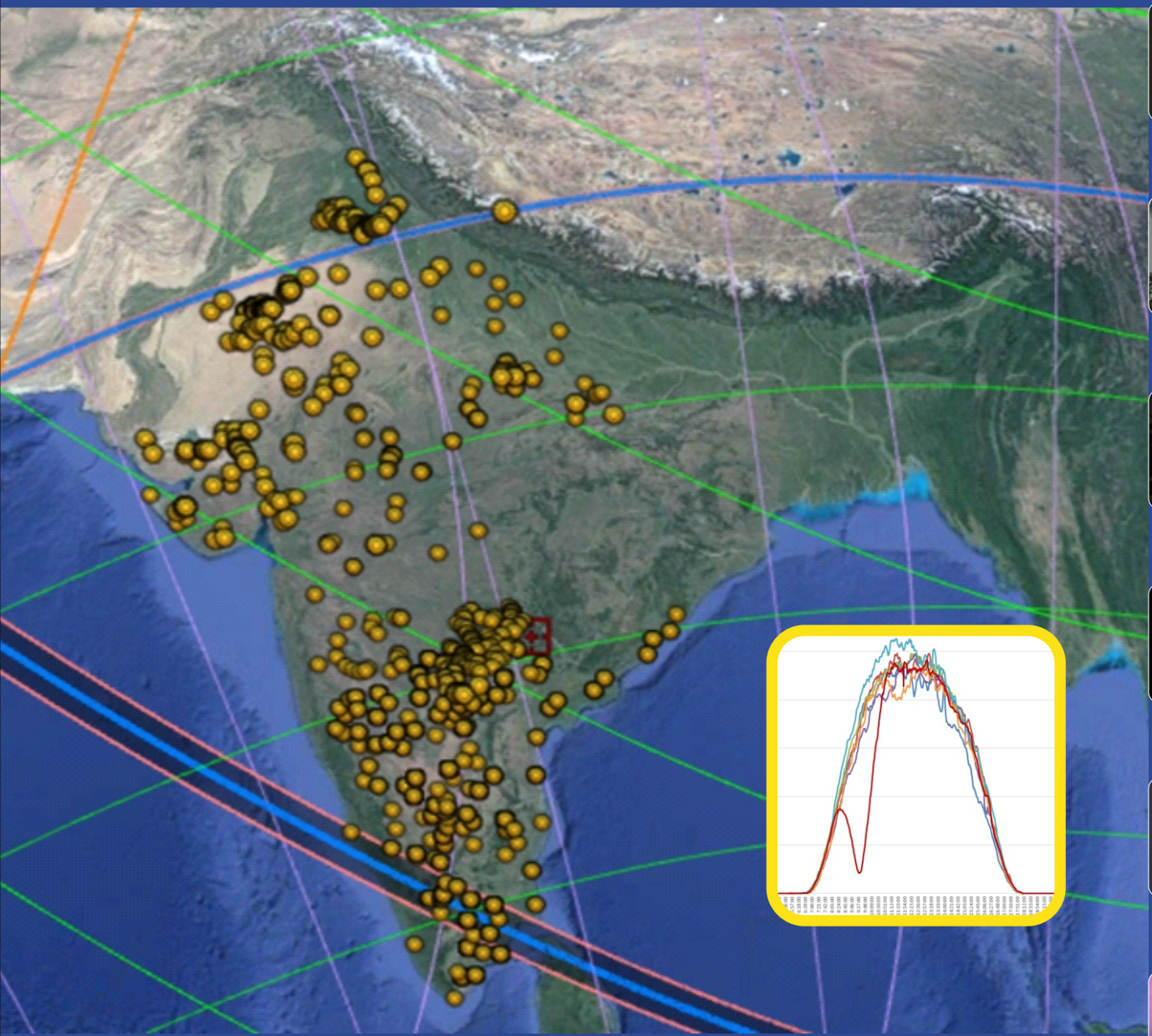
SOLAR ECLIPSE
26th December 2019

Analysis of its impact on Indian Power System - A report



Ahmedabad

Kochi

Dindigul

Madurai

Chennai

Bhubaneswar

Power System Operation Corporation Ltd.

(A Government of India Enterprise)

January 2020

SOLAR ECLIPSE
26th December 2019

Analysis of its impact on Indian Power System - A report

Power System Operation Corporation Ltd.
(A Government of India Enterprise)

January 2020

Foreword

The unveiling of an astronomical event such as solar eclipse has an impact on power systems having, high penetration of solar generation. India experienced one such astronomical event on 26th December 2019, when annular solar eclipse impacted solar generation across the country. Before the event, POSOCO had worked out likely impact of the solar eclipse on Indian power system and same was shared with all stakeholders. The report also outlined the operational preparedness required at both the state and regional levels to mitigate the impact of solar eclipse on the Indian power system.

With the successful handling of the impact of solar eclipse on 26th December 2019, I am happy to note that POSOCO has further put together a post event analysis report, which covers areas such as solar generation forecasting, ramp estimation, demand variation, behaviour of PV plants during solar eclipse. The report emphasises on more meticulous demand & RE forecasting and coordination among DISCOMs/SLDCs/RLDCs in load management. The variation in Global Horizontal irradiance during solar eclipse for plants falling in annular and partial eclipse zone have been analysed in the report.

In the backdrop of 300 GW of Solar generation capacity to be installed by year 2029 -30 which shall account for 36% share in India's energy mix, I would like to believe that these two reports would serve the system operators in understanding the behavior of solar eclipse phenomenon on PV plants in India and help in reliable and secure operation of the Indian power system.

I wholeheartedly congratulate team POSOCO who worked in preparation of these reports. I also sincerely thank SLDCs, Solar Generating plants and India Meteorological Department who extended their timely support by sharing relevant data & contributed towards making these reports.

केवा

KVS Baba
Chairman & Managing Director, POSOCO

Table of Contents

List of Figures

List of Acronyms

ATC: Available Transfer Capability

ACE: Area Control Error

ER: Eastern Region

ERLDC: Eastern Regional Load Despatch Centre

GHI: Global Horizontal Irradiance

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

ISGS: Inter State Generating Station

IEGC: Indian Electricity Grid Code

NLDC: National Load Dispatch Centre

NR: Northern Region

NRLDC: Northern Regional Load Despatch Centre

NER: North Eastern Region

NERLDC: North Eastern Regional Load Despatch Centre

OCC: Operational Coordination Committee

POSOCO: Power System Operation Corporation Ltd.

PV: Photovoltaic

RRAS: Reserve Regulation Ancillary Services

RPC: Regional Power Committee

RE: Renewable Energy

RSD: Reserve Shutdown

RLDC: Regional Load Dispatch Centre

SCED: Security Constrained Economic Despatch

SLDC: State Load Dispatch Centre

SR: Southern Region

SRLDC: Southern Regional Load Despatch Centre

SCADA: Supervisory Control and Data Acquisition

TTC: Technical Coordination Committee

UPV: Utility-Scale PV System

URS: Un-Requisitioned Surplus Power

WR: Western Region

WRLDC: Western Regional Load Despatch Centre

Executive Summary

India experienced an annular solar eclipse on 26th December 2019. The annularity was visible mainly in Southern India i.e. in the states of Kerala, Tamil Nadu and Karnataka while the rest of the country witnessed partial eclipse of the sun.

In order to assess likely impact of solar eclipse on Indian power system, a report was published by Power System Operation Corporation Ltd (POSOCO) in November 2019. The report is available at

https://posoco.in/wp-content/uploads/2019/12/Solar-Eclipse-26th-December-2019-Indian-Power-System-likely-impacts-and-preparedness-A-report.pdf.

It was estimated that maximum shortfall of solar generation would be 7823 MW and solar generation reduction was expected to be at average ramp rate of 13MW/minute between 08:05 AM - 09:30 AM (1 hour 25 minutes) and after the maximum eclipse is over, the addition of solar generation between 09:30 AM-11:20 AM (1 hour 40 minutes) was expected to be at average ramp rate of 122 MW/minute (Fig. 1).

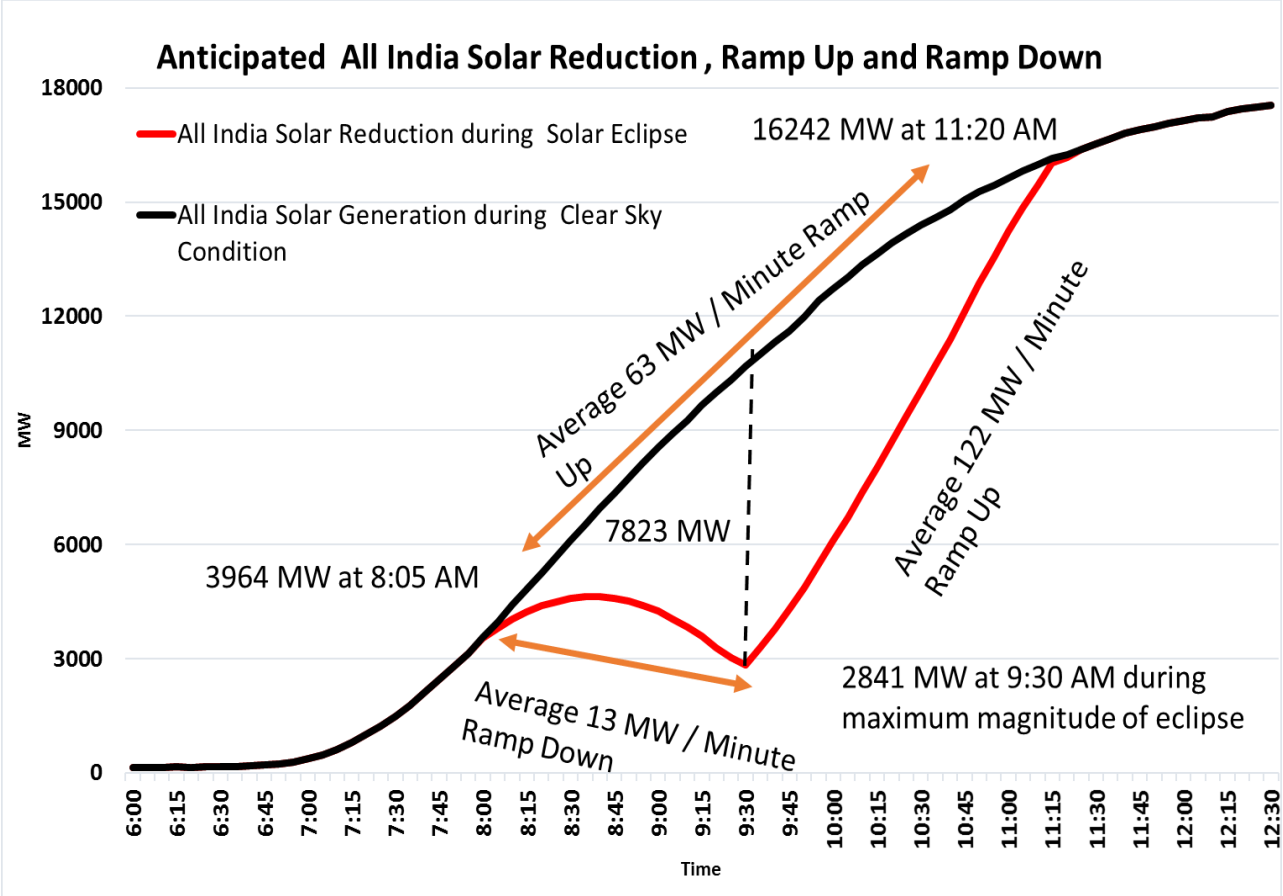


Figure 1: Estimated all India Solar Reduction and Ramp Up and Ramp Down Rate

Further, the report highlighted that during eclipse on 26th December 2019, there would be a depression in demand due to nuances of human behaviour. From earlier instances of solar eclipses, it was collated that during eclipse temples are closed, small commercial shops postpone their activities, cooking activity is postponed and generally people prefer to confine themselves indoor. This human behaviour leads to average reduction in power demand by 2-3%. However, after the eclipse is over, demand is expected to rise. It was also estimated that during 26th December 2019 annular solar eclipse major impact would be felt on Southern Region solar generation as it has the highest penetration of solar energy along with highest obscuration. Therefore, support from Thermal, Hydro and Gas generation was required to tackle the variations in ramp rates during eclipse.

The post event report showcases the operational planning carried out, real time grid management and the key learnings.

Solar generation variation during solar eclipse

The compiled data shows that during the event 6.5 GW(Fig.2) of solar generation reductions took place with respect to 25th December 2019. This was due to cloudy conditions in Southern and Western Region and Fog in Northern Region on 25th December 2019. All India estimated solar generation ramp up and ramp down rates observed on day of event were in approximation to the estimated values. During the eclipse, average ramp down rate was 11.6 MW/minute from 08:03 hrs to 09:30 hrs against estimated value of 13 MW/minute and average ramp up rate was 123 MW/minute from 09:30 hrs to 11:20 hrs against estimated value of 122 MW/minute (Fig.3).

It is now analysed that the difference in estimated and actual solar generation can be attributed to the methodology of considering the mean obscuration of each state for solar generation, which did not take into cognisance the factor of diversity in the geographical spacing of various generating units within the physical boundaries of each state.

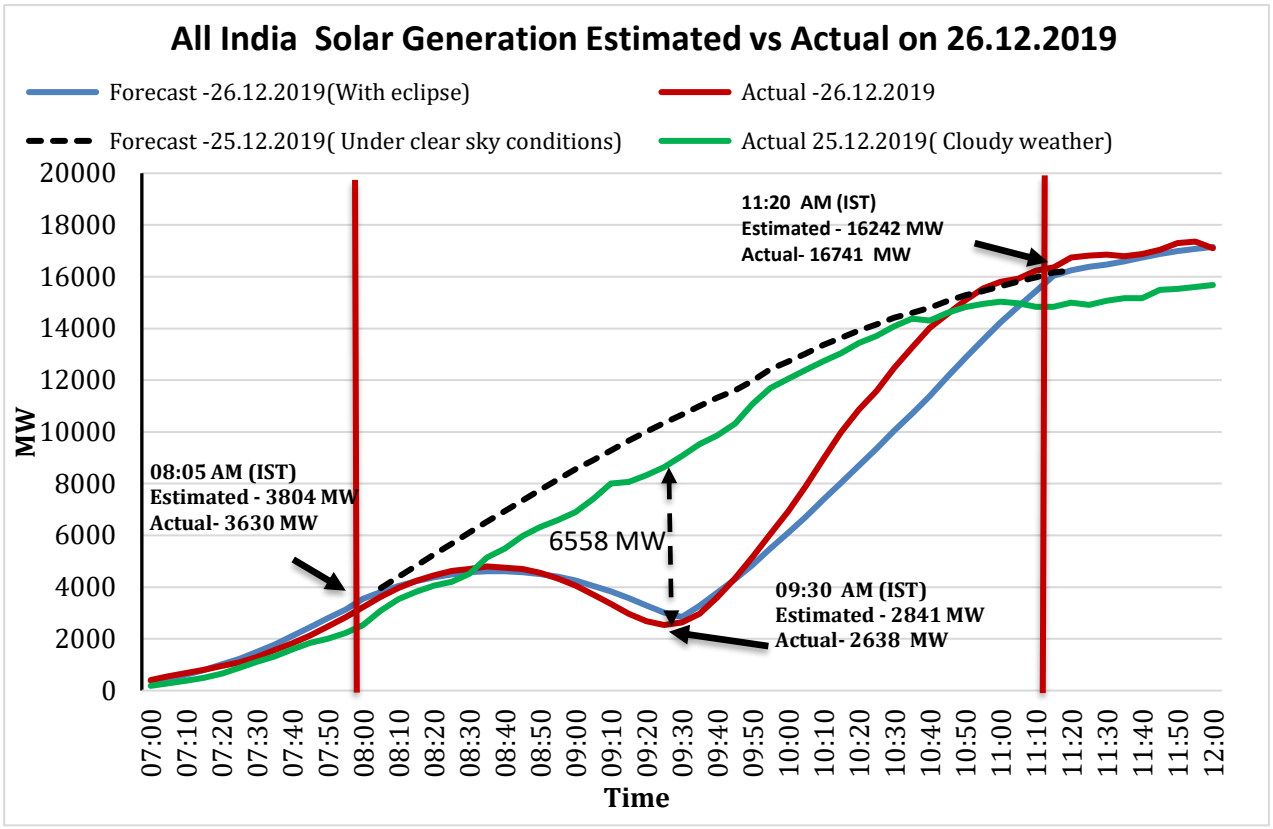


Figure 2: All India Solar Generation Estimated vs Actual on 26.12.2019

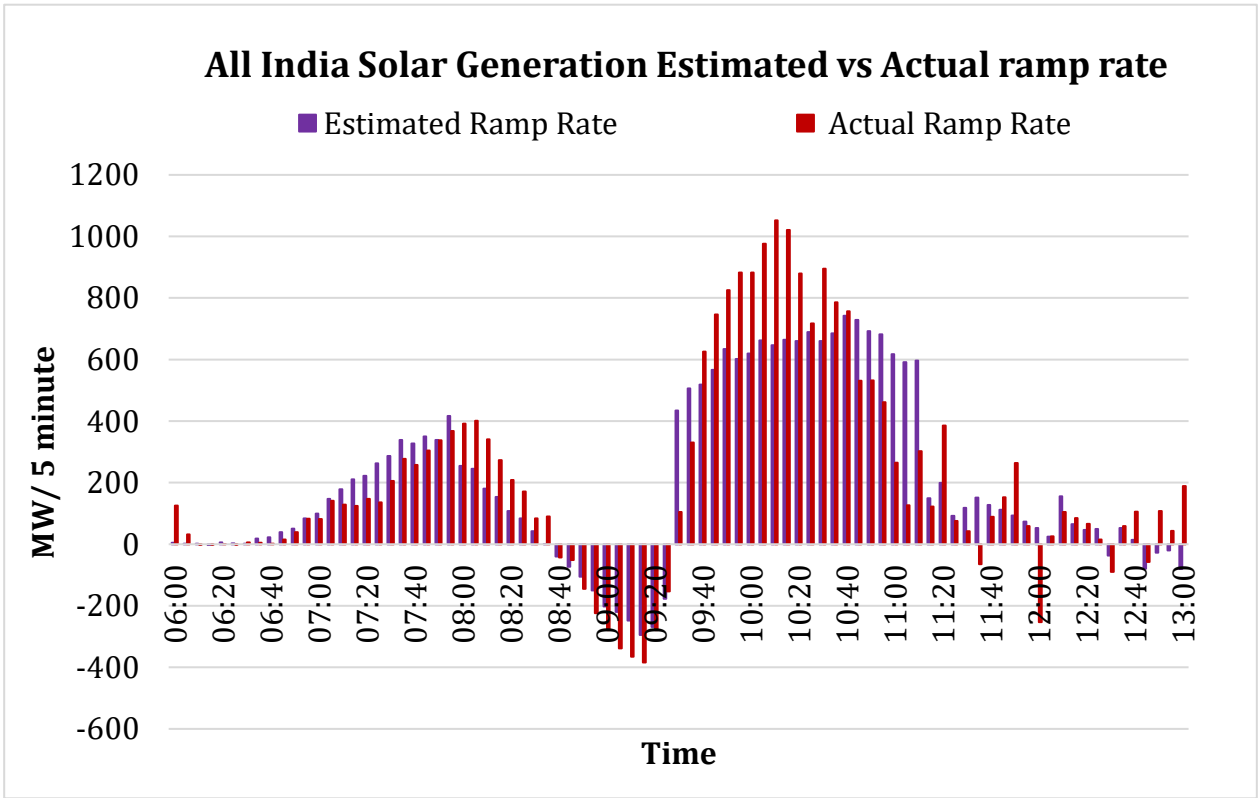


Figure 3: All India Solar Generation Estimated vs Actual ramp rate

Demand variation during solar eclipse

Based on previous solar eclipse events occurrences in India, it was estimated that all India demand shall reduce by an average of around 2-3 % of previous day demand with 4-5 % maximum instantaneous demand reduction. The demand variation showed a similar trajectory during 26th December 2019 event also, as demand reduced by 2.4% with an instantaneous maximum reduction of 4.2 %.

However, it was also observed that all India demand increased by 6372 MW after the eclipse was over, which was more than 3000-3500 MW of anticipated increase. The demand crossed 170 GW, which was highest ever in the month of December 2019. The pattern of human behavior in India is unique since cultural factors get intertwined with astronomical events like solar eclipses and lunar eclipses. Majority of the people in India re-start and undertake a lot of activities as soon as solar eclipse gets over i.e. taking baths, opening of closed shops, opening of temples, preparation of fresh food which leads to spurt in demand.

The regional basis demand variations are summarised as below:

- Reduction of 3992 MW was observed in Southern Region during eclipse compared to previous day. After end of eclipse Southern regional demand increased by 3700 MW due to sudden increase in domestic load (mainly geyser load) and agriculture load.
- Western Region demand on solar eclipse day was also observed to be less than the demand of 25th December 2019. The maximum reduction observed was 1847MW at 10:15hrs. At the end of solar eclipse, the demand started increasing and crossed the previous day demand.
- Eastern Region demand reduction was to the tune of 1000 MW with 700-750 MW increase in demand after end of eclipse.
- There was not much change in demand of Northern Region, however, around 800 MW increase in demand was observed after end of eclipse.

Generation variation during solar eclipse

In order to mitigate the variation in solar generation due to eclipse, advisories were issued by respective Regional load despatch centres wherein, all states were requested to vary their hydro/gas generation based on the real time solar generation reduction as per the proposed ramp rates. Since maximum impact was estimated in Southern Region,

two units of Kudgi Thermal Power Station on RRAS and one unit of Vallur Thermal Power Station was brought on bar at 00:00 hrs of 26th December 2019. All ISGS hydro generators varied their generation as per real time frequency. During eclipse hydro generation was varied to the tune of 6000 MW. Gas generation in Western Region and Northern Region were kept on bar from 05:00 hrs of 26th December 2019 to cater ramp issues during morning demand as well as solar eclipse period. Gas generation was varied to the tune of 1000 MW. Thermal Inter State Generating Stations (ISGS) in Southern Region were excluded from Security Constrained Economic Despatch (SCED) since 03:00 hrs to mitigate congestion in inter-regional corridors towards Southern Region.

Frequency profile during solar eclipse

Frequency was 66% of time within IEGC band during the period of solar eclipse. The maximum and minimum frequency was 50.24 Hz at 08:04 hrs and 49.70 Hz at 11:10 hrs respectively. The average frequency during the solar eclipse period was 50.01 Hz.

Variation of GHI with obscuration (%)

It was observed that the GHI at plants located in Karnataka and Tamil Nadu which experienced annular eclipse, started reducing when obscuration at these locations were more than 10%. The observed GHI became zero when obscuration reached 90%. However, in case of plants located in Rajasthan and Gujarat, which experienced partial eclipse, GHI started reducing when obscuration reached 20%.

Summary table:

Parameters	Values		
Type of eclipse/date	Annular /26th December 2019		
Solar eclipse start time	08:03 AM (Dwarka)		
Maximum eclipse time	09:30 AM		
Solar eclipse end time	12:03 PM (Port Blair)		
Visibility of annularity	Southern part of India		
Maximum % Obscuration	93.10%(Madurai)		
All India Demand	Maximum	170616 MW	
	Minimum	153644 MW	
	Average	161440 MW	
Average demand reduction during solar eclipse w.r.t previous day	2.4% or 3972 MW		
Maximum demand reduction w.r.t. previous day	4.2 % or 6868 MW		
Rise in demand after end of solar eclipse (10:50 hrs to 11:37 hrs)	3.8 % or 6372 MW		
Solar generation reduction during solar eclipse	Estimated	7.8 GW (w.r.t. clear sky conditions)	
	Actual	*6.5 GW (w.r.t. 25.12.2019)	
All India average ramp down rate (08:03 hrs to 09:30 hrs)	Estimated	13 MW/minute	
	Actual	11.6 MW/minute	
All India average ramp up rate (09:30 hrs to 11:30 hrs)	Estimated	122 MW/minute	
	Actual	123 MW/minute	
Frequency (Hz)	Maximum	50.24	
	Minimum	49.70	
	Average	50.01	
% of time frequency within IEGC band	66 %		
Thermal generation variation during solar eclipse	2000 MW		
Hydro generation variation during solar eclipse	6000 MW		
Gas generation variation during solar eclipse	1000 MW		

*Cloudy conditions prevailed in Southern and Western Region and Fog in Northern Region on 25th and 26th December 2019.

Chapter - 1 : Pre event preparedness

1.1 Operational planning

All the constituents were sensitized in OCC (Operational coordination committee) as well as TCC (Technical coordination committee) / RPC (Regional power committee) meetings in all regions. During the solar eclipse, in order to ensure reliable and secure grid operation and to address solar generation reduction and ramping issues at all India level, all constituents and load despatch centres were advised to take necessary preparedness measures such as:

(i) To carry out day ahead/Intraday forecast diligently for 26th December 2019.

(ii) To identify the resources and keep it on bar to meet the variation in generation from solar PV plants and behind the meter solar. Facilitation of planned outages of transmission elements in and towards Southern Region on 26th December 2019 after 12:00 hrs.

(iii) To maintain adequate spinning reserves in Southern Region, ISGS/SGS units closed under Reserve shut down to be brought on-bar by 04:00 hrs on 26th December 2019. Having additional units would be helpful to meet ramp requirements as well.

(iv) Scheduling of ISGS and state hydro generation to be carried out in an optimum manner so as to meet the net demand as well as net demand ramp during the occurrence of eclipse. Hydro stations shall be used for regulation purpose to maintain the frequency within IEGC band. All the thermal generation (including states) to be maximized in Southern Region by 07:00 hrs of 26th December 2019.

(v) Gas-based units to be brought on bar by 05:00 hrs of 26th December 2019 to meet morning demand ramp and to take care of any unit tripping.

(vi) All regional entities were advised to maintain their interchange as per schedule and avoid any deviation in real-time.

(vii) Thermal ISGS in Southern Region to be excluded from SCED by 03:00 hrs of 26th December 2019 by NLDC so as to avoid congestion in inter-regional corridors towards SR.

(viii) Separate RRAS dispatch instructions for Southern Region ISGS to be issued by NLDC to maintain the load-generation balance in real-time.

(ix) In order to maintain voltages near solar parks within IEGC band, reactive compensating devices such as reactors, STATCOMs etc. to be kept in service and VAR absorption/injection capabilities of solar inverters to be utilized.

(x) To keep HVDC set points in a manner such that adequate margin in inter-regional corridors is available to tackle any contingency during solar output variation.

(xi) To keep all the defence mechanisms such as UFR, SPS etc. in service.

(xii) Ensuring RGMO/FGMO in service in all regions to take care of any contingency.

(xiii) System parameters viz. important line loadings, voltages, ICT loadings at major stations etc. should be closely monitored and proactive action be taken to maintain the system parameters within permissible limits.

(xiv) Round the clock availability of SCADA data at each control room should be ensured.

(xv) All the control centres to remain in alert mode to avoid any contingency.

(xvi) Coordination among NLDC/RLDC and SLDCs was emphasised.

A detailed operational planning was prepared and circulated among RLDCs. The details of operational planning is enclosed as **Annexure-I**

In addition to above, advisory to the constituents were also issued by respective RLDCs.

1.2 Installed and telemetered capacity of solar generation

The installed capacity of ground mounted solar generation is 30203 MW and rooftop solar is 2311 MW (as on 30th November 2019). Out of this around 4900 MW of ground mounted solar and 2311 MW total capacity of rooftop solar are not telemetered (**Annexure-II**). For secure and reliable operation of the grid, data telemetry from solar plants is very important with increase in capacity over time.

Chapter - 2 : Real time system operation

2.1 All India

2.1.1 Demand forecast vs actual on 26th December 2019

It was estimated that all India demand would reduce by an average of 2-3 % of previous day demand along with 4- 5 % instantaneous maximum demand reduction, which was based on previous solar eclipse event occurrences in India. The pattern of demand variance observed on 26th December 2019 showed that on an average around 2.4% demand reduced with an instantaneous maximum demand reduction of 4.2 %. Further, it was observed that all India demand increased by about 6372 MW i.e. by 3.8 %, when eclipse got over. It is also pertinent to mention that record 170 GW+ demand in December 2019 occurred post eclipse, which was all time highest in December 2019. All India Demand from 24th to 26th December 2019 is given below (Fig. 4):

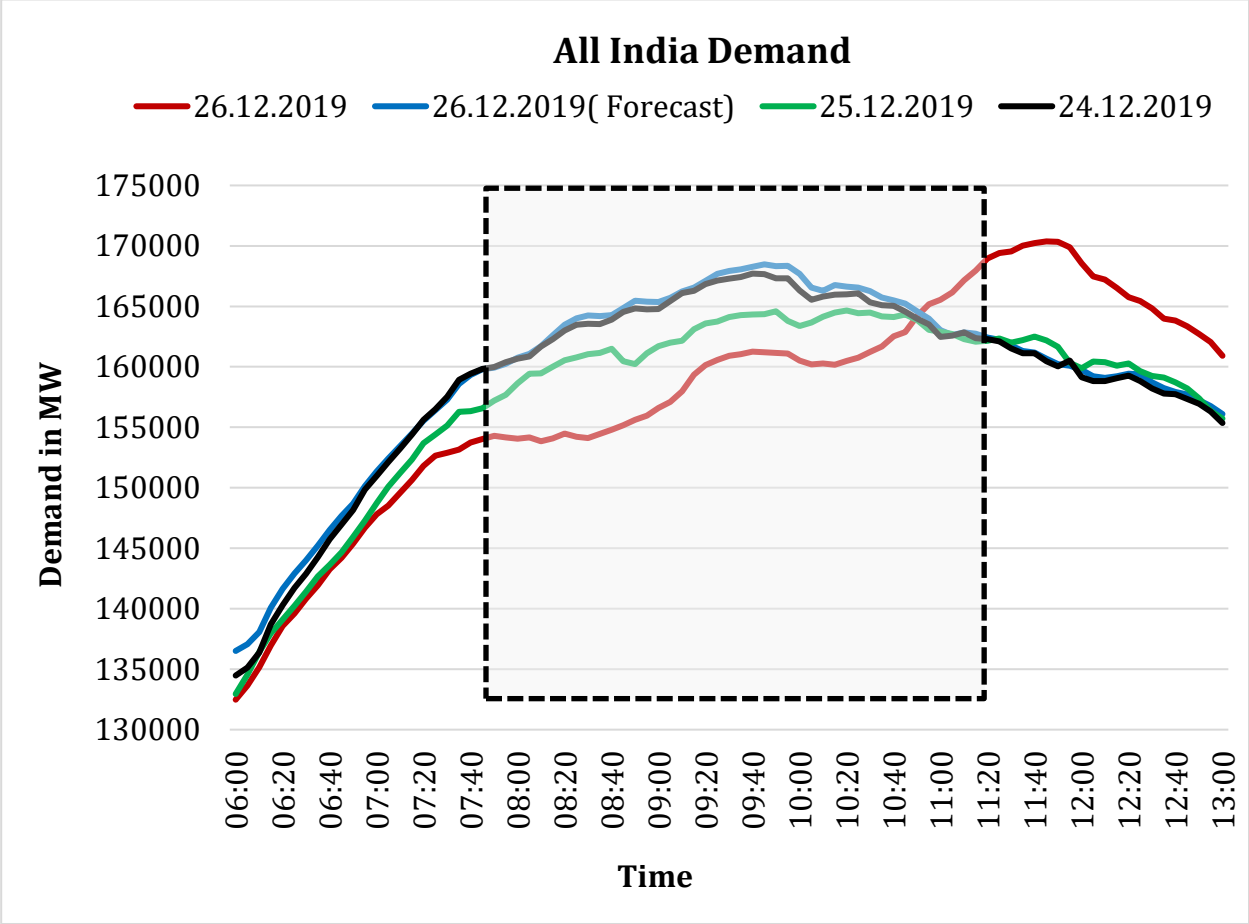


Figure 4: All India Demand

2.1.2 Frequency on 26th December 2019

Frequency was observed outside IEGC band before and after the eclipse. Frequency was 66% of time within IEGC band during the period of solar eclipse (Fig.5). After end of eclipse (i.e. 11:00 hrs.) all India demand increased by 6372 MW which lead to low frequency of 49.70 Hz at 11:10 hrs. However, drop in frequency was arrested by increasing the generation from Hydro and Gas plants. The frequency recovered to 49.90 Hz within 14 minutes.

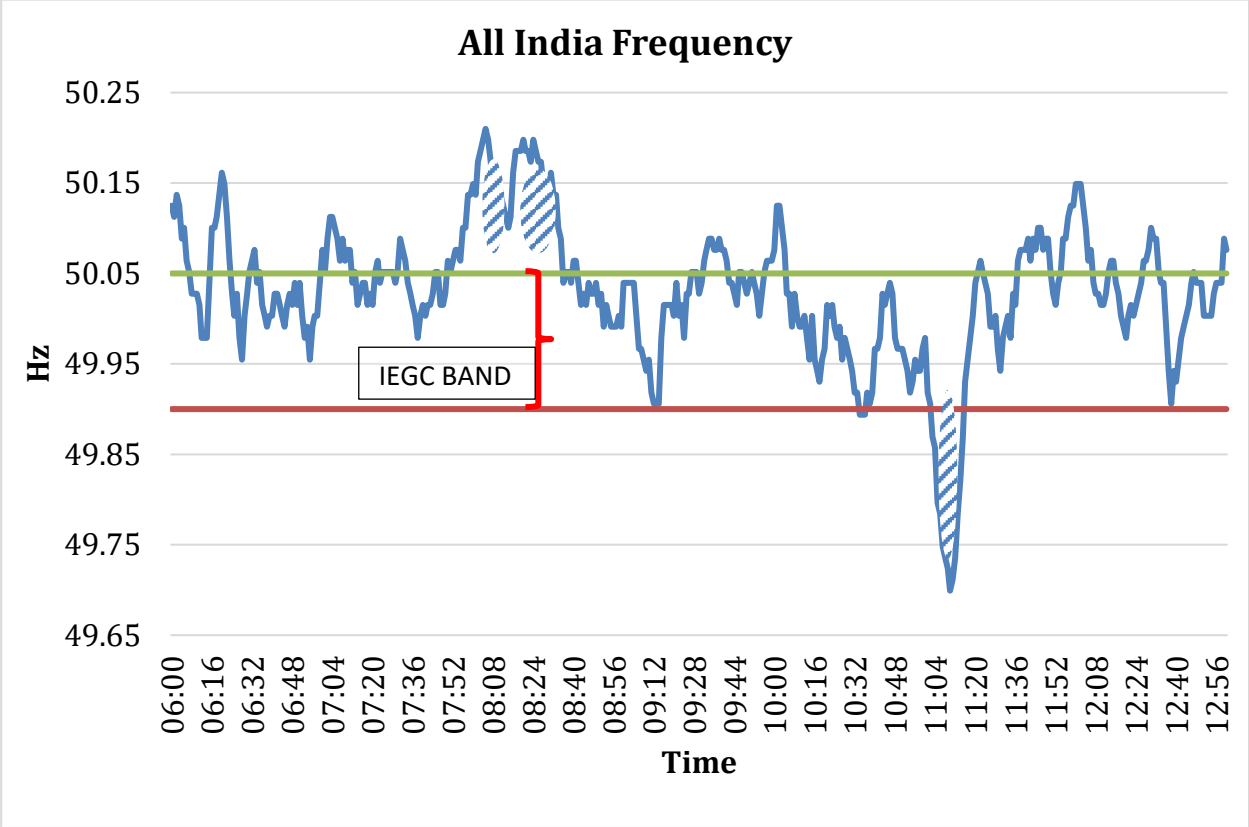


Figure 5: All India Frequency on 26.12.2019

2.1.3 Solar forecast vs actual on 26th December 2019

It was estimated that maximum solar generation reduction due to the eclipse would be 7.8 GW on all India basis (at 09:30 hrs) under clear sky conditions. However, during the event on 26th December 2019, 6.5 GW of solar generation reduction was observed w.r.t. 25th December 2019(Fig.6). Further, it is to mention that cloudy conditions were prevailing in Southern as well as Western Region and Fog in Northern Region on 25th December 2019 (Fig.7) due to which solar generation was less compared to a clear sky day. If clear sky condition is considered i.e. normal day on 25th December 2019 then solar generation difference with actual would be 8 GW as envisaged in the first study report prior to eclipse.

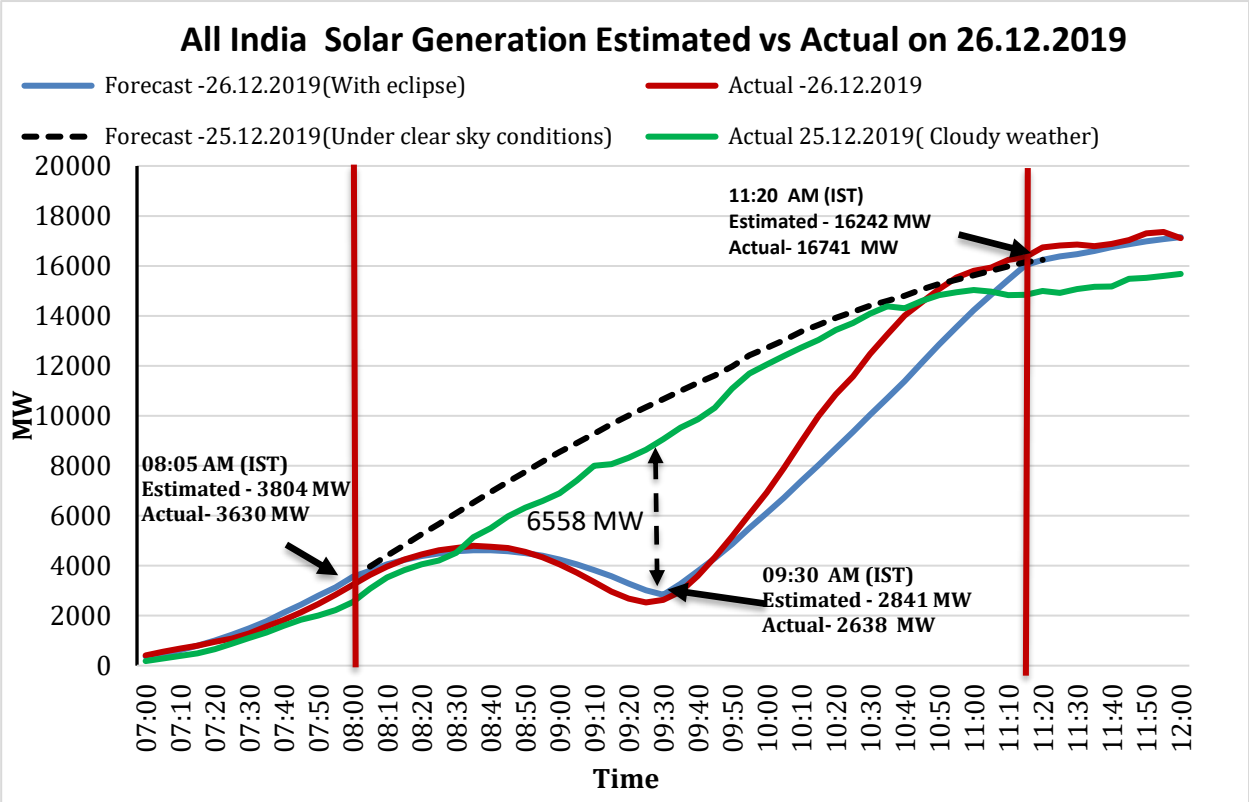


Figure 6: All India Solar Generation Estimated vs Actual on 26.12.2019

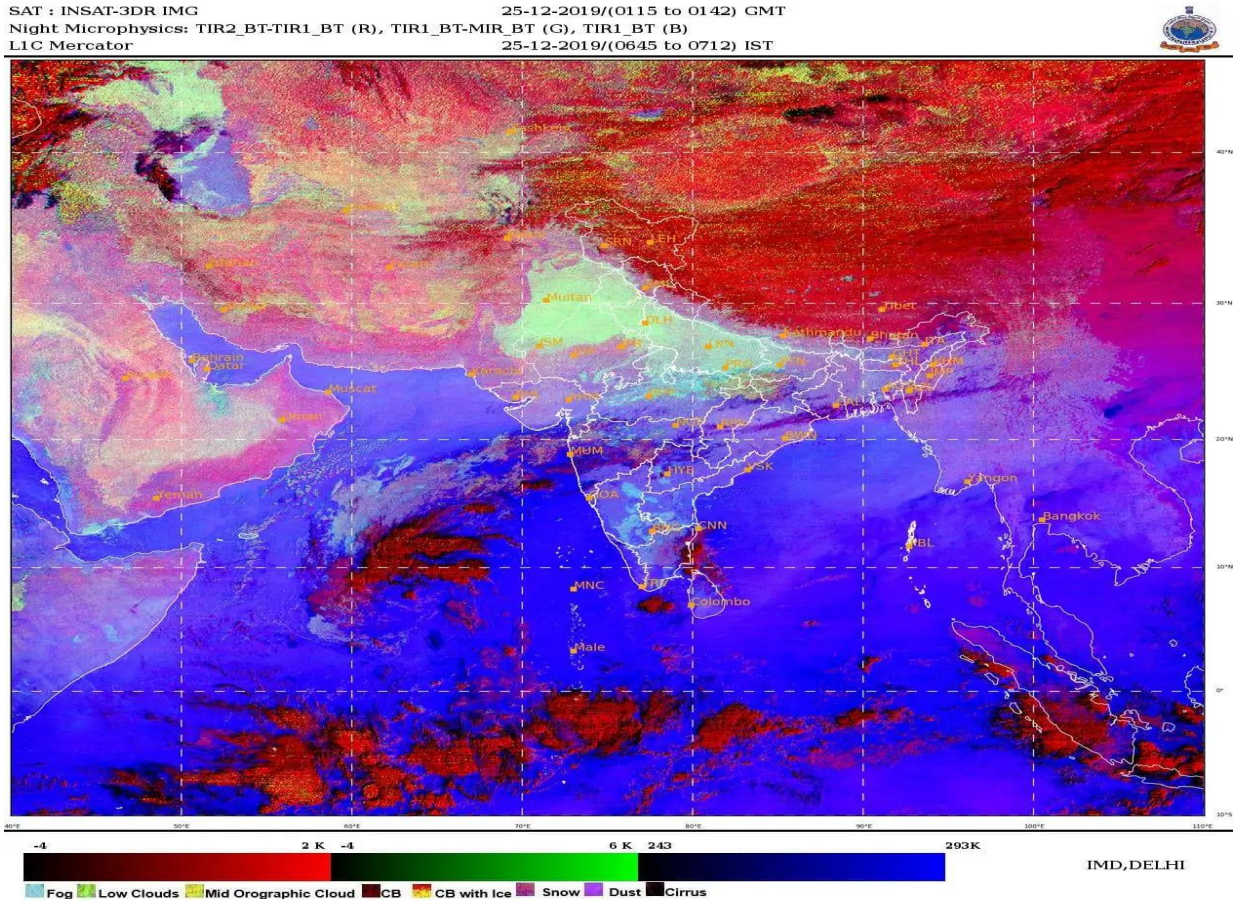


Figure 7: Satellite Image on 25.12.2019

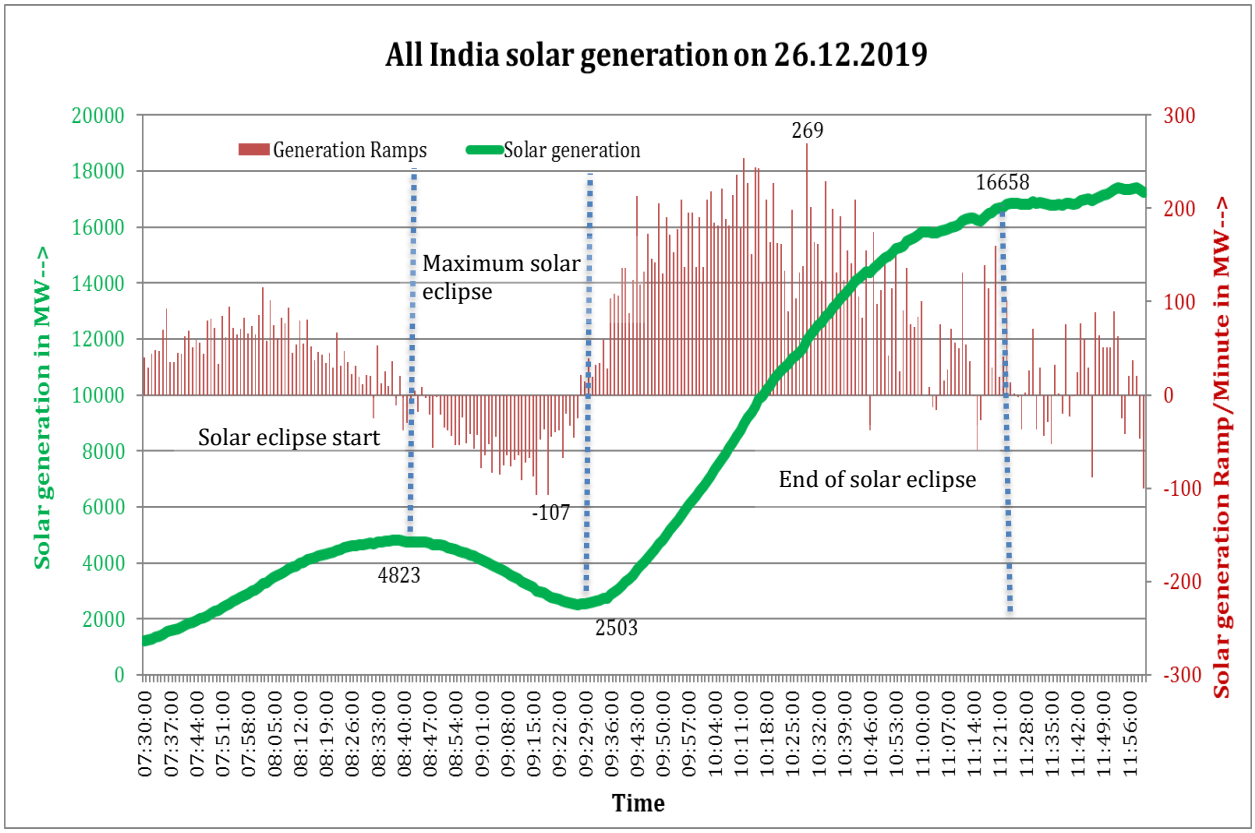


Figure 8: All India Solar Generation on 26.12.2019

All India solar generation was 4823 MW at 08:39 hrs. Till 08:39 hrs generation has increasing trend even though eclipse had started approximately at 08:03 hrs. During this period daily solar ramps dominated the eclipse impact and net ramp rate remained positive till 08:39 hrs. After 08:39 hrs solar generation started reducing at an average ramp of 47 MW/minute till 09:27 hrs and maximum ramp of 107 MW/min was observed at 09:19 hrs. Solar generation touched minimum of 2503 MW at 09:27 hrs. (Maximum eclipse point), total reduction of 2320 MW in solar generation happened due to solar eclipse, which is 48 % of pre eclipse generation.

All India estimated solar generation ramp up and ramp down rates observed were close to the estimated values. Average ramp down rate was estimated as 13 MW/ minute (from 08:03 hrs to 09:30 hrs.) while average ramp up rate was estimated as 122 MW/minute (from 09:30 hrs to 11:20 hrs). During the eclipse, average ramp down rate was 11.6 MW/minute from 08:03 hrs to 09:30 hrs and average ramp up rate was 123 MW/minute from 09:30 hrs to 11:20 hrs. Five minute average ramp during solar reduction period is given below (Fig.9):

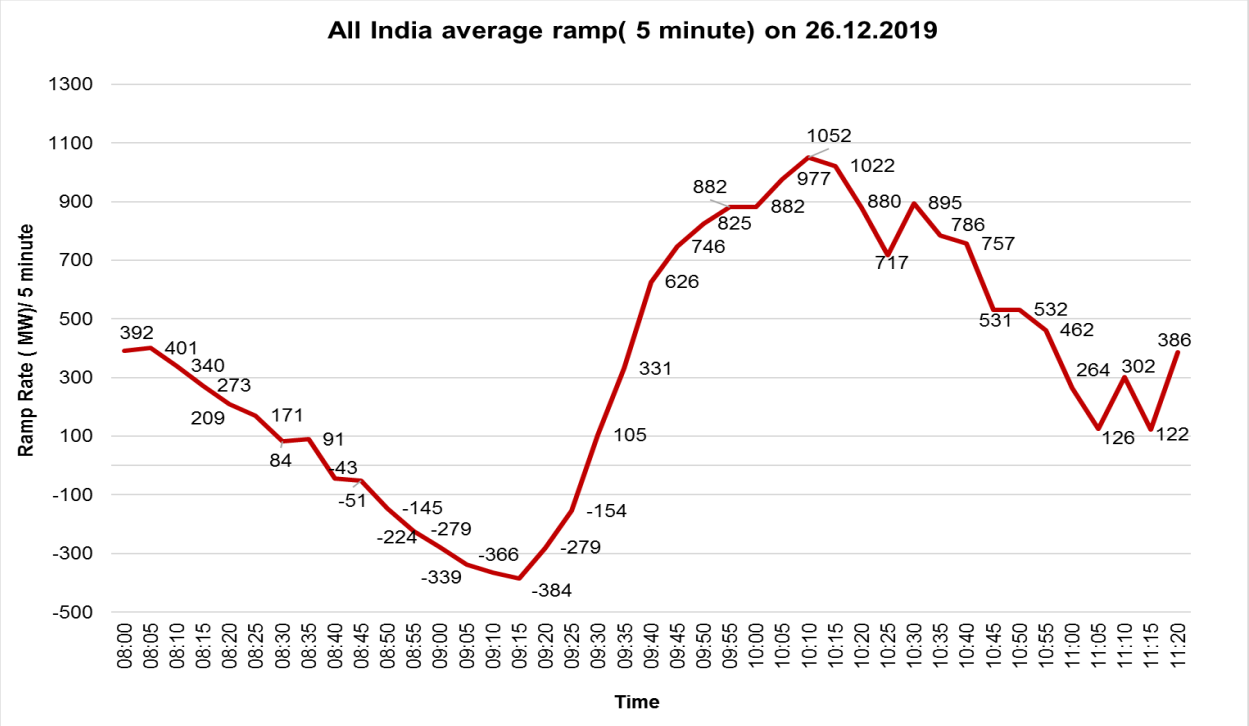


Figure 9: All India average ramp (5 minute) during solar eclipse

All India solar generation estimated vs actual ramp rate is tabulated below:

All India Ramp Rate	Time	Estimated Ramp Rate	Actual Ramp Rate
Average Ramp Down Rate	08:03 hrs to 09:30 hrs	13 MW/ minute	11.6 MW/minute
Average Ramp Up Rate	09:30 hrs to 11:20 hrs	122 MW/minute	123 MW/minute

2.1.4 Generation (Thermal, Gas and Hydro) from 24th to 26th December 2019

Thermal Generation

In view of anticipated solar reduction in Southern Region, two units of Kudgi Thermal Power Station on RRAS and one unit of Vallur Thermal Power Station were brought on bar at 00:00 hrs of 26th December 2019.

