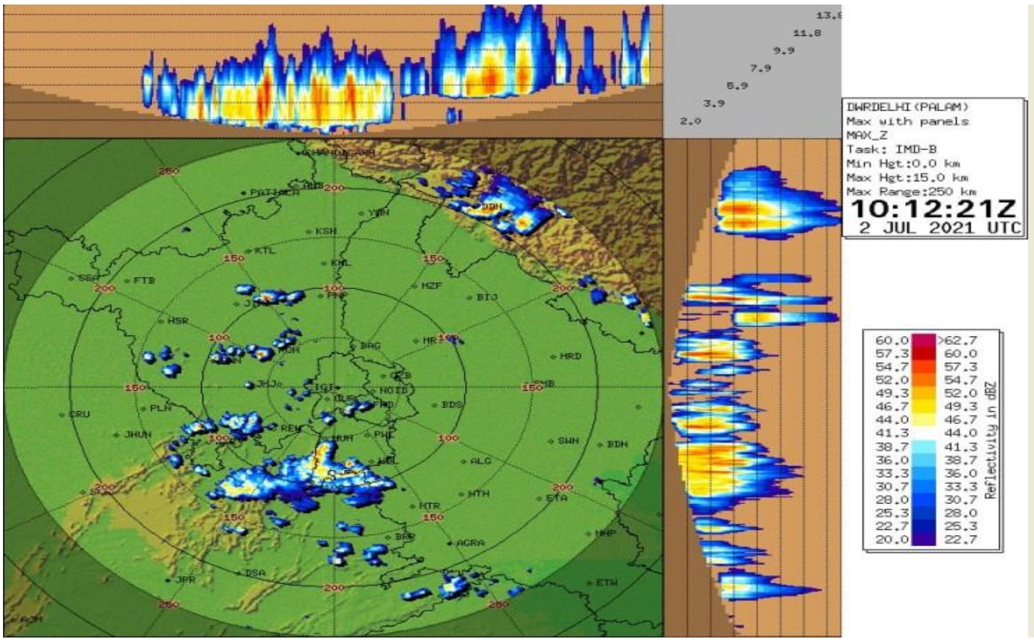
02.07.2021



BSES

BSES Rajdhani Power Limited

02.07.2021



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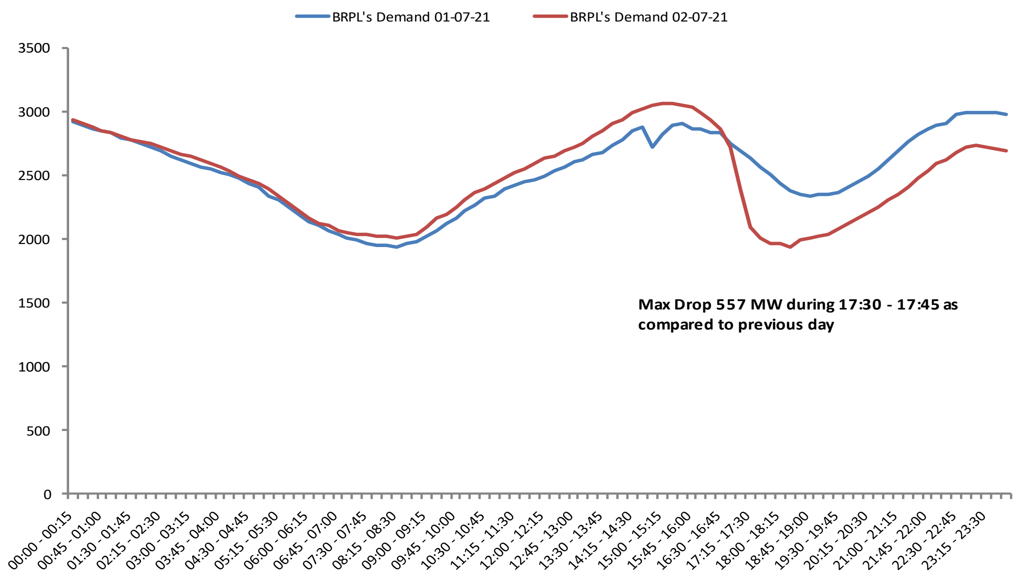