Thermal ISGS in Southern Region were excluded from Security Constrained Economic Despatch (SCED) from 03:00 hrs of 26th December 2019 to mitigate congestion in inter-regional corridors towards Southern Region. It was again revived at 11:25 hrs. Thermal generation was varied to the tune of 2000 MW during eclipse period.

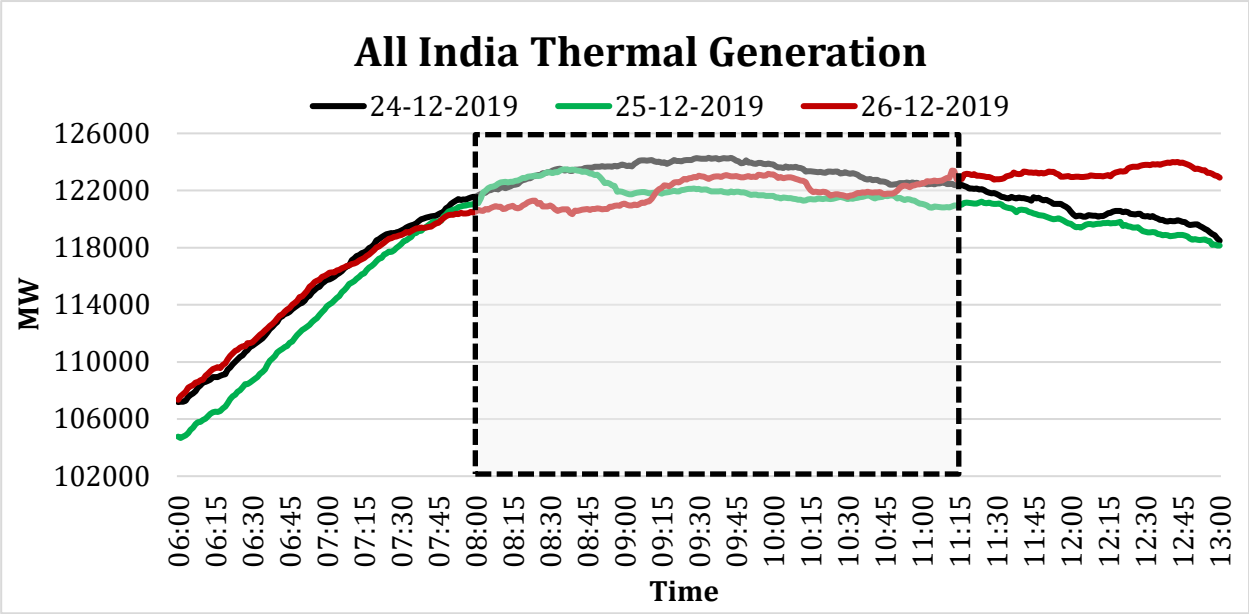


Figure 10: All India Thermal Generation from 24.12.2019 to 26.12.2019

Gas Generation

Gas generation in Western and Northern Region was kept on bar from 05:00 hrs of 26th December 2019 to cater ramp issues during morning demand as well as flexing of generation during solar eclipse period. In view of fast ramping requirement and to counter deficit in solar generation, and increase in demand after eclipse was over, Gas generation was varied to the tune of 1000 MW during eclipse period. All India gas generation graph is given below:

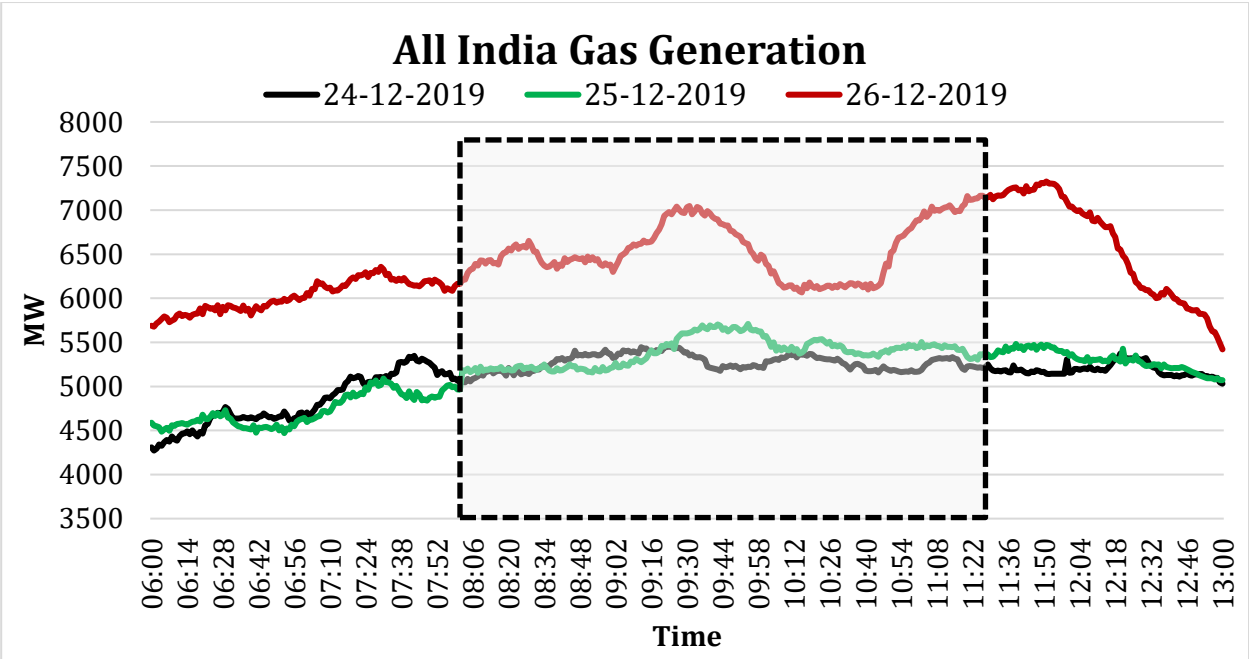


Figure 11: All India Gas Generation from 24.12.2019 to 26.12.2019

Reserve Regulation Ancillary Services (RRAS) were proactively used during eclipse period to maintain the grid frequency within the IEGC band.

Hydro Generation

All ISGS/state hydro generators varied their generation as per real time frequency. As per all India hydro generation graph depicted below, it may be observed that during eclipse hydro generation has been varied to the tune of 6000MW.

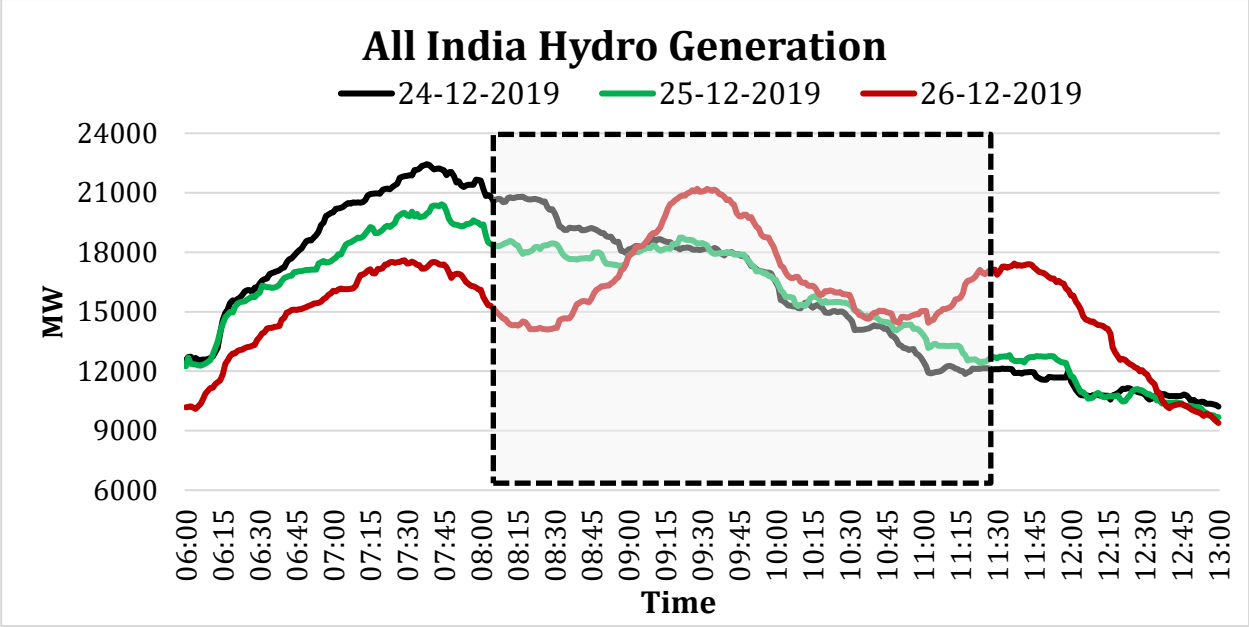


Figure 12: All India Hydro Generation from 24.12.2019 to 26.12.2019

Source wise generation stacked charts

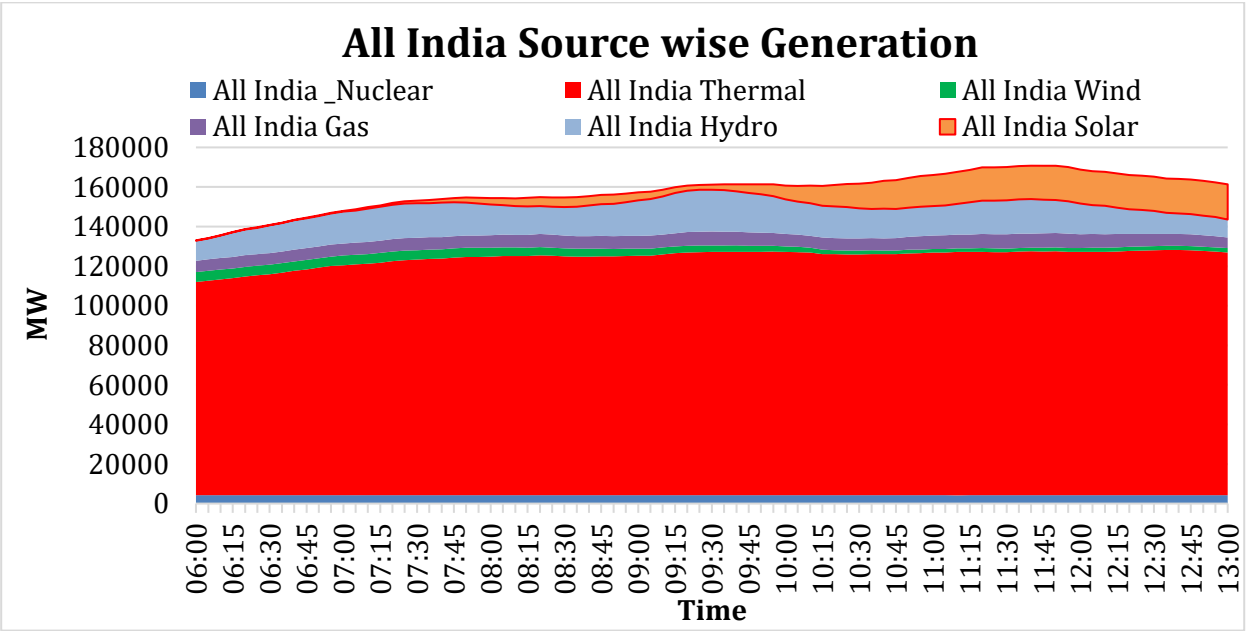


Figure 13: All India Source wise Generation

All India source wise generation for 26th December 2019 is as given above (Fig.13). It is very much evident from the graph that all states varied their hydro/gas generation based on the real time solar generation reduction as per the proposed scheduling. ISGS hydro generation in Western Region and Northern Region were scheduled to cater generation deficit during eclipse.

2.2 Southern Region

2.2.1 Demand forecast vs actual on 26th December 2019

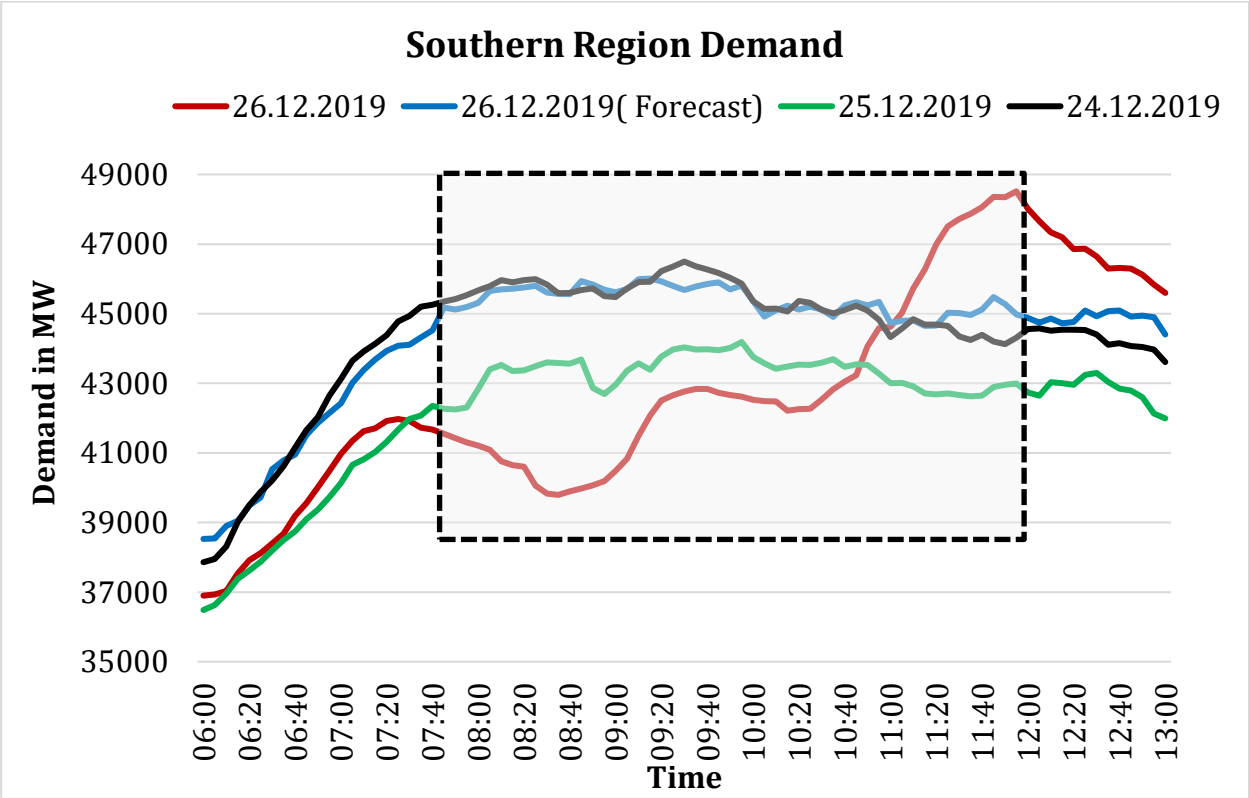


Figure 14: Southern Region Demand

It was estimated that Southern Region demand will reduce by an average of 2-3 % of previous day demand along with 4- 5 % instantaneous maximum demand reduction which was based on previous solar eclipse event occurrences in Southern Region of India.

The pattern of demand variance observed on 26th December 2019 shows that on an average around 4 % demand reduction occurred with an instantaneous maximum demand reduction of 8.8 %. Further, it was observed that before eclipse some of Southern Region states has restricted power supply to agricultural loads and hence reduction in demand can be seen from 7:25 to 8:26 hrs. Around 9:00 hrs. Karnataka demand increased, which is a daily load

change over time for the state. After 10:25 hrs agricultural loads were released by the states (Increase in demand can be seen in demand plot after 10:20 hrs) as solar generation was in increasing trend.

After end of eclipse (i.e. 11:00 hrs), Southern regional demand increased by 3700 MW from 44637 to 48348 MW due to sudden increase in domestic load (mainly geyser load) and agriculture load as informed by states which was much higher than estimated value. Import on interregional corridor increased from 2826 MW at 10:45 hrs to 5197 MW at 11:30 hrs i.e increase of 2371 MW.

2.2.2 Solar generation forecast vs actual on 26th December 2019

It was estimated that maximum solar generation reduction in Southern Region due to the eclipse would be 5.8 GW at 09:30 hrs under clear sky conditions. During the event on 26th December 2019, 5.8 GW of solar generation reduction was observed with respect to 25th December 2019(Fig.16), which is in line with estimated solar generation.

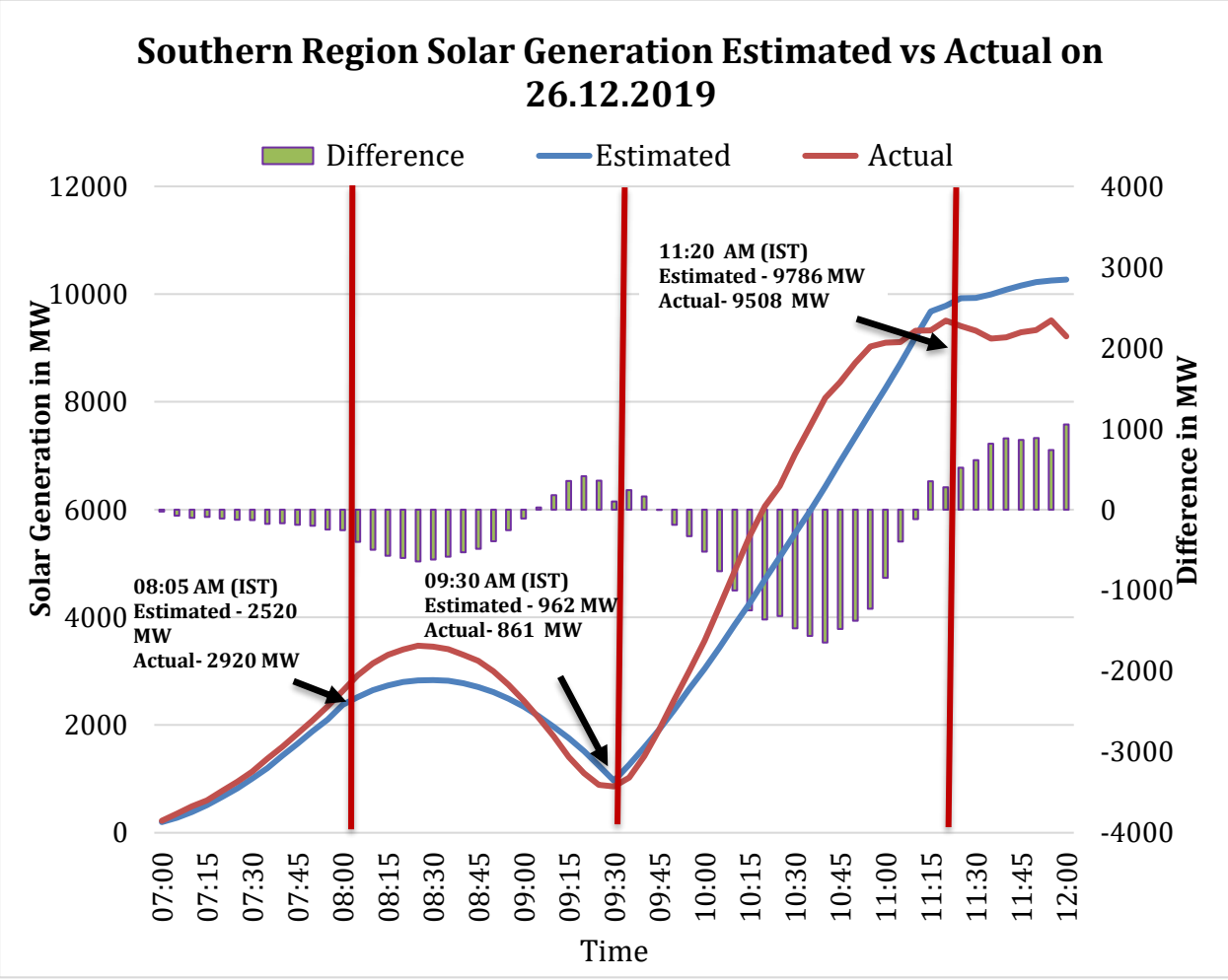


Figure 15: Southern Region Solar Generation Estimated vs Actual on 26.12.2019

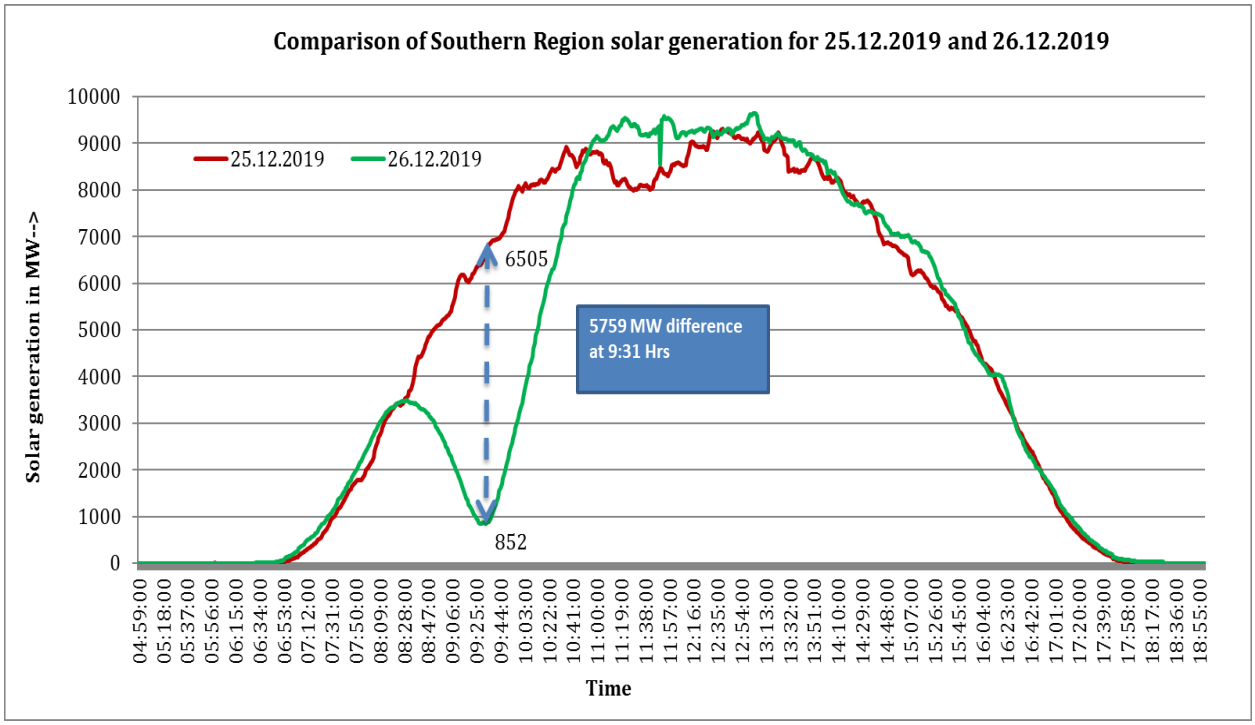


Figure 16: Comparison of Southern Region Solar Generation for 25.12.2019 and 26.12.2019

Southern Region solar generation on 26th December 2019 from 7:30 hrs to 12:00 hrs is plotted below which includes eclipse period (08:06 hrs to 11:17 hrs approx.)

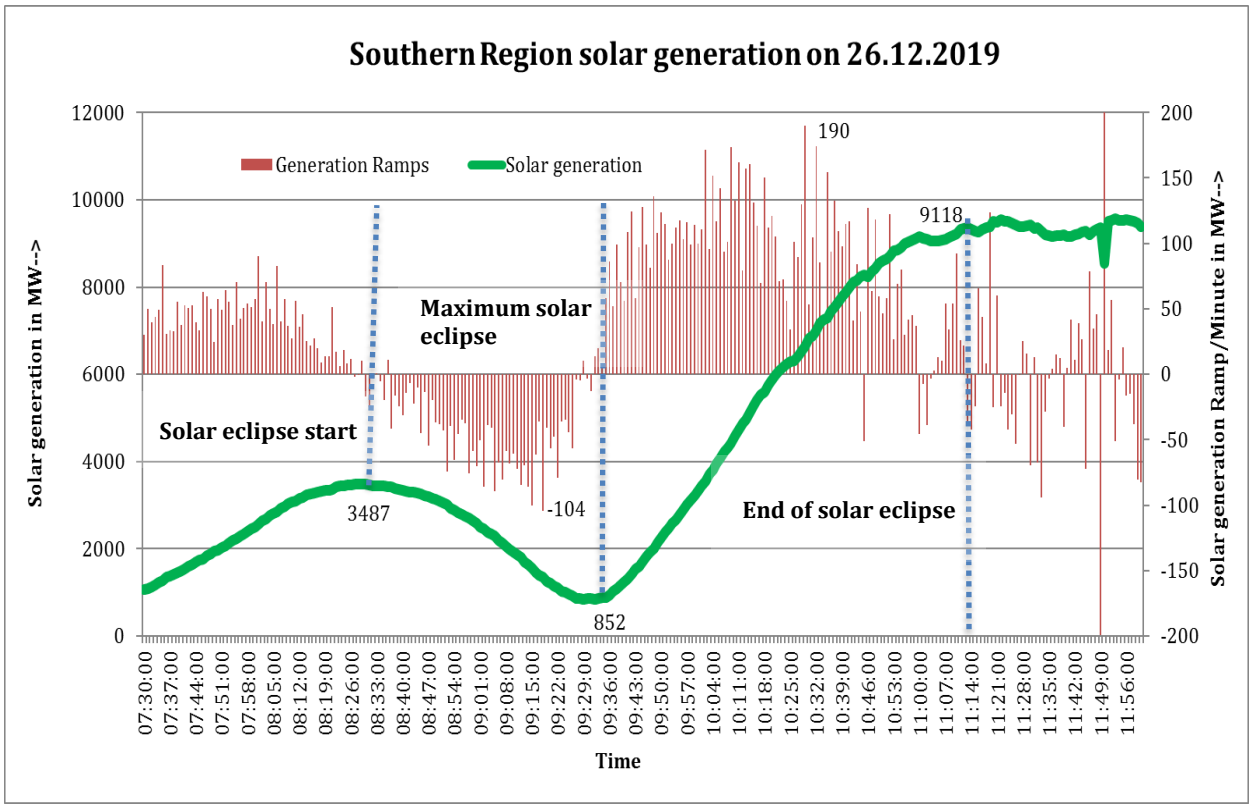


Figure 17: Southern Region Solar Generation on 26.12.2019

Maximum solar generation of 3487 MW was observed at 08:30 hrs. Till 08:30hrs generation has increasing trend even though eclipse had started approximately at 08:06 hrs. During this period daily solar ramps dominated the eclipse impact and net ramp rate remained positive till 08:30 hrs.

After 08:30hrs solar generation started reducing at an average ramp of 43 MW/minute till 09:31hrs and maximum ramp of 104 MW/minute was observed at 09:18hrs. Solar generation touched minimum of 852 MW at 09:31hrs (Maximum eclipse point), total reduction of 2635 MW in solar generation happened due to solar eclipse, which is 76% of pre eclipse generation. Five minute average ramp during solar reduction period is given below:

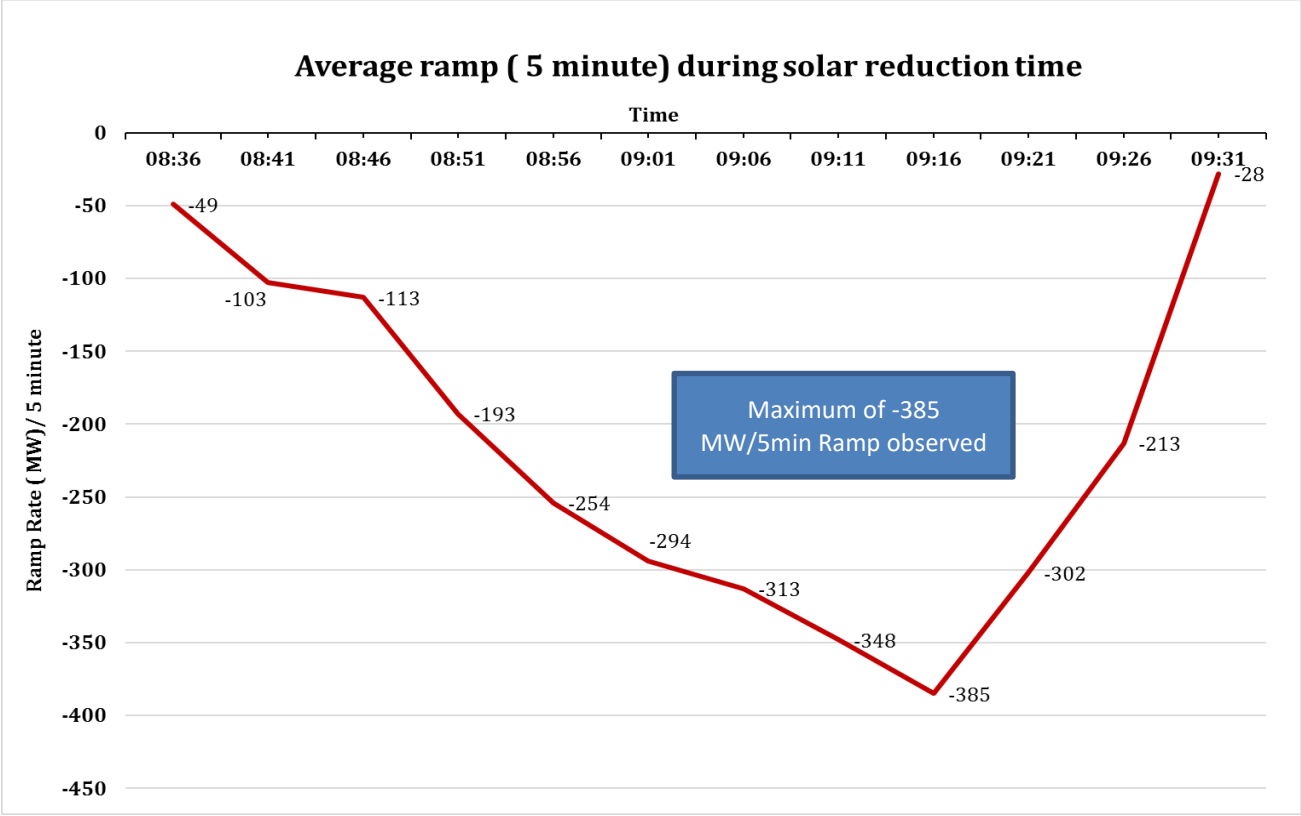


Figure 18: Southern Region average ramp (5 minute) during solar reduction time

From 9:31hrs solar generation started increasing till 11:00hrs at average ramp rate of 95 MW/minute and maximum ramp of 190 MW/minute observed at 10:29hrs. Five-minute average ramp during solar increase period is given below:

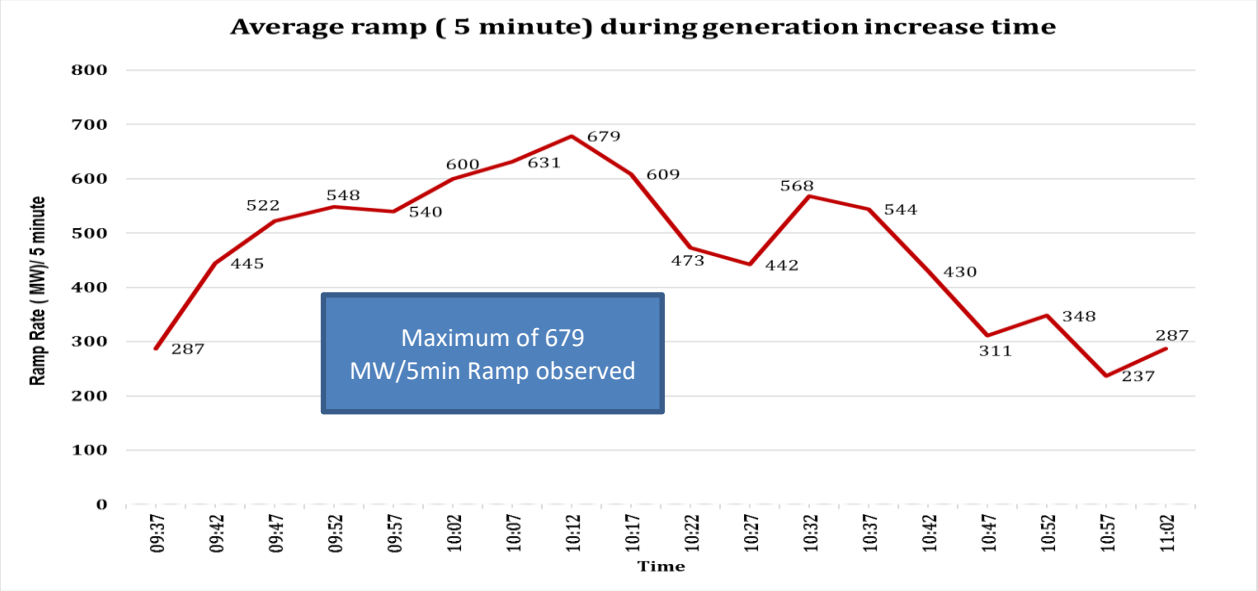


Figure 19: Southern Region average ramp (5 minute) during solar increasing time

2.2.3 Generation (Thermal, Gas and Hydro) from 24th to 26th December 2019

Thermal Generation

In view of anticipated solar reduction in Southern Region, two units of Kudgi on RRAS and one unit of Vallur was brought on bar at 00:00 hrs of 26th December 2019.

Thermal ISGS in Southern Region were excluded from Security Constrained Economic Despatch (SCED) from 03:00 hrs of 26th December 2019 to mitigate congestion in inter-regional corridors towards Southern Region (Fig.20 &21).

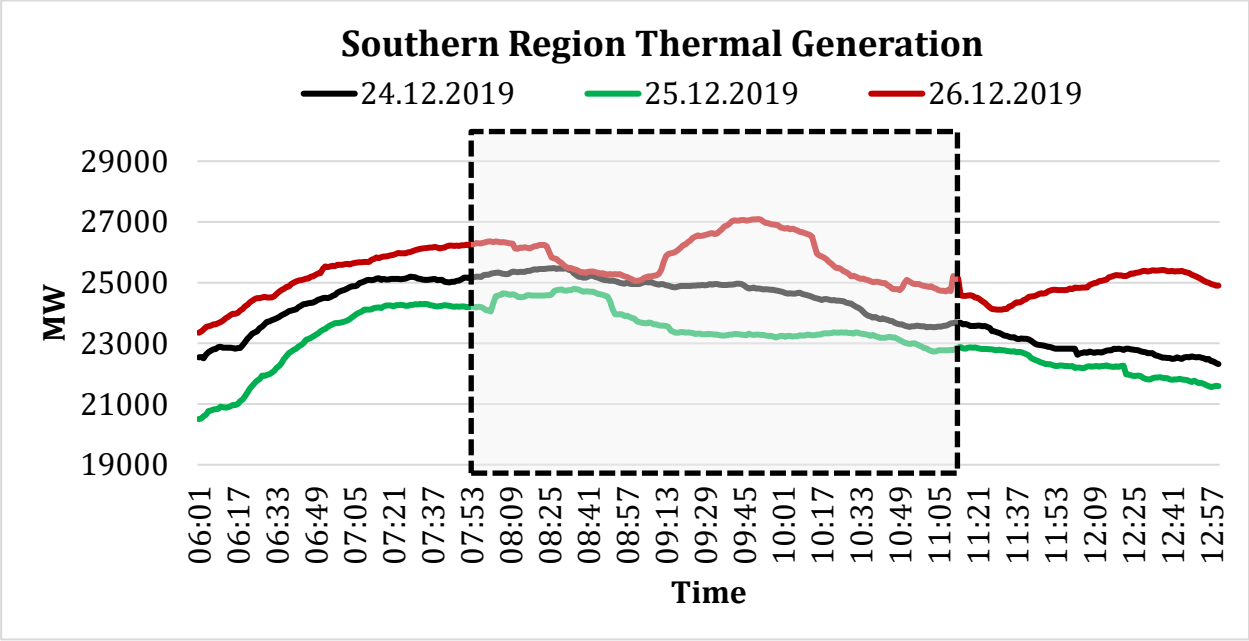


Figure 20: Southern Region Thermal Generation from 24.12.2019 to 26.12.2019

Gas Generation

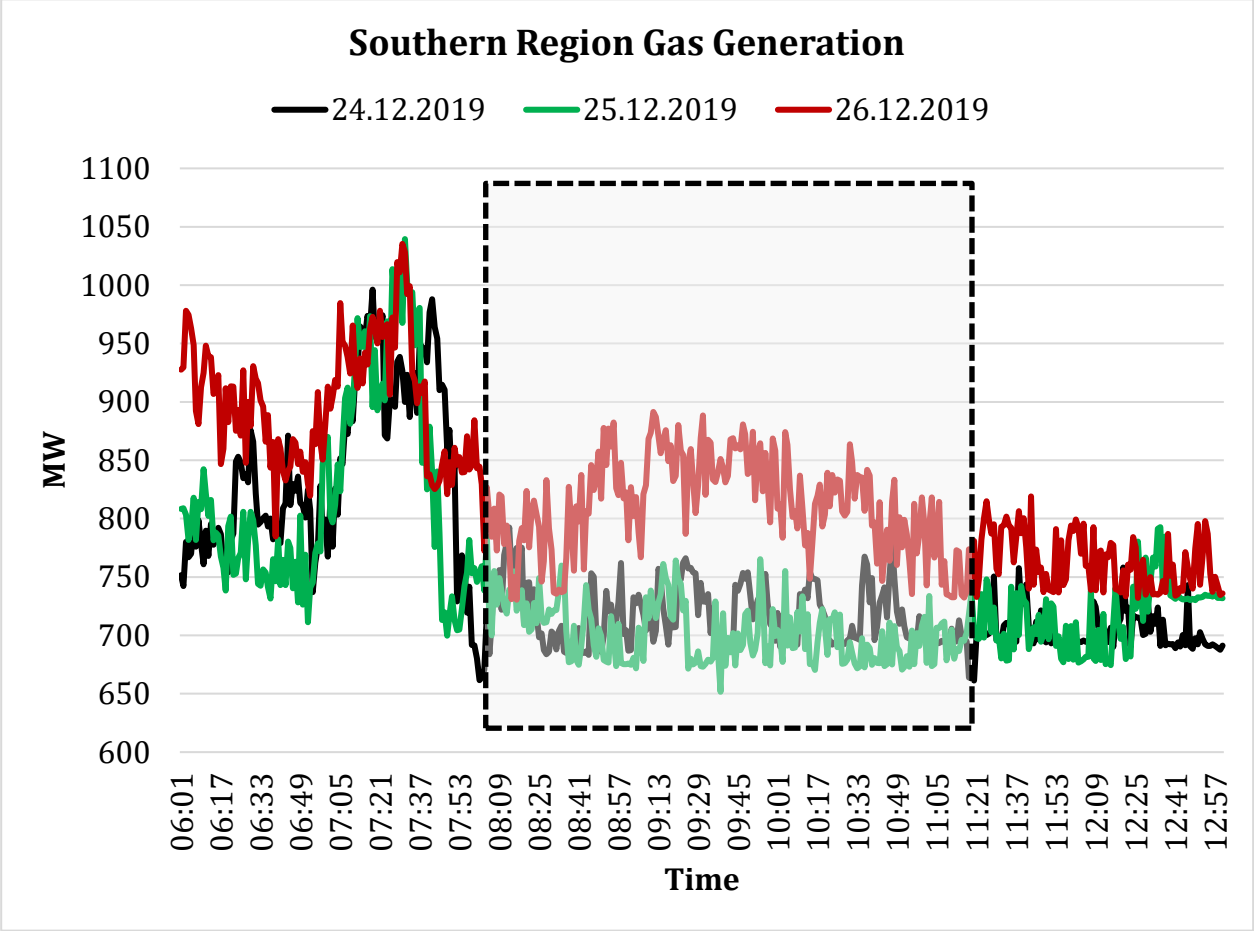


Figure 21: Southern Region Gas Generation from 24.12.2019 to 26.12.2019

Hydro Generation

In view of anticipated solar reduction in Southern Region, planning of hydro generation was done in such way that

1. At start of eclipse, hydro generation was maintained at 2230 MW and picked up once solar generation reduction started due to eclipse. At maximum eclipse, hydro generation was 6314 MW. Around 4084 MW of hydro generation was increased from start of eclipse to maximum eclipse
2. After maximum eclipse, hydro generation was ramped down to 3672 MW i.e. a reduction of 2642 MW. However, at 10:20 hrs. agricultural load picked up therefore, further reduction in hydro was not carried out.

Southern Region hydro generation from 24th to 26th December 2019 is given below:

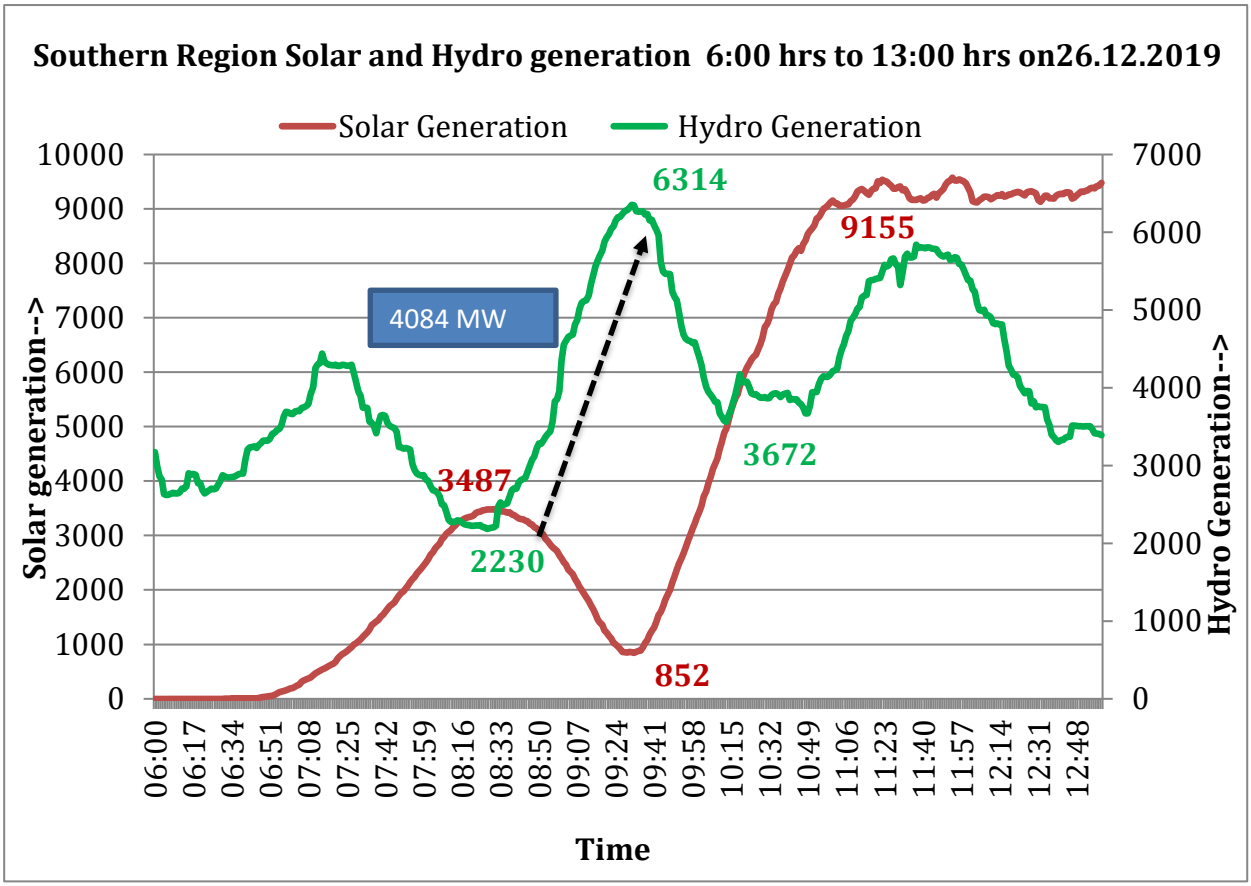


Figure 22: Southern Region Solar and Hydro Generation 6:00 hrs to 13:00 hrs on 26.12.2019

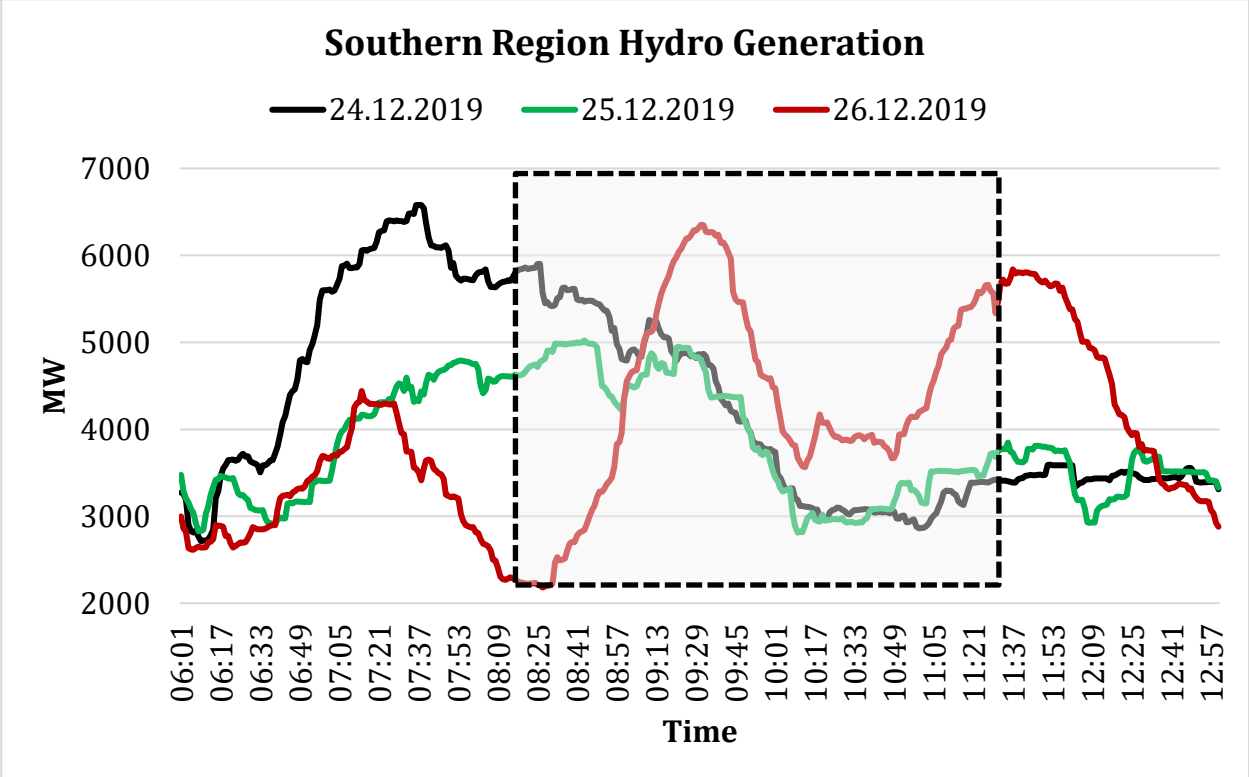


Figure 23: Southern Region Hydro Generation from 24.12.2019 to 26.12.2019

Southern Region source wise generation stacked charts

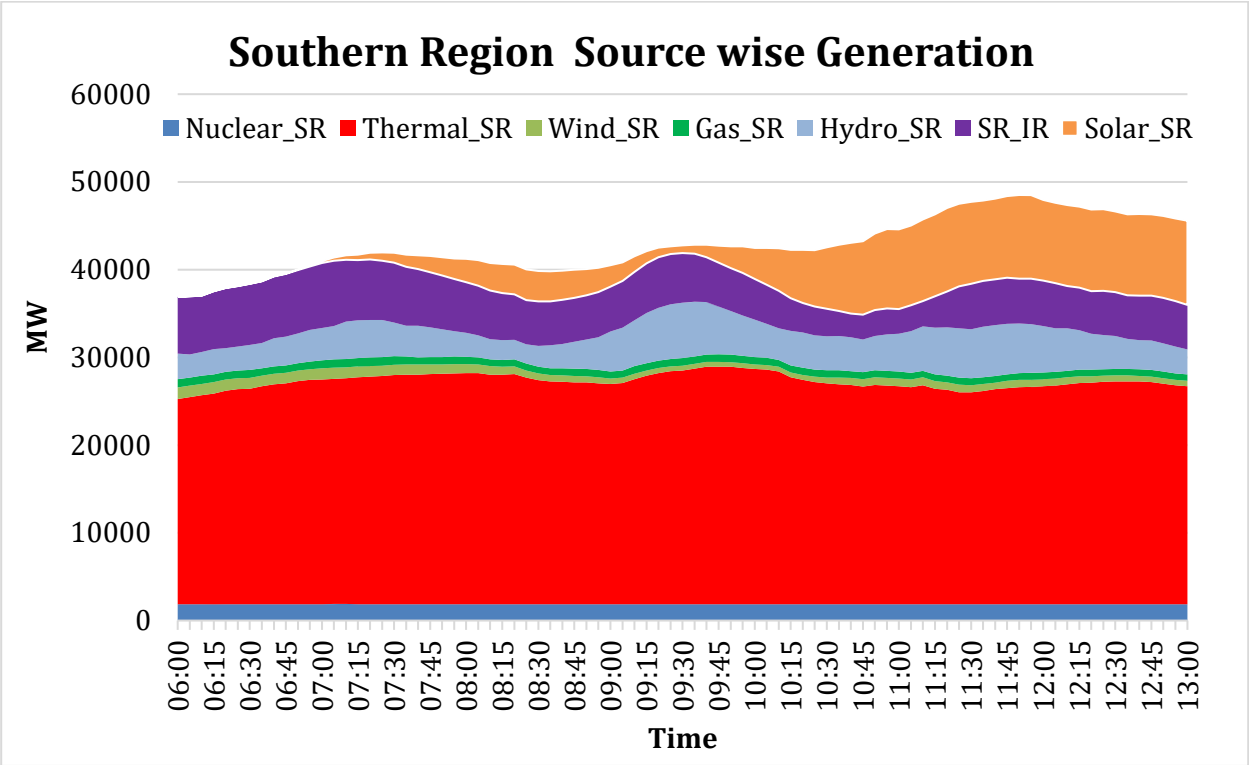


Figure 24: Southern Region Source wise Generation

From the above stack graph, it can be observed that prior to start of the eclipse Southern Region states reduced hydro generation and maintained at minimum levels as per the operation planning.

When solar generation started reducing states hydro generation picked up and at the same time increase in ISGS thermal generation also can be seen due to increase in states requisition and RRAS UP regulation. Hydro generation and ISGS generations were backed down after maximum impact of the eclipse was over.

2.3 Western Region

In view of anticipated solar reduction in Western Region following steps were taken by WRLDC control room and Western Region constituents during the solar eclipse

1. Constituents were advised to counter the variation in solar generation due to eclipse by deploying flexible generating sources (Hydro and Gas) in their control areas.
2. Four units of Sardar Sarovar Project (SSP) were kept on bar before start of the eclipse to counter the sharp ramp during decline in eclipse.

3. Fifty (50) MW of generation was reduced at each unit of SSP (unit-3, 4, 5, 6) with effect from 09:45 hrs. Total 160 MW was reduced from 09:45 hrs (967MW) to 10:45 hrs (807MW). Further SSP was instructed not to withdraw their machines till 11:35 hrs.
4. Four (4) GTs of Kawas and Three (3) GTs of Gandhar were brought on bar to manage the demand. As per system requirement, generation in Kawas and Gandhar were regulated to control frequency in co-ordination with NLDC.
5. Gujarat regulated around 200 MW in Adani Power Ltd. (APL) and Essar Power Gujarat Ltd. (EPGL) to manage their demand during solar eclipse.
6. Maharashtra regulated Koyna hydro stage-1 and 2 to manage their demand during solar eclipse.

2.3.1 Demand forecast vs actual on 26th December 2019

It was estimated that Western Region demand will reduce by an average of 1 % demand during solar eclipse. However, it was observed that Western Region demand on 26th December 2019 reduced an average around 1.8 % w.r.t. to previous day demand.

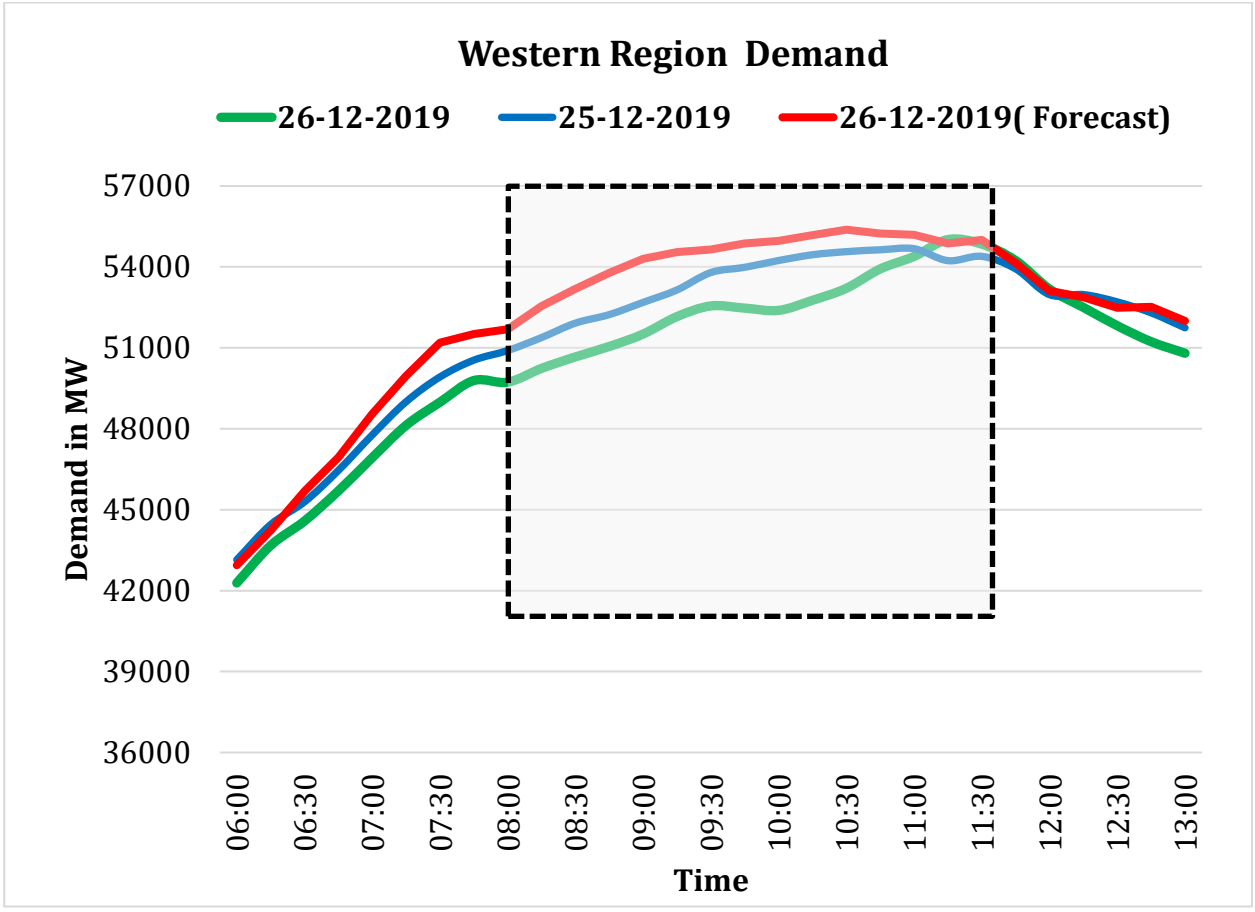


Figure 25: Western Region Demand

2.3.2 Solar generation forecast vs actual on 26th December 2019

Based on the mean obscuration for Western Region states, forecast considering the clear sky day (22.12.2019) was also prepared. Comparison for Western Region aggregated solar generation is shown below:

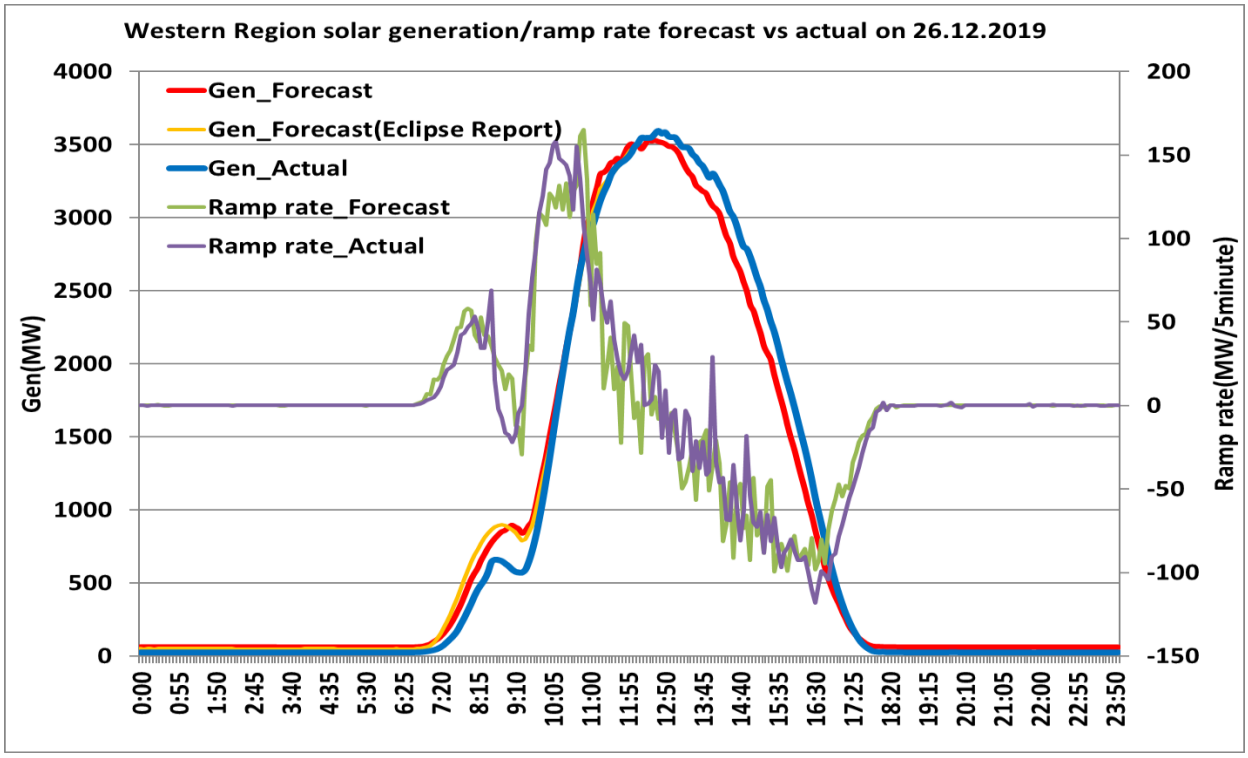


Figure 26: Western Region solar generation/ramp forecast vs actual on 26.12.2019

It is observed that obscuration calculation is suitable for eclipse day generation forecast with minor error of around 250MW during maximum solar eclipse time. In the forecast calculation considered in the eclipse report, March 2019 solar generation has been considered with capacity growth to predict the solar generation on solar eclipse day (26.12.2019) shown in yellow colour. To see impact in each state, State-wise solar generation and ramp rate forecast comparison with actual is attached as **Annexure-III.**

Average ramp forecasted block wise is also compared with actual ramp rate (MW/ Time block) calculated for state and Western Region for the period 08:00 hrs to11:30 hrs and shown in table given below. Maximum block wise ramp-down forecasted for Western Region based on obscuration calculation was 26MW/ Time block at 09:15 hrs but the actual ramp-down observed in Western Region was 57MW/ Time block at 09:00 hrs. Similarly, forecasted ramp-up in Western Region solar generation was maximum 461MW/Time block whereas actual maximum ramp-up observed was 459MW/ Time block at 10:00 hrs.

Table: 15 minutes average Western Region solar generation ramp forecast vs actual on solar eclipse day

Time	Average Forecasted Ramp(MW/Time block)				Average Actual Ramp(MW/ Time block)			
	MP	Gujarat	Maharashtra	WR	MP	Gujarat	Maharashtra	WR
08:00	103	40	14	158	81	57	11	149
08:15	78	58	-2	134	61	49	4	115
08:30	62	41	4	107	32	96	7	135
08:45	38	21	-3	55	-13	-4	-8	-26
09:00	8	29	-14	23	-29	-23	-4	-57
09:15	-26	21	-21	-26	-7	25	-2	15
09:30	20	113	34	167	75	130	20	226
09:45	144	139	54	337	142	203	37	382
10:00	171	143	55	369	170	231	59	459
10:15	159	156	67	382	172	209	57	438
10:30	163	161	49	373	196	166	47	409
10:45	169	174	118	461	202	81	50	334
11:00	170	41	48	259	182	43	-19	206
11:15	80	38	7	125	155	38	-12	181
11:30	21	30	23	74	93	31	5	130

It can be observed from the above table that ramp rate for the state solar generation is not negative during period of start to maximum of eclipse in few 15 minutes average time blocks. It is due to averaging of generated solar power for the time block of 15 minutes. The same has been observed in Gujarat forecast ramp.

In Western Region, solar generation started reducing at 8:38 hrs from 648 MW to the minimum generation of 576 MW at 09:24 hrs during the peak of solar eclipse. Maximum ramp down observed was 20 MW/minute during 08:38 hrs to 09:24 hrs. Average ramp down during this period was 5 MW/minute. After 09:24 hrs, solar generation in Western Region started increasing with maximum ramp up rate of 56 MW/minute and it reached 3343 MW at 11:37 hrs with higher average ramp rate of 22 MW/minute.

It is also observed that maximum Western Region solar generation reduction was 771MW with respect to previous day (25.12.2019) during the period of solar eclipse. The estimated solar generation reduction was 1164 MW with respect to clear sky day solar generation of Western Region. It can also be seen from the solar generation pattern of Arinsun RUMS - 250MW (Fig.29) that 25th December 2019 was cloudy and thus the generation was highly fluctuating. Whereas on 22nd December 2019, the sky was mostly clear and generation on

that day was smooth. Hence, Western Region solar generation on solar eclipse day is also compared with solar generation 22nd December 2019. The maximum drop in Western Region solar generation has been observed to be 1407 MW at 09:30 hrs during the peak eclipse time with respect to reference clear sky day of 22nd December 2019.

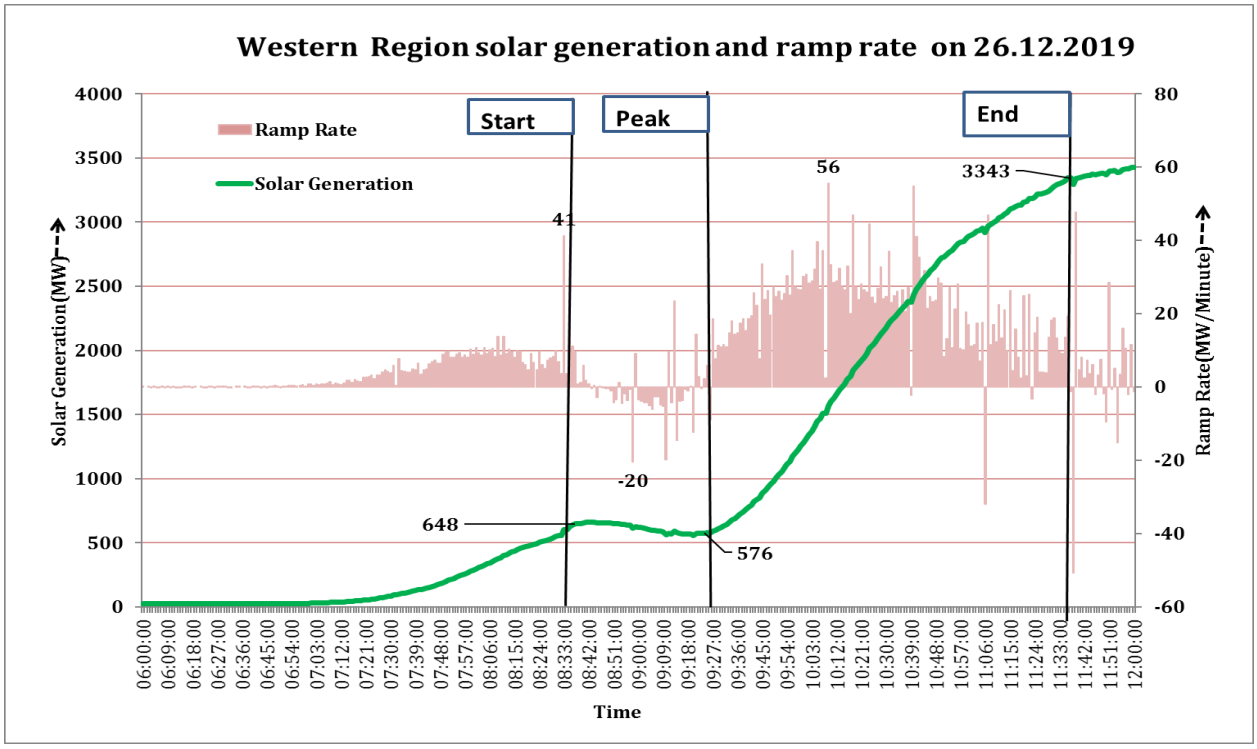


Figure 27: Western Region solar generation and ramp rate during solar eclipse

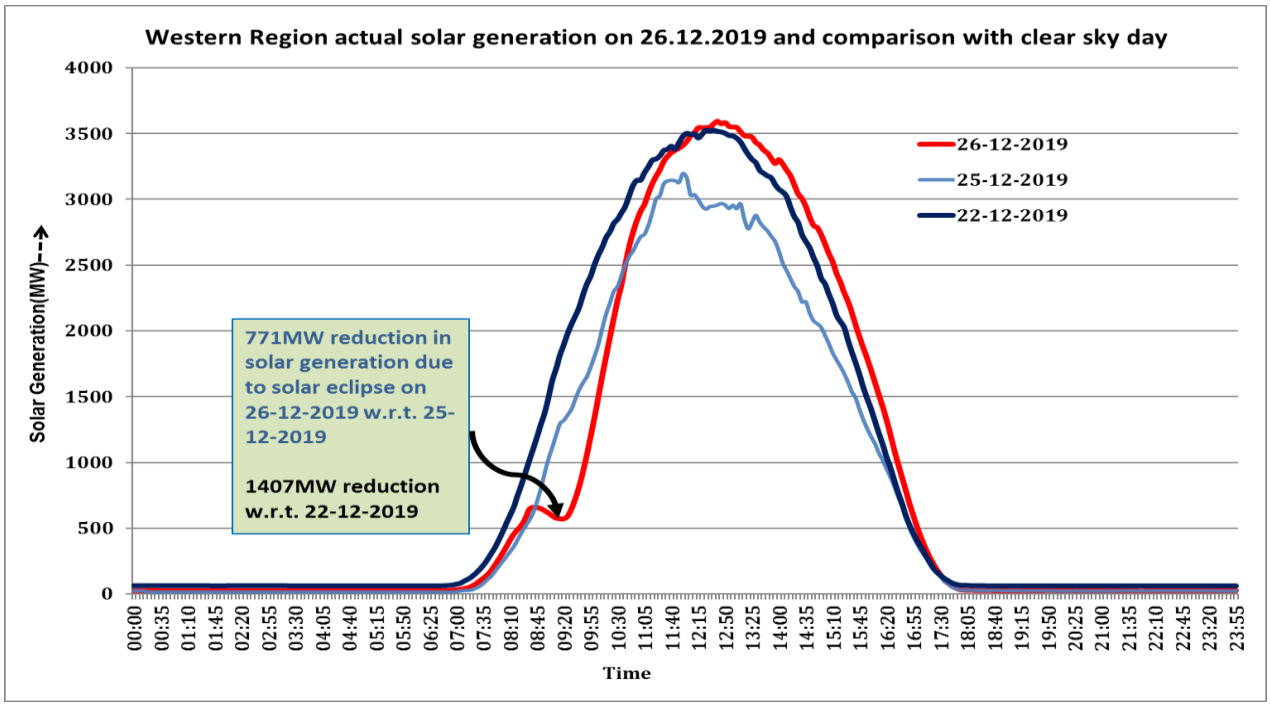


Figure 28: Western Region actual solar generation on 26.12.2019 comparison with clear sky day

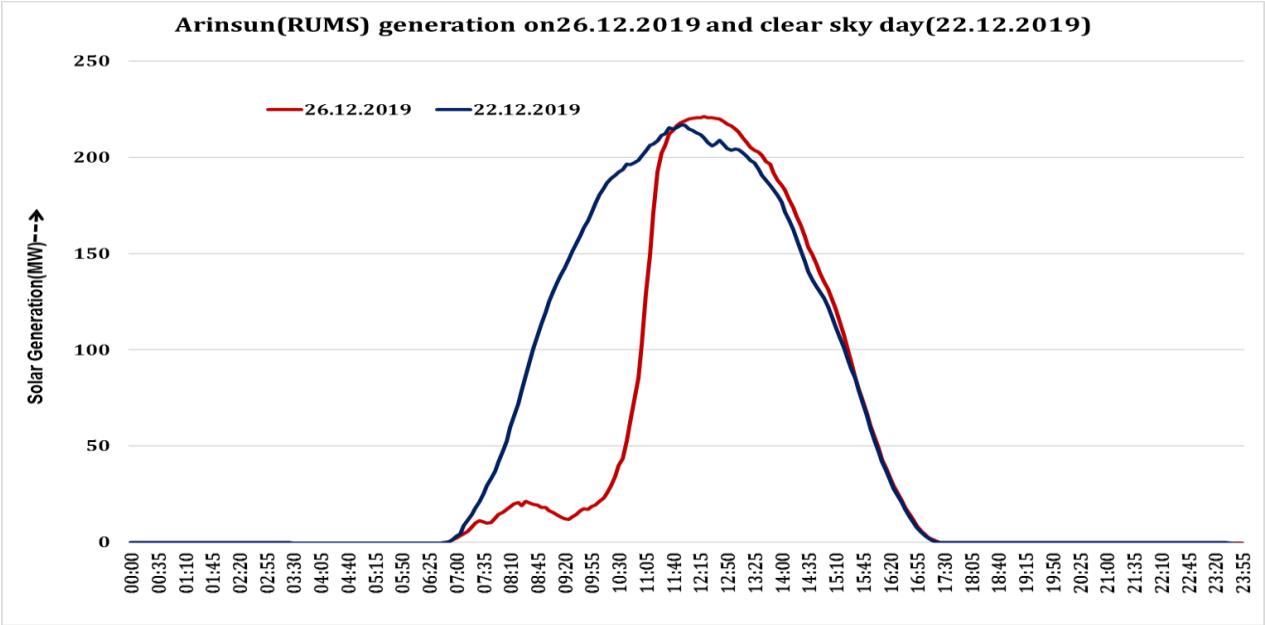
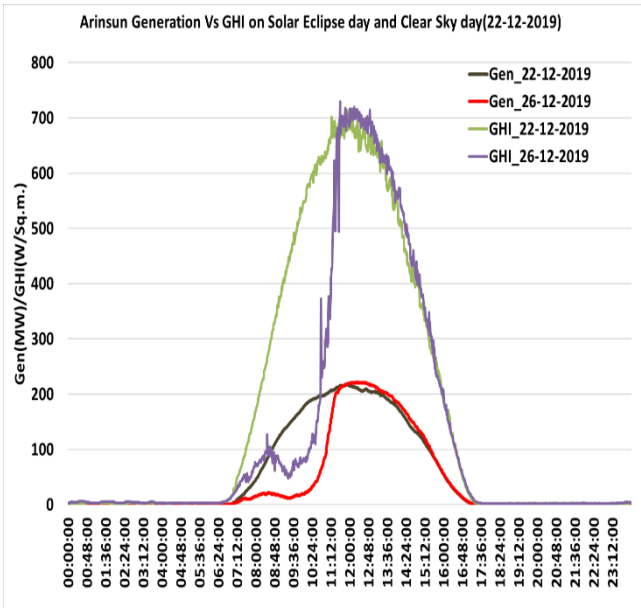
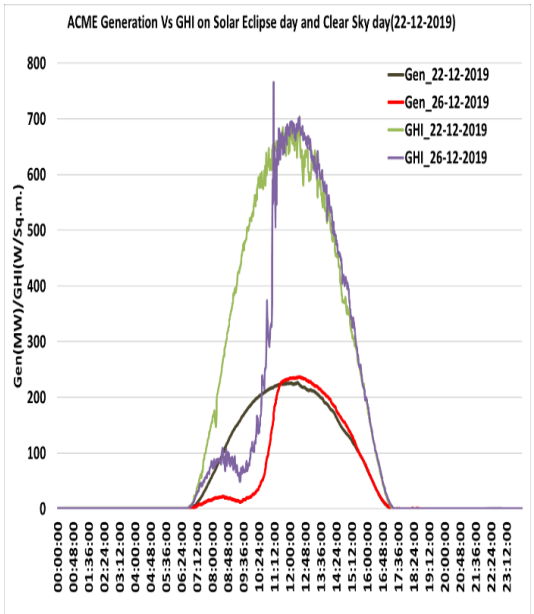


Figure 29: Arinsun actual solar generation on 26.12.2019 and clear sky day (22.12.2019)

At WRLDC, the GHI is telemetered for all ISTS solar plants that is measured through Pyranometer at site. Currently, there are three ISTS solar plants at RUMS (Rewa Ultra Mega Solar) i.e. Mahindra, Arinsun and ACME. Installed capacity as on 31st December 2019 at Arinsun and ACME is 250MW each, whereas installed capacity at Mahindra is 235 MW. The plot of the solar generation and GHI on clear sky day and solar eclipse day for all three plants are shown below:





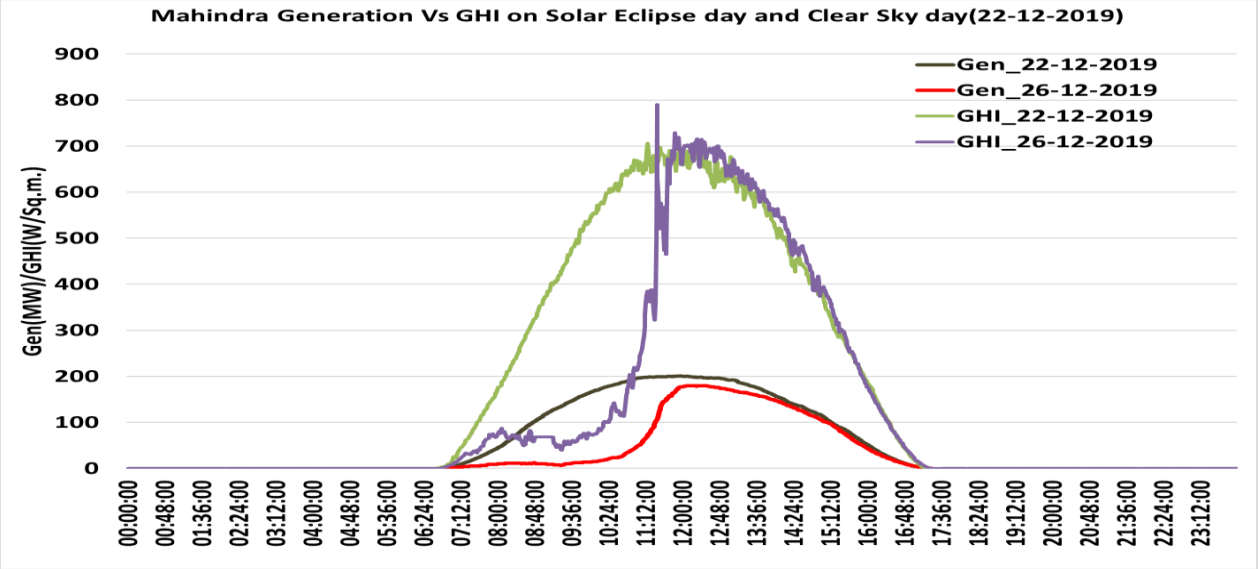


Figure 30: WR ISTS plants actual solar generation and GHI on 22.12.2019 and 26.12.2019

It is observed that solar generation followed the exactly same pattern of GHI during the solar eclipse day. At these ISTS solar plants, generation was very less (18 MW i.e. around 60MW lesser than clear sky day) during start of eclipse (~08:00 hrs). It has not reduced much during maximum solar eclipse time ~ 09:30hrs. also up to 10:30hrs, the generation at these plants was less than 50 MW after that as GHI started picking up with high ramp, the generation reached above 220 MW at Arinsun and ACME and 180MW at Mahindra.

2.3.3 Generation (Thermal, Gas and Hydro) from 24th to 26th December 2019

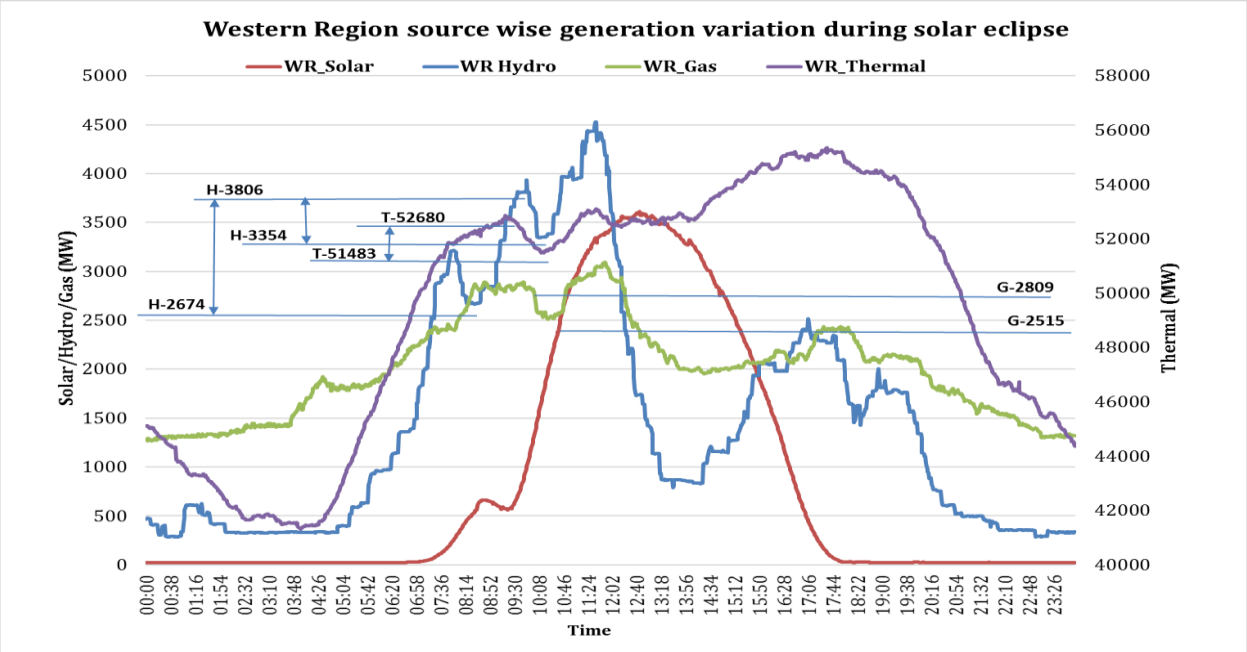


Figure 31: Western Region source wise generation variation on 26.12.2019

Further, the fuel wise generation is plotted (Fig.31) for 26th December 2019 to observe the actual impact and action taken in real time. It can be observed that at around 08:38 hrs the hydro generation started picking up from 2674 MW to 3806MW in Western Region. Total hydro generation was increased by 1122 MW till 09:38 hrs and after that it was reduced to 3354 MW at 10:19 hrs. To control the reduction in demand during maximum solar eclipse, Thermal generation was reduced from 52680 MW at 09:26 hrs to 51483 MW at 10:16 hrs. Also during this time, Gas generation was reduced by ~300 MW to mitigate the increase in ramp of solar generation.

The graph for Thermal, Gas and Hydro generation from 24th to 26th December 2019 is given below:

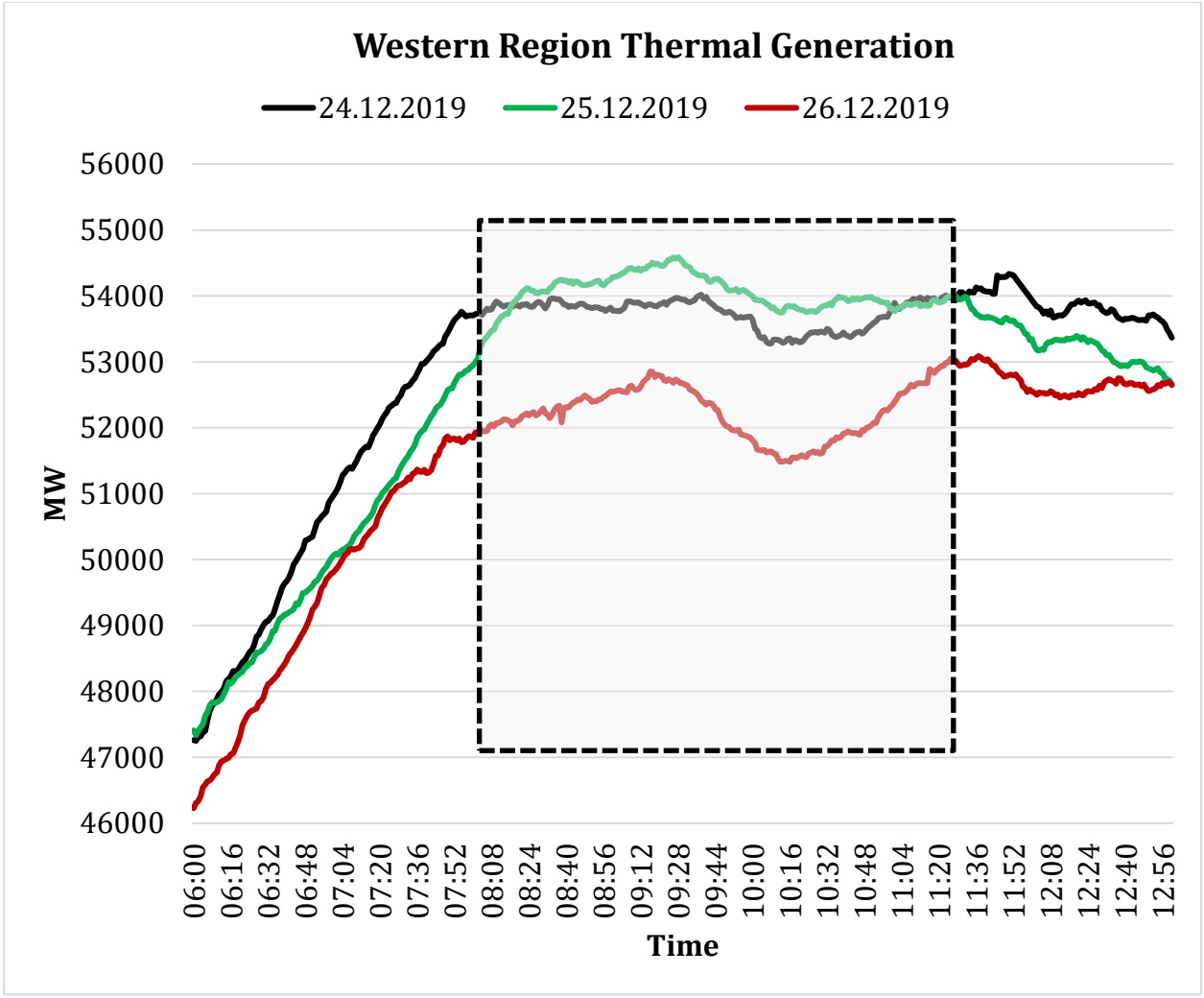


Figure 32: Western Region Thermal Generation from 24.12.2019 to 26.12.2019

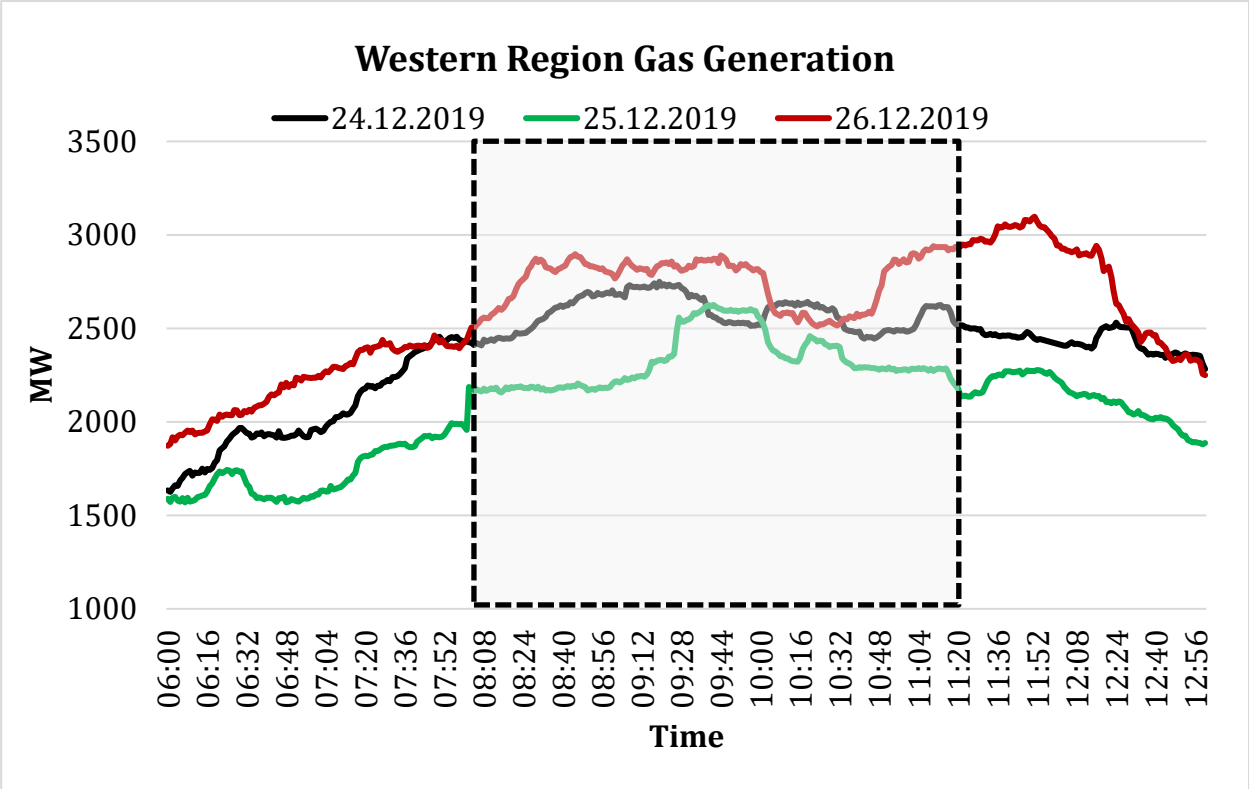


Figure 33: Western Region Gas Generation from 24.12.2019 to 26.12.2019

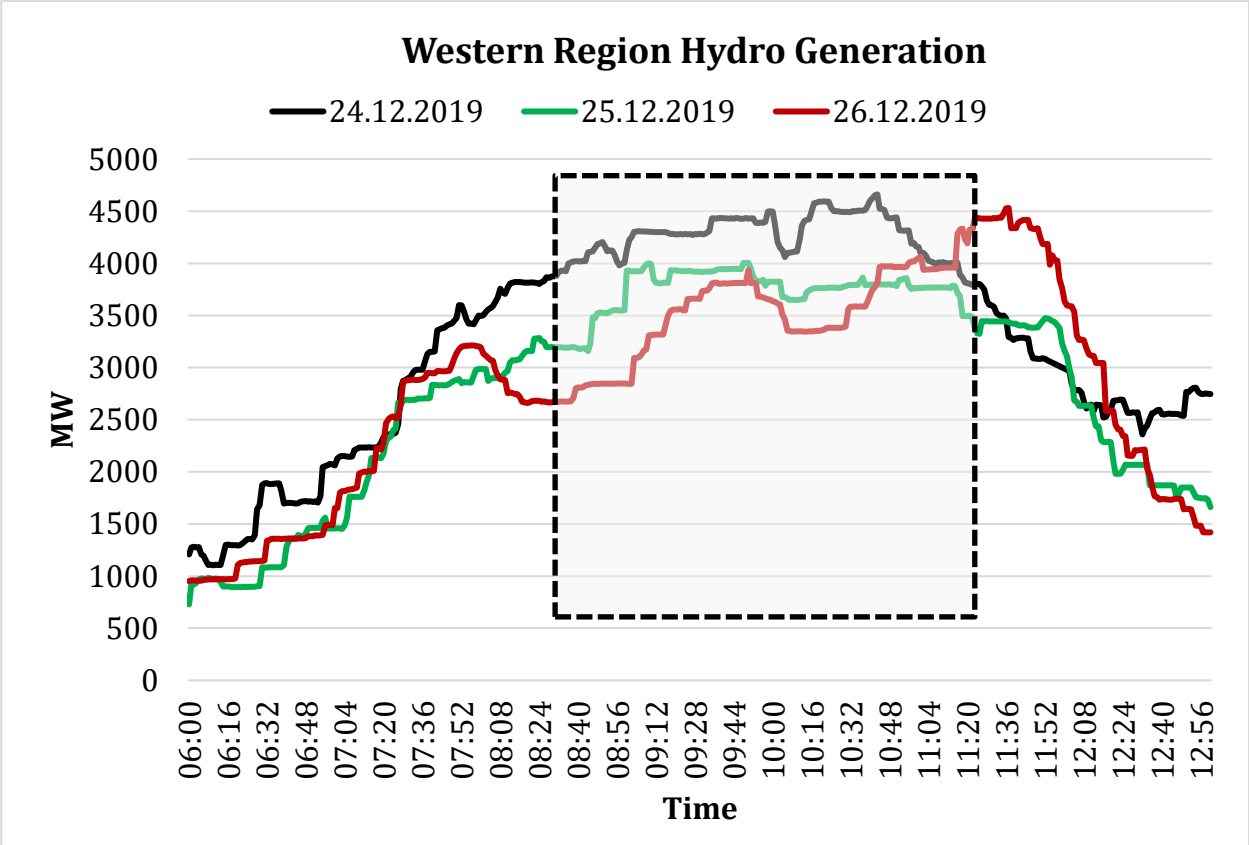


Figure 34: Western Region Hydro Generation from 24.12.2019 to 26.12.2019

Western Region source wise generation stacked charts

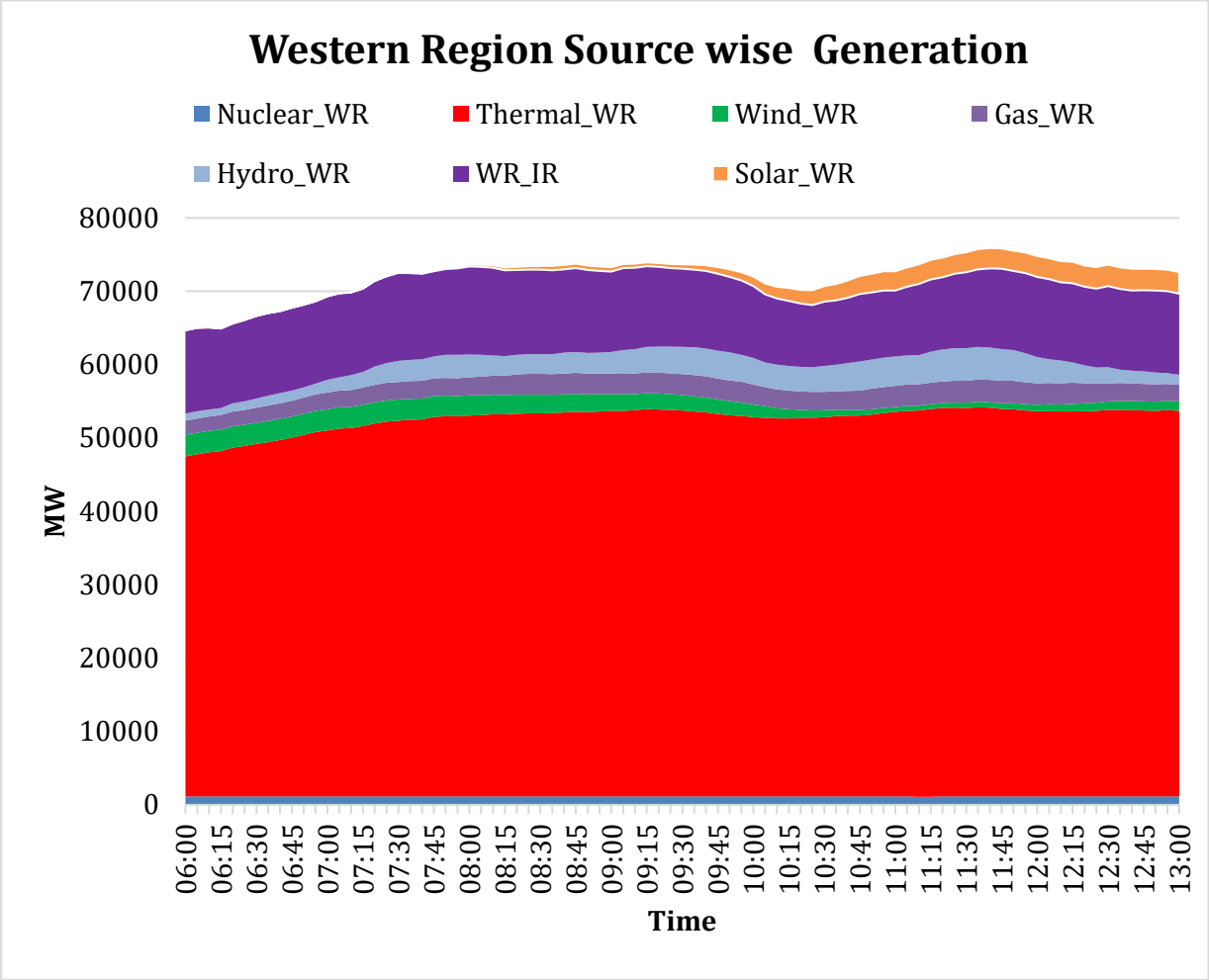


Figure 35: Western Region Source wise Generation

2.4 Northern Region

In view of anticipated solar reduction in Northern Region following steps were taken by NRLDC control room and Northern Region constituents during the solar eclipse

- Northern Region Central sector hydro generation was scheduled in consonance with solar eclipse. During morning peak, 2000 MW hydro generation was reduced as compared to normal day and the deficit was fulfilled through RRAS support in RLNG fuel (Gas generation).
- The hydro generation was flexed in Tehri, Koldam, Dulhasti, Dhauliganga, NJPC, Rampur, Bhakra and Dehar HEPs. Hydro generation was increased by 2200 MW w.r.t. normal day during solar eclipse. The plant wise hydro generation on 26th December is attached as **Annexure-IV**

- The hydro generation was increased after solar eclipse got over in view of rise in demand to maintain the load generation balance.
- Gas based generation through RRAS was flexed for peaking requirement of morning hours and also during solar eclipse to maintain load generation balance. 1500 MW of gas generation was increased through RRAS during solar eclipse.

Rajasthan purchased additional power from IEX to mitigate the effect of reduced solar generation due to solar eclipse.

Apart from above, Jawahar Sagar Power Station (3x 33=99 MW) and Mahi Phase-1 (2x25=50 MW) were also taken on bar.

2.4.1 Demand forecast vs actual on 26th December 2019

It was estimated that Northern Region demand will reduce by an average of 1 % demand during solar eclipse. However, it was observed that Northern Region demand on 26th December 2019 during solar eclipse was similar to normal day.

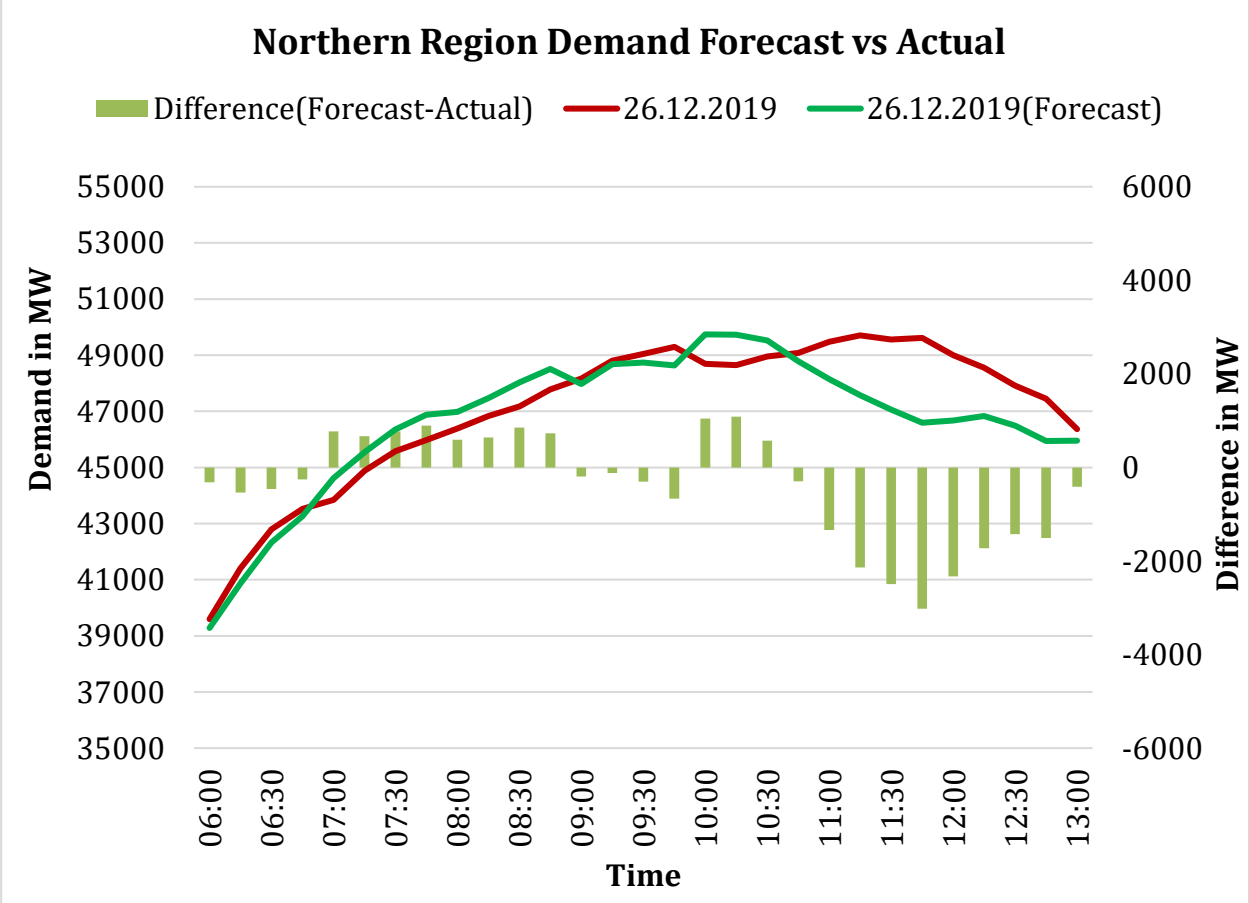


Figure 36: Northern Region demand forecast vs actual on 26.12.2019

It can be seen from above that during solar eclipse period the difference between forecasted demand and actual demand was less than 1%, however after the end of eclipse, demand picked up and difference was to the tune of 4%. Northern Region demand from 24th to 26th December 2019 is given below:

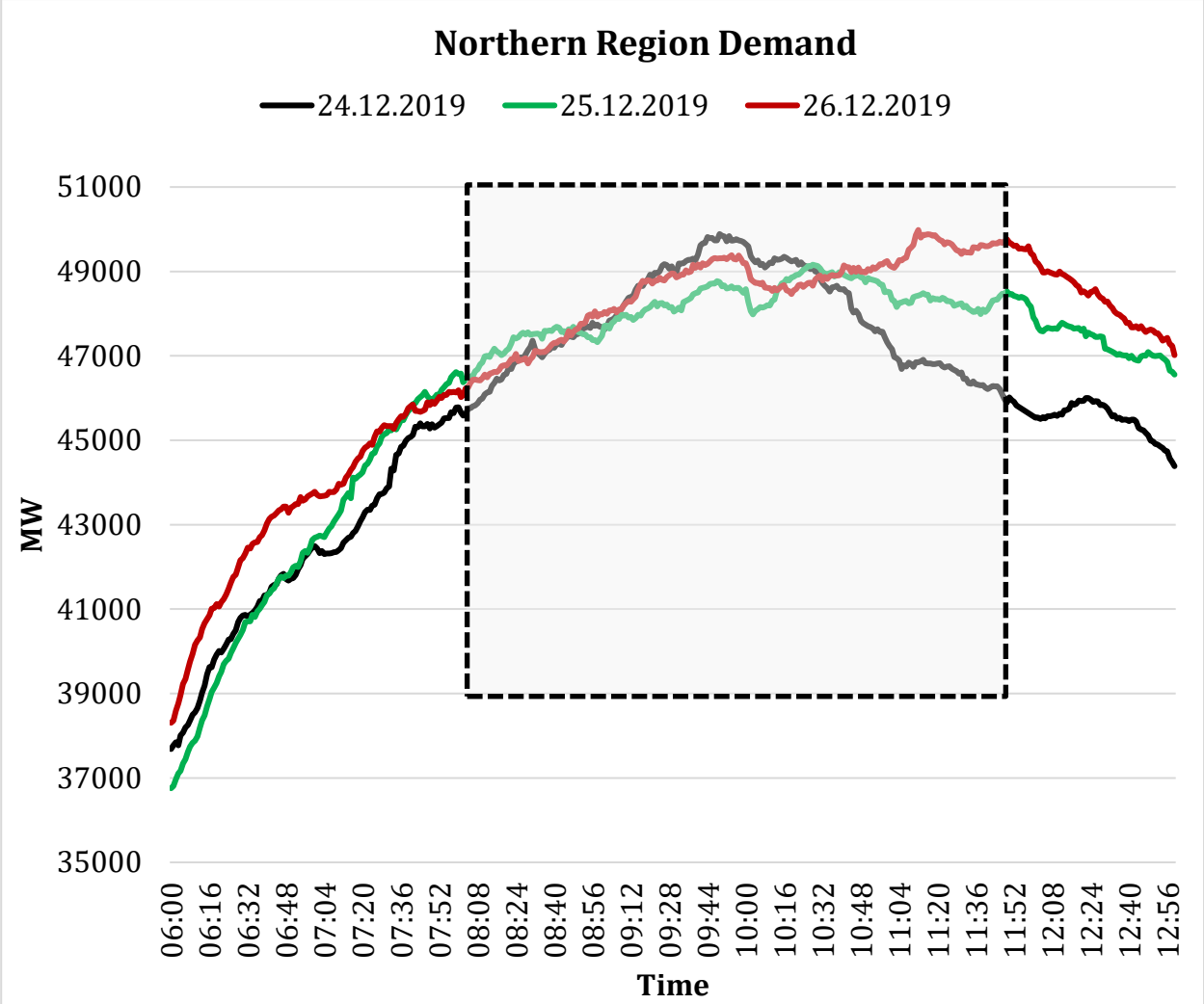


Figure 37: Northern Region Demand

2.4.2 Solar generation forecast vs actual on 26th December 2019

Solar eclipse started in the Northern Region at 08:15 hrs and ended at 11:07 hrs. On 25th December 2019, very dense fog prevailed in west Rajasthan, Punjab and Uttar Pradesh leading to less generation from solar plants. In comparison to 25 December 2019, Fog spread was lesser on 26th December 2019(Fig. 38).