BSES Rajdhani Power Limited

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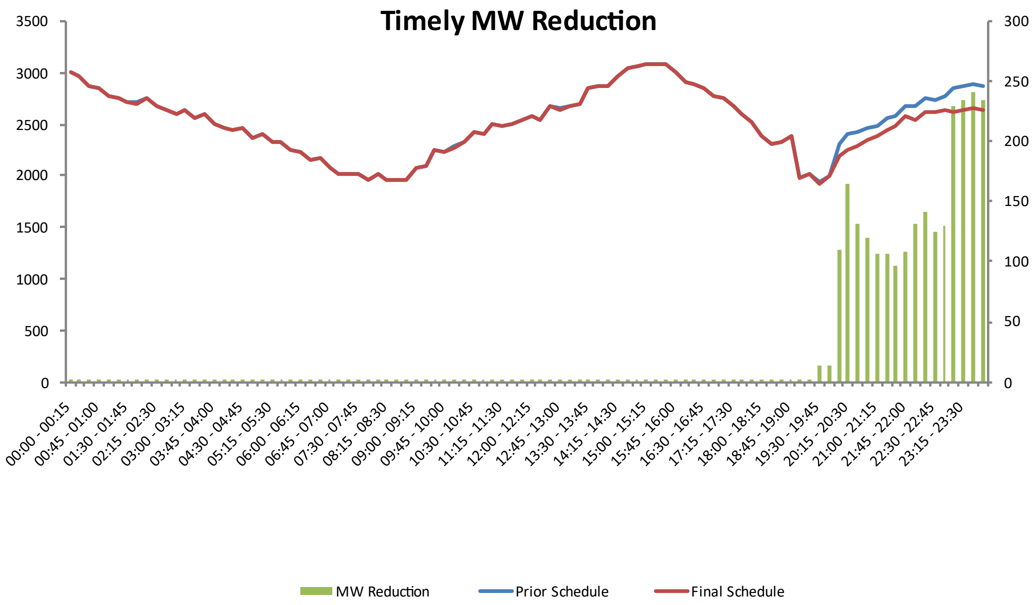

Reduced Mus – 0.62 MUs

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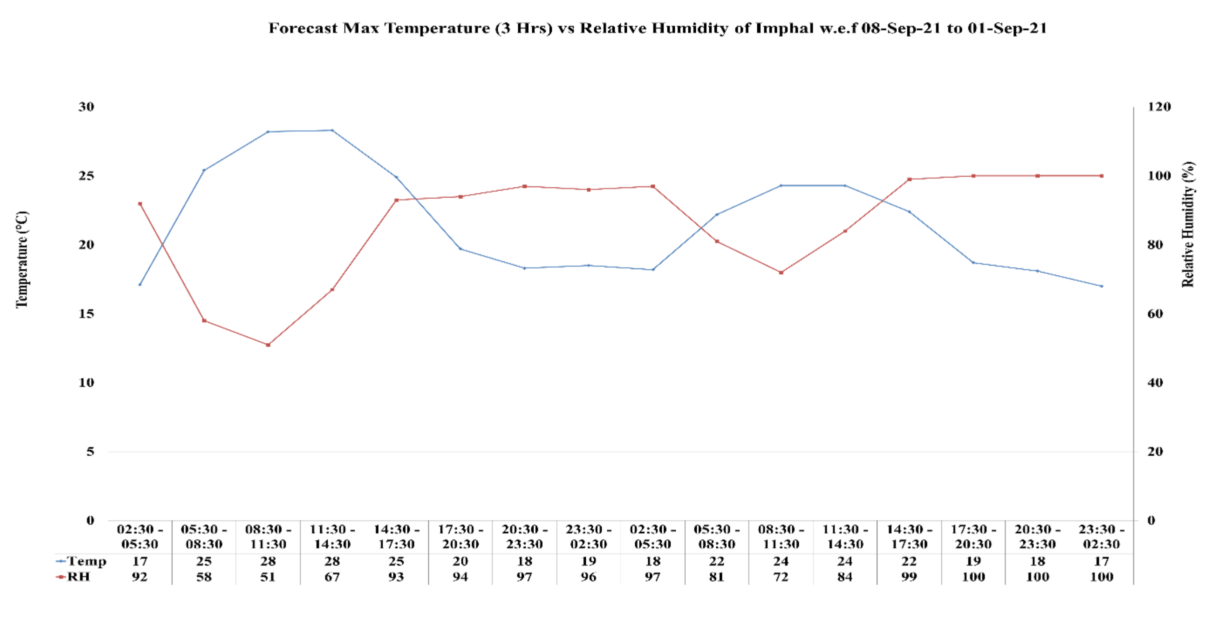
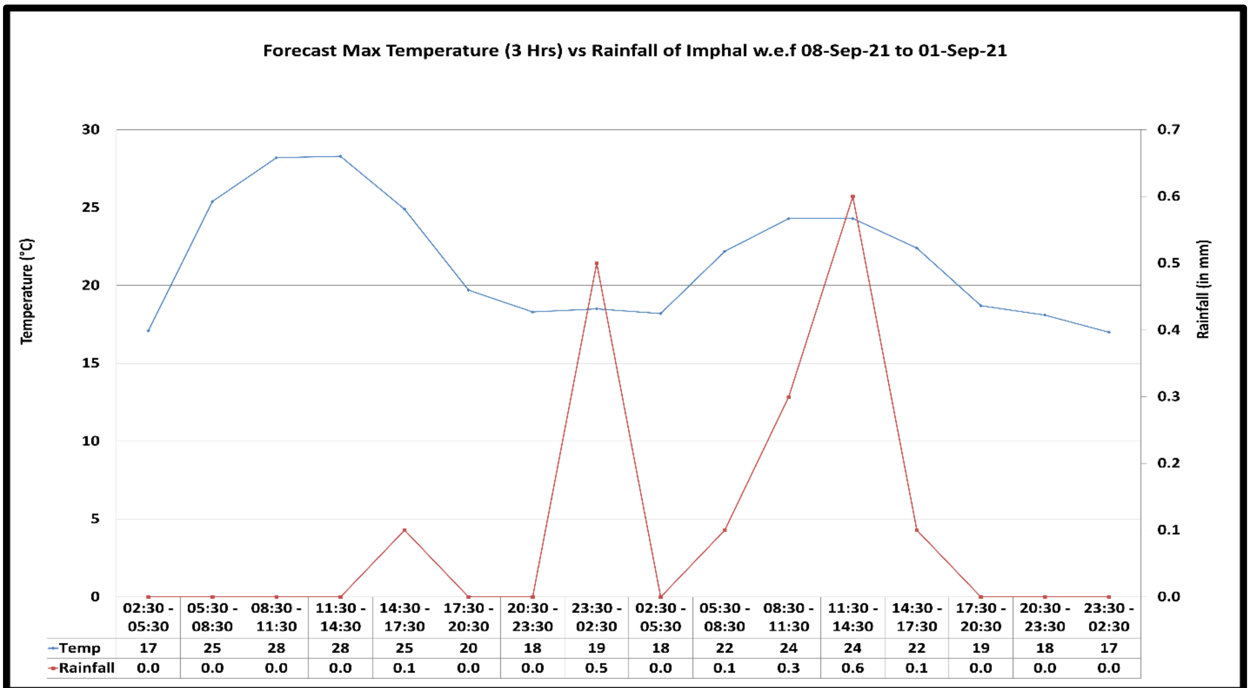
Annexure-VIII