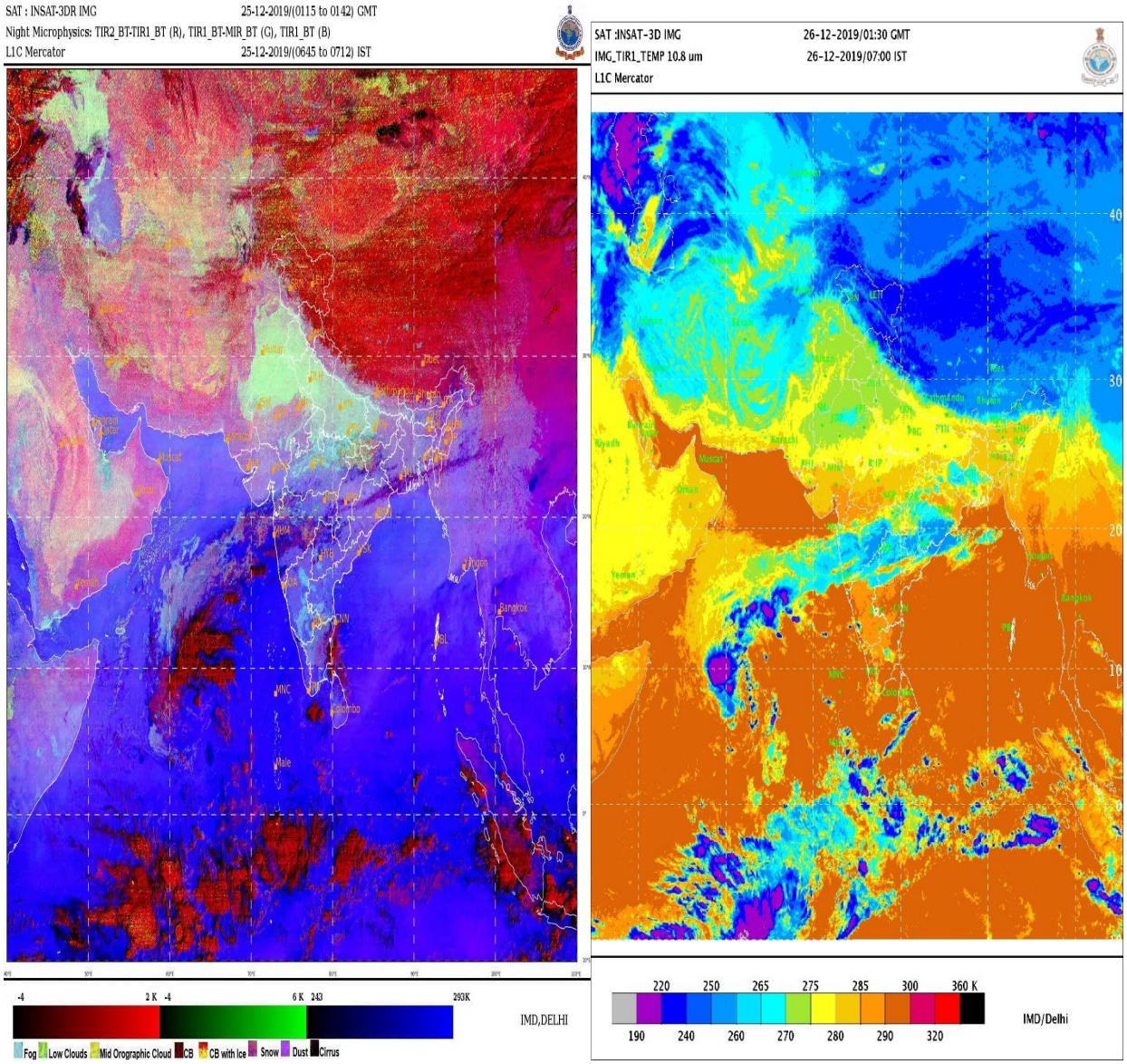


Figure 38: Satellite Image 25.12.2019 and 26.12.2019

It was estimated that maximum solar generation reduction in Northern Region due to the eclipse would be 928 MW at 09:30 hrs under clear sky conditions. However, during the event on 26th December 2019, 918 MW at 09:30 hrs of solar generation reduction was observed with respect to 24th December 2019(clear sky conditions). Further, an in-house–solar forecasting module based on GFS model was used to forecast the day ahead solar generation (Fig.40) for 26th December 2019. It can be observed that the error was minimum in day ahead forecast during solar eclipse period. Most of the solar generators are located in Western Rajasthan where obscuration started decreasing at 09:22 hrs, therefore the solar generation picked up 6-7 minutes early compared to Southern Region leading to a small shift in ramp up of solar generation.

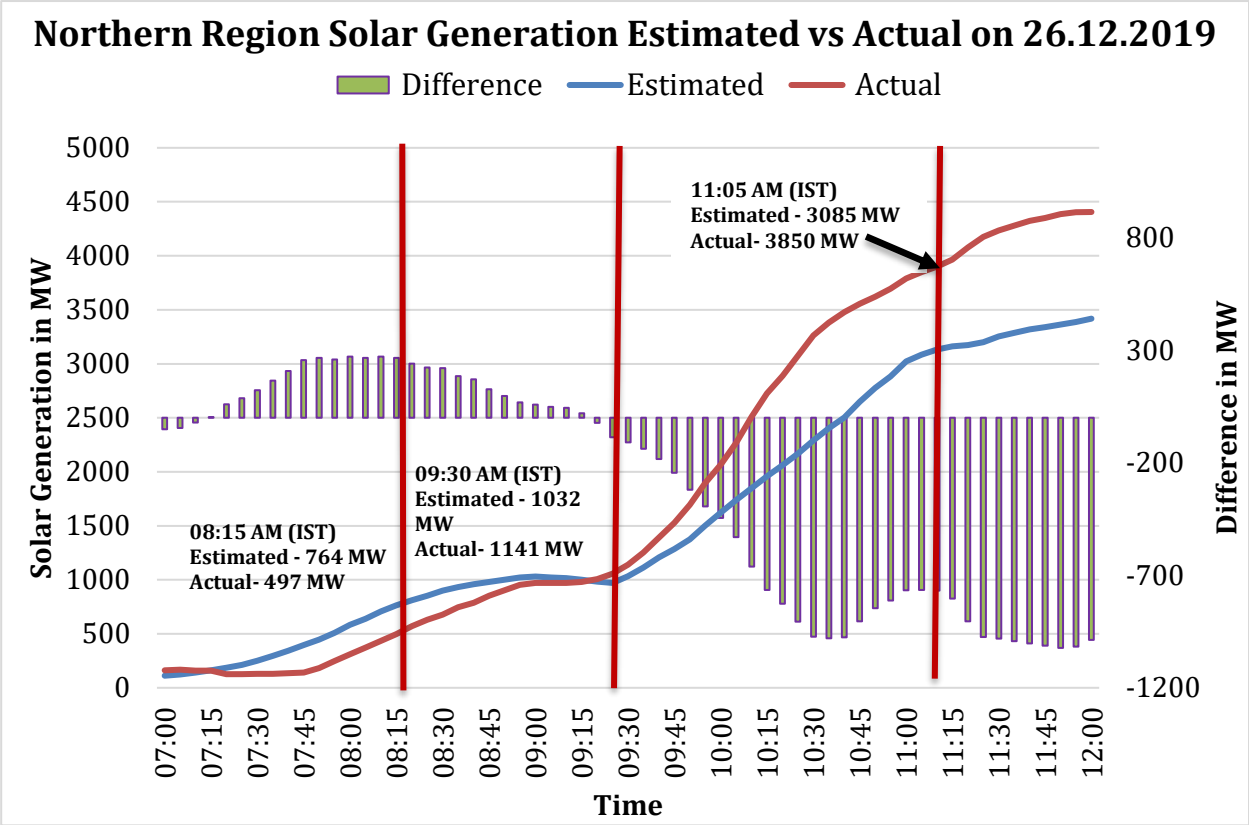


Figure 39: Northern Region Solar Generation Estimated vs Actual on 26.12.2019

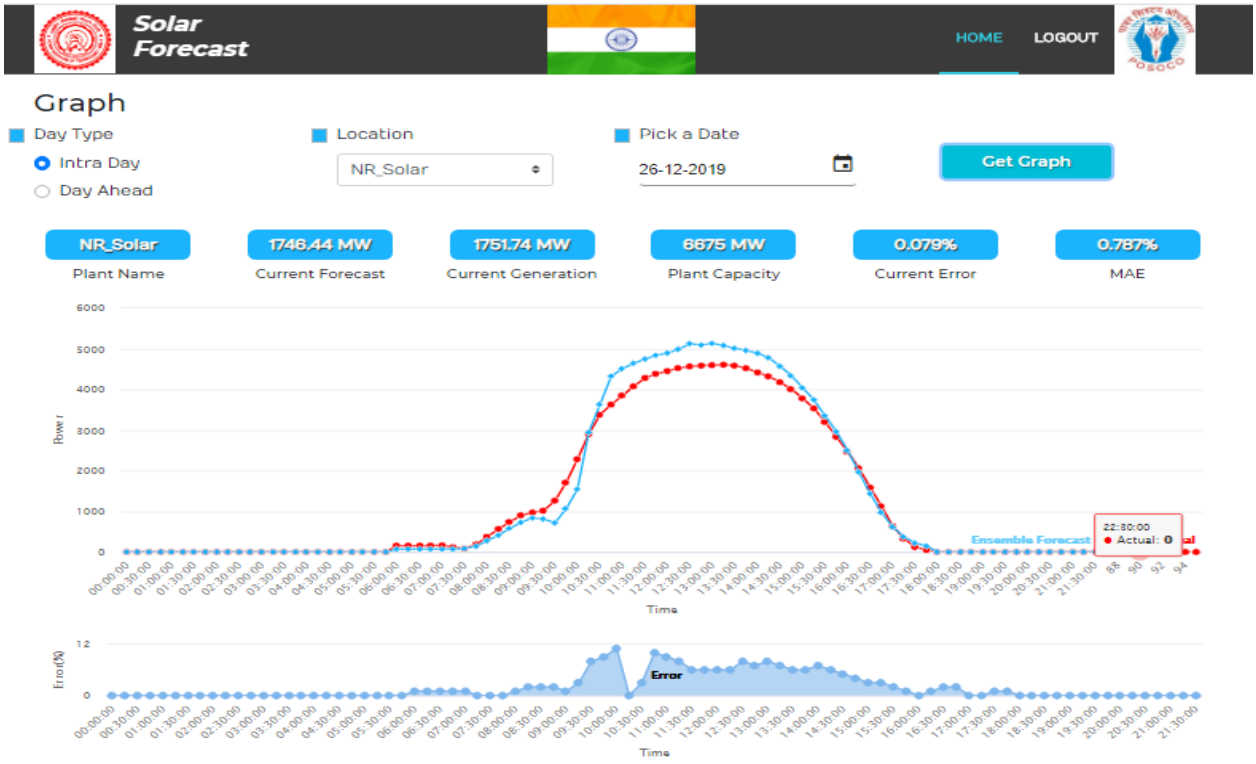


Figure 40: Northern Region day ahead solar forecast vs actual on 26.12.2019

The Northern Region solar generation during solar eclipse is plotted in figure 41. It is observed that during initial period of the solar eclipse i.e. from 08:15 hrs to 08:30 hrs, normal ramp up of solar generation dominated the impact of eclipse. However, from 08:30 hrs to 08:55 hrs the average ramp rate of solar generation was 12 MW /minute in comparison to 20 MW/minute on a normal day. During maximum eclipse period, the regional solar generation was 950-1000 MW against 2000 MW on a normal day. Northern Region witnessed around 50% of obscuration, therefore total reduction was approximately 50 % of the generation available on a normal day. After maximum eclipse, the solar generation increased from 09:25 hrs onwards with average ramp rate of 29 MW/ minute until the end of solar eclipse at 11:00 hrs.

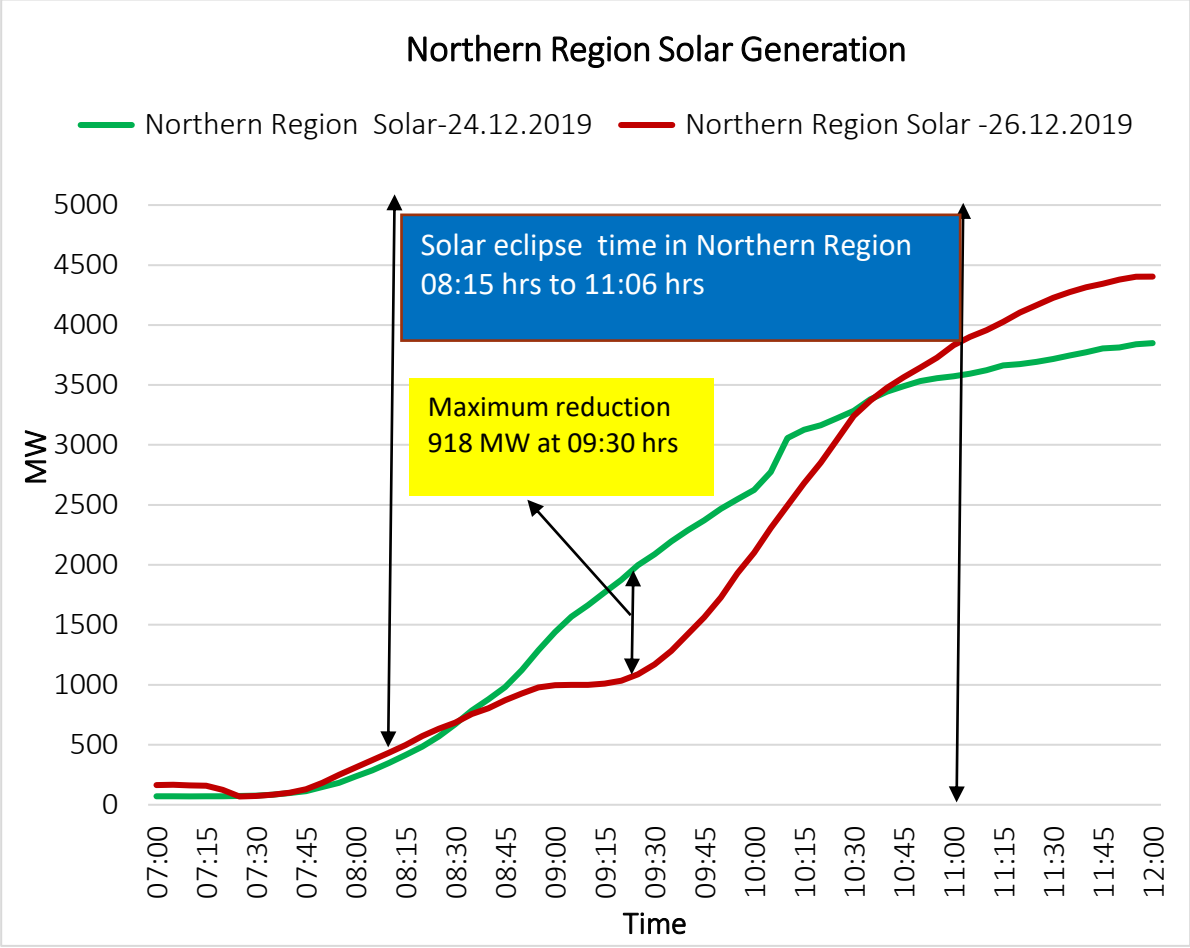


Figure 41: Northern Region solar generation on 26.12.2019

The state of Rajasthan recorded maximum reduction of 700 MW solar generation at time of maximum eclipse (Fig.42). The ramp up rate of solar generation during 08:25 hrs to 09:30 hrs was 4.71 MW/minute compared to 15-16 MW/minute on a normal day.

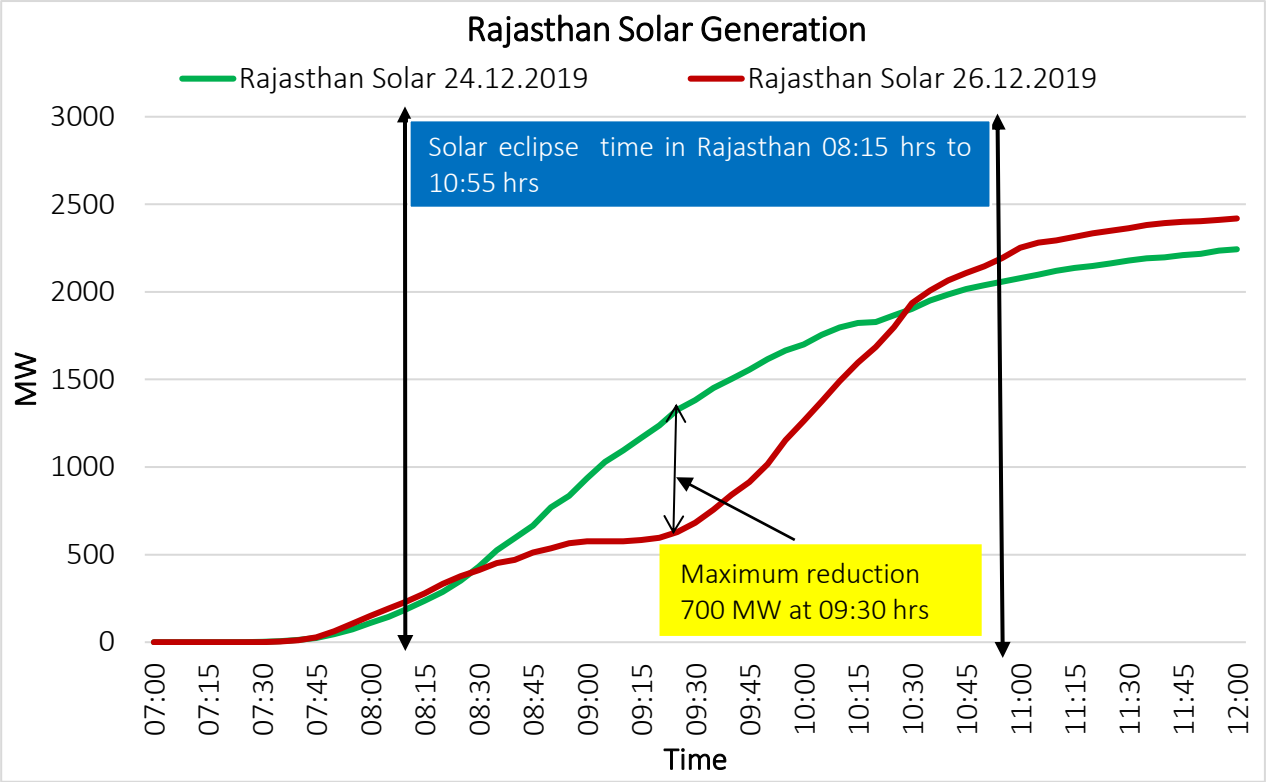


Figure 42: Rajasthan solar generation on 26.12.2019

The state of Punjab recorded maximum reduction of 19 MW solar generation at time of maximum eclipse

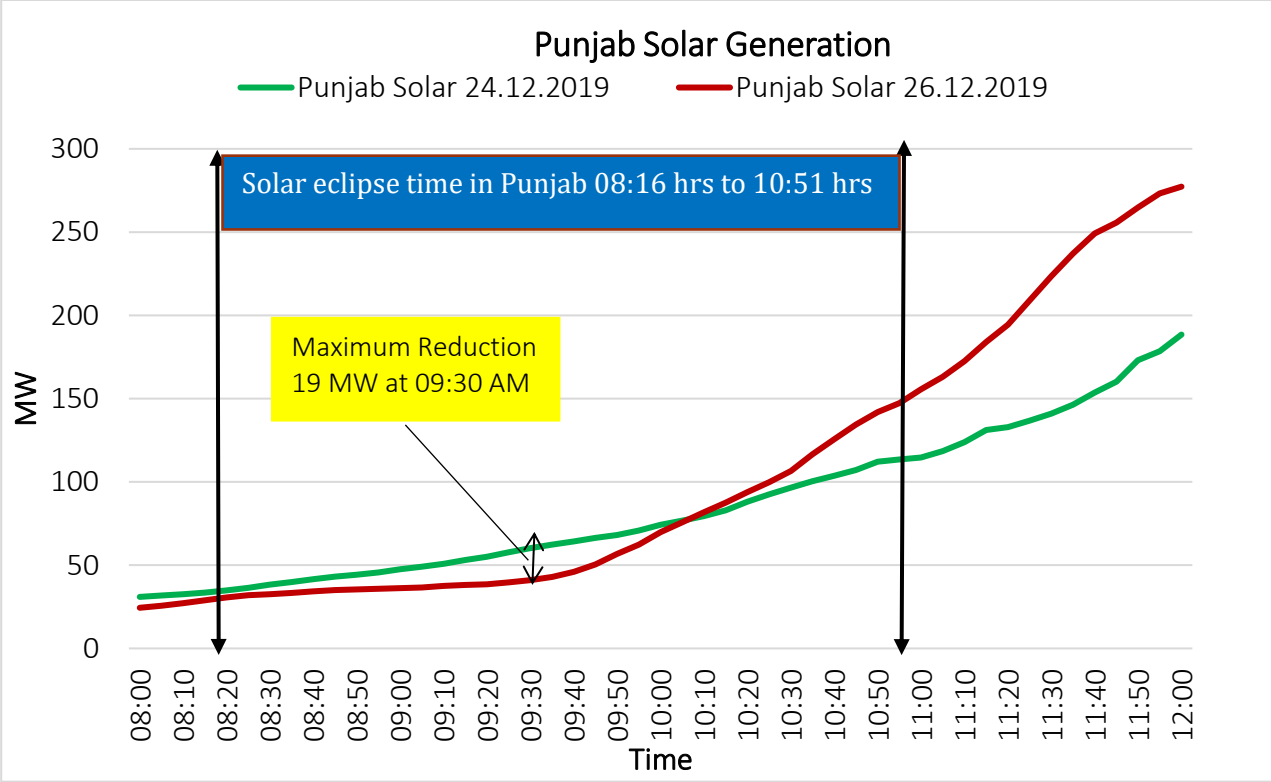


Figure 43: Punjab solar generation on 26.12.2019

The state of Uttar Pradesh recorded maximum reduction of 35 MW solar generation at time of maximum eclipse.

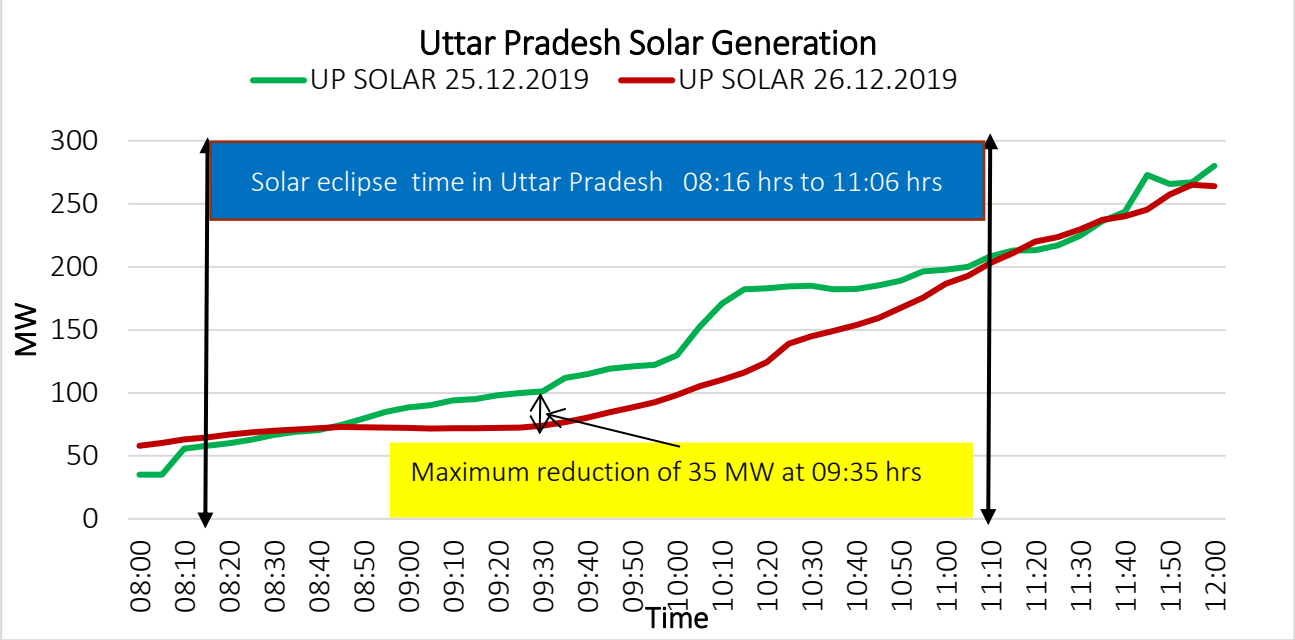


Figure 44: Uttar Pradesh solar generation on 26.12.2019

ISTS connected plant wise solar generation profile for 24th to 26th December 2019 is attached as **Annexure- V.**

2.4.3 Generation (Thermal, Gas and Hydro) from 24th to 26th December 2019

The graph for Thermal, Gas and Hydro generation from 24th to 26th December is given below:

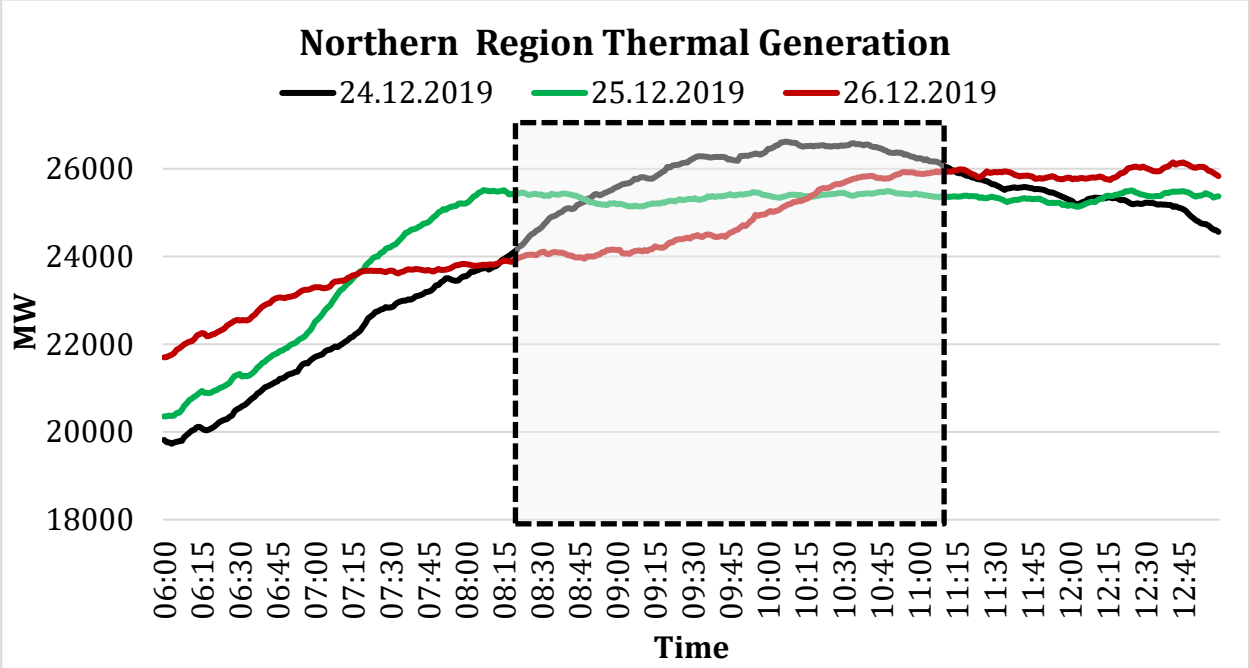


Figure 45: Northern Region Thermal Generation from 24.12.2019 to 26.12.2019

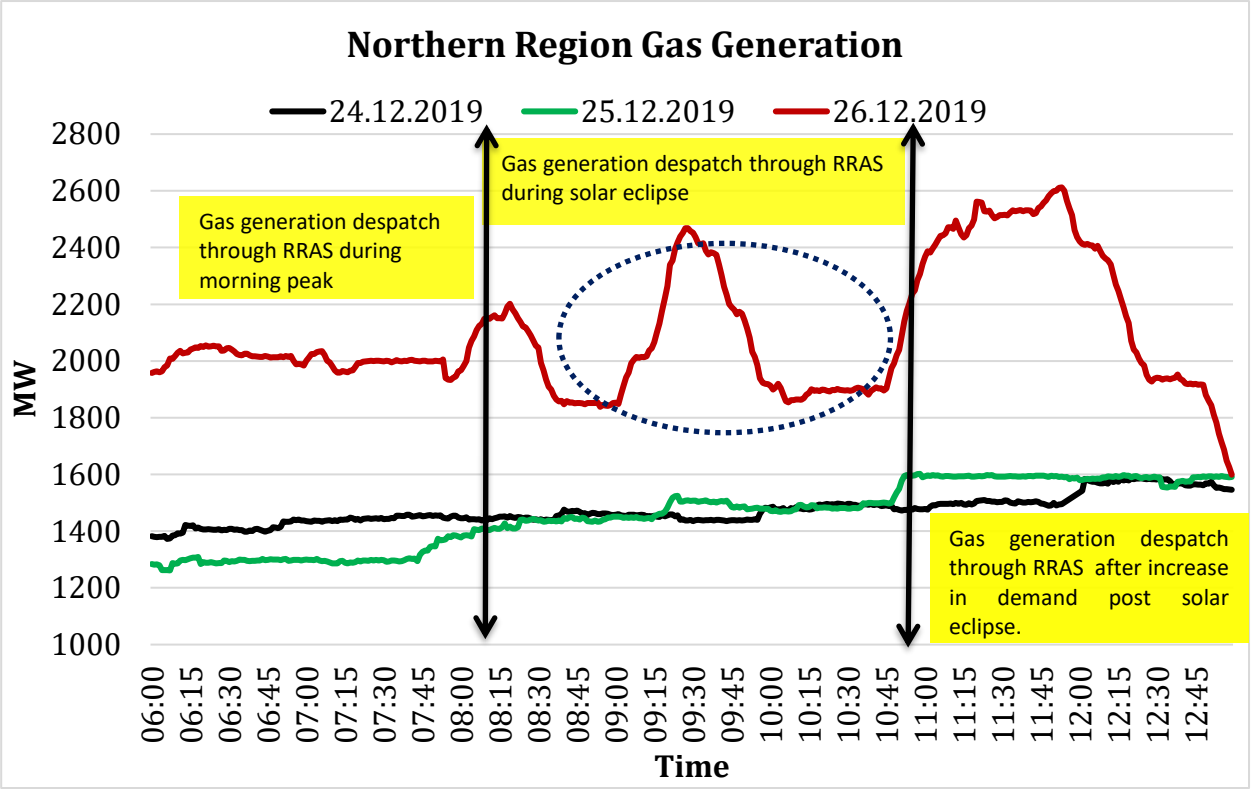


Figure 46: Northern Region Gas Generation from 24.12.2019 to 26.12.2019

Generation from gas based power stations were varied to the tune of 1500 MW through RRAS during solar eclipse (Ref. Fig 46).

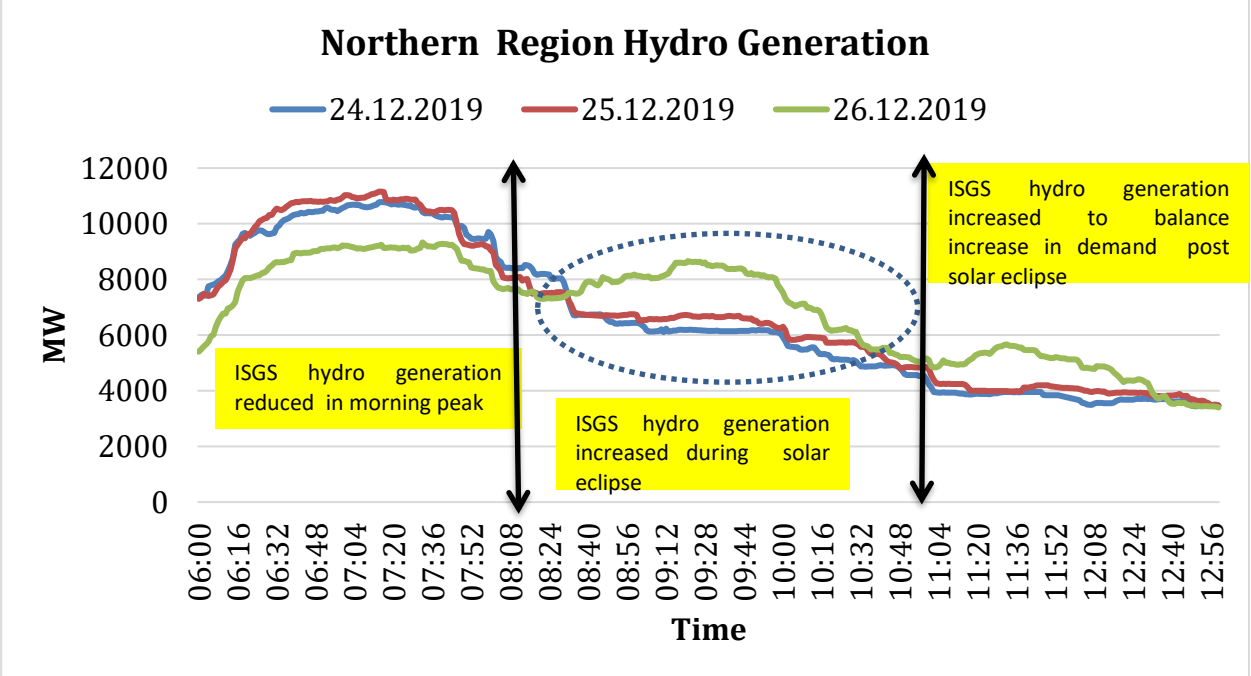


Figure 47:Northern Region Hydro Generation from 24.12.2019 to 26.12.2019

Hydro generation was increased by 2200 MW with respect to normal day during solar eclipse (Ref Fig.47).

Northern region source wise generation on 26th December 2019 is depicted below:

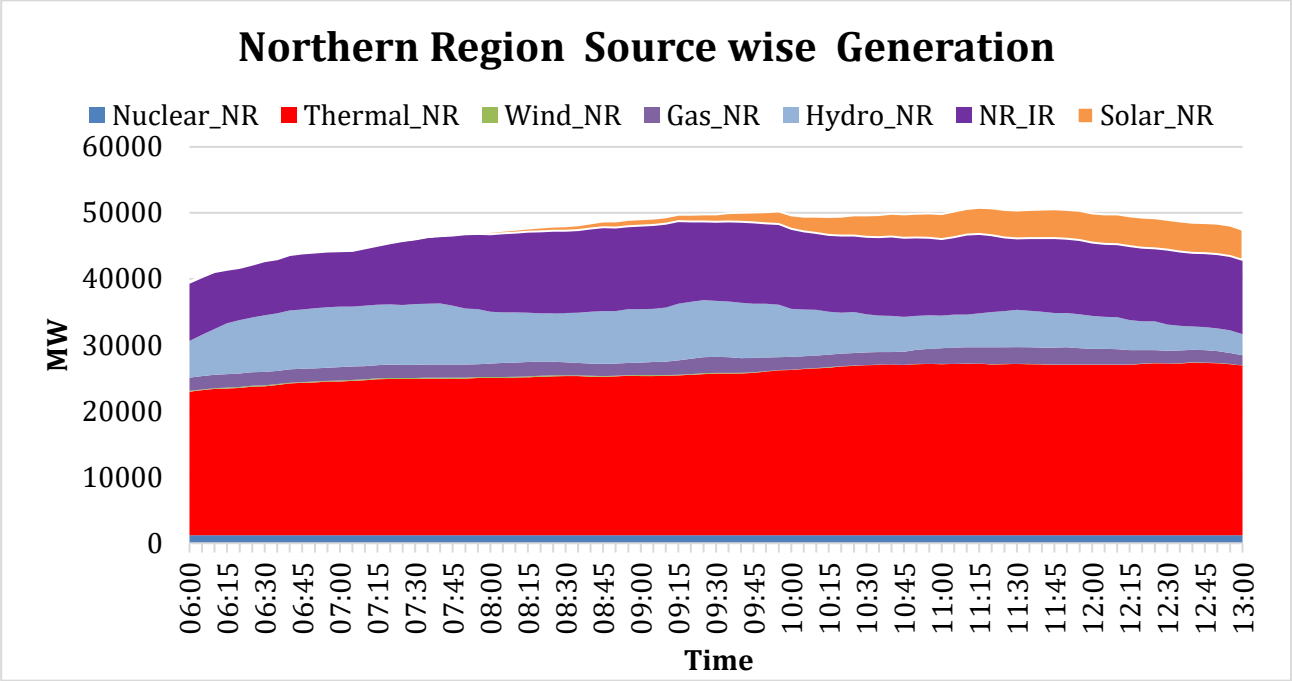


Figure 48: Northern Region Source wise Generation

Chapter - 3 : Regulation of inter-regional power flow on 26th Dec 2019

As per the recommendation of solar eclipse report, Southern Region being the highest impacted region, HVDC flows towards Southern Region via Talcher-Kolar and Gazuwaka were regulated on 26th December 2019 to control line loading on inter-regional corridor as well as to keep margin in HVDC for any contingency. Flows of HVDC's are given below:

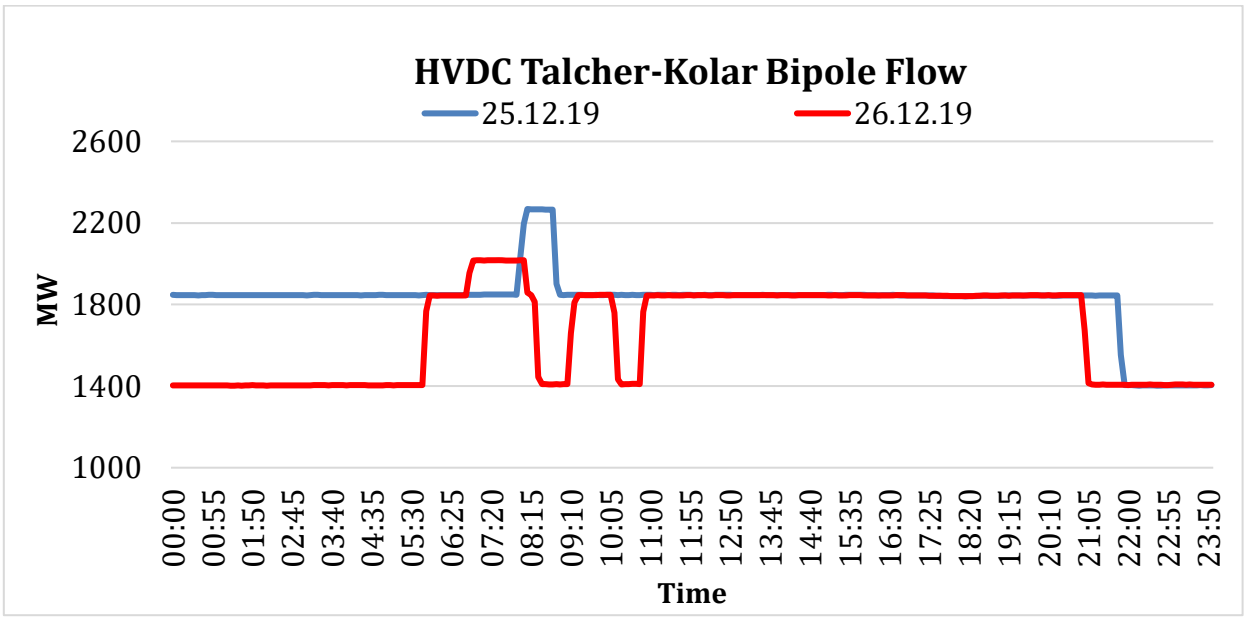


Figure 49: HVDC Talcher-Kolar Bipole flow

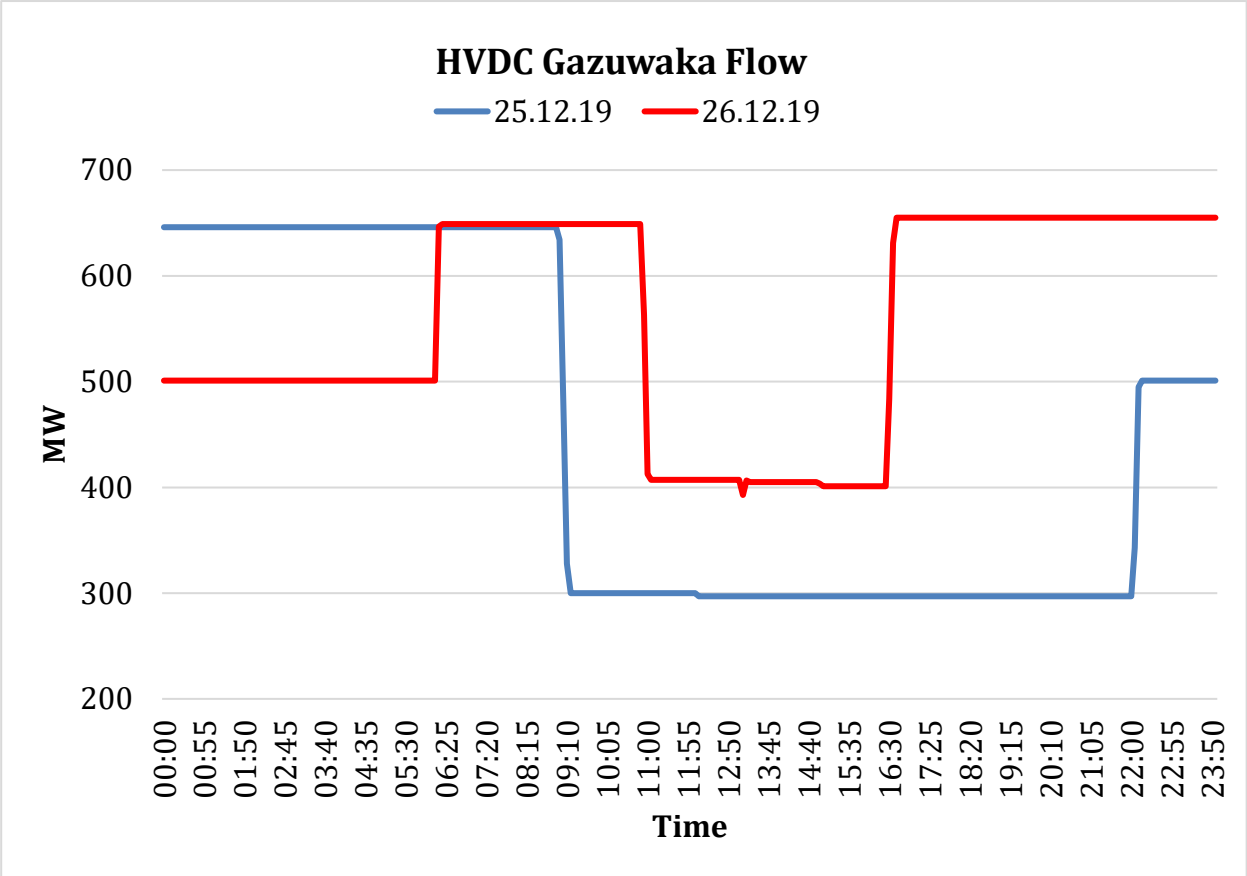


Figure 50: HVDC Gazuwaka flow

Chapter - 4 : Post-despatch analysis

4.1 Analysis of demand during solar eclipse

4.1.1 All India Demand

The pattern of demand variance observed on 26th December 2019 showed that on an average around 2.4% demand reduced with an instantaneous maximum demand reduction of 4.2 %. Further, it was observed that All India demand increased by 6372 MW i.e. by 3.8 % after eclipse got over. It is also pertinent to mention that record 170 GW+ demand in December 2019 occurred post eclipse which was all time highest in December 2019.

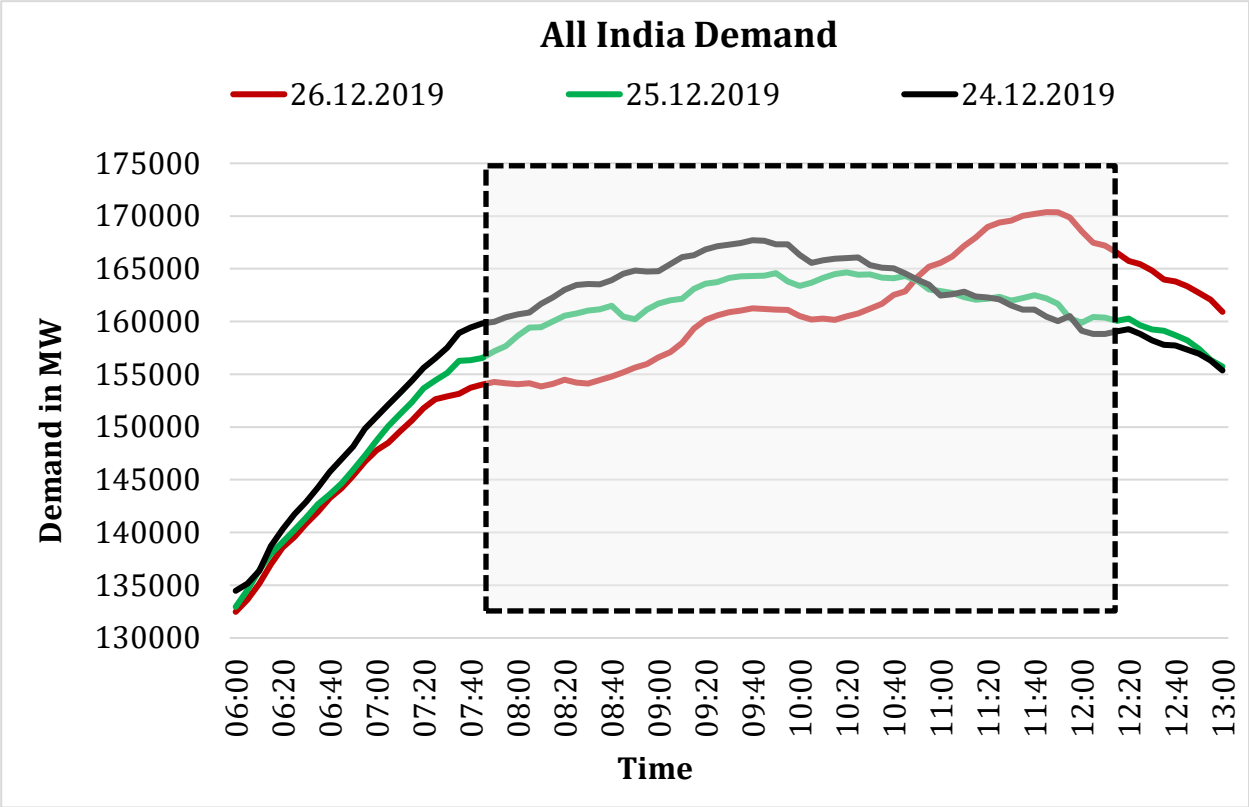


Figure 51: All India Demand from 24.12.2019 to 26.12.2019

4.1.2 All India Area Control Error

Area control error (ACE) is the difference between actual and scheduled drawl within a control area, taking frequency bias into account.

Negative values of ACE denote under drawl and positive values of ACE denote over drawl by control area from the grid.

All India ACE after end of solar eclipse was to the tune of 4500MW, which was mainly contributed by Southern and Northern Region States over drawls.

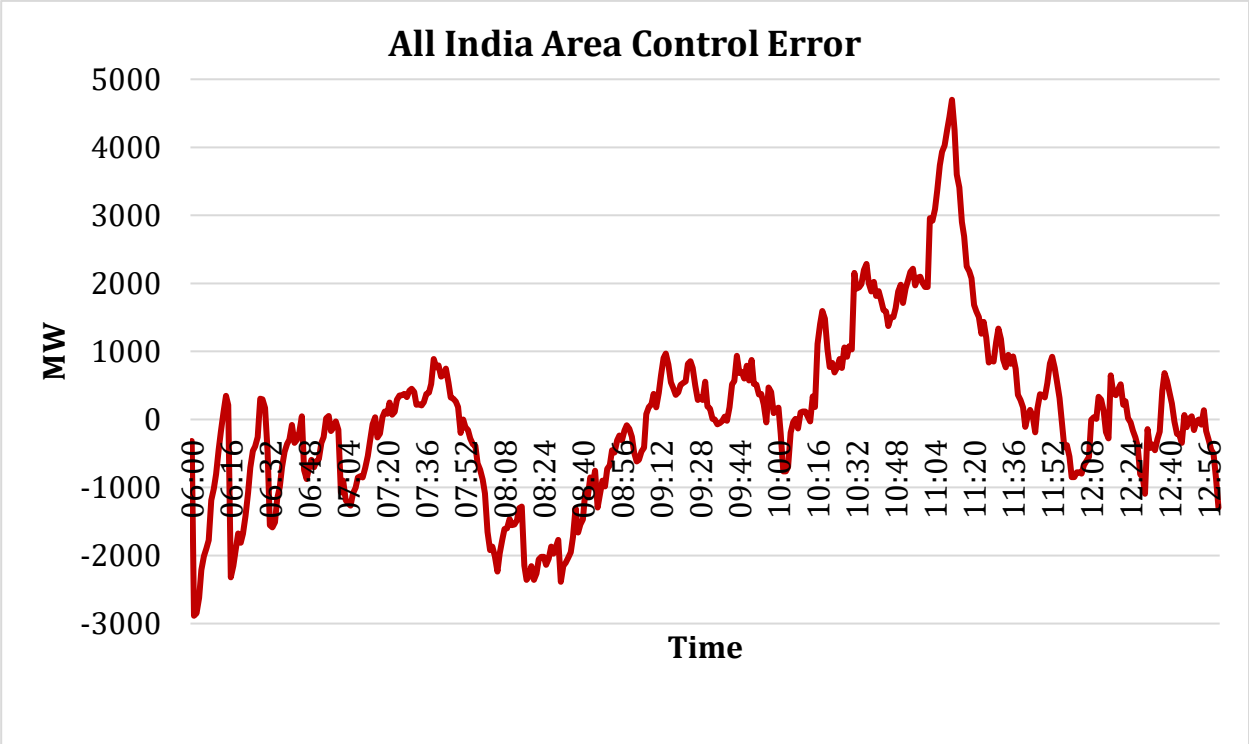


Figure 52: All India Area Control Error on 26.12.2019

The above ACE variation highlights the need for secondary/tertiary control. In the interest of reliable and safe grid operation, Hon'ble Commission in its order dated 28th August 2019 has directed that all thermal ISGS stations with installed capacity of 200 MW and above and all hydro stations having capacity exceeding 25 MW excluding Run-of-River hydro projects whose tariff is determined or adopted by CERC shall be AGC enabled and the ancillary services including secondary control through AGC be implemented. Further, accurate load forecasting and renewable energy forecasting is the first step towards reliability as generating units gets committed based on forecasts.

4.1.3 Southern Region Demand

It was observed that before eclipse some of Southern Region states has restricted power supply to agricultural loads and hence reduction in demand can be seen from 7:25 hrs to 8:26 hrs. Around 9:00 hrs Karnataka demand increased which is a daily load change over pattern of the state. After 10:25 hrs agriculture loads were released by the states (Increase in demand can be seen in the demand plot after 10:20 hrs) as solar generation was in increasing trend.

After end of eclipse (i.e.11:00 hrs) Southern regional demand increased by 3700 MW from 44637 to 48348 MW due to sudden increase in domestic load (mainly geyser load) and agriculture loads as informed by states which was much higher than estimated.

As 25th December is holiday, 24th December is chosen for comparison with eclipse day demand. On 26th December Southern Region demand was on the lower side compared to 24th December 2019 due to long holidays. A gap of 1400-2000MW could be seen between these two days. Southern Region demand for the period 6:00 hrs to 13:00 hrs plotted below for better visualisation of demand variations during eclipse time.

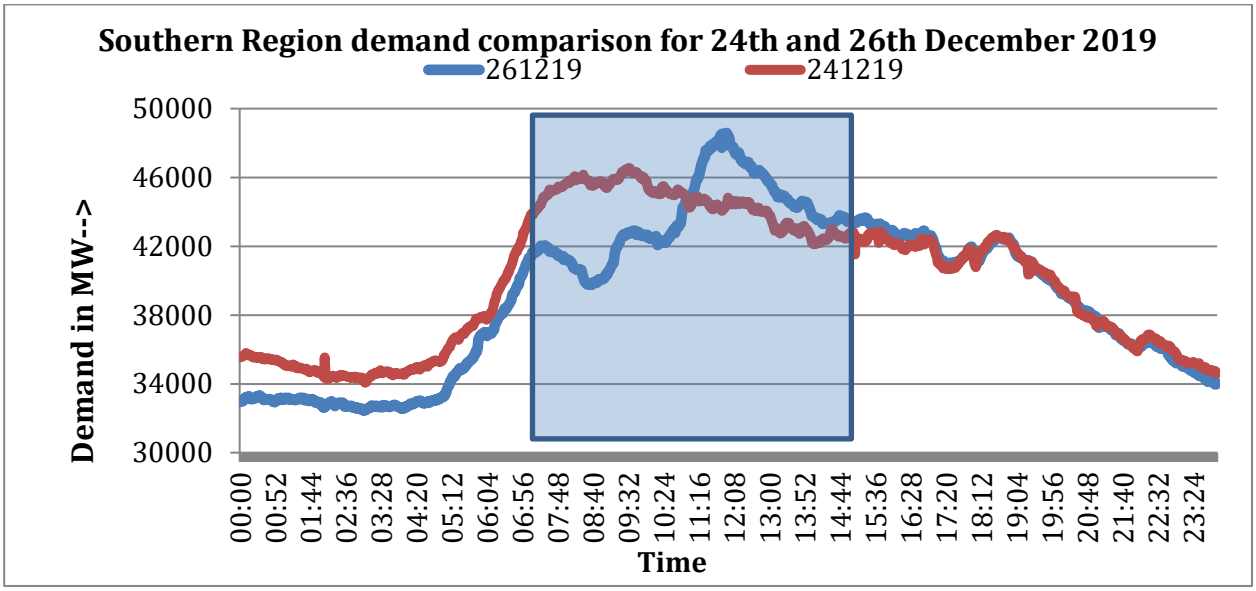


Figure 53: Southern Region demand comparison for 24.12.2019 and 26.12.2019

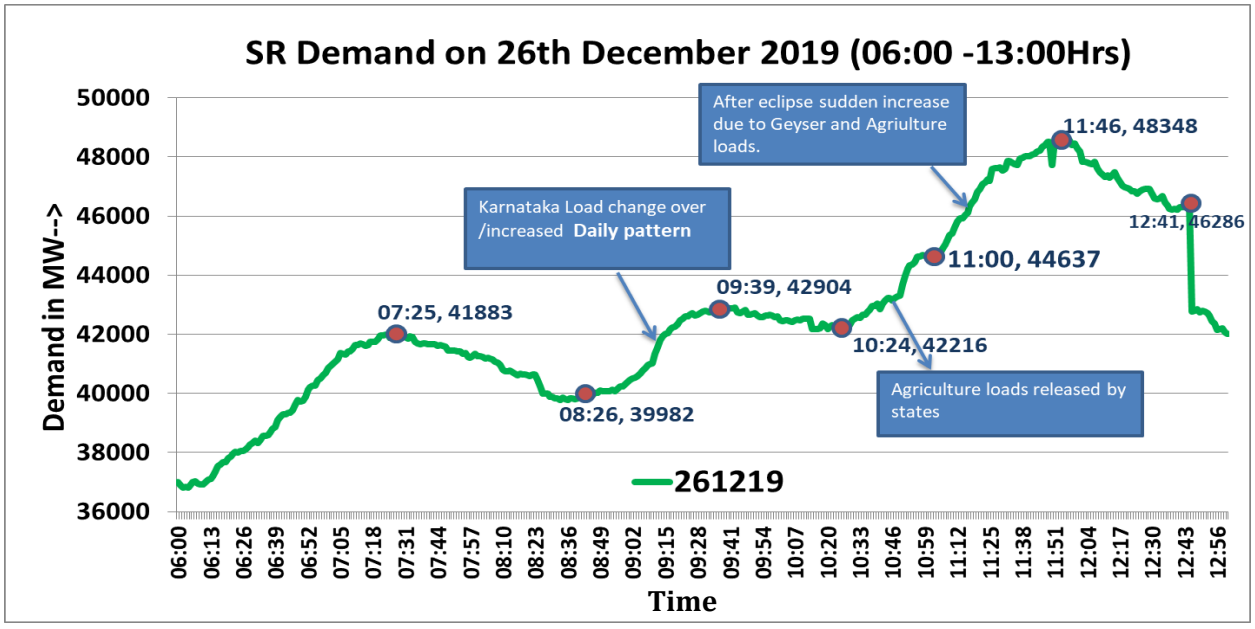


Figure 54: Southern Region Demand on 26.12.2019

Southern states demand comparison for 24th December 2019 and 26th December 2019 attached as **Annexure-VI.**

A comparison of two solar eclipses that affected Southern Region is tabulated below. It may be noted that in both events, previous day was a holiday i.e. 14th January 2010 (Pongal) and 25th December 2019 (Christmas).

Solar eclipse 15.01.2010 vs Solar eclipse 26.12.2019		
Parameters	**Solar Eclipse 15.01.2010**	**Solar Eclipse 26.12.2019**
Type of Eclipse	Annular	Annular
Solar eclipse start time	11:00 AM	08:03 AM
Maximum eclipse time	13:10 PM	09:30 AM
Solar eclipse end time	15:15 PM	12:03 PM
Visibility of annularity	Southern part of India	Southern part of India
% Obscuration	84.41%	93.10%
Average demand of Southern Region	22460 MW	39000 MW
Average demand reduction during solar eclipse w.r.t previous day	2.5 % or 589 MW	4 % or 1757 MW
Maximum demand reduction w.r.t previous day	5 % or 1218 MW	9 % or 3992 MW
Rise in demand after end of solar eclipse	3 % or 687 MW (15:12 to 16:00 hrs)	8.8 % or 3936MW (11:00 to11:57 hrs)
Solar generation reduction during solar eclipse	Not applicable	5759 MW
Shortage	Peak MW (6.24 %) Energy MU (5.5 %)	Peak MW (0.00%) Energy MU (0.24 %)

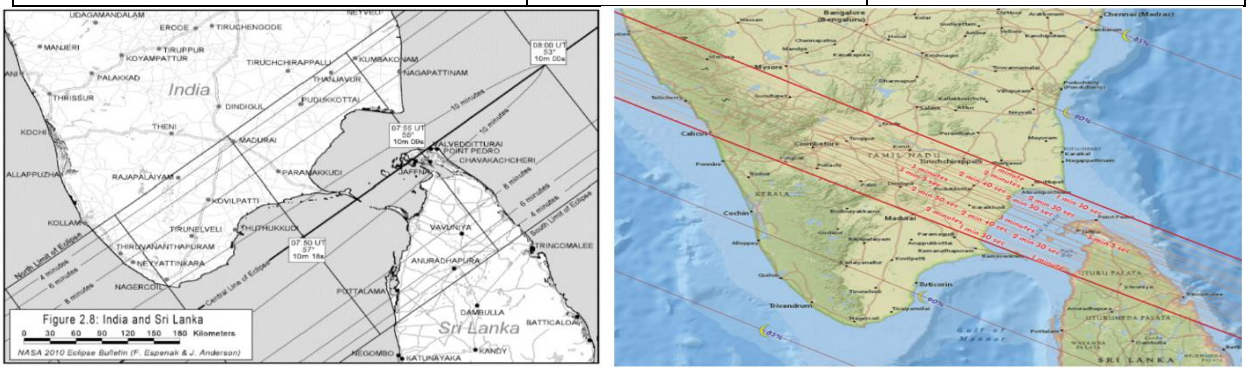


Figure 55: Path of annular solar eclipse on15.01.2010 and 26.12.2019

4.1.4 Southern Region Area Control Error

Figure below shows area control error for Southern Region. It can be observed that the deviation was of the tune of 1200-1500 MW during the period of maximum eclipse i.e. 09:15 to 09:30 hrs. Again after the end of the eclipse, when demand picked up the deviation was to the tune of 2500 MW.

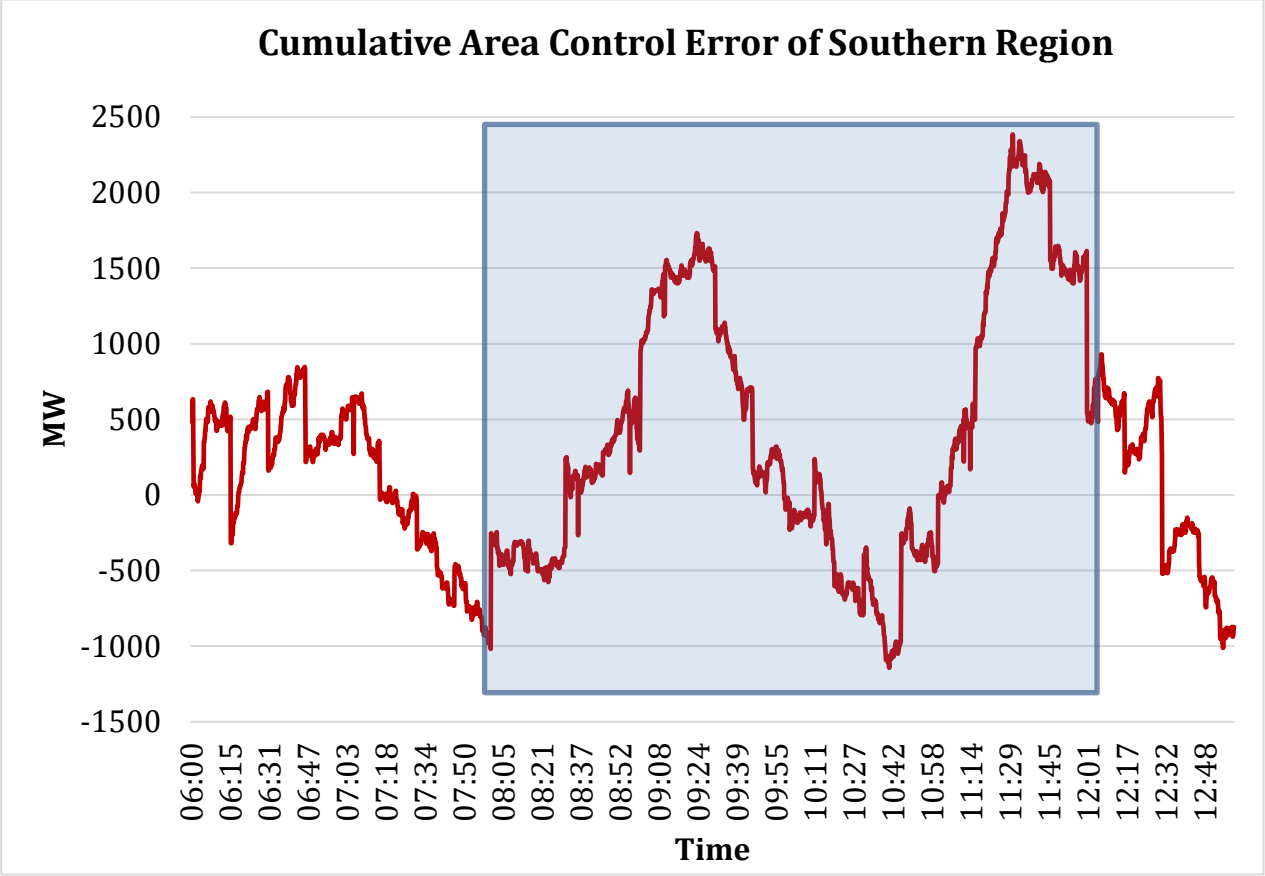


Figure 56: Cumulative Area Control Error of Southern Region

4.1.5 Western Region Demand

Western Region demand on solar eclipse day was observed to be less than the demand on 25th Dec 2019. The difference in demand increased at around 08:00 hrs with start of the solar eclipse and maximum difference observed 1847MW at 10:15 hrs. At the end of solar eclipse, the demand started increasing and reached above the previous day demand. Western states demand comparison for 25th December 2019 and 26th December 2019 attached as **Annexure-VII.**

Western Region demand from 24th December 2019 to 26th December 2019 is given below:

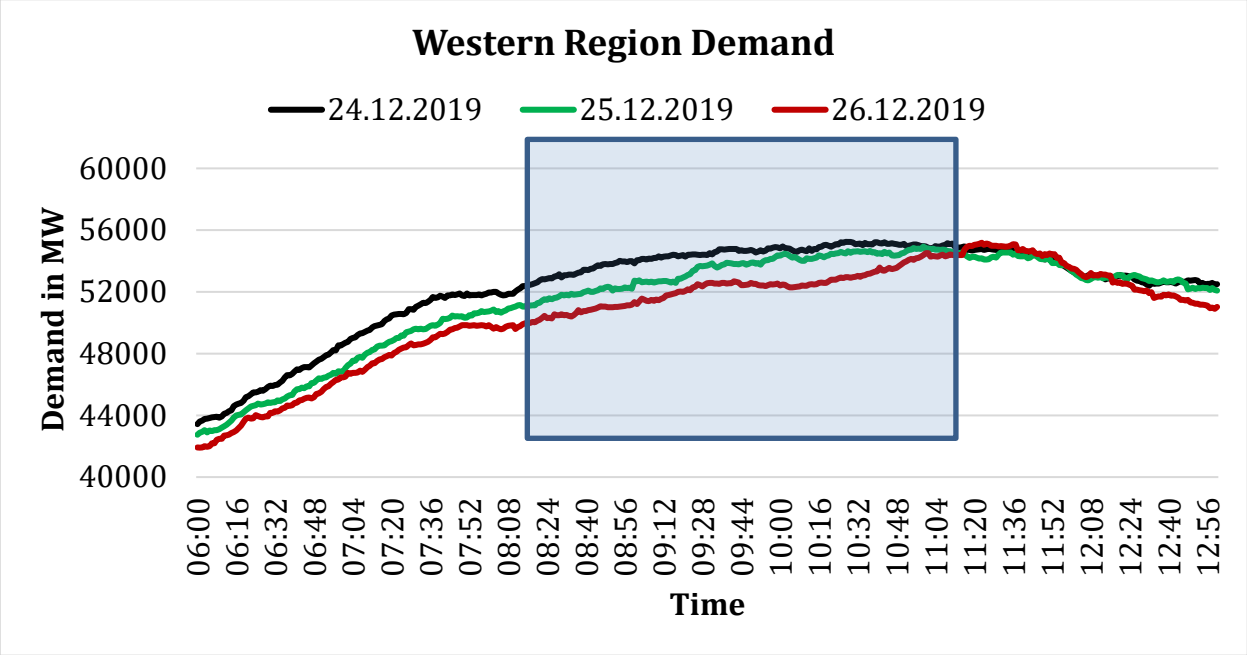


Figure 57: Western Region demand from 24.12.2019 to 26.12.2019

4.1.6 Western Region Area Control Error

Figure below shows area control error for Western Region. It can be observed that the deviation was of the tune of 400MW during period of maximum eclipse i.e. 09:15 to 09:30 hrs. Again after the end of the eclipse, when demand picked up the deviation was to the tune of 500 MW.

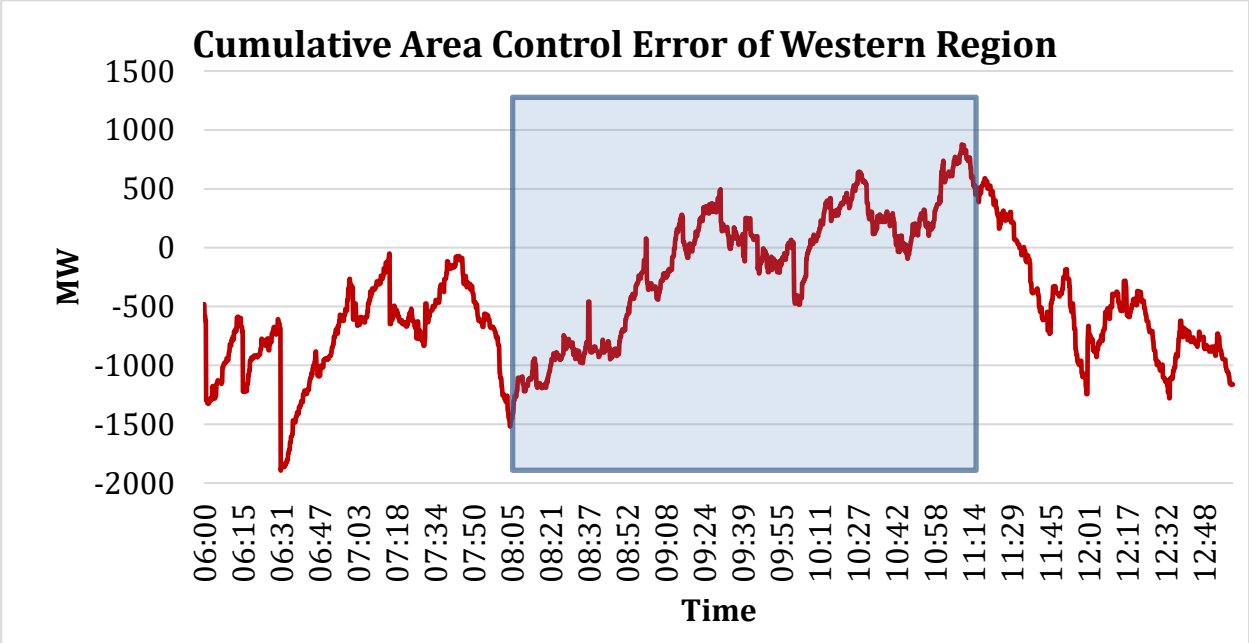


Figure 58: Cumulative Area Control Error of Western Region

4.1.7 Northern Region Demand

In Northern Region demand during solar eclipse was similar to normal day, however there was increase of around 800 MW after end of the eclipse. Northern states demand comparison for 25th December 2019 and 26th December 2019 attached as **Annexure-VIII.**

Northern Region demand from 24th December 2019 to 26th December 2019 is given below:

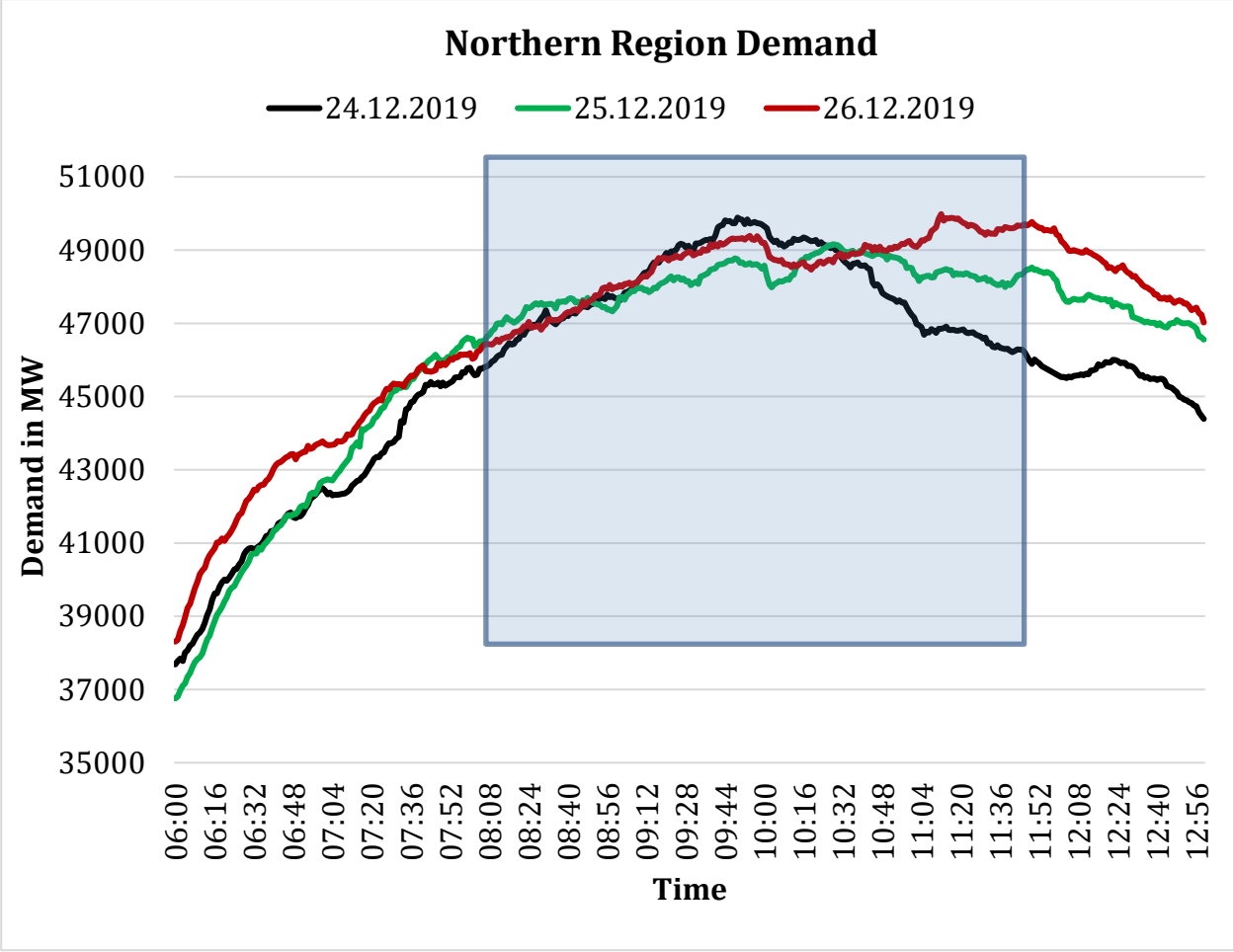


Figure 59: Northern Region Demand from 24.12.2019 to 26.12.20190

4.1.8 Northern Region Area Control Error

Figure below shows area control error for Northern Region. It can be observed that earlier to eclipse ACE was on negative side due to load curtailment carried out by Uttar Pradesh. The deviation was of the tune of 200 MW during period of maximum eclipse i.e. 09:15 to 09:30 hrs. Again after the end of the eclipse, when demand picked up the deviation was to the tune of 1500 MW.

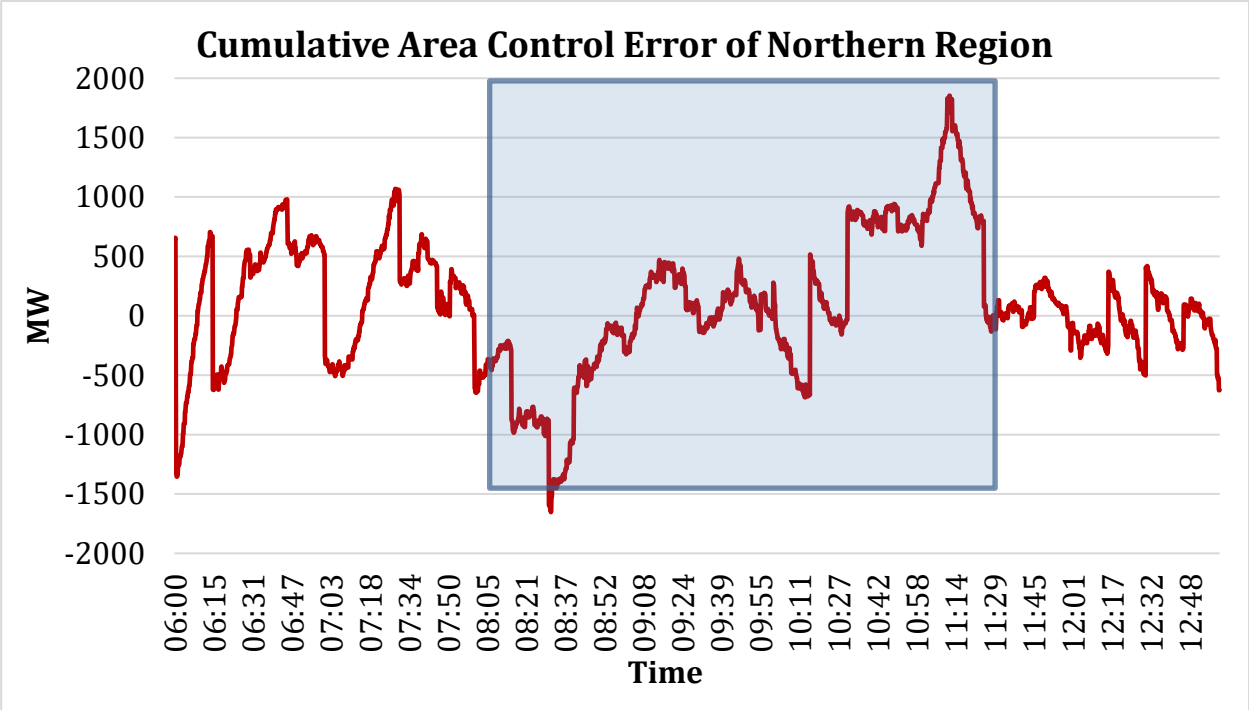


Figure 60: Cumulative Area Control Error of Northern Region

4.1.9 Eastern Region Demand

In Eastern Region, demand reduction during solar eclipse was to the tune of 1000 MW and 700-750 MW increase in demand after the end of eclipse. During solar eclipse and after end of the eclipse, the state of Bihar, Odisha and West Bengal demand was impacted due to different practices prevailing in Indian culture during astronomical events. After start of the eclipse average demand reduction with respect to normal day in Odisha, West Bengal & Bihar were 625 MW, 180MW and 200 MW respectively. However, after the end of the eclipse, the demand increased in all the three states. The maximum increase in demand of about 1000 MW was observed in Odisha followed by 490 MW in west Bengal and 250 MW in Bihar. The demand pattern of Bihar, Odisha and West Bengal state of Eastern Region are attached as **Annexure- IX.**

Eastern Region demand from 24th to 26th December 2019 is given below:

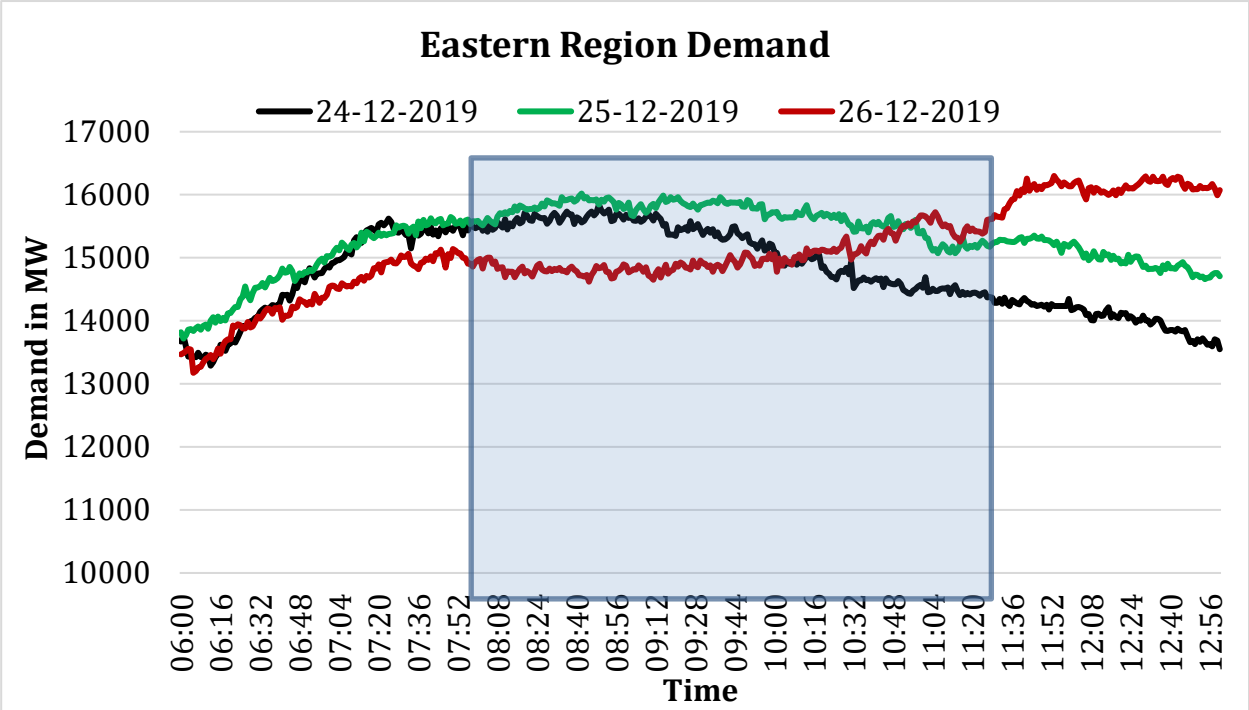


Figure 61: Eastern Region demand from 24.12.2019 to 26.12.2019

4.1.10 Eastern Region Area Control Error

Figure below shows area control error for Eastern Region. It can be observed that the deviation was of the tune of 200 MW during period of maximum eclipse i.e. 09:15 to 09:30 hrs. Again after the end of the eclipse, when demand picked up the deviation was to the tune of 400 MW.

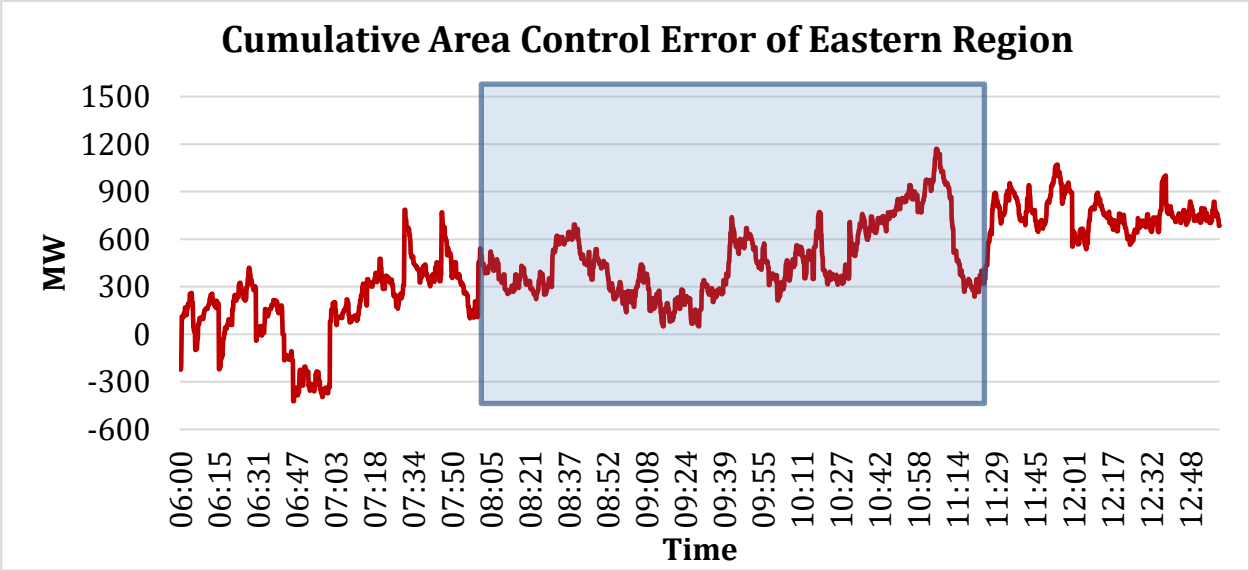


Figure 62: Cumulative Area Control Error of Eastern Region

All RE rich states Schedule vs Actual and Area Control Error graphs are enclosed as **Annexure X & XI.**

4.2 Wind generation during solar eclipse

Southern Region

It was observed that in Southern Region, correlation coefficient between wind and solar from 06:00 hrs to 13:00 hrs is -0.46.

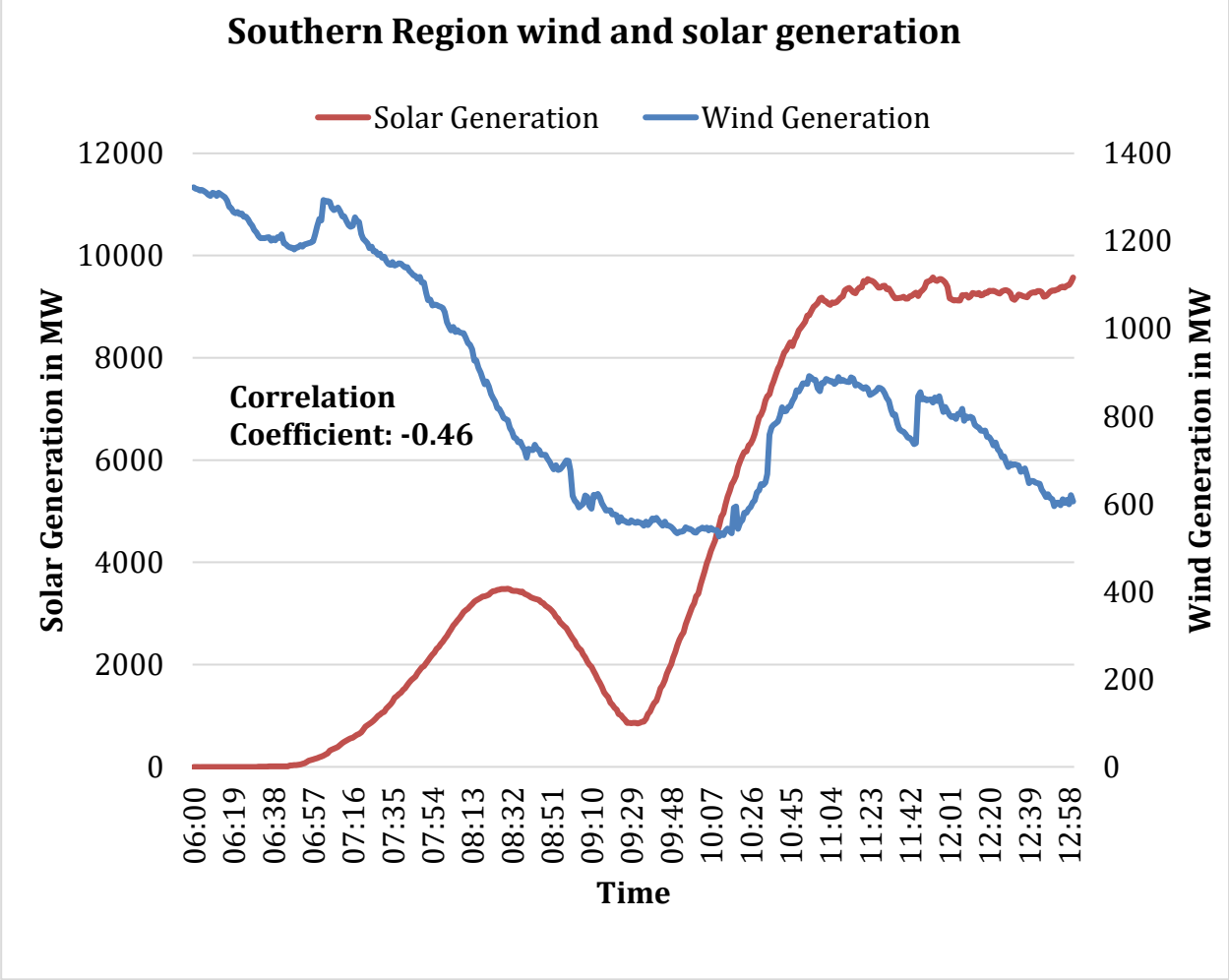


Figure 63: Southern Region wind and solar generation

Western Region

It was observed that wind generation in Western Region reduced when solar generation started increasing after impact of maximum solar eclipse. The correlation coefficient between wind and solar from 06:00 hrs to 13:00 hrs is -0.96. Solar generation increased after maximum solar eclipse time while wind generation started reducing in MP and Gujarat.

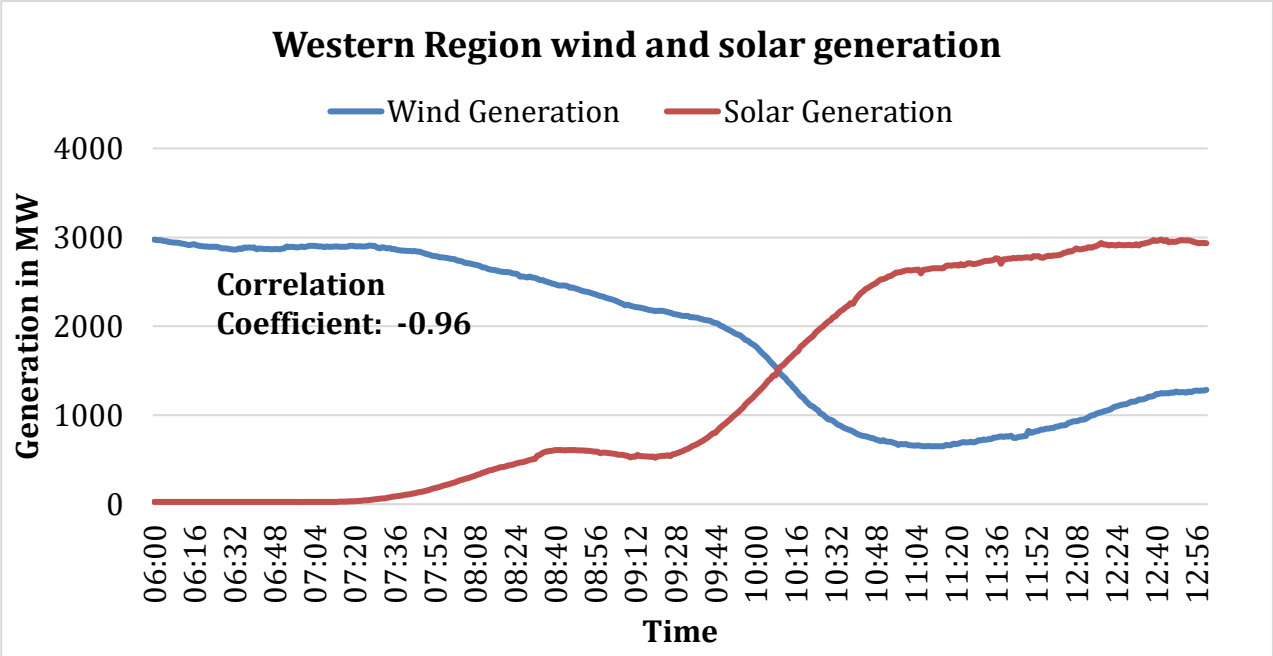


Figure 64:Western Region wind and solar generation

Northern Region

It was observed that wind generation in Northern Region reduced when solar generation started increasing after impact of maximum solar eclipse. The correlation coefficient between wind and solar from 06:00 hrs to 13:00 hrs is -0.95.

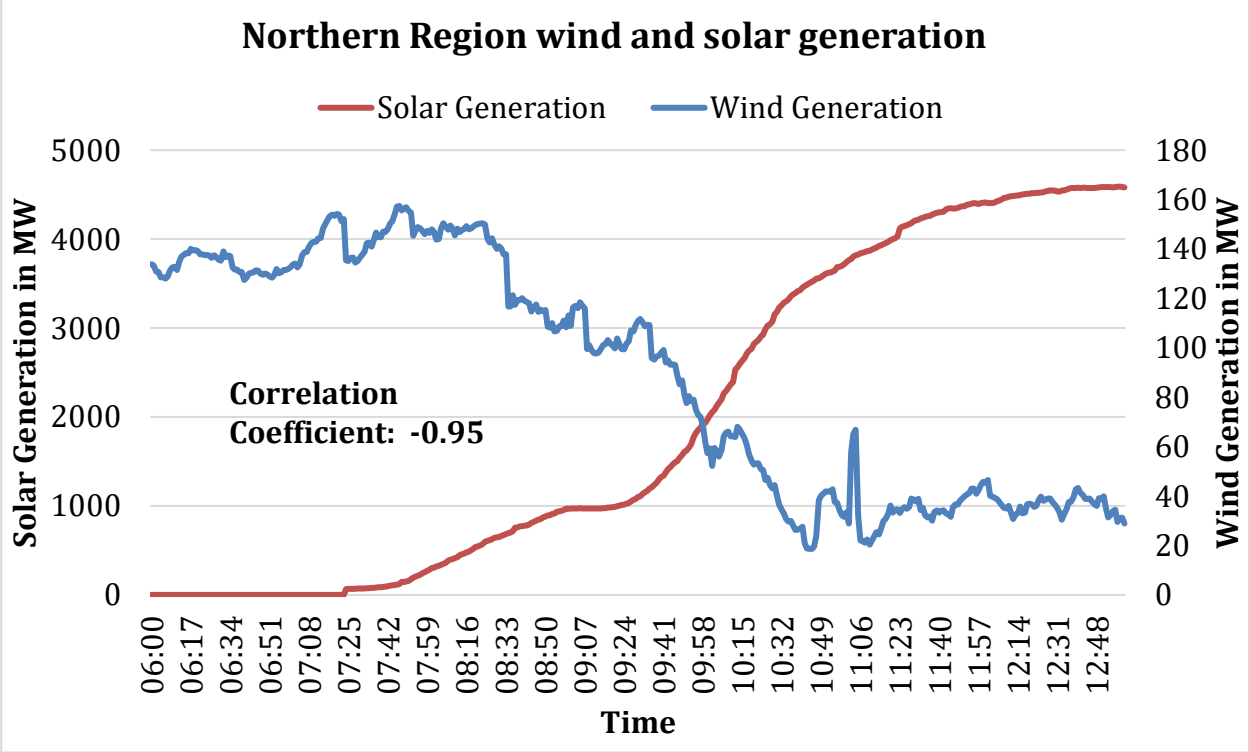


Figure 65:Northern Region wind and solar generation

Utility Scale Solar Power Plant Controller

The solar plants having Power Plant Controller (PPC) would be of great help for system operators to manage the ramp rate. At present, 250MW capacity of solar plants in Southern region and 1360MW capacity of solar plants in Northern Region have PPC installed.
Since major impacted area of eclipse was Southern Region, thus PPC would not have much impact for controlling ramp in this event. Hence this capacity was not utilised. However, in future for solar eclipse on 21st June 2020, PPC control installed on Northern Region plants may be useful during ramp variations.

4.3 Behaviour of PV plant during solar eclipse

During solar eclipse the amount of solar radiation reaching the earth's surface decreases but only in the areas affected by penumbra and umbra. Three types of PV plant were chosen for post event analysis based on their geographical location i.e. location falling either in annular eclipse or partial eclipse zone:

a) PV plant having obscuration more than 85 %
b) PV Plant having obscuration between 60-85 %
c) PV Plant having obscuration of less than 60 %

Data for GHI (Global horizontal irradiance) was obtained from 7 PV plants:

1. Azure Power, Bhadla (Rajasthan)
2. Renew Solar Power , Bhadla (Rajasthan)
3. SB Energy,Bhadla (Rajasthan)
4. Kamuthi (Tamil Nadu)
5. Pavagada(Karnataka)
6. NP Kunta(Andhra Pradesh)
7. Charnka (Gujarat)

For analysis purpose, obscuration of Bikaner time shifted by 3 minutes has been considered for all 3 PV plants located at Bhadla (Rajasthan), which observed partial eclipse. In case of PV plant at Kamuthi, which observed annular eclipse (93.2%), obscuration of nearest city Madurai has been considered. For Pavagada plant (86.27%), obscuration of nearest city

Bangalore, for NP Kunta plant (84.72%), obscuration of nearest city Kurnool and for Charnka plant (66.52%), obscuration of nearest city Ahmedabad has been considered.