A Typical Forecast Report for Manipur



	02:30 - 05:30	05:30 - 08:30	08:30 - 11:30	11:30 - 14:30	14:30 - 17:30	17:30 - 20:30	20:30 - 23:30	23:30 - 02:30	02:30 - 05:30	05:30 - 08:30	08:30 - 11:30	11:30 - 14:30	14:30 - 17:30	17:30 - 20:30	20:30 - 23:30	23:30 - 02:30
Temp	17	25	28	28	25	20	18	19	18	22	24	24	22	19	18	17
RH	92	58	51	67	93	94	97	96	97	81	72	84	99	100	100	100



	02:30 - 05:30	05:30 - 08:30	08:30 - 11:30	11:30 - 14:30	14:30 - 17:30	17:30 - 20:30	20:30 - 23:30	23:30 - 02:30	02:30 - 05:30	05:30 - 08:30	08:30 - 11:30	11:30 - 14:30	14:30 - 17:30	17:30 - 20:30	20:30 - 23:30	23:30 - 02:30
Temp	17	25	28	28	25	20	18	19	18	22	24	24	22	19	18	17
Rainfall	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.5	0.0	0.1	0.3	0.6	0.1	0.0	0.0	0.0

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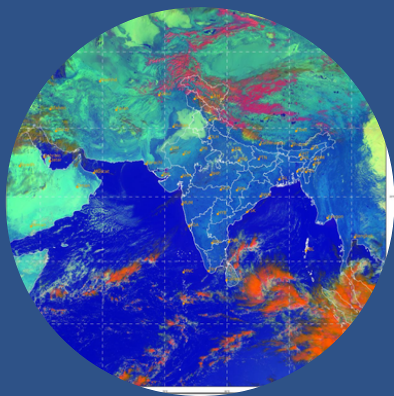

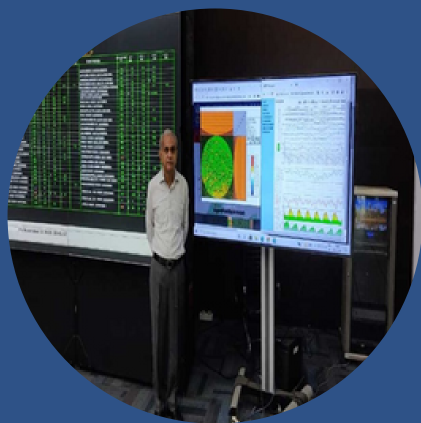

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