The Correlation between Obscuration and GHI for different plants from 0 to 10 % ,10 % to 20 % and more than 30 % obscuration is tabulated below:

Name of the plant	Plant capacity (MW)	Location of the plant	Maximum obscuration (%)	Correlation Coefficient between GHI and % Obscuration		
				0 % to 10 %	10% to 20 %	30 % to End of solar eclipse
Kamuthi Solar Park	648	Kamuthi, Tamil Nadu	93.10	0.91	-0.91	-0.91
Pavagada Solar Park	2050	Pavagada, Karnataka	86.27	0.69	-0.97	-0.95
NP Kunta Solar Park	650	Anantpur, Andhra Pradesh	84.72	0.84	0.86	-0.97
Charnka Solar Park	590	Charnka, Gujarat	66.52	0.97	0.95	-0.94
Azure Power Thirty Four Pvt Ltd	130	Bhadla, Rajasthan	55.14	0.96	0.99	-0.97
Renew Solar Power Pvt Ltd.	50	Bhadla, Rajasthan	55.14	0.96	0.99	-0.97
SB Energy Four Power Pvt. Ltd.	200	Bhadla, Rajasthan	55.14	0.82	0.99	-0.96

The chart below shows variation of GHI with percent obscuration of Sun at different solar pants:

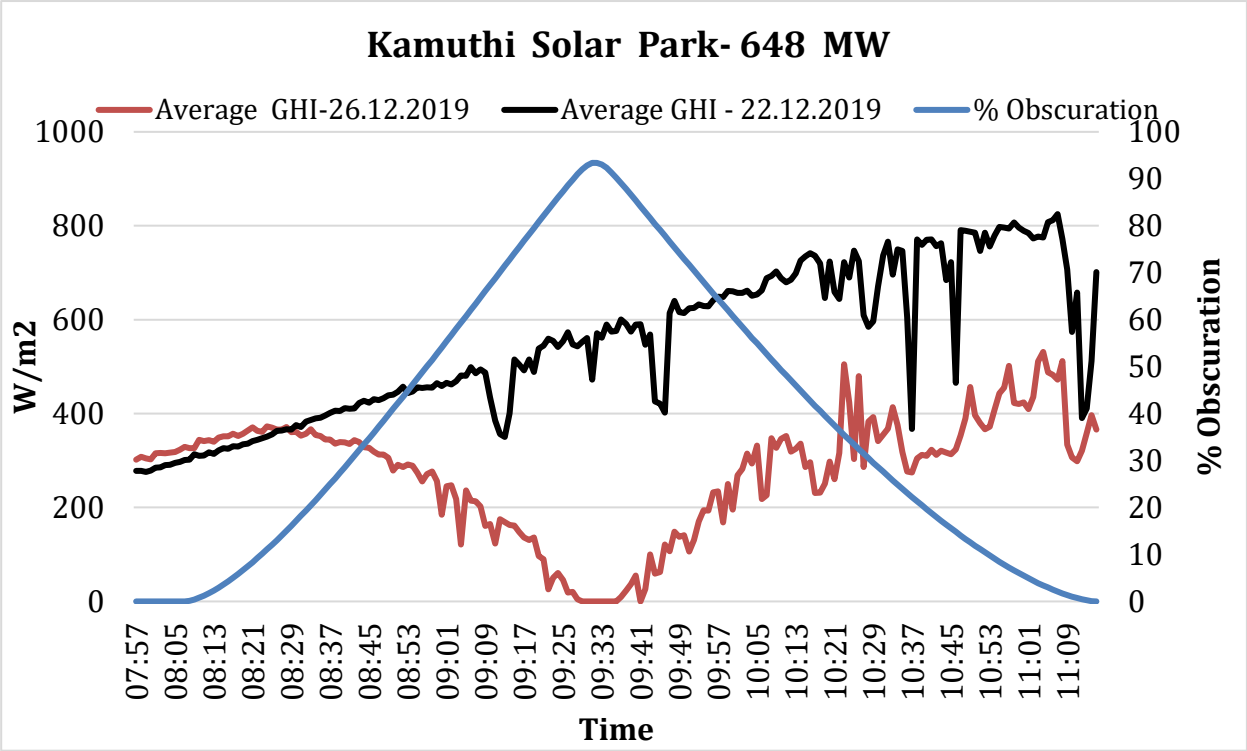


Figure 66: Kamuthi Solar Park GHI and % of Obscuration on 26.12.2019

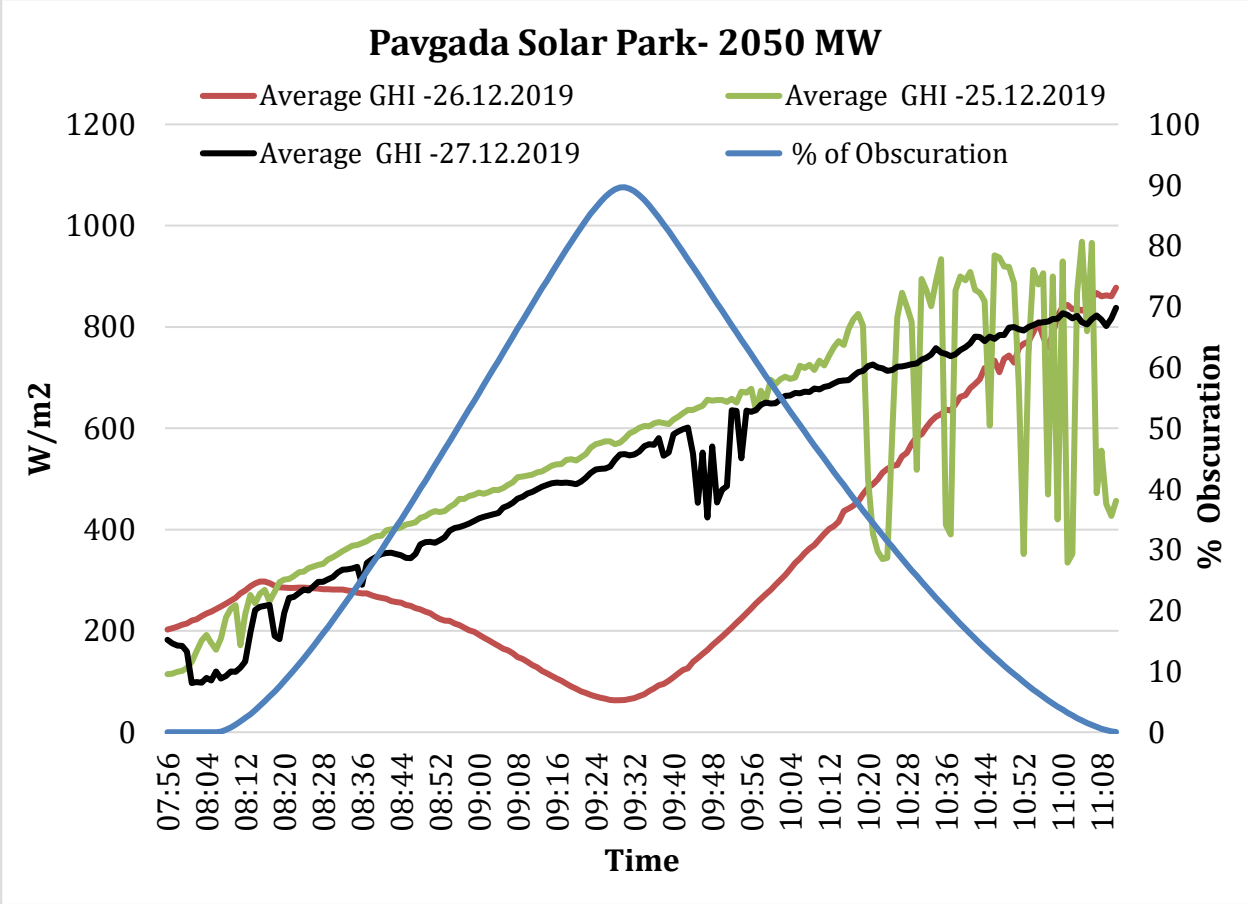


Figure 67: Pavgada Solar Park GHI and % of Obscuration on 26.12.2019

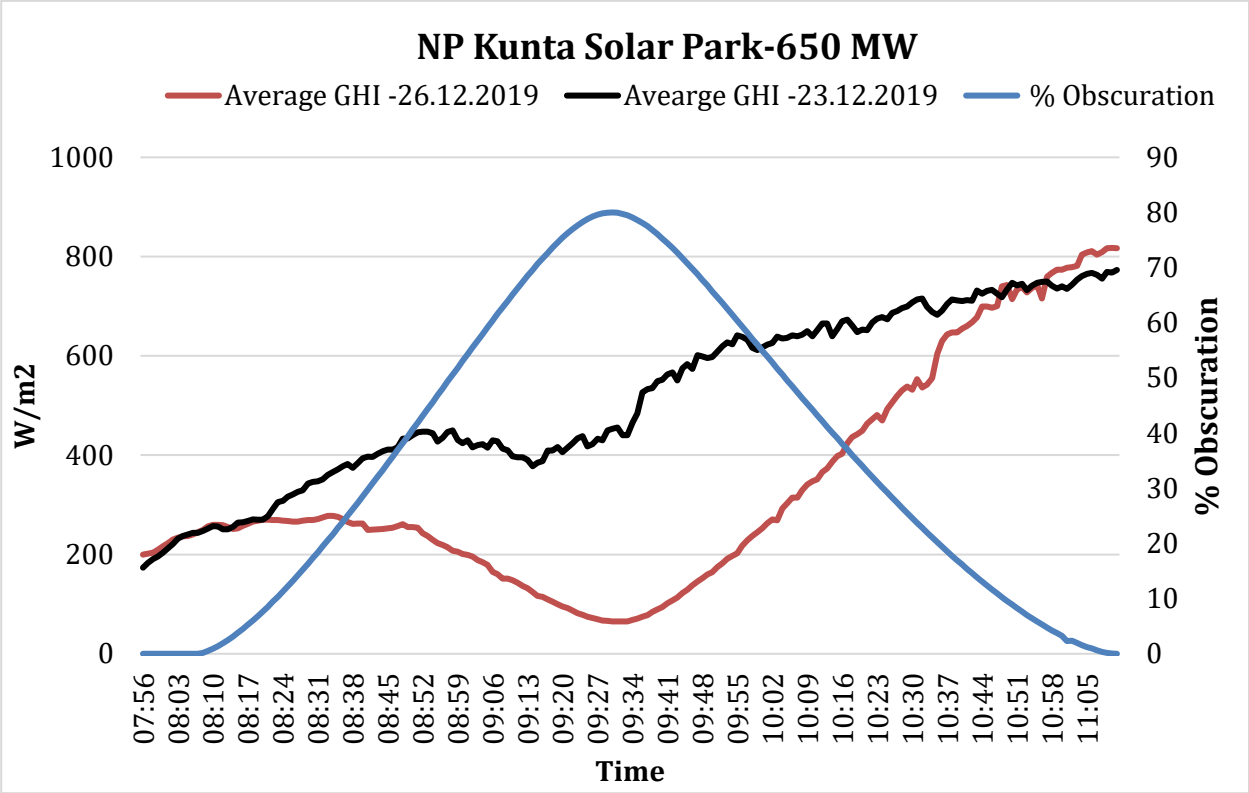


Figure 68: NP Kunta Solar Park GHI and % of Obscuration on 26.12.2019

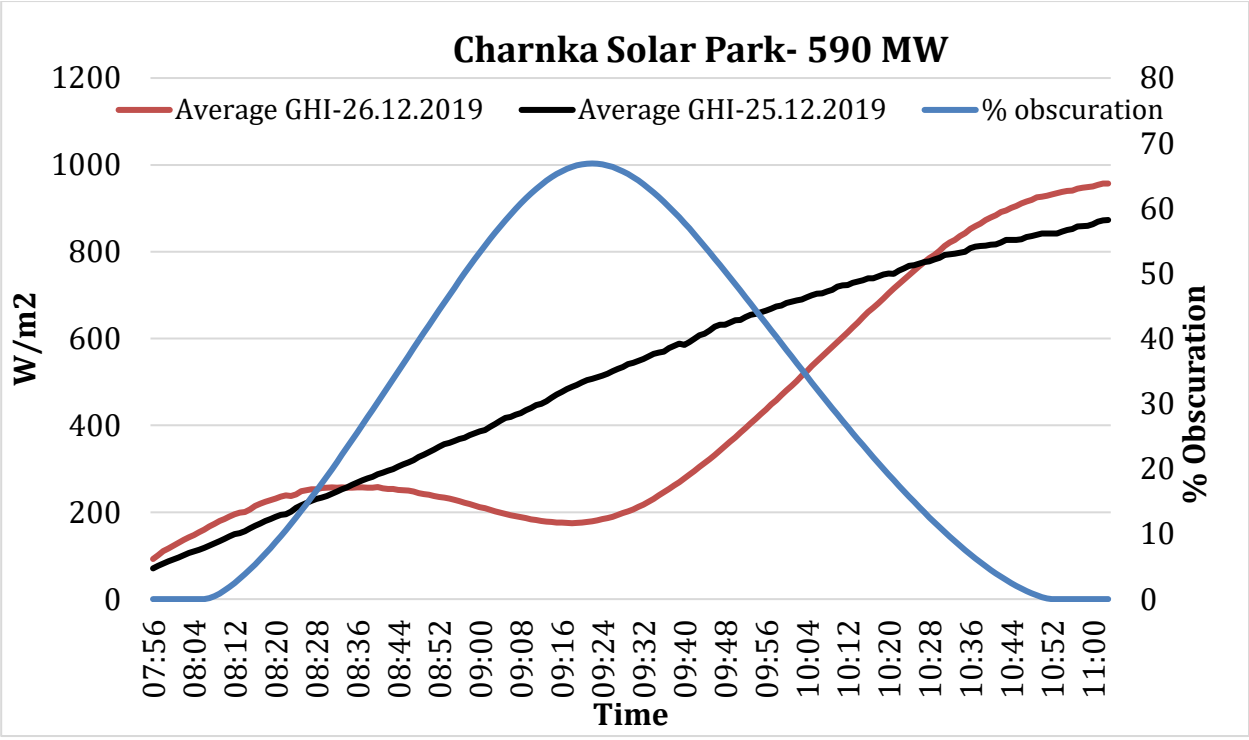


Figure 69: Charnka Solar Park GHI and % of Obscuration on 26.12.2019

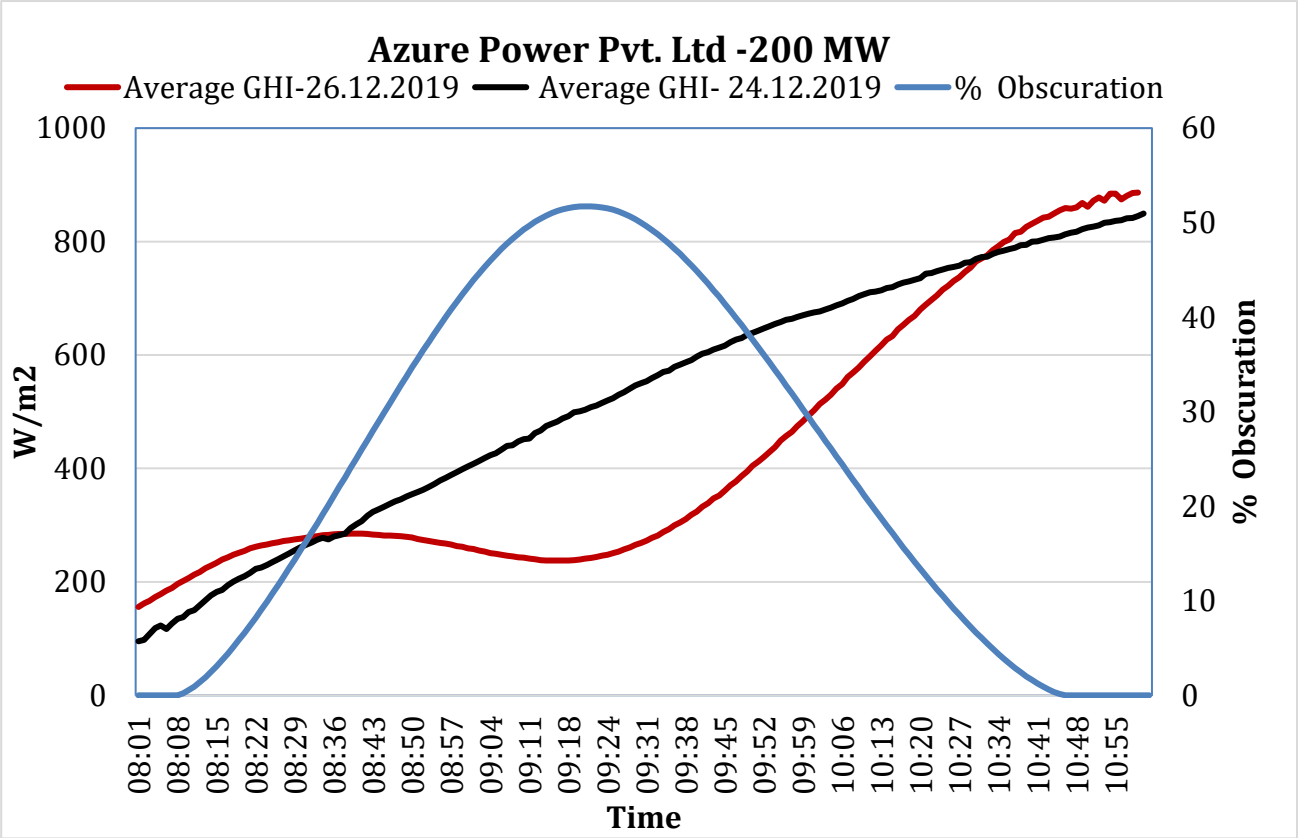


Figure 70: Azure Power Pvt Ltd. GHI and % of Obscuration on 26.12.2019

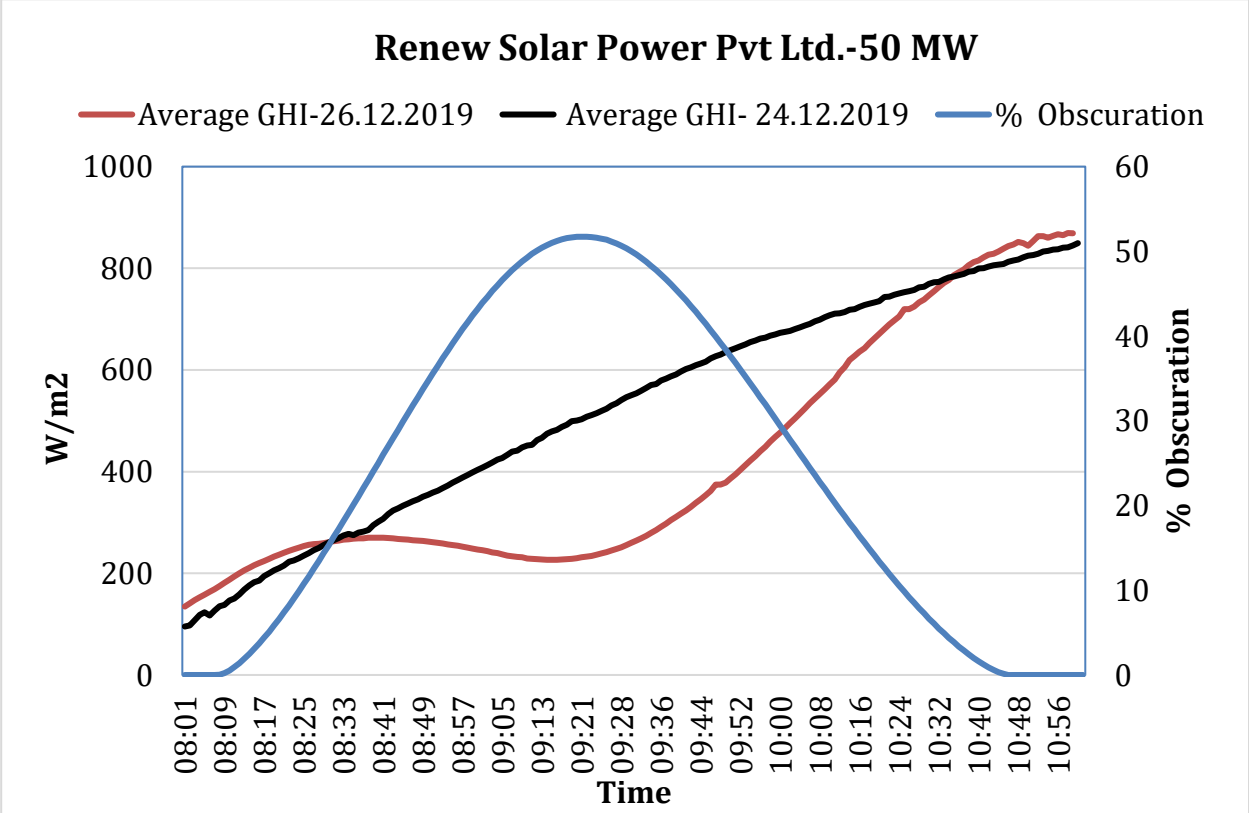


Figure 71: Renew Solar Power Pvt Ltd. GHI and % of Obscuration on 26.12.2019

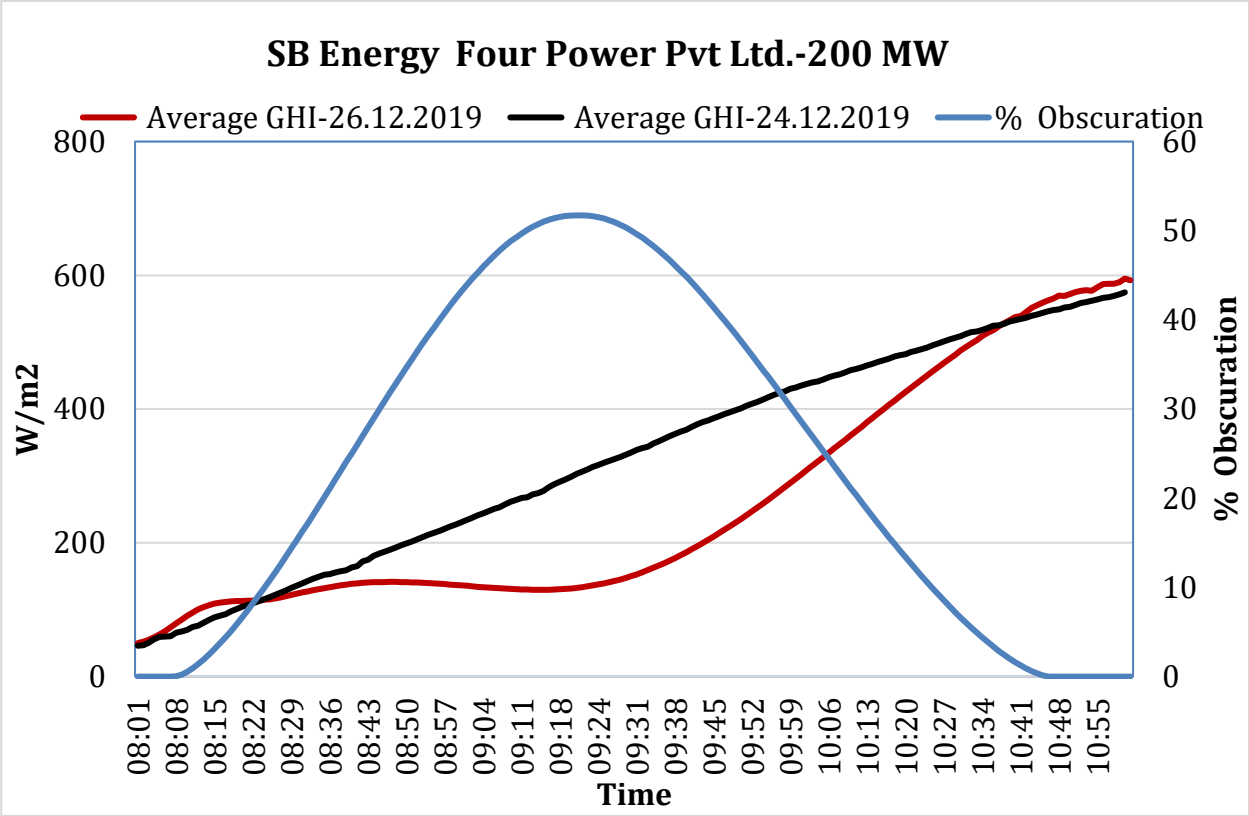


Figure 72: SB Energy Four Power Pvt Ltd. GHI and % of obscuration on 26.12.2019

It can be observed that the plants which experienced more than 85 % obscuration, located in Karnataka & Tamil Nadu i.e. Pavgada & Kamuthi GHI started reducing from 10% obscuration onwards. There was a negative correlation of 0.91 & 0.97 between obscuration and GHI when obscuration was more than 10%. The observed GHI became zero when obscuration reached 90%. Kamuthi solar park has reported that few inverters tripped when GHI became zero during the period of maximum obscuration.

However, in case of plants located in Rajasthan & Gujarat, which experienced less than 85 % obscuration, GHI started reducing from 20% obscuration onwards. A positive correlation is observed till obscuration reaches 20% at locations experiencing partial eclipse. However, after that negative correlation of 0.94 to 0.97 was observed at these locations.

Chapter - 5 : Key learnings

Planning related:

1. A more meticulous operational planning needs to be put in place to regulate generation both during demand reduction period occurring at start of the eclipse and period of increase in demand after eclipse gets over. The generation scheduling may be carried out for every 5 minutes.
2. It was observed that before starting and after the end of solar eclipse, the area control error (ACE) of the some of the states were too high due to inappropriate generation scheduling and load management. This lead to deviation of frequency beyond IEGC band for a small fraction of time. In a planned event, high schedule deviation by the state control area may be taken care of in future to avoid any untoward situation.
3. Support from Generators helped during high and low frequency duration and assisted in keeping the grid security intact.

Forecasting related:

4. The pattern of human behaviour in India is unique, since cultural factors get intertwined with astronomical events like solar eclipses and lunar eclipses. Majority of the people in India re-start and undertake a lot of activities as soon as solar eclipse gets over i.e. taking baths, opening of closed shops, opening of temples, preparation of fresh food which leads to spurt in demand. Therefore, more accurate demand estimation should be done during any such astronomical events.
5. The hypothesis that reduction in total solar irradiance level is directly proportional to magnitude of solar eclipse i.e. obscuration suitably fitted in solar generation reduction and increase during solar eclipse is verified. Forecasted ramps were almost in line with actual ramps observed during solar eclipse. However, the difference in estimated and actual ramp rate can be attributed to the methodology of considering the mean obscuration of each state for solar generation, which did not take into cognisance the factor of diversity in the geographical spacing of various generating units within the physical boundaries of each state. Therefore, if available obscuration at each plant location should be considered for estimation of solar generation or nearby plants may be grouped together to estimate the generation in future events.

Coordination related:

6. Load groups should not be taken in/out of service during eclipse period. Any change in load profile should be carried out in consultation with RLDC/NLDC.

Availability of real time telemetry and astronomical data:

7. Presently 4.9 GW of ground mounted solar generation is not telemetered. The data availability from these stations is of utmost important to ensure secure and reliable operation of the grid.
8. In forthcoming solar eclipse on 21st June 2020, India Meteorological Department may be requested to provide obscuration at Lat/Long of solar parks to estimate the irradiance more accurately.

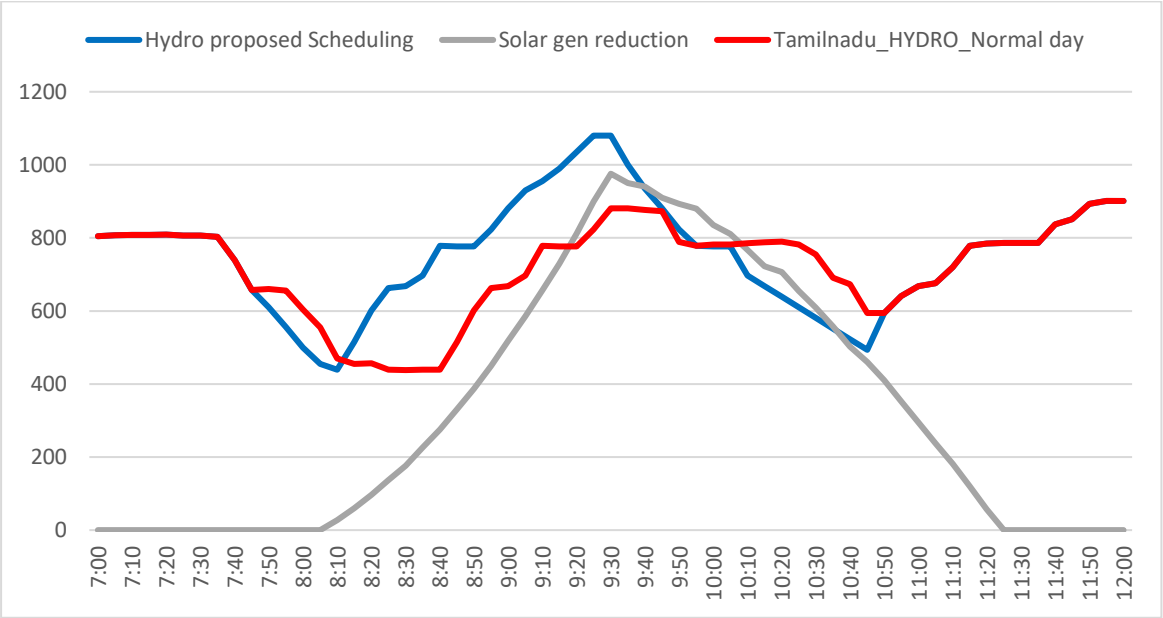
Behaviour of PV plants during solar eclipse:

9. It was observed that the plants which experienced more than 85 % obscuration, located in Karnataka & Tamil Nadu i.e. Pavgada & Kamuthi GHI started reducing from 10% obscuration onwards. The observed GHI became zero when obscuration reached 90%. However, in case of plants located in Rajasthan & Gujarat, which experienced less than 85 % obscuration, GHI started reducing from 20% obscuration onwards.

Southern Region Operation Planning:

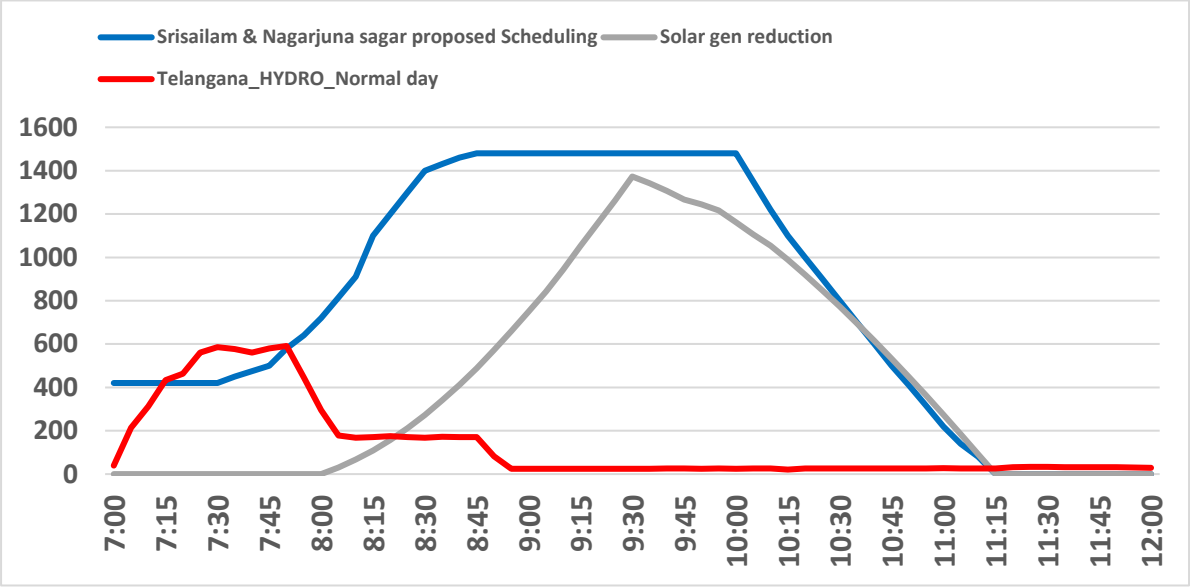
Tamil Nadu:

- As per the forecast, likely 950MW solar reduction is anticipated in Tamil Nadu.
- As per present daily trends, minimum and maximum hydro generation in Tamil Nadu is in the tune of 400MW and 1200MW respectively. It is prudent to utilize this 800MW reserves during eclipse period starting from 0800hrs to 1120hrs. Scheduling of kadamparai(400MW), Kundah(585MW), Pushep_Pykara Ultimate(209MW) etc., state owned hydro may be carried out to cater ramping during eclipse.



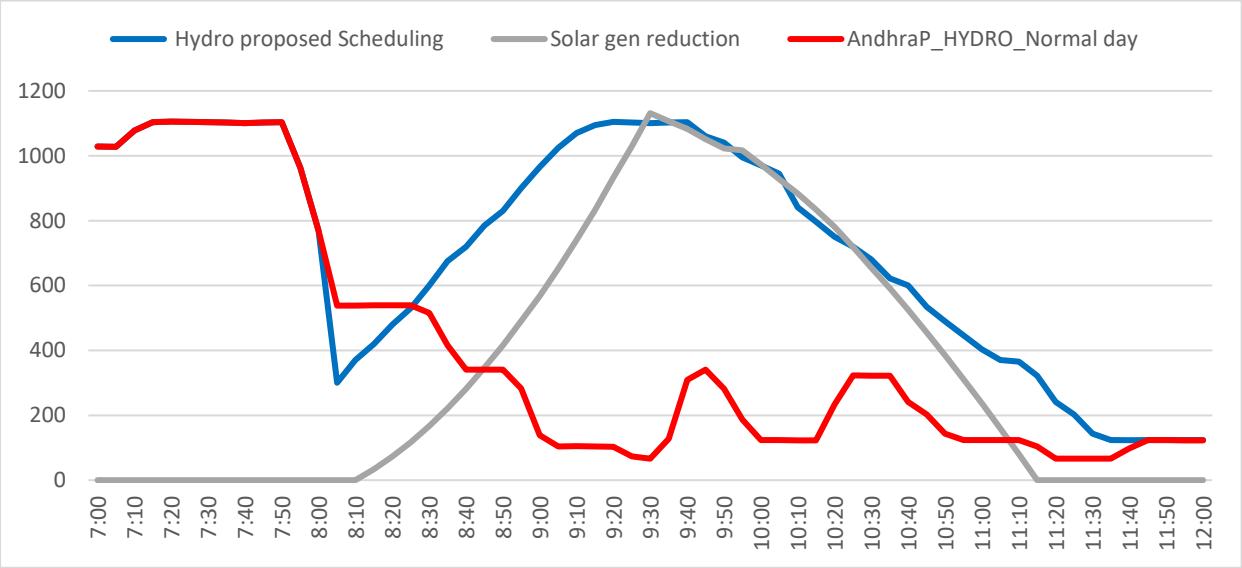
Telangana:

- As per the forecast, likely 1340MW solar reduction is anticipated in Telangana.
- As per the operational planning submitted by Telangana SLDC, they will schedule Srisailam LB and Nagarjunasagar to meet ramping requirement during eclipse.



Andhra Pradesh:

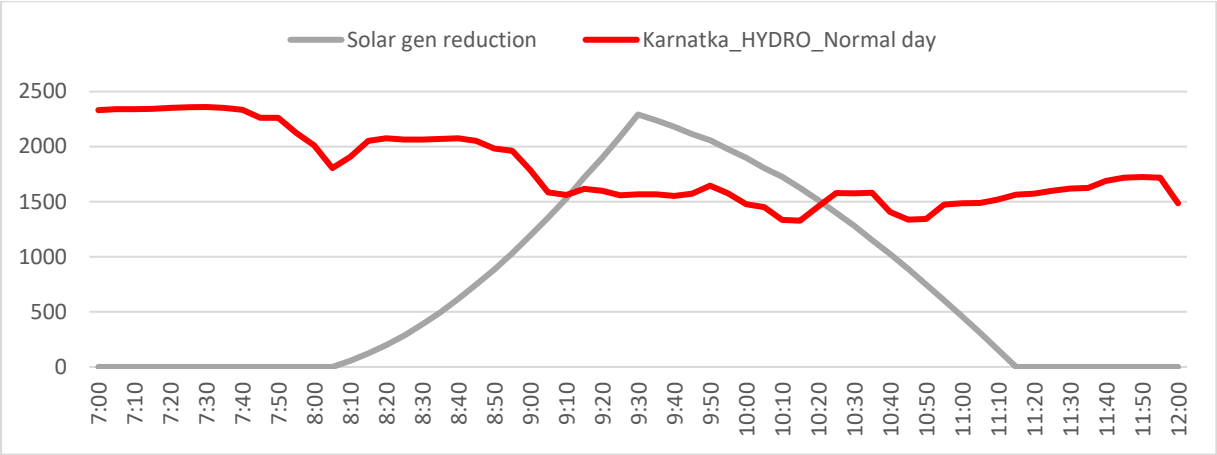
- As per the forecast, likely 1100MW solar reduction is anticipated in Andhra Pradesh.
- As per present daily trends, minimum and maximum hydro generation in Andhra pradesh is in the tune of 100MW and 1100MW respectively. 900MW reserves may be utilized during eclipse period starting from 0800hrs to 1120hrs. Therefore, it requested to carryout scheduling of Srisailam RB(770MW), Lower Sileru(460MW), upper Sileru(240MW)., state owned hydro may be carried out to cater ramping during eclipse.



Karnataka:

- As per the forecast, likely 2200MW solar reduction is anticipated in Karnataka.

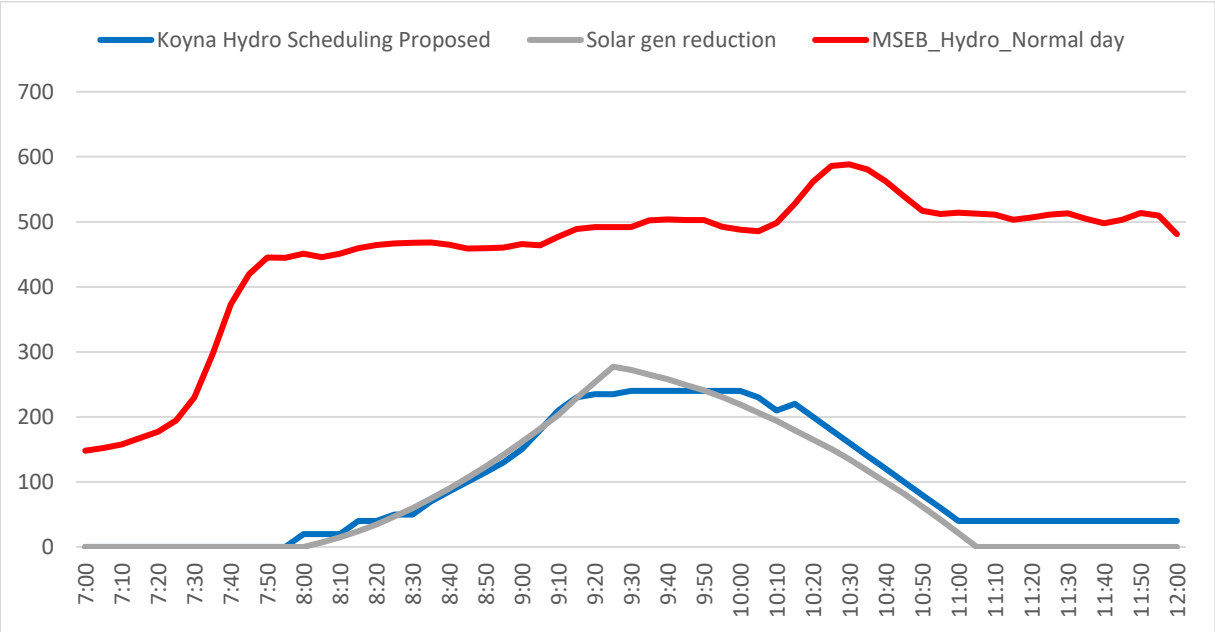
- Karnataka may be requested to requisitioned their share in all ISGS thermal power plant as well as bring state owned thermal units on bar to meet morning demand and ramp. Further, hydro generation may be kept for catering solar reduction during eclipse and may schedule in Nagjhari(900MW), Sharavathy(1035MW),Varahi(460MW) to meet ramp rate requirement in real time.



<u>Western Region Operation Planning:</u>

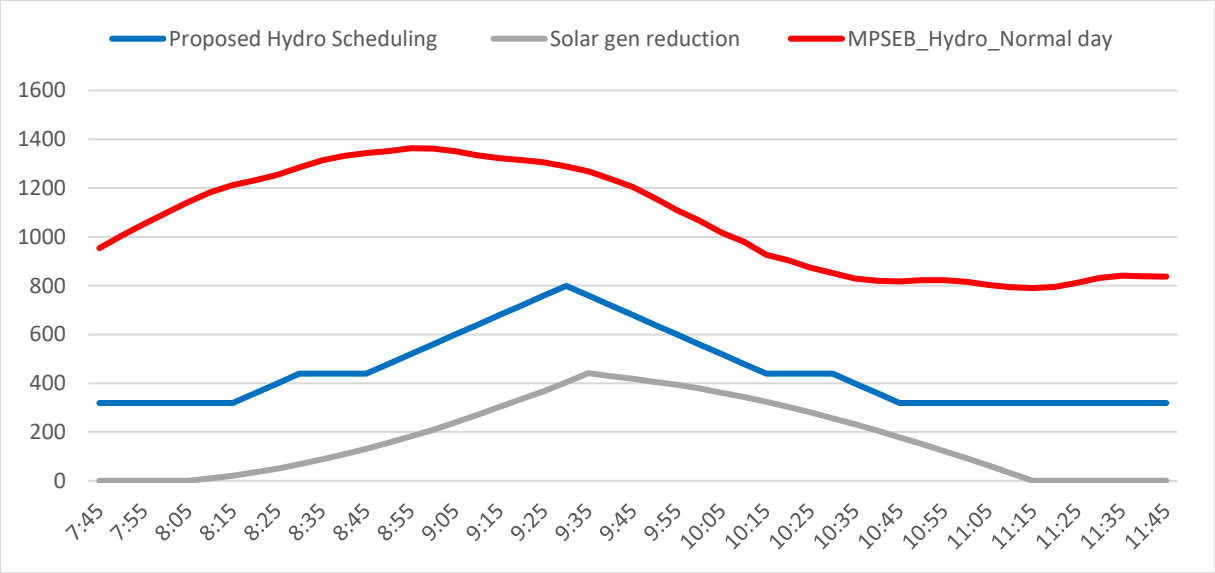
Maharashtra:

- As per the forecast, likely 280MW solar reduction is anticipated in Maharashtra.
- As per the operational planning submitted by MSEB SLDC, they will schedule 40 to 240MW Kyona Stg-I and II to meet ramping requirement during eclipse. Relevant graph is as given below:



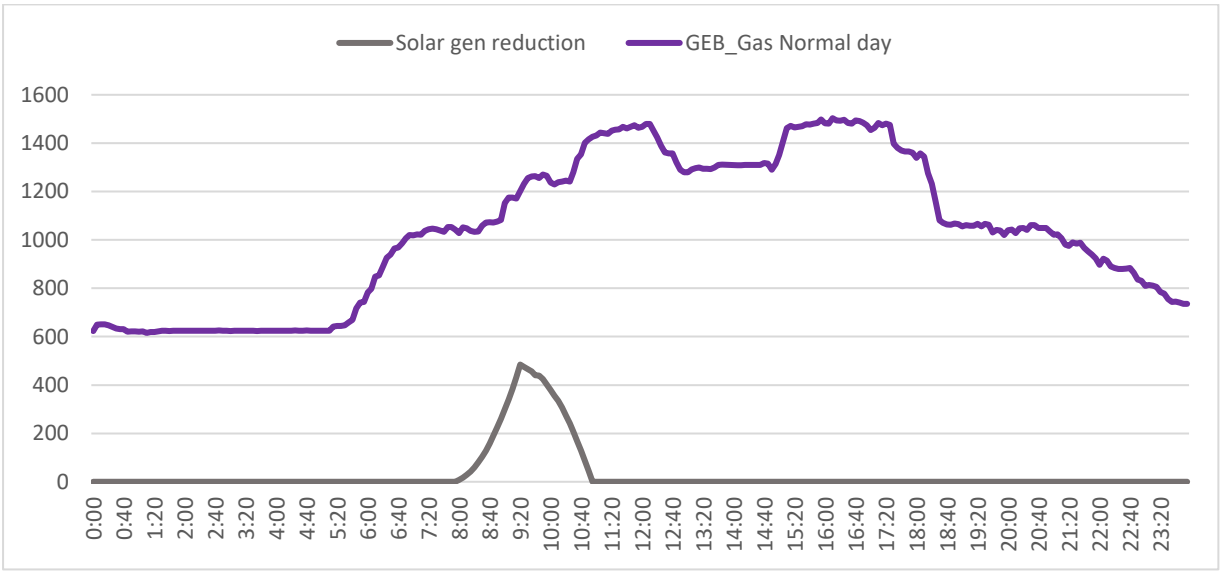
Madhya Pradesh:

- As per the forecast, likely 400MW solar reduction is anticipated in Madhya Pradesh.
- As per the daily hydro generation trends of MP, hydro Generation at Indrasager (1000MW) and Omkareshwar (520MW) may be varied to cater reduction solar generation.



Gujarat:

- As per the forecast, likely 500MW solar reduction is anticipated in Gujarat.
- Gujarat may be requested to manage their solar reduction by varying gas generation in DGBP, Sugen, GPEC, UNO Sugen. Typical day gas generation in Gujarat is as given below:



Northern Region Operational Planning

Rajasthan:

- As per the forecast, likely 650MW solar reduction is anticipated in Rajasthan.

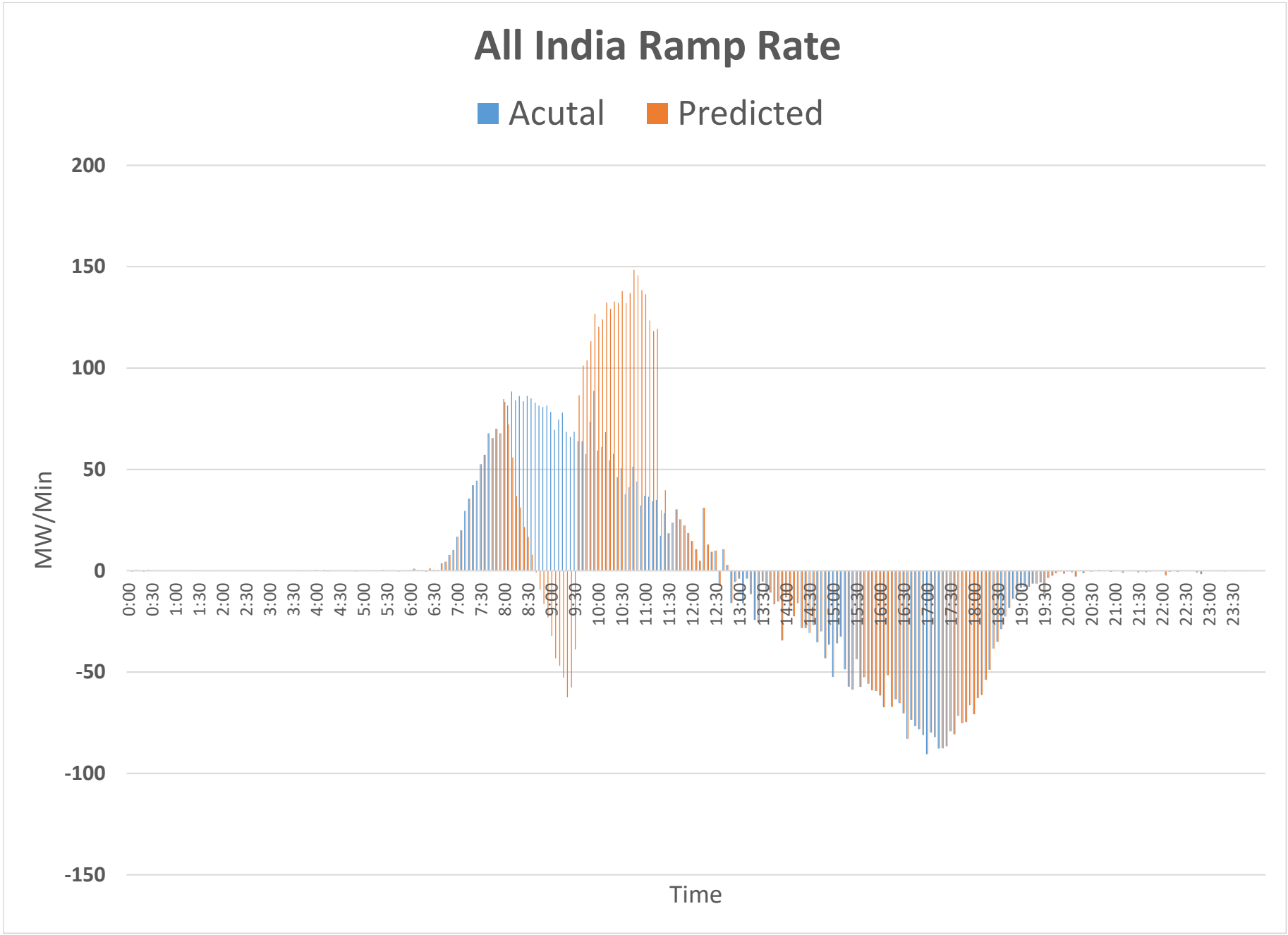
- Rajasthan has purchased additional power from IEX to mitigate the effect of reduced solar generation due to solar eclipse. Block wise purchase from power exchange is shown below: -

26.12.2019	
Block Time	Additional
07:30 - 07:45	14
07:45 - 08:00	79
08:00 - 08:15	100
08:15 - 08:30	200
08:30 - 08:45	300
08:45 - 09:00	400
09:00 - 09:15	500
09:15 - 09:30	600
09:30 - 09:45	500
09:45 - 10:00	500
10:00 - 10:15	400
10:15 - 10:30	300
10:30 - 10:45	200
10:45 - 11:00	154
11:00 - 11:15	100
11:15 - 11:30	43
11:30 - 11:45	50
11:45 - 12:00	50

NRLDC and WRLDC:

- Regional centers are also requested to schedule central sector ISGS hydro plants (SSP, Tehri, Pong, Chamera, and Bhakra) as per the solar eclipse timings i.e from 0800hrs to

  1120hrs to meet the required ramp rate during eclipse.
- All India forecasted ramp during eclipse is attached as Annexe-A
- As per latest IMD forecast, isolated and scattered rains are forecasted in various parts
- Tamil Nadu, Karnataka and Telangana (attached as Annexe-B).
- Five minutes' time blockwise hydro generation and anticipated solar reduction is attached as Annexe-C


All India Ramp Rate
Acutal
Predicted
200
150
100
50
0
-50
-100
-150
MW/Min
0:00
0:30
1:00
1:30
2:00
2:30
3:00
3:30
4:00
4:30
5:00
5:30
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00
17:30
18:00
18:30
19:00
19:30
20:00
20:30
21:00
21:30
22:00
22:30
23:00
23:30
Time

CHENNAI REGIONAL FORECAST ISSUED AT 1300 HOURS IST (MID DAY) ON 24.12.2019

Met Sub. Division	Rainfall Forecast / Warning for next 5 days										Weather outlook (for subsequent 2 days) valid from 0830 hrs IST of 29.12.2019 to 0830 hrs IST of 31.12.2019
	Day 1 valid from 1300 hrs IST of 24.12.2019 upto 0830 hrs IST of 25.12.2019		Day 2 valid from 0830 hrs IST of 25.12.2019 upto 0830 hrs IST of 26.12.2019		Day 3 valid from 0830 hrs IST of 26.12.2019 upto 0830 hrs IST of 27.12.2019		Day 4 valid from 0830 hrs IST of 27.12.2019 upto 0830 hrs IST of 28.12.2019		Day 5 valid from 0830 hrs IST of 28.12.2019 upto 0830 hrs IST of 29.12.2019		
	Forecast	Warning	Forecast	Warning	Forecast	Warning	Forecast	Warning	Forecast	Warning	
Tamil Nadu & Puducherry	SCT	Heavy rain is likely to occur at isolated places	SCT	NIL	ISOL	NIL	ISOL	NIL	ISOL	NIL	No significant change
Kerala	ISOL	NIL	SCT	NIL	SCT	NIL	ISOL	NIL	ISOL	NIL	No significant change
Lakshadweep	SCT	NIL	SCT	NIL	SCT	NIL	ISOL	NIL	ISOL	NIL	No significant change
Coastal Karnataka	ISOL	NIL	SCT	NIL	SCT	NIL	ISOL	NIL	ISOL	NIL	No significant change
North interior Karnataka	DRY	NIL	ISOL	NIL	ISOL	NIL	ISOL	NIL	DRY	NIL	No significant change
South interior Karnataka	ISOL	NIL	SCT	NIL	SCT	NIL	ISOL	NIL	ISOL	NIL	No significant change
Coastal Andhra Pradesh	ISOL	NIL	DRY	NIL	DRY	NIL	ISOL	NIL	ISOL	NIL	No significant change
Rayalaseema	ISOL	NIL	DRY	NIL	DRY	NIL	DRY	NIL	DRY	NIL	No significant change
Telangana	DRY	NIL	DRY	NIL	ISOL	NIL	DRY	NIL	ISOL	NIL	No significant change

Spatial rainfall distribution

% Stations reporting Rainfall	Category	% Stations reporting Rainfall	Category
76-100	Widespread (WS/ most places)	26-50	Scattered (SCT/isolated places)
51-75	Fairly Widespread (FWS/ many places)	1 -25	Isolated (ISOL)
No Rain	Dry		

Rainfall intensity

Heavy rain	64.5 – 115.5 mm (7 – 11 cm)
Very heavy rain	115.6- 204.4 mm (12 - 20 cm)
Extremely heavy rain	>204.4 mm (21 cm or more)

भारतसरकार
भारतीयमौसमविज्ञानविभाग
प्रादेशिकमौसमविज्ञानकेन्द्र
नयानं: 6, कालेजरोड, चेन्नै – 600006
दूरभाष : 044- 28271951

GOVERNMENT OF INDIA
INDIA METEOROLOGICAL DEPARTMENT
Regional Meteorological Centre
New No. 6, College Road, Chennai–600006
Phone: 044- 28271951

COLOR CODED WEATHER WARNINGS

Based on interaction and inputs from stake holders and government departments like NDMA involved in the management of weather related disastrous events, IMD issues weather warnings using color codes. These warnings are mainly meant for administrators to keep ready and position their resources to handle situations arising out of weather related disastrous events. The following colour codes are used by IMD to provide inputs to disaster management authorities for management of severe weather events:

No warning
Be updated
Be prepared
Take action

In the National level weather warnings in map form, red color over a state *does not mean the entire state is under threat* (unless otherwise explicitly mentioned). Rather, finer details related to the colored warnings will be available at website *www.imdchennai.gov.in*. Hence there is no need for unwarranted panic on noticing red color shading over the entire State in the state / subdivisional level warning map issued at the national level.

****

Legend:

North Tamil Nadu (NTN) districts	Chennai, Kancheepuram, Tiruvallur, Cuddalore, Villupuram, Thanjavur, Tiruvarur, Nagapattinam, Pudukottai, Vellore, Tiruvannamalai, Krishnagiri, Dharmapuri, Salem, Namakkal, Nilgiris, Tiruppur, Coimbatore, Erode, Karur, Tiruchirapalli, Ariyalur, Perambalur.
South Tamil Nadu (STN) districts	Ramanathapuram, Tirunelveli, Thoothukudi, Kanyakumari, Sivagangai, Virudhunagar, Theni, Dindigul, Madurai.
Interior Tamil Nadu (ITN) districts	Vellore, Tiruvannamalai, Krishnagiri, Dharmapuri, Salem, Namakkal, Nilgiris, Tiruppur, Coimbatore, Erode, Karur, Tiruchirapalli, Ariyalur, Perambalur Sivagangai, Virudhunagar, Theni, Dindigul, Madurai.
North interior Tamil Nadu (NITN) districts	Vellore, Tiruvannamalai, Krishnagiri, Dharmapuri, Salem, Namakkal, Nilgiris, Tiruppur, Coimbatore, Erode, Karur, Tiruchirapalli, Ariyalur, Perambalur.
South interior Tamil Nadu (SITN) districts	Sivagangai, Virudhunagar, Theni, Dindigul, Madurai.
Coastal Tamil Nadu (CTN) districts	Chennai, Kancheepuram, Tiruvallur, Cuddalore, Villupuram, Thanjavur, Tiruvarur, Nagapattinam, Pudukottai, Ramanathapuram, Tirunelveli, Thoothukudi, Kanyakumari.
North Coastal Tamil Nadu (NCTN) districts	Chennai, Kancheepuram, Tiruvallur, Cuddalore, Villupuram, Thanjavur, Tiruvarur, Nagapattinam, Pudukottai.
South Coastal Tamil Nadu (SCTN) districts	Ramanathapuram, Tirunelveli, Thoothukudi, Kanyakumari.
Delta districts	Thanjavur, Tiruvarur, Nagapattinam.
PDC	Puducherry.

	Andhra		Tamilnadu		Telangana		Maharashtra		Madhya Pradesh	
Time	**Proposed Hydro Scheduling**	Solar gen reduction	**Proposed Hydro Scheduling**	Solar gen reduction	**Proposed Hydro Scheduling**	Solar gen reduction	**Proposed Hydro Scheduling**	Solar gen reduction	Proposed Hydro Scheduling	Solar gen reduction
7:00	1028	0	805	0	420	0	0	0		0
7:05	1028	0	807	0	420	0	0	0		0
7:10	1078	0	808	0	420	0	0	0		0
7:15	1104	0	808	0	420	0	0	0		0
7:20	1105	0	809	0	420	0	0	0		0
7:25	1105	0	807	0	420	0	0	0		0
7:30	1103	0	806	0	420	0	0	0		0
7:35	1102	0	803	0	450	0	0	0		0
7:40	1101	0	739	0	475	0	0	0		0
7:45	1102	0	657	0	500	0	0	0	319	0
7:50	1104	0	610	0	580	0	0	0	319	0
7:55	963	0	556	0	640	0	0	0	319	0
8:00	769	0	500	0	720	0	20	0	319	0
8:05	300	0	455	0	815	30	20	7	319	0
8:10	370	0	439	28	910	67	20	15	319	10
8:15	420	34	515	60	1100	108	40	24	319	21
8:20	480	73	601	97	1200	158	40	35	359	35
8:25	530	117	662	137	1300	212	50	47	399	50
8:30	600	167	668	176	1400	273	50	60	439	68
8:35	675	222	697	226	1430	340	70	74	439	87
8:40	720	281	778	276	1460	411	85	90	439	108
8:45	785	346	776	330	1480	488	100	106	439	130
8:50	830	416	777	387	1480	572	115	124	479	156
8:55	900	490	823	450	1480	660	130	142	519	182
9:00	965	568	881	518	1480	749	150	161	559	208
9:05	1025	652	930	586	1480	842	180	182	599	238
9:10	1070	740	955	656	1480	943	210	203	639	270
9:15	1095	833	990	729	1480	1052	230	229	679	303
9:20	1105	932	1035	812	1480	1157	235	253	719	336
9:25	1102	1029	1080	899	1480	1262	235	277	759	368
9:30	1101	1131	1080	976	1480	1373	240	272	799	404
9:35	1102	1107	1000	950	1480	1342	240	265	759	442
9:40	1104	1083	935	941	1480	1306	240	258	719	430
9:45	1060	1051	881	910	1480	1267	240	249	679	418
9:50	1040	1023	823	893	1480	1244	240	241	639	405
9:55	995	1017	778	880	1480	1217	240	231	599	394
10:00	970	973	777	835	1480	1162	240	219	559	379
10:05	945	927	776	810	1350	1106	230	206	519	361
10:10	841	883	697	767	1220	1055	210	194	479	343
10:15	797	834	668	722	1100	989	220	179	439	324
10:20	750	780	639	707	1000	920	200	165	439	303
10:25	720	718	610	654	900	848	180	151	439	281
10:30	680	655	581	609	800	773	160	135	439	256
10:35	622	591	552	558	700	695	140	117	399	232
10:40	600	525	523	503	600	615	120	100	359	205
10:45	534	455	494	460	500	533	100	82	319	178
10:50	490	385	594	410	410	449	80	62	319	151
10:55	446	312	640	352	315	363	60	42	319	122
11:00	403	236	668	295	220	274	40	21	319	92
11:05	370	159	676	238	140	184	40	0	319	63
11:10	365	80	719	182	80	93	40	0	319	31
11:15	322	0	778	120	0	0	40	0	319	0
11:20	241	0	784	57	0	0	40	0	319	0
11:25	203	0	786	0	0	0	40	0	319	0
11:30	143	0	786	0	0	0	40	0	319	0
11:35	123	0	787	0	0	0	40	0	319	0
11:40	123	0	837	0	0	0	40	0	319	0
11:45	123	0	851	0	0	0	40	0	319	0
11:50	124	0	893	0	0	0	40	0		0

Annexure- II

Solar Generation Installed and Telemetered Capacity as on 30th November 2019

Region	State	Ground Mounted (MW)	Ground Mounted Telemetered (MW)	Roof Top (MW)	Telemetered Roof Top (MW)
Southern Region	Andhra Pradesh	3231	2970	88	0
	Karnataka	6941	5851	233	0
	Kerala	100	87	41	0
	Tamil Nadu	2945	648	156	0
	Telangana	3530	3475	90	0
	Pondicherry	0	0	5	0
	Total	**16747**	**13030**	**614**	**0**
Western Region	Chhatisgarh	216	166	16	0
	Goa	1	0	4	0
	Gujarat	2291	2123	413	0
	Madhya Pradesh	2188	2179	49	0
	Maharashtra	1447	1447	215	0
	Dadar & Nagar	2	0	3	0
	Daman & Diu	10	0	6	0
	Total	**6156**	**5915**	**705**	**0**
Northern Region	Haryana	131	0	118	0
	Himachal	17	0	15	0
	Jammu &	8	0	11	0
	Punjab	829	829	119	0
	Rajasthan	4536	4536	207	0
	Uttar Pradesh	899	899	146	0
	Uttarakhand	239.78	100	75.61	0
	Chandigarh	6	0	31	0
	Delhi	9	0	139	0
	Total	**6675**	**6364**	**860**	**0**
Eastern Region	Bihar	139		10	
	Jharkhand	19	0	19	0
	Odisha	384	0	14	0
	Sikkim	0	0	0	0
	West Bengal	66	0	43	0
	Total	**608**	**0**	**86**	**0**
North Eastern Region	Arunachal	1	0	4	0
	Assam	11	0	31	0
	Manipur	0	0	4	0
	Meghalaya	0	0	0	0
	Mizoram	0	0	1	0
	Nagaland	0	0	1	0
	Tripura	5	0	4	0
	Total	**17**	**0**	**46**	**0**
All India	**Total**	**30203**	**25309**	**2311**	**0**

Annexure- III

Western Region state-wise solar generation and ramp rate forecast comparison with actual

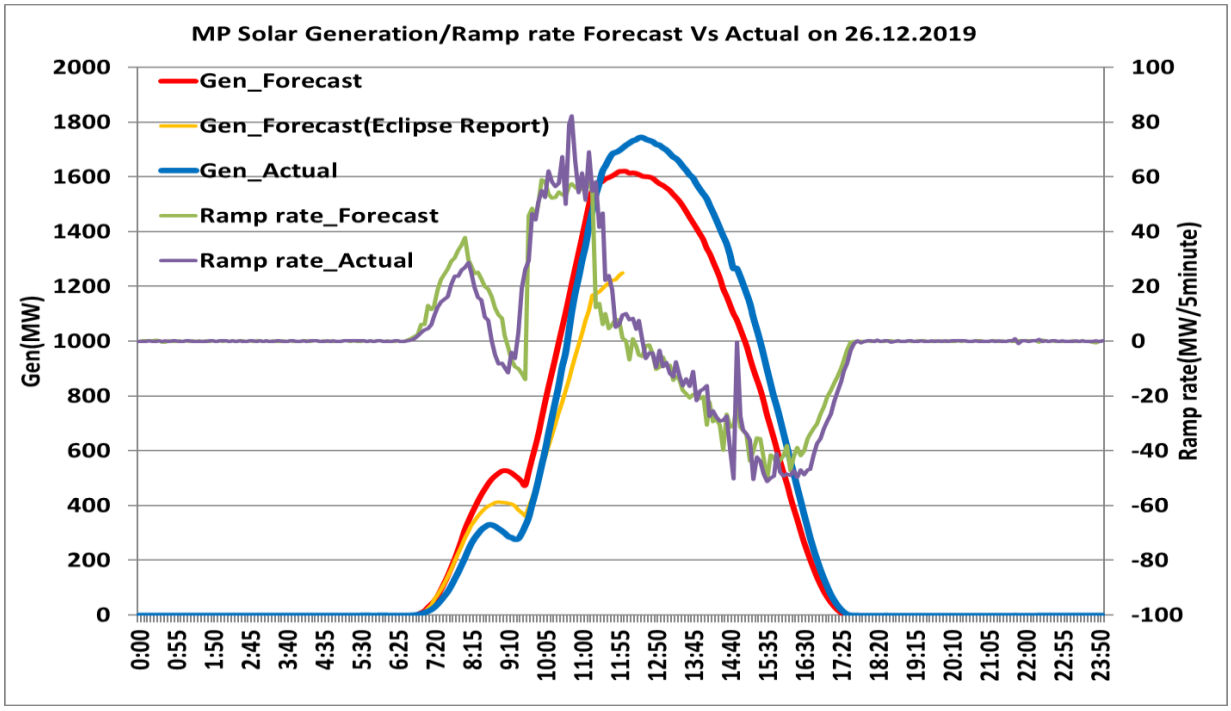


Figure 73: Madhya Pradesh generation/ramp rate forecast vs actual on 26.12.2019

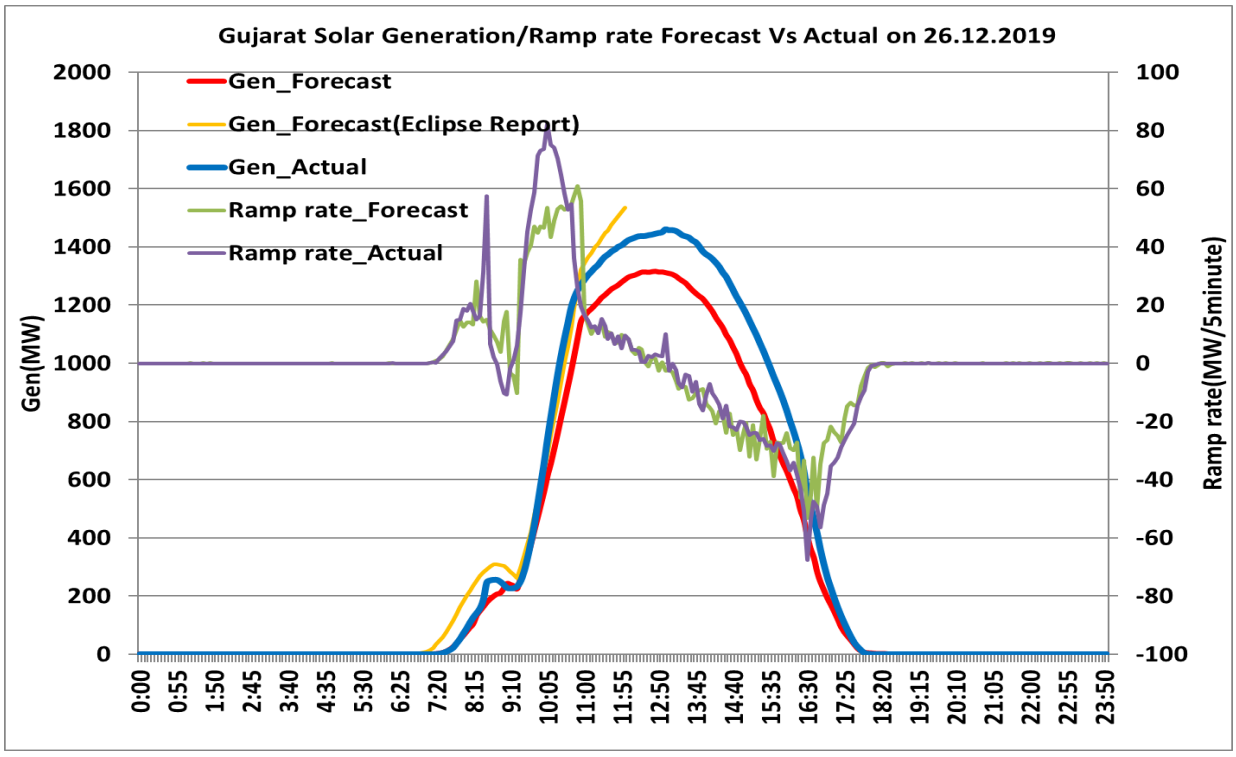


Figure 74: Gujarat generation/ramp rate forecast vs actual on 26.12.2019

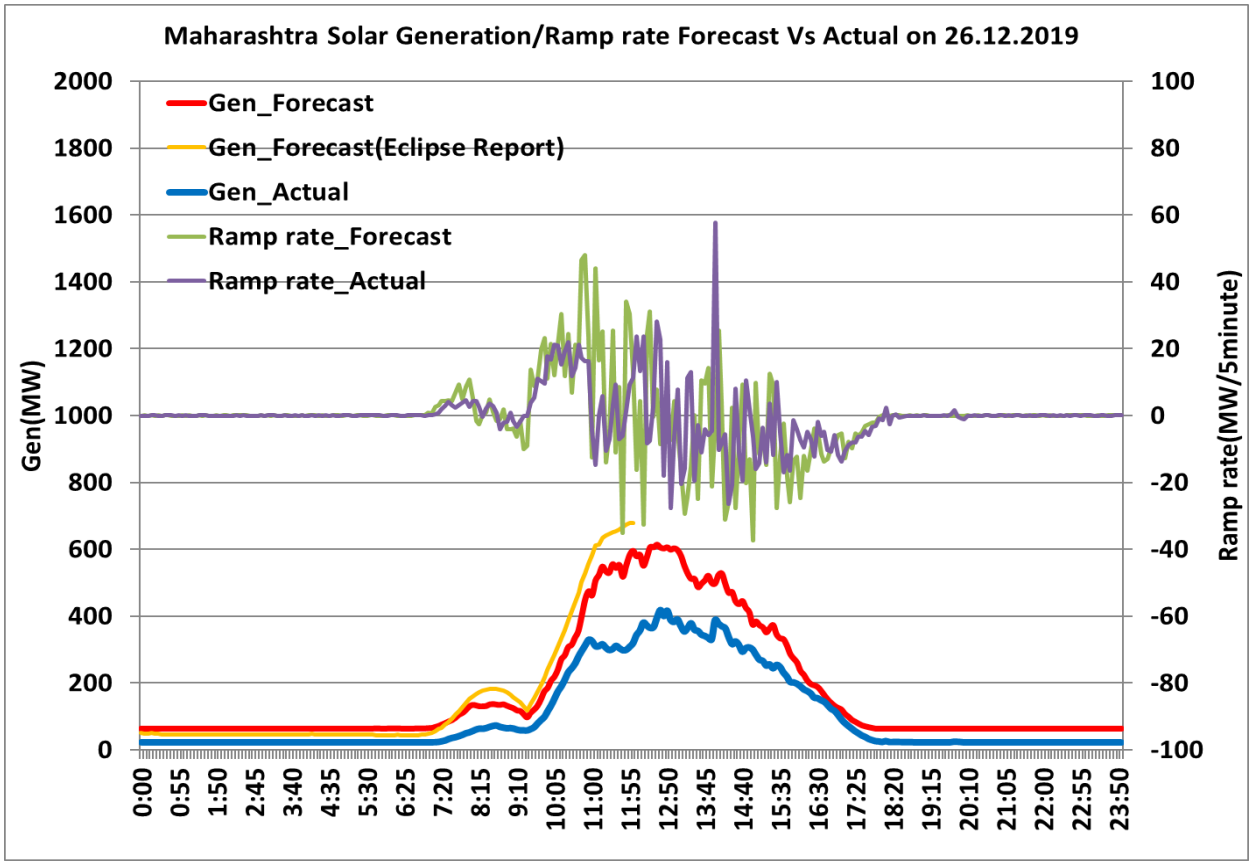


Figure 75: Maharashtra generation/ramp rate forecast vs actual on 26.12.2019

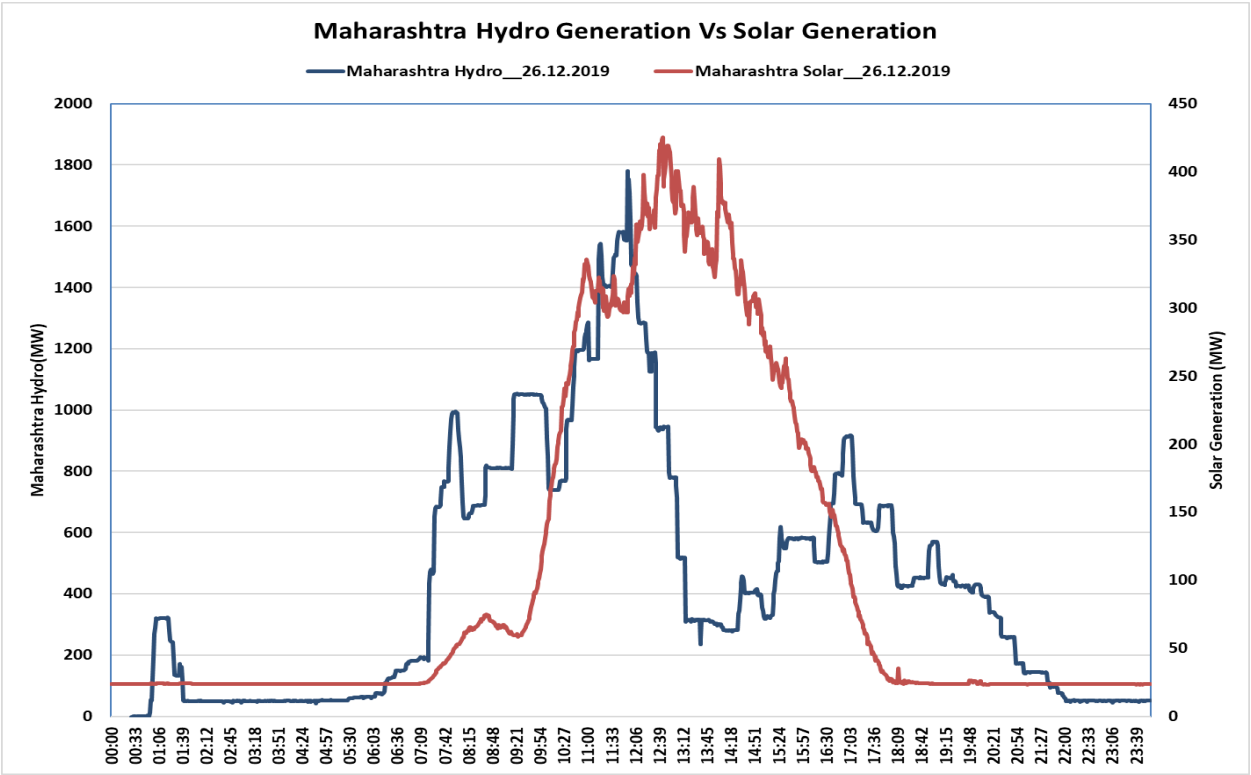


Figure 76: Maharashtra hydro generation vs solar generation on 26.12.2019

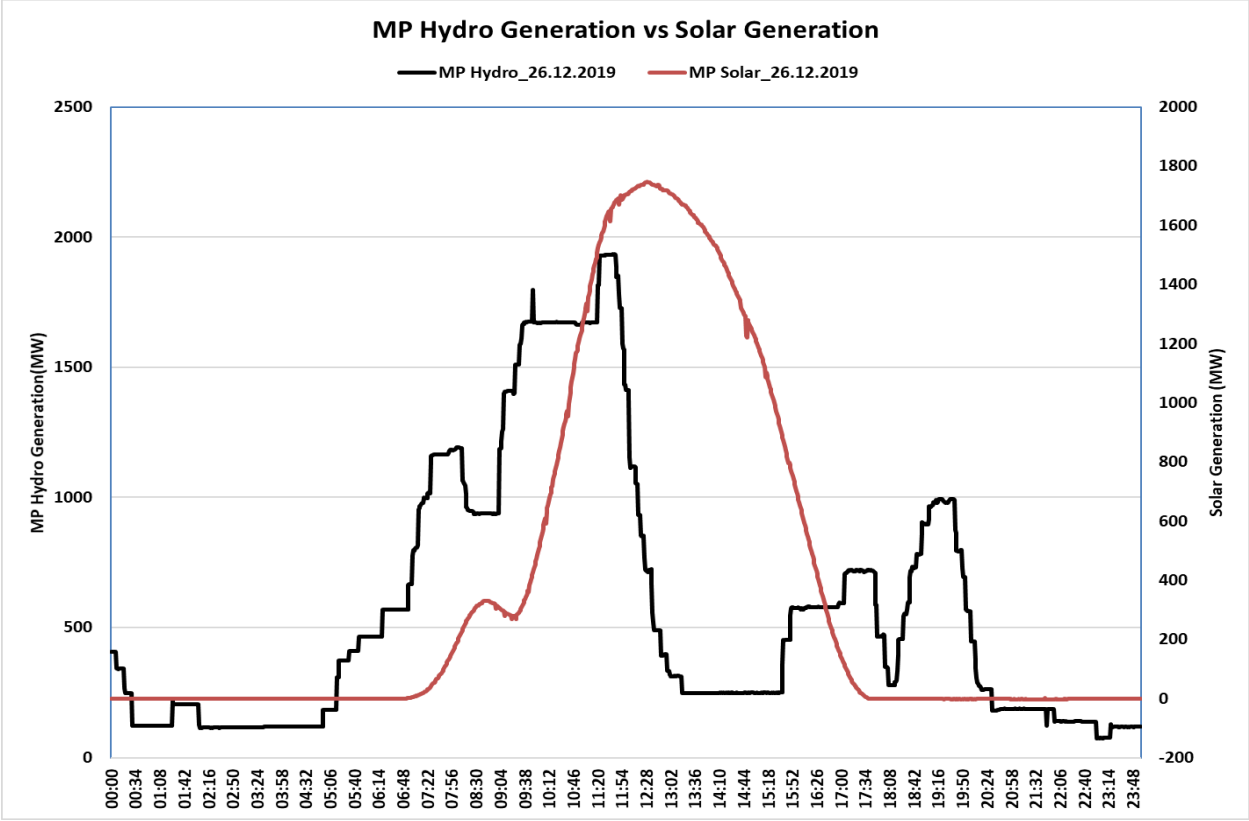


Figure 77: Madhya Pradesh hydro generation vs solar generation on 26.12.2019

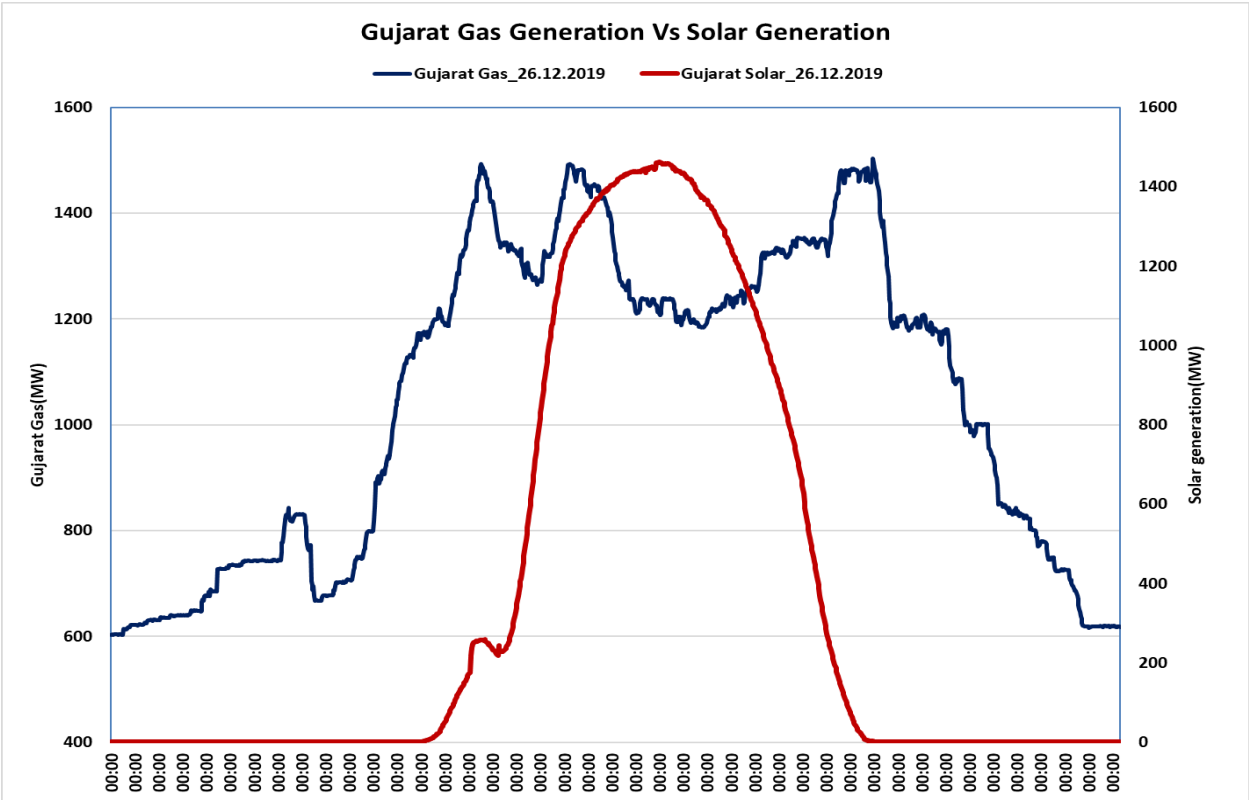


Figure 78: Gujarat hydro generation vs solar generation on 26.12.2019

Annexure-IV

Northern Region Hydro and Gas Generation variation during solar eclipse on 26th December 2019

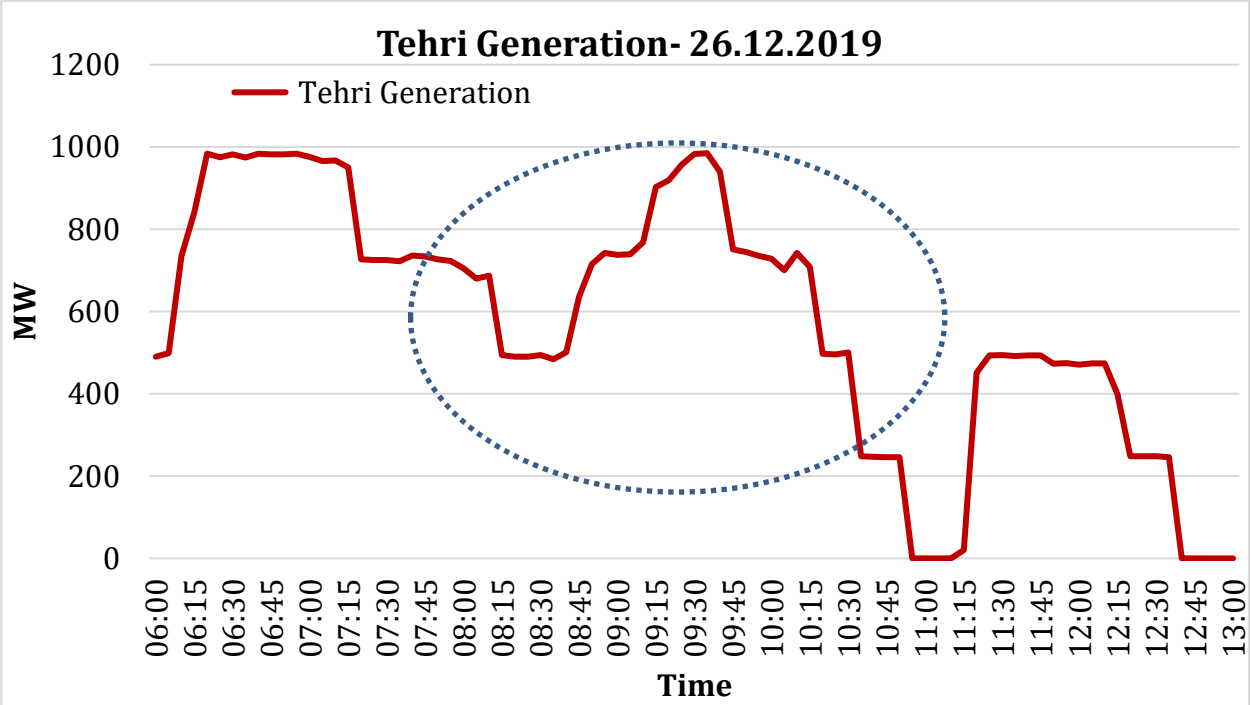


Figure 79: Tehri Generation on 26.12.2019

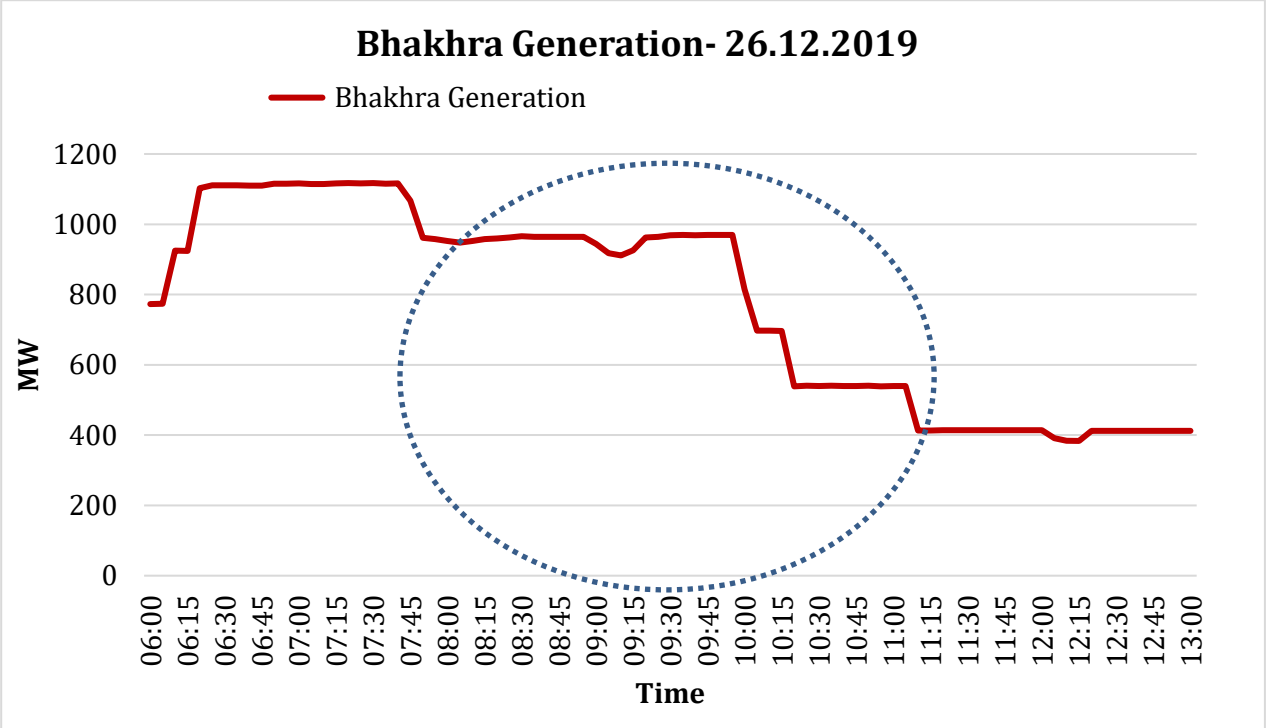


Figure 80: Bhakhra Generation on 26.12.2019

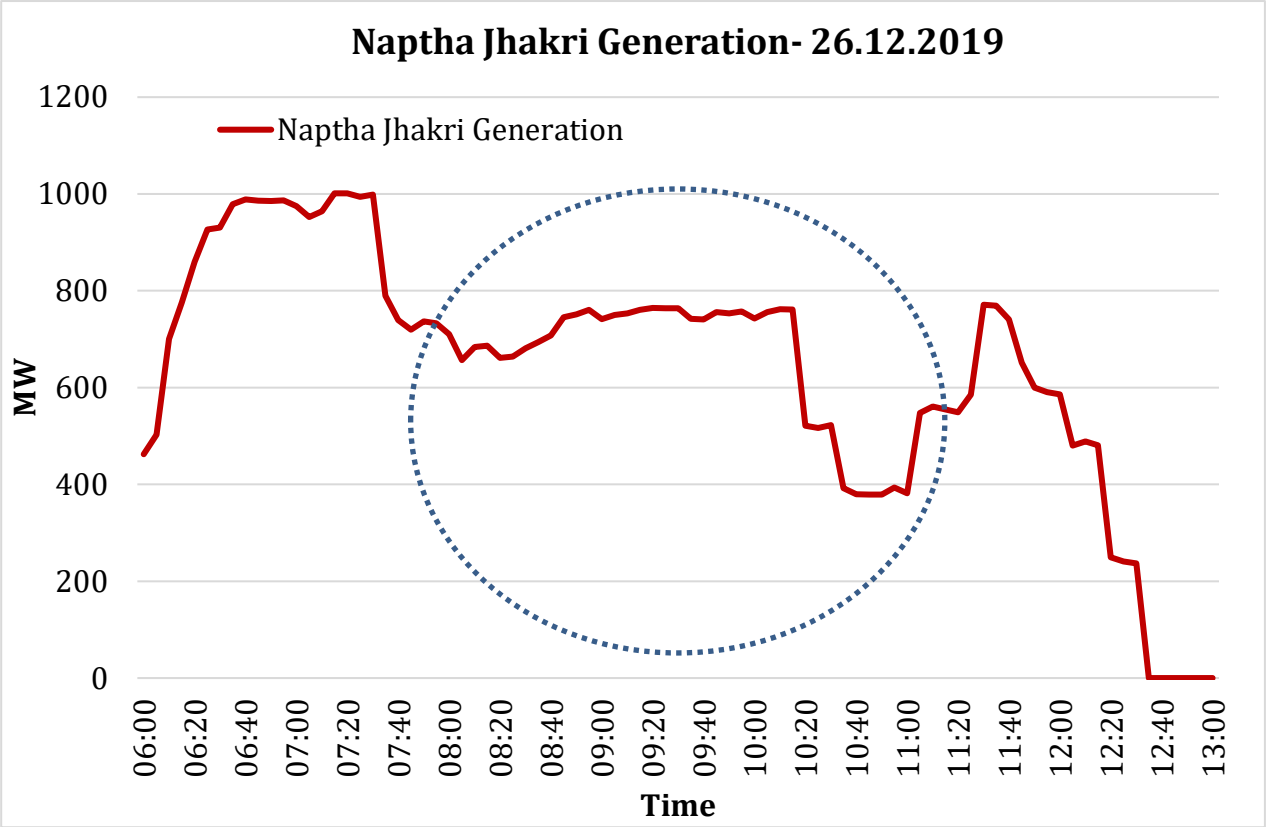


Figure 81: Naptha Jhakri Generation- 26.12.2019

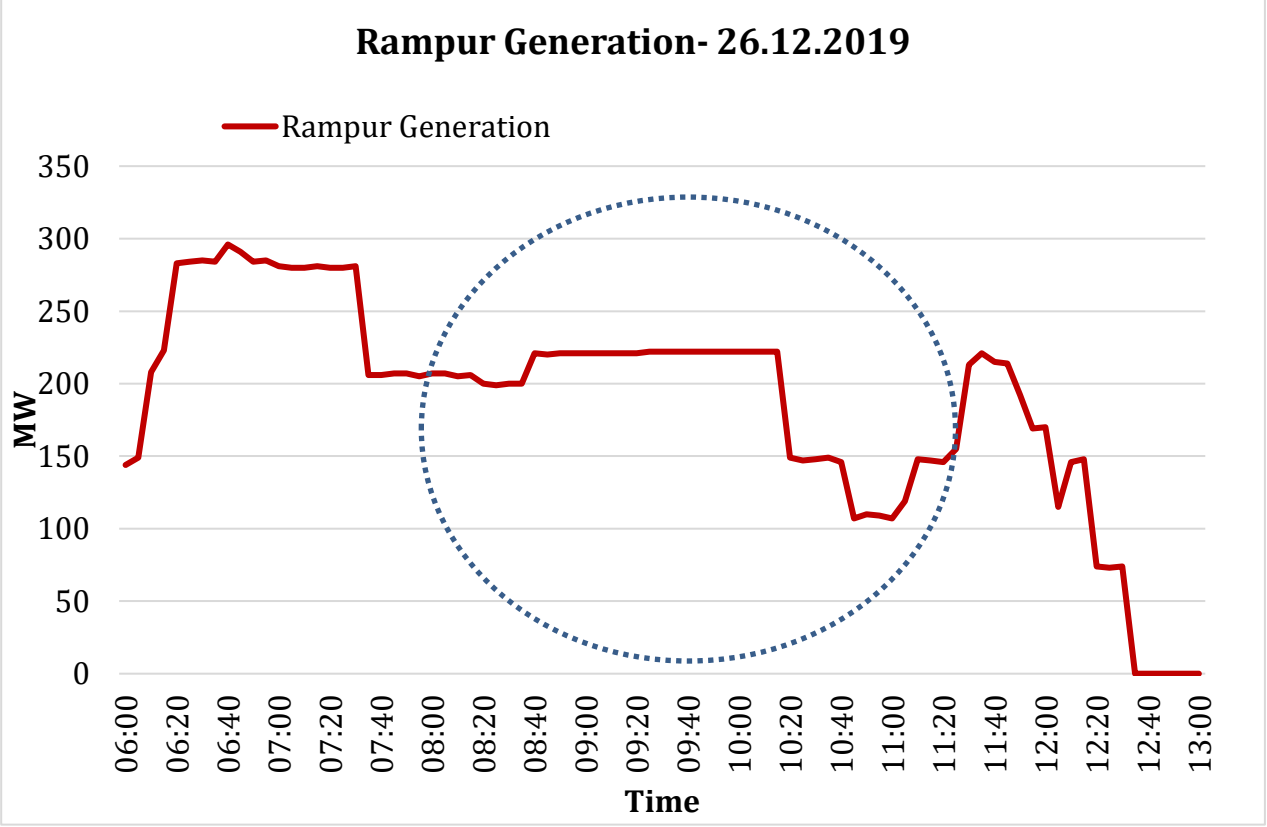


Figure 82: Rampur Generation on 26.12.2019

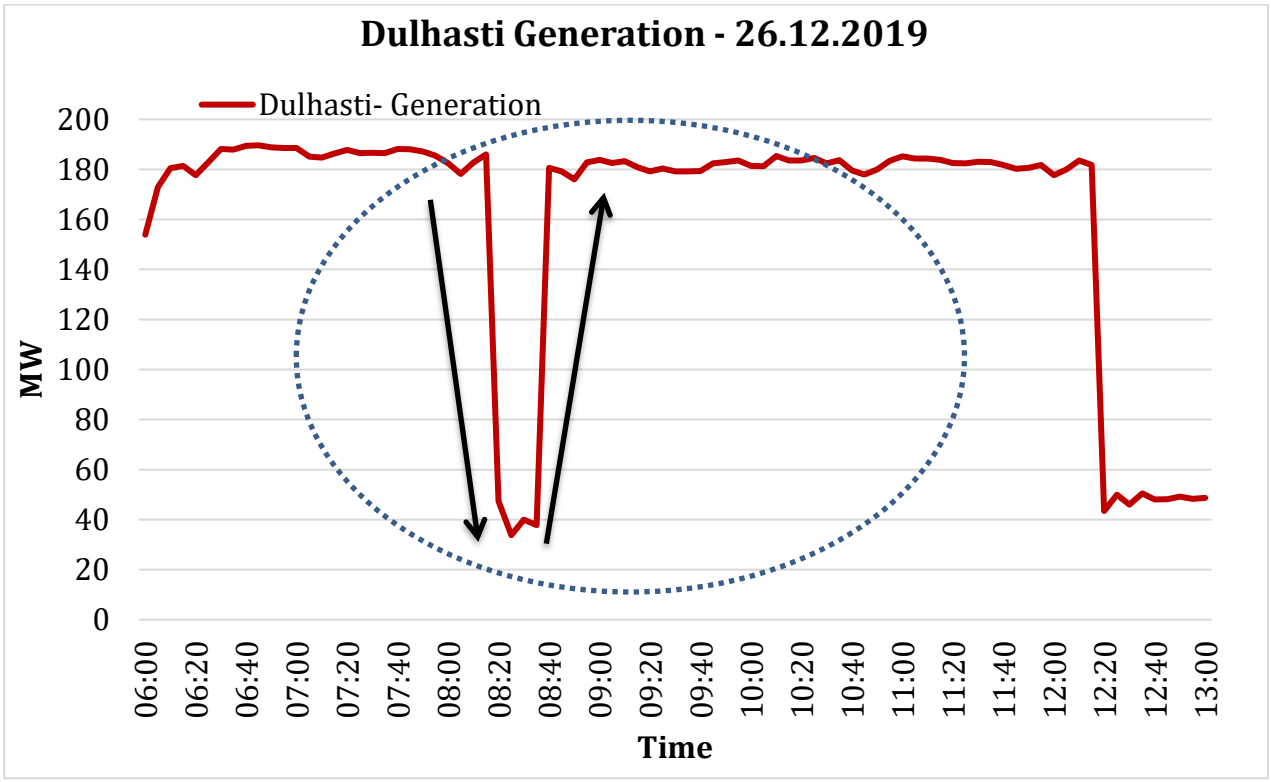


Figure 83: Dulhasti Generation on 26.12.2019

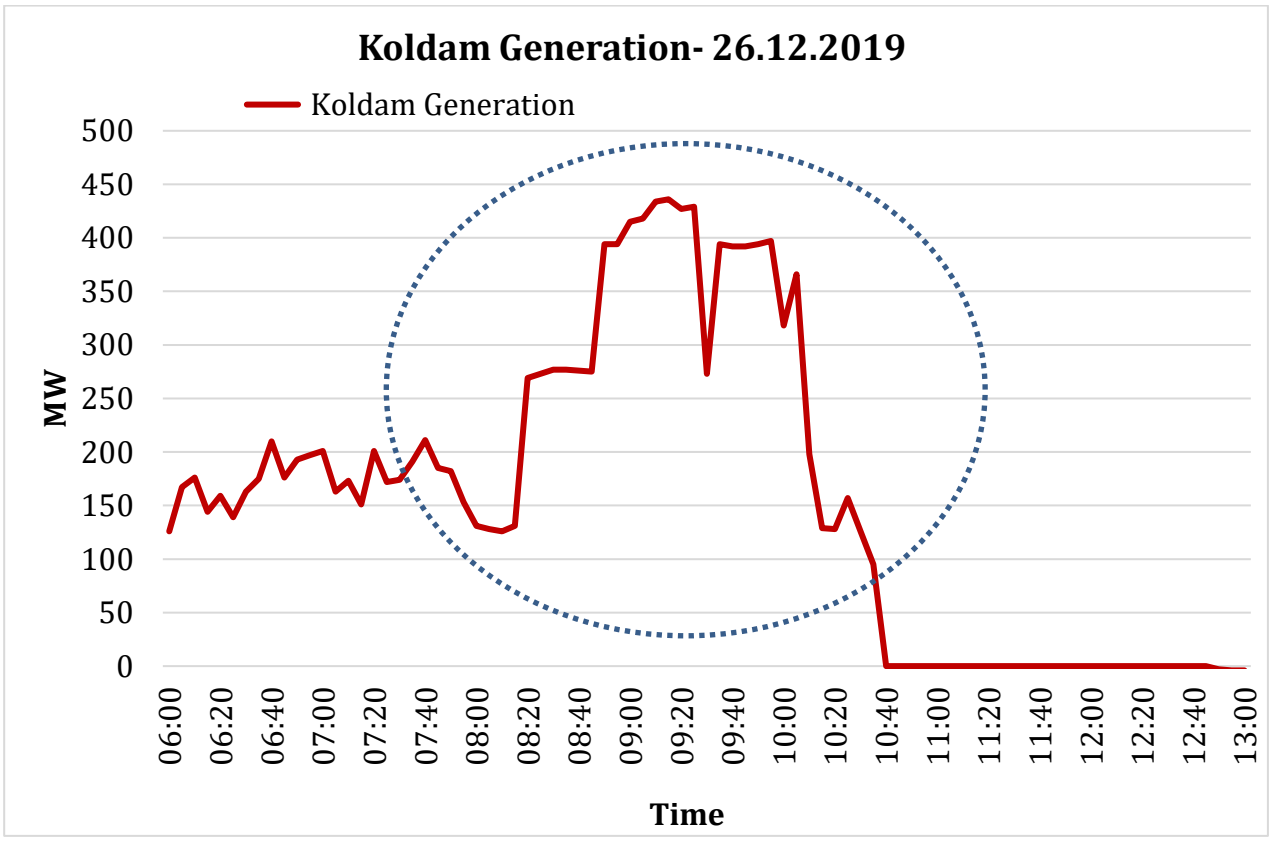


Figure 84: Koldam Generation on 26.12.2019

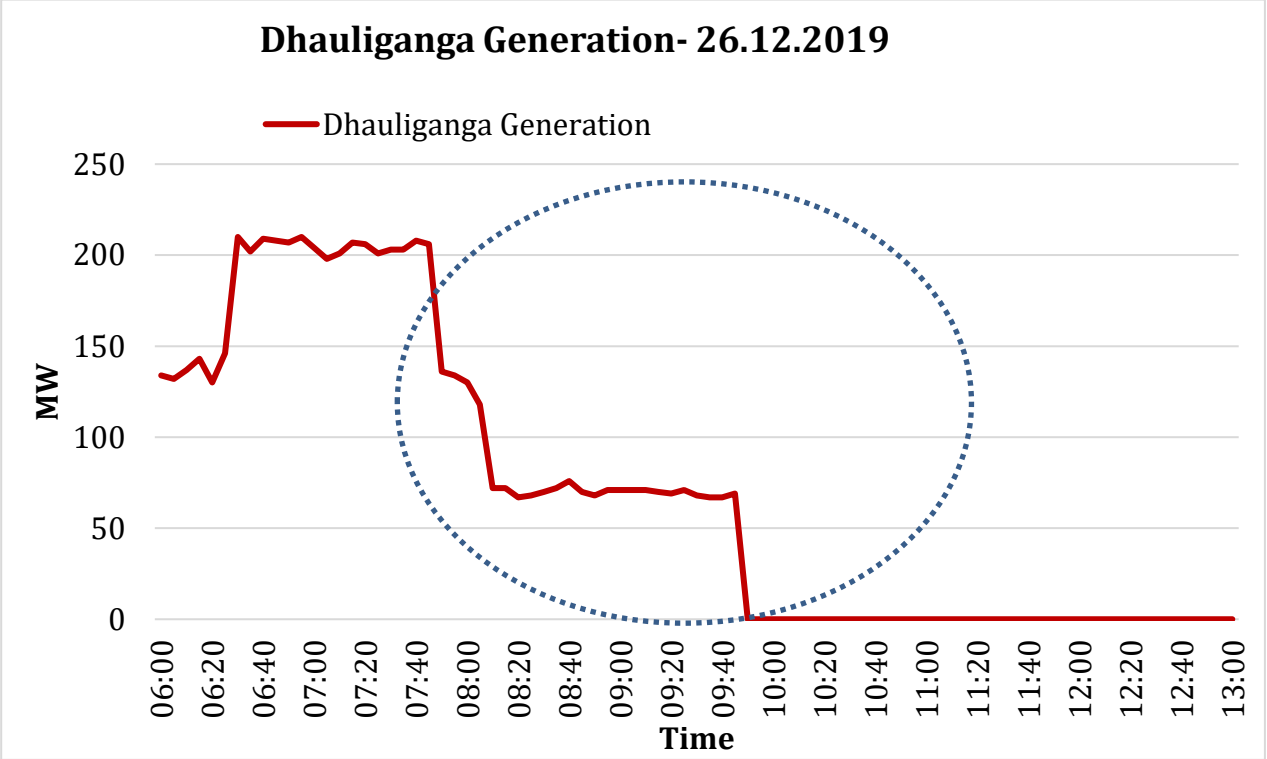


Figure 85: Dhauliganga Generation on 26.12.2019

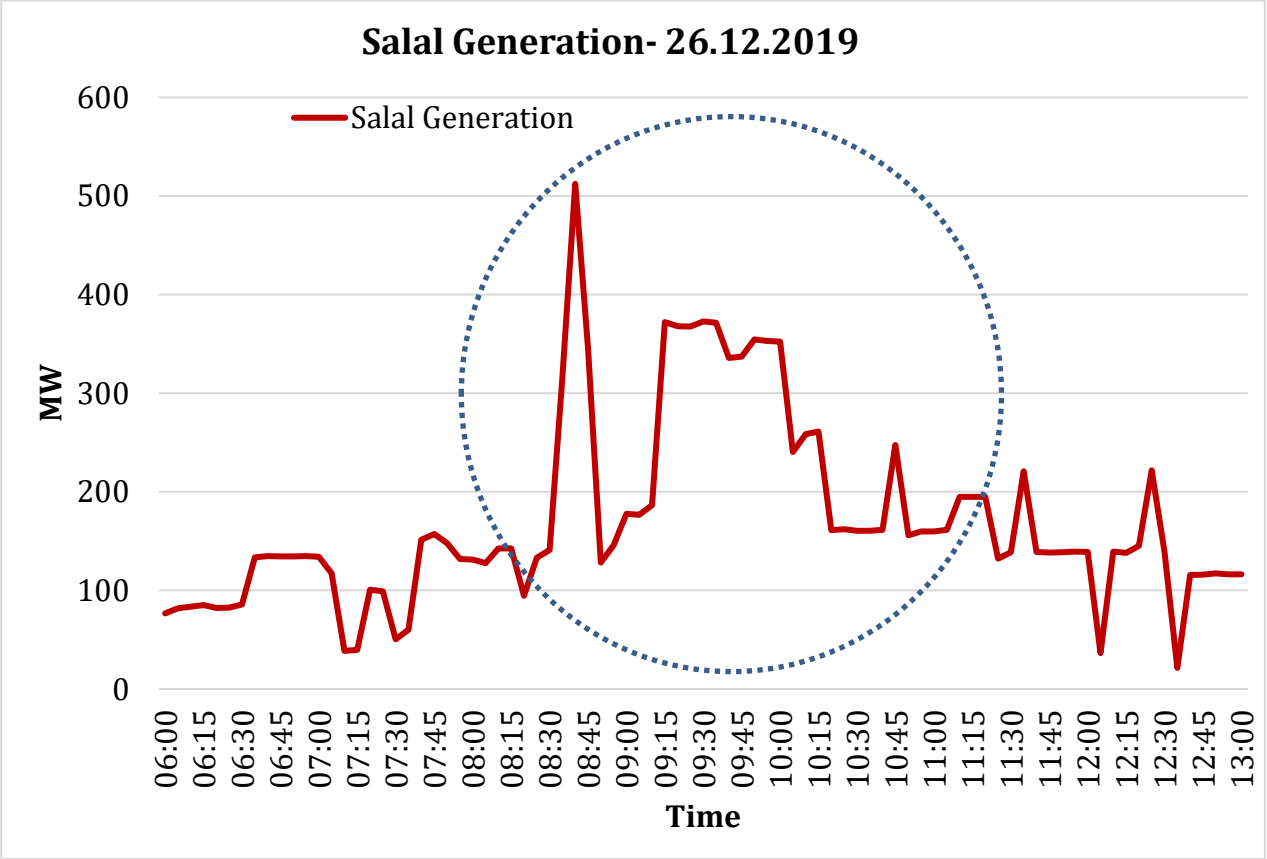


Figure 86: Salal Generation on 26.12.2019

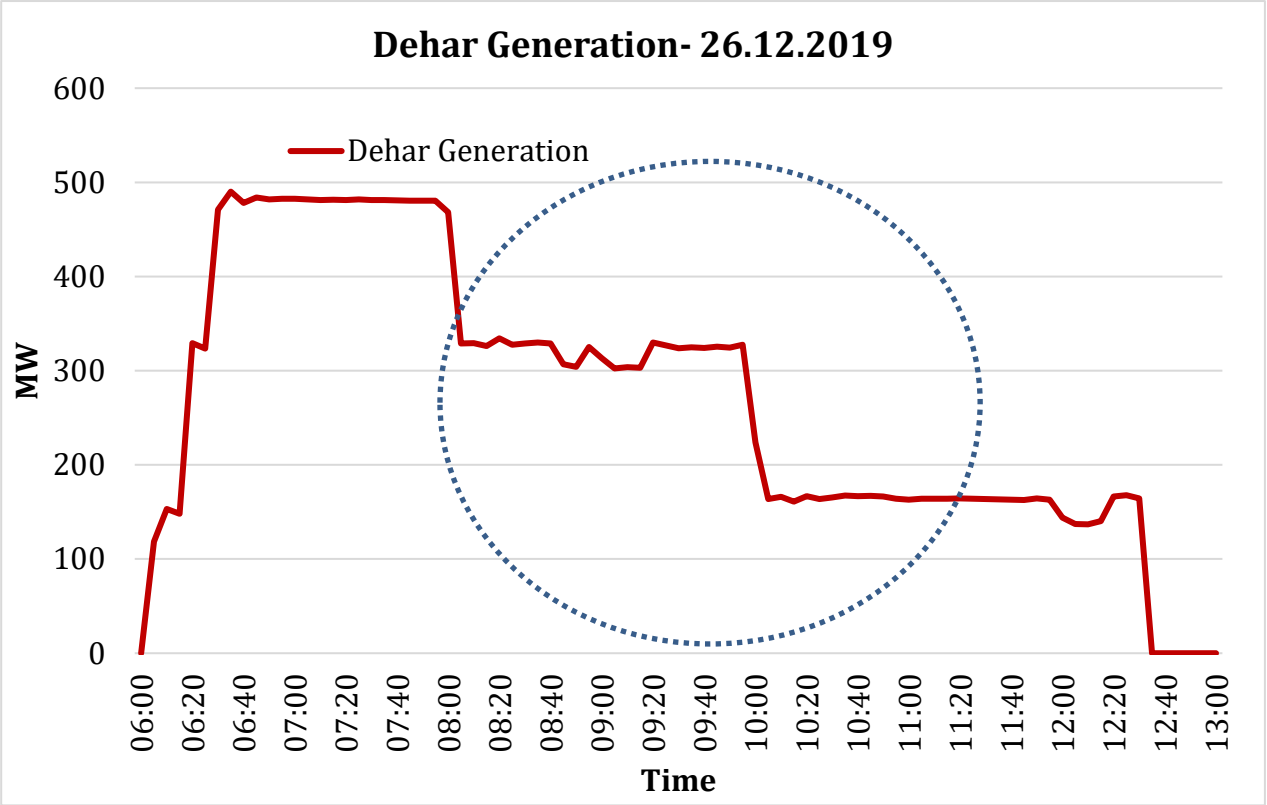


Figure 87: Dehar Generation on 26.12.2019

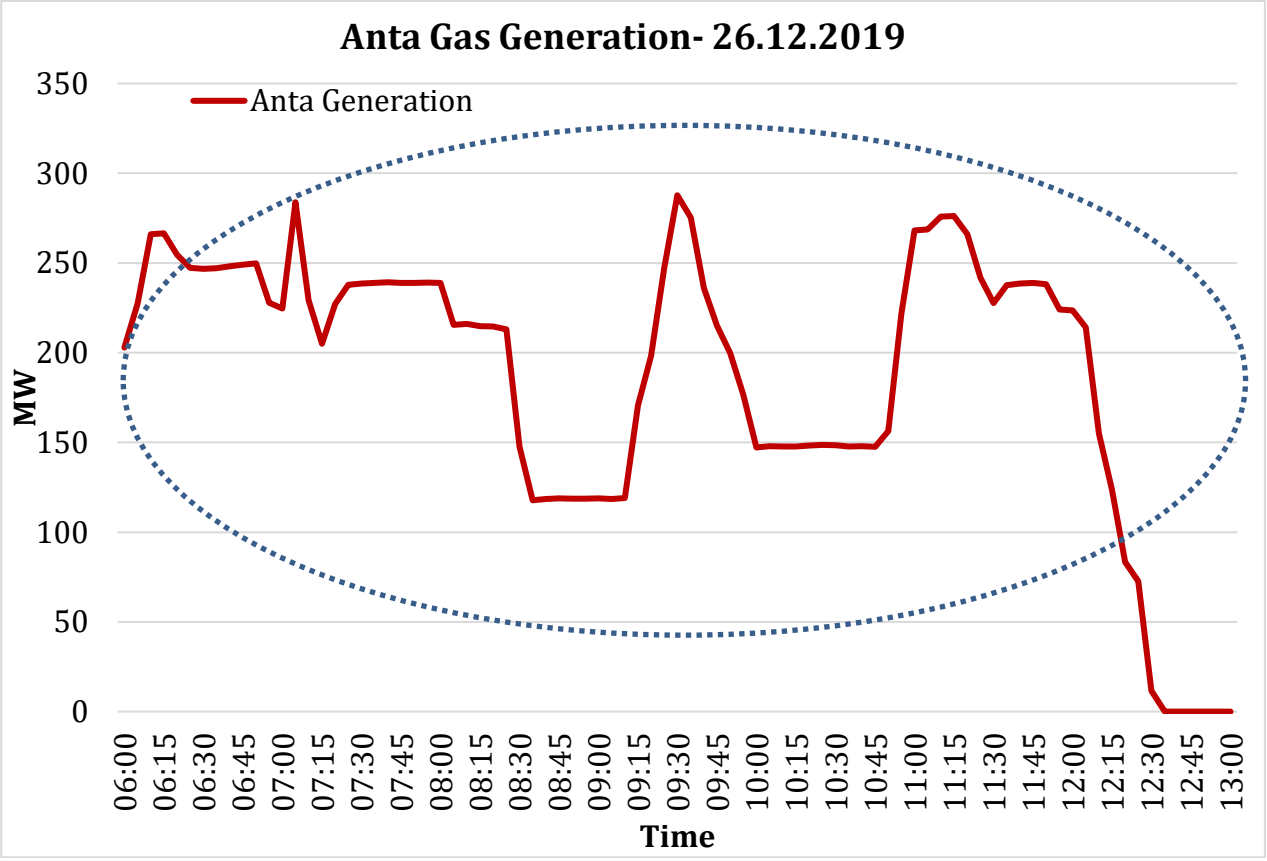


Figure 88: Anta Gas Generation on 26.12.2019

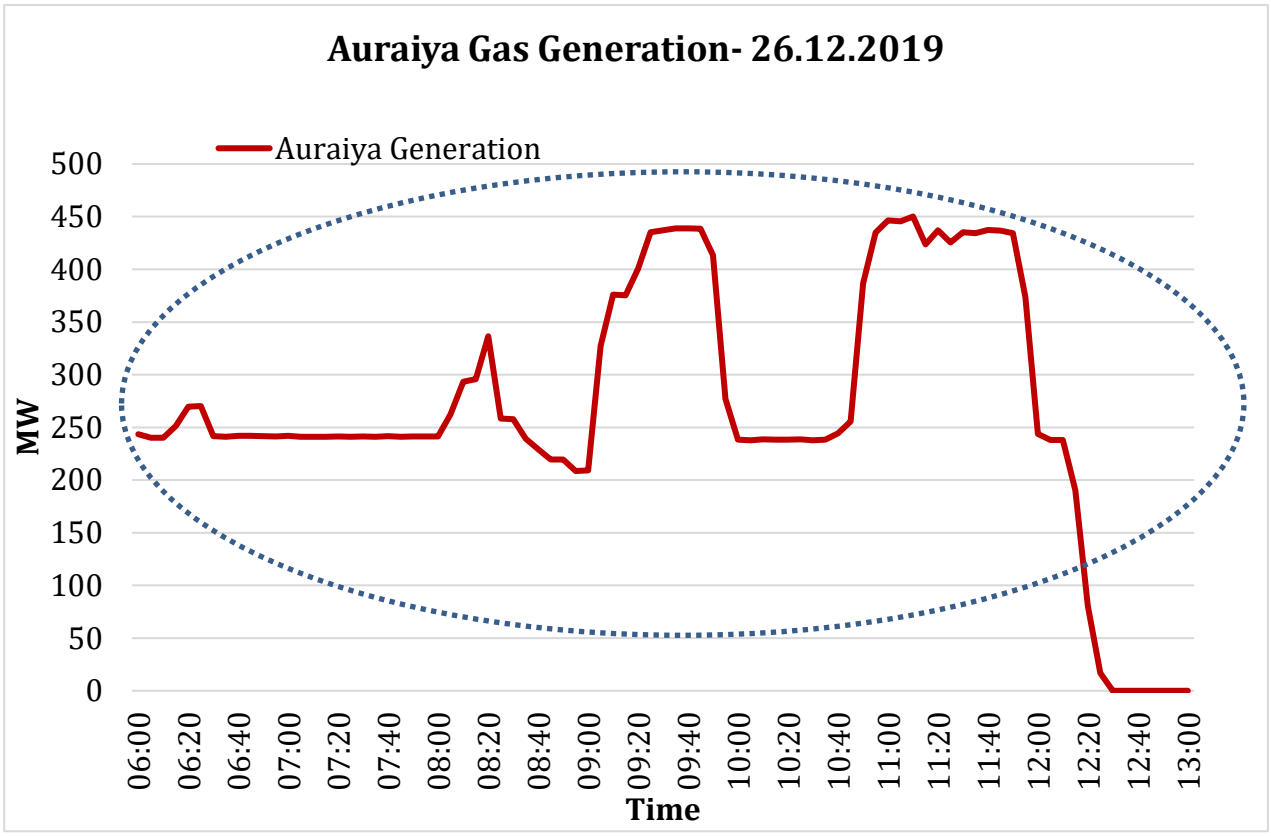


Figure 89: Auraiya Gas Generation on 26.12.2019

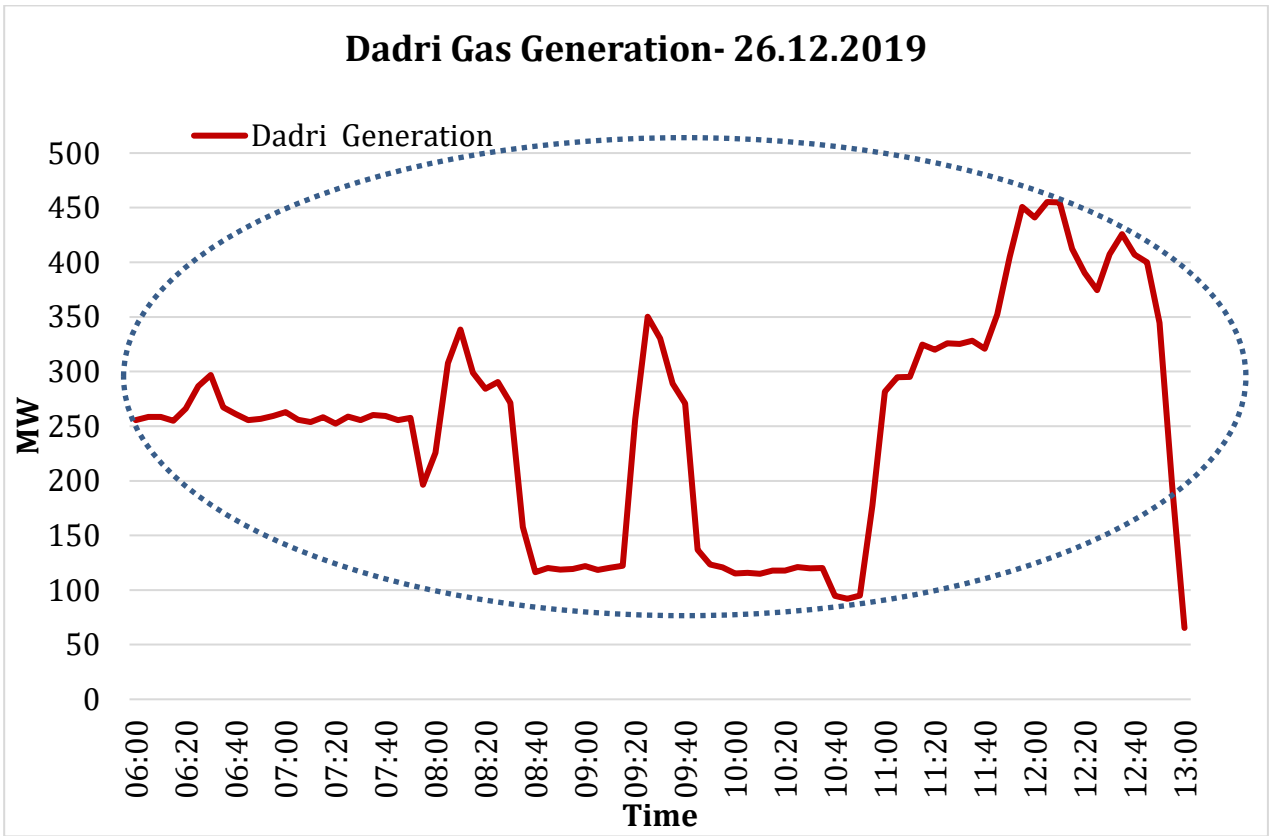


Figure 90: Dadri Gas Generation- 26.12.2019

Northern Region ISTS connected solar plant

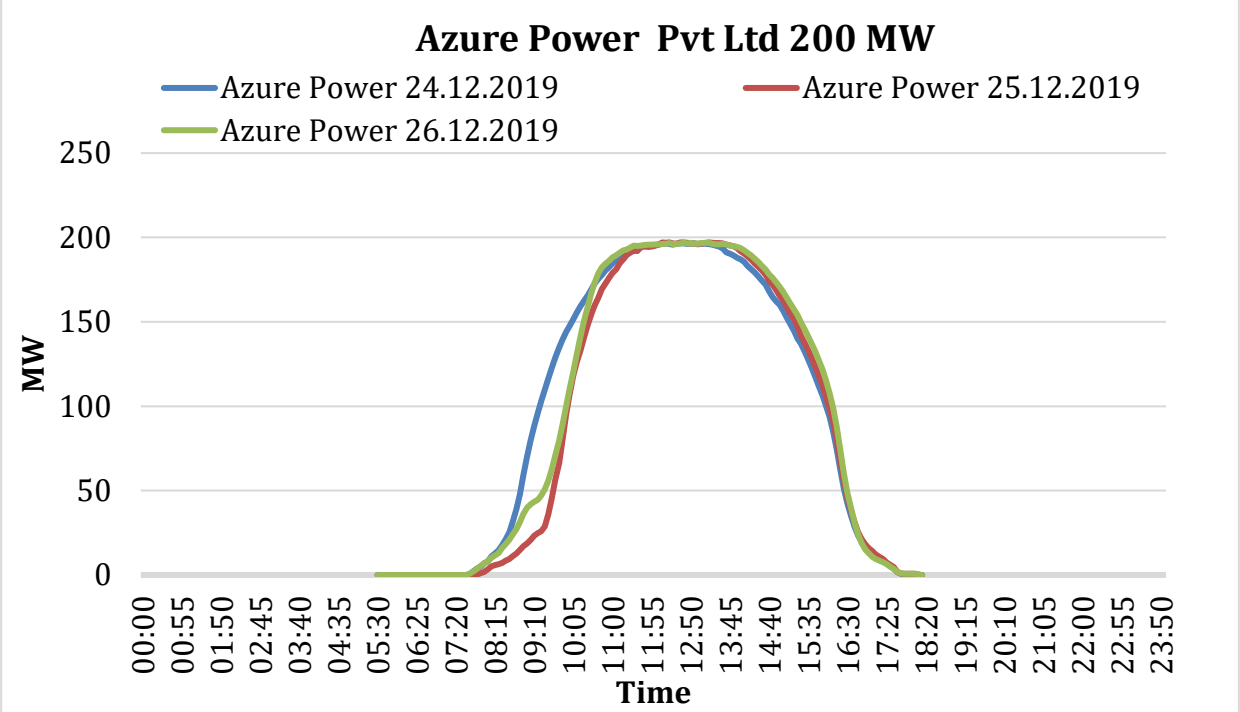


Figure 91: Azure Power Pvt Ltd (200 MW) solar generation on 26.12.2019

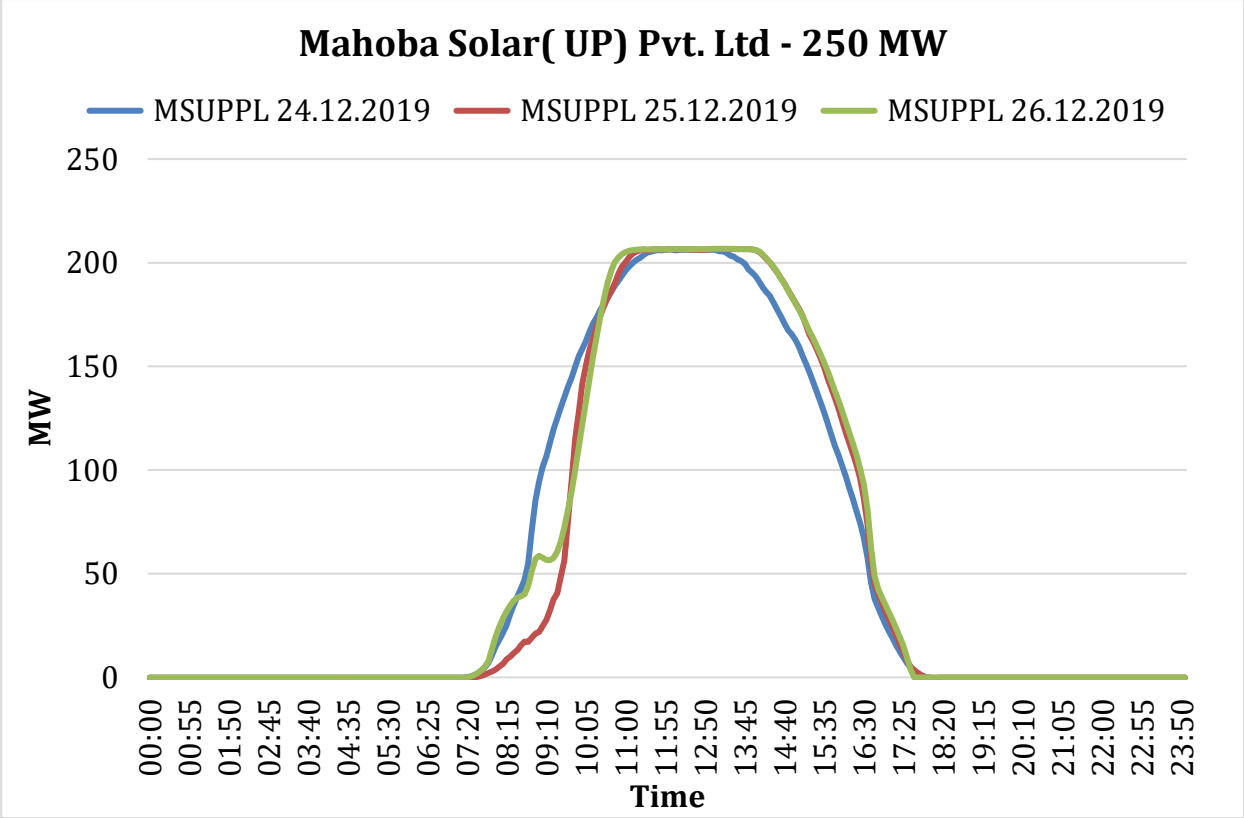


Figure 92: Mahoba Solar(UP) Pvt. Ltd (250 MW) solar generation on 26.12.2019

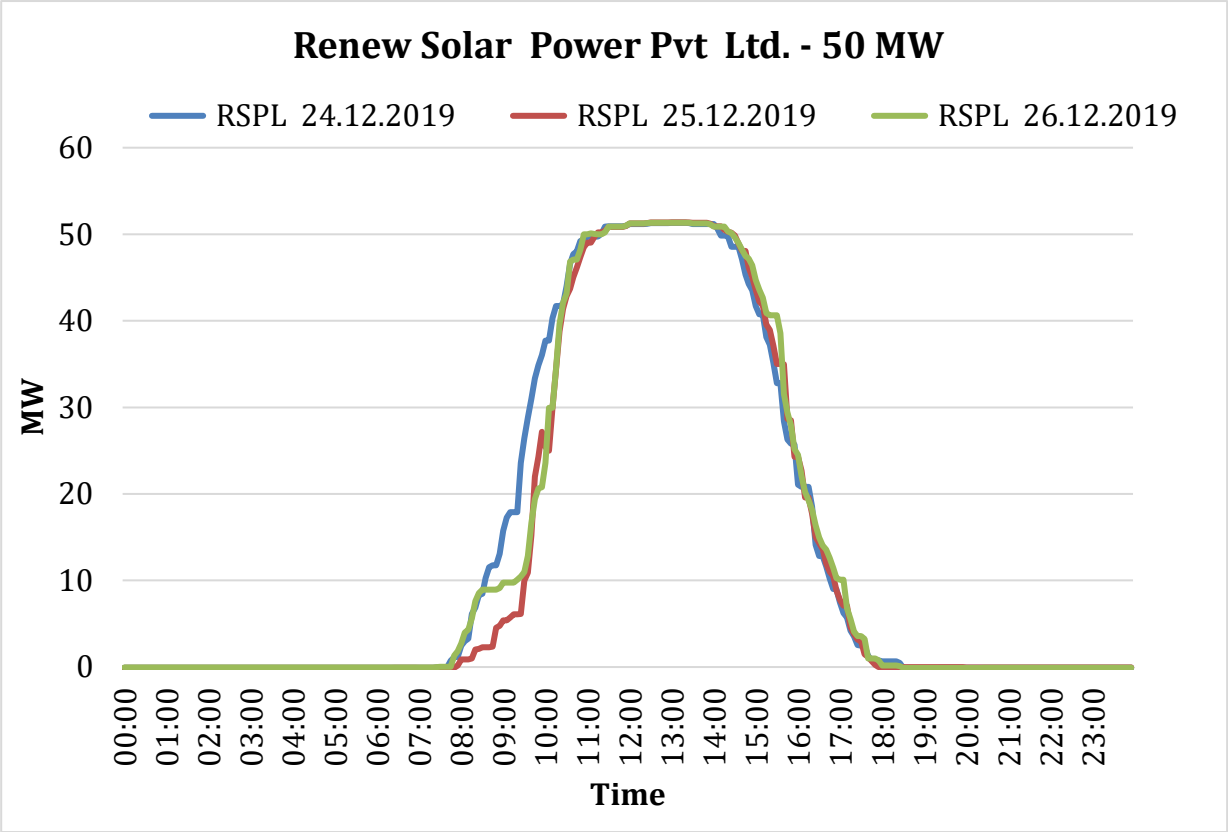


Figure 93: Renew Solar Power Pvt Ltd. (50 MW) solar generation on 26.12.2019

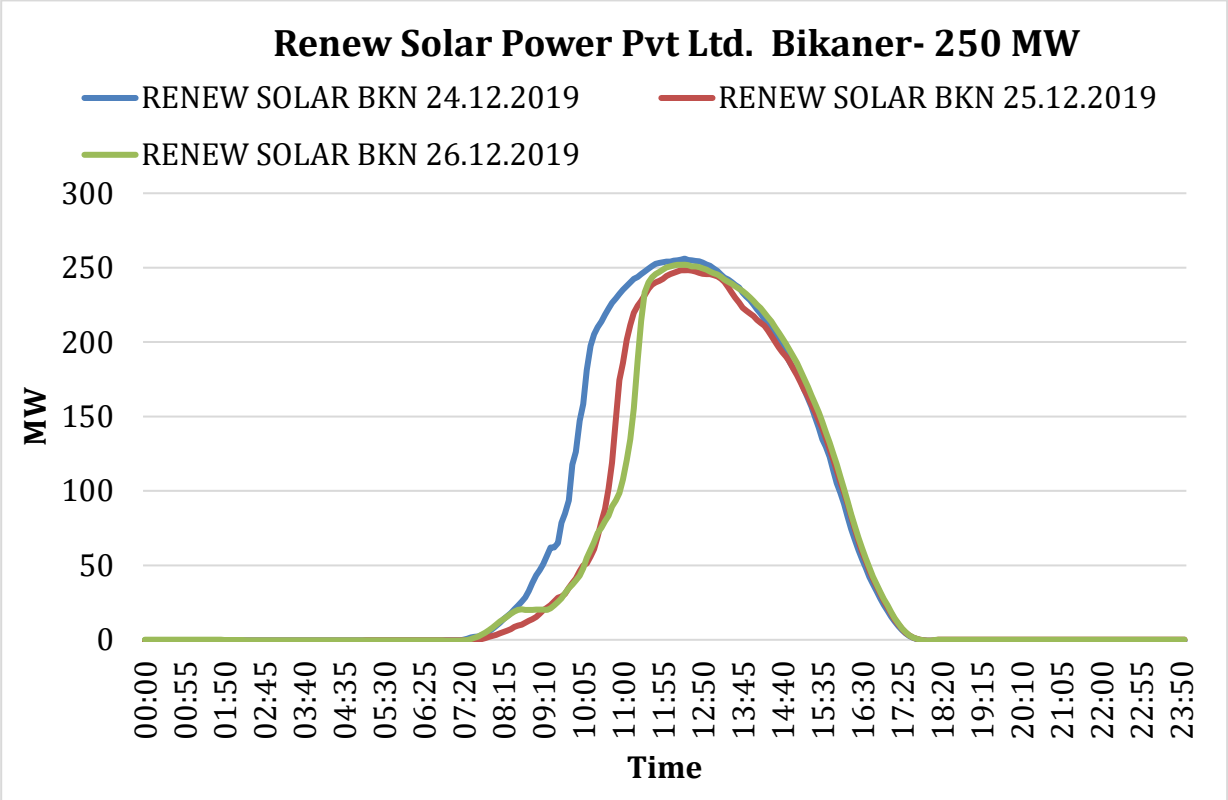


Figure 94: Renew Solar Power Pvt Ltd. Bikaner (250 MW) solar generation on 26.12.2019

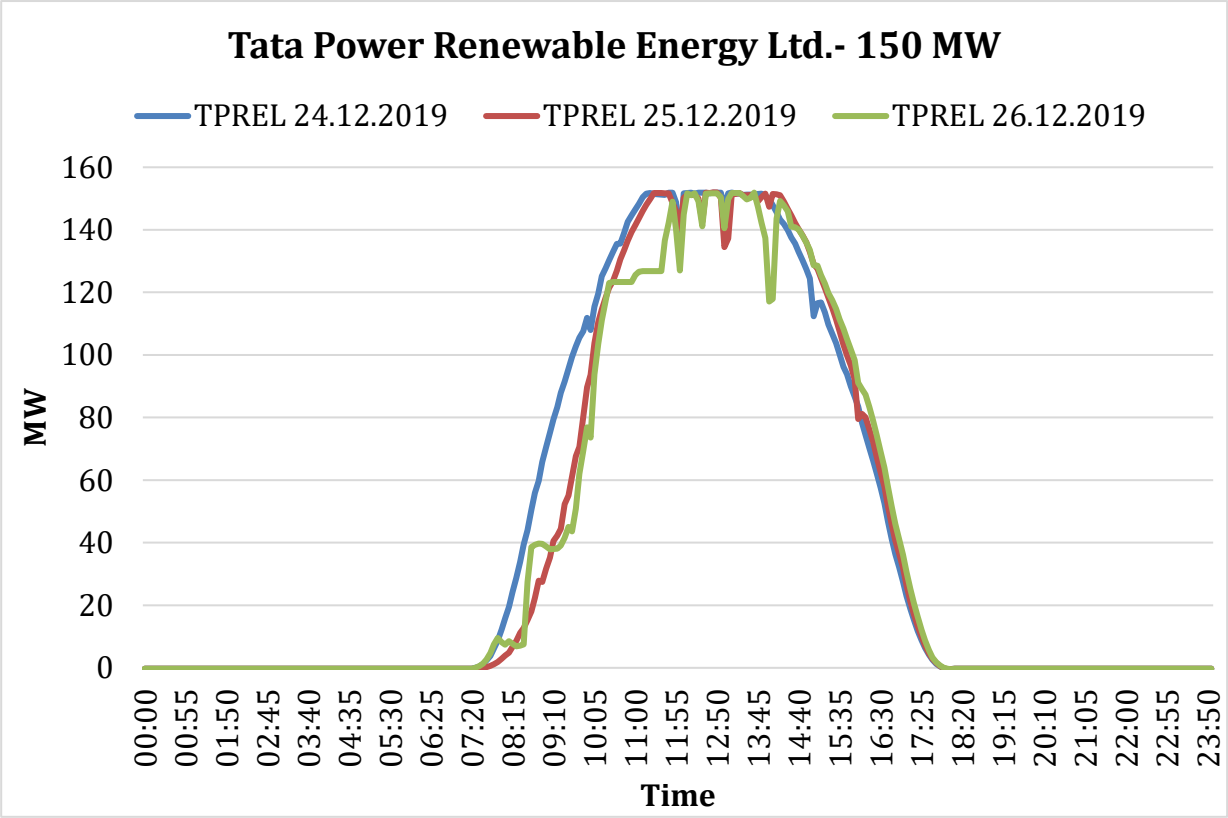


Figure 95: Tata Power Renewable Energy Ltd. (150 MW) solar generation on 26.12.2019

Southern Region states demand comparison for 24th and 26th December 2019

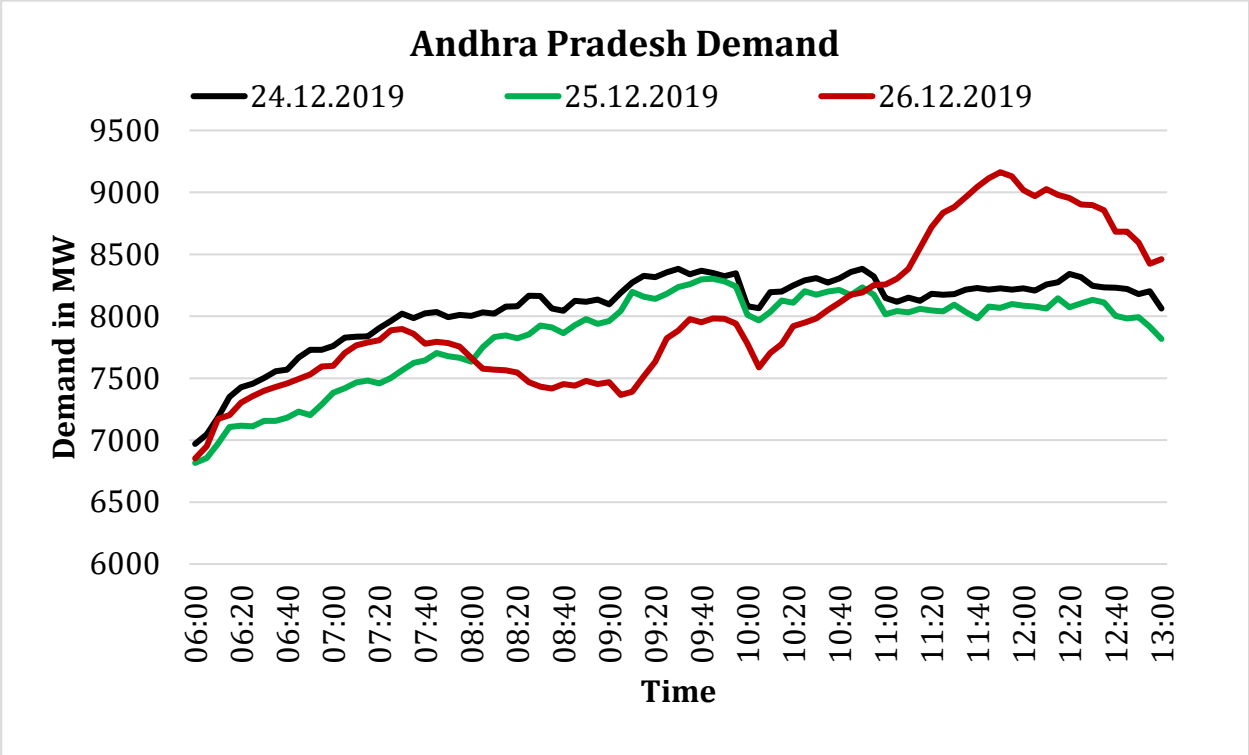


Figure 96: Andhra Pradesh Demand

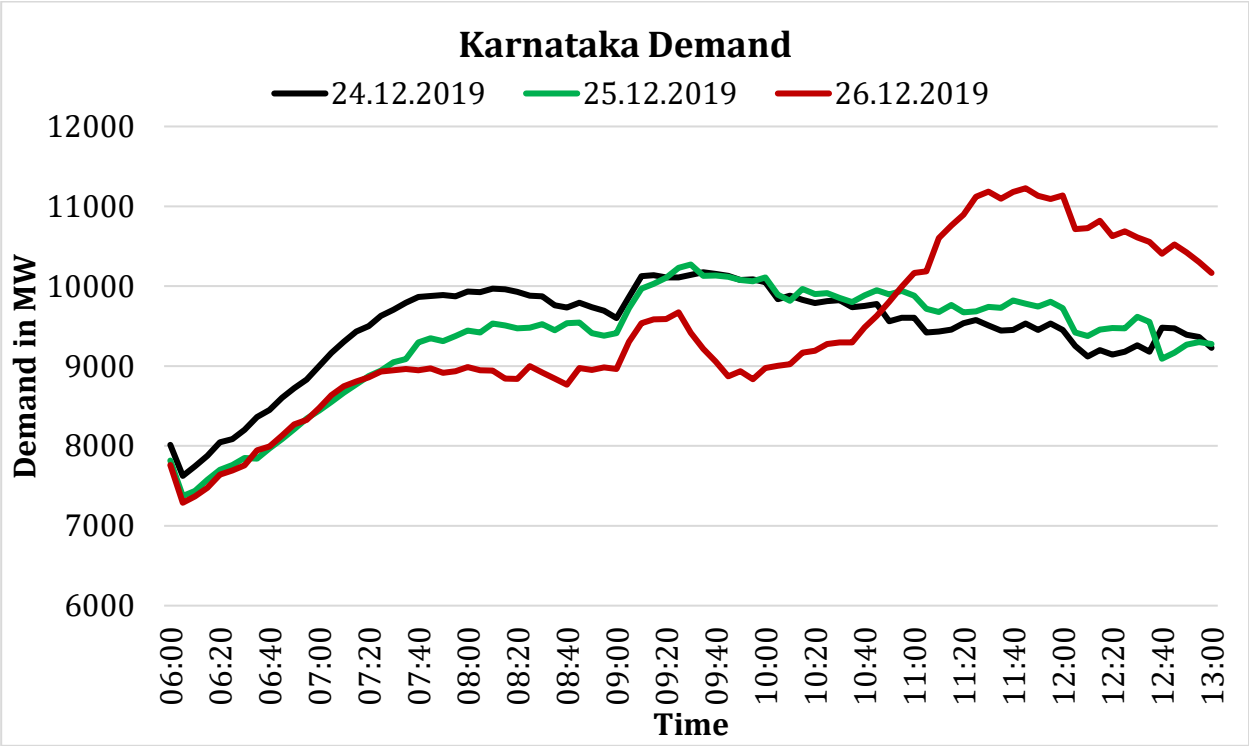


Figure 97: Karnataka Demand

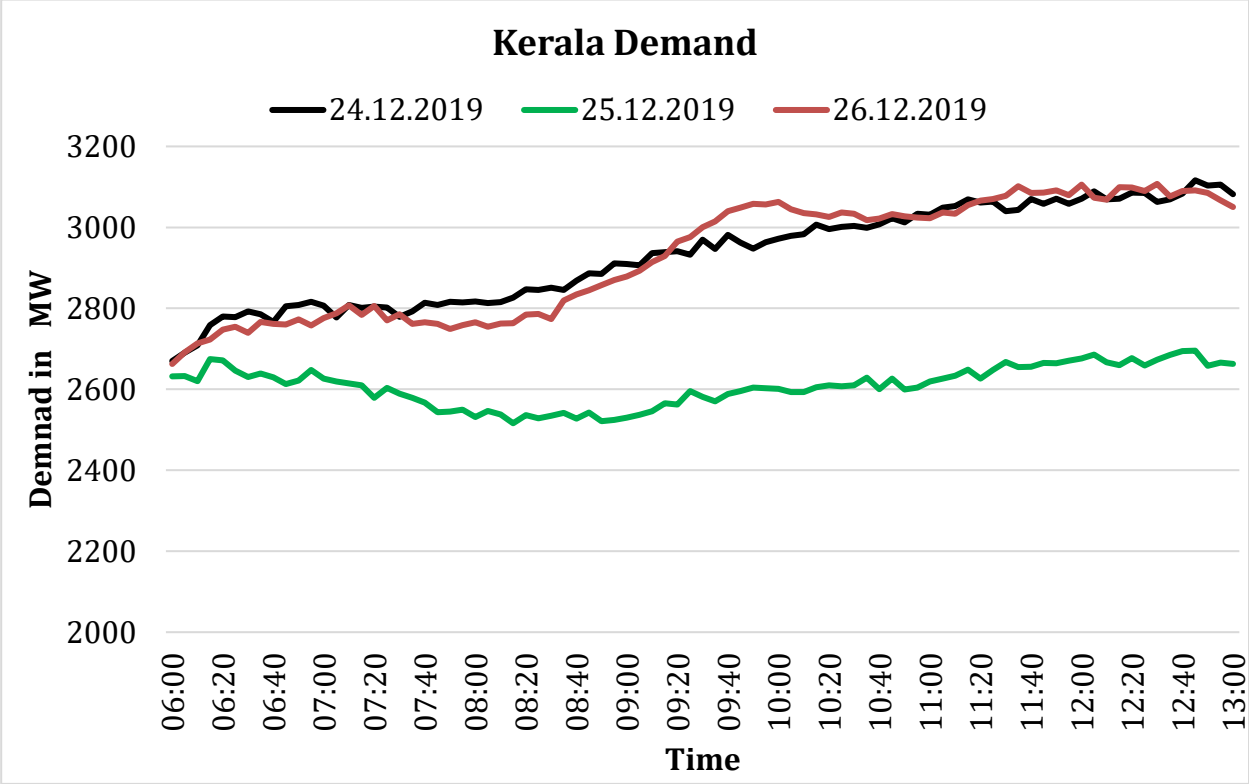


Figure 98: Kerala Demand

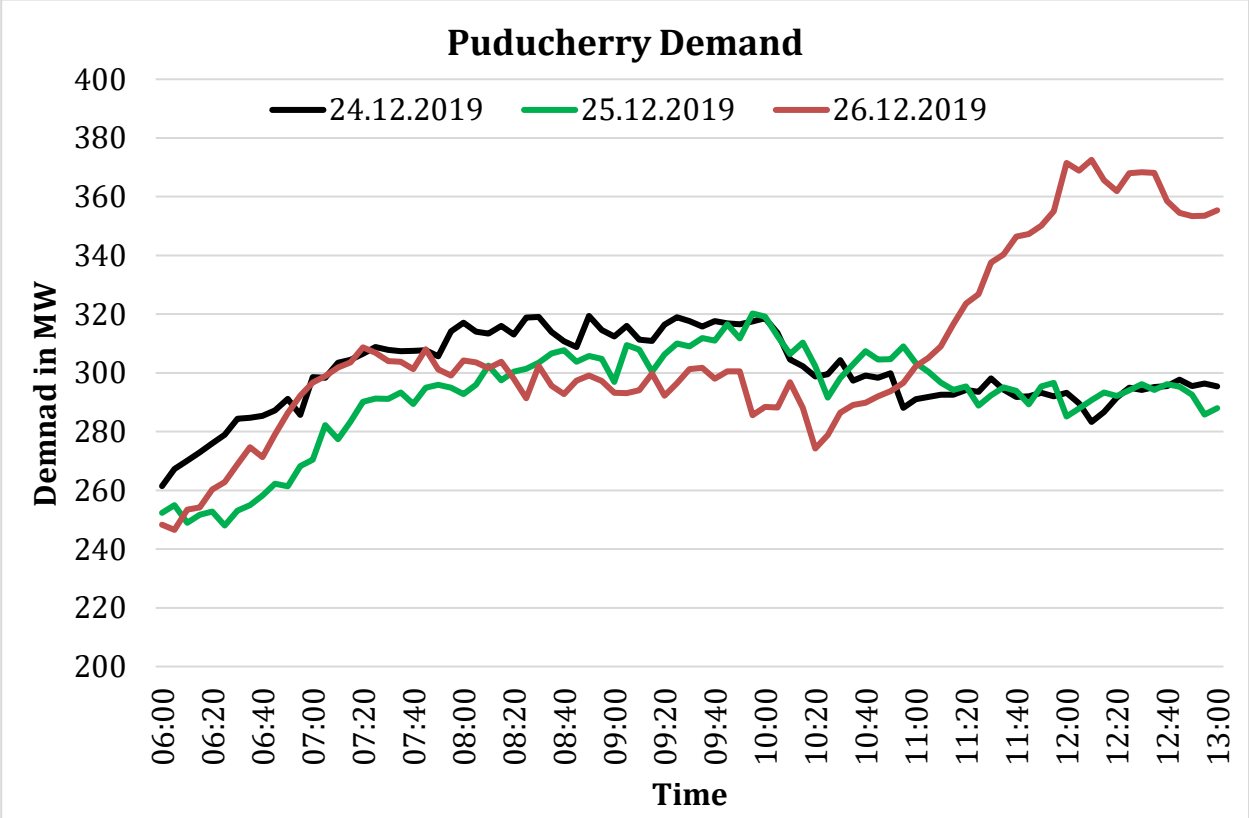


Figure 99: Puducherry Demand

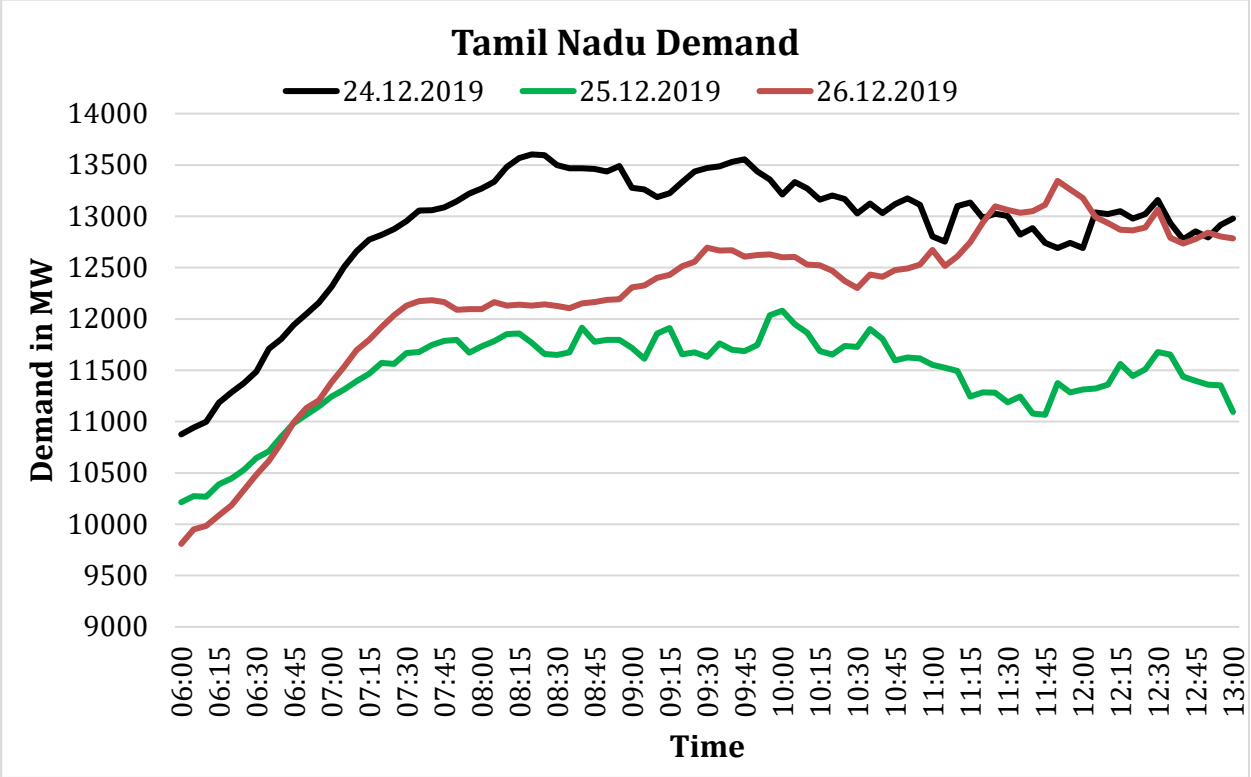


Figure 100: Tamil Nadu Demand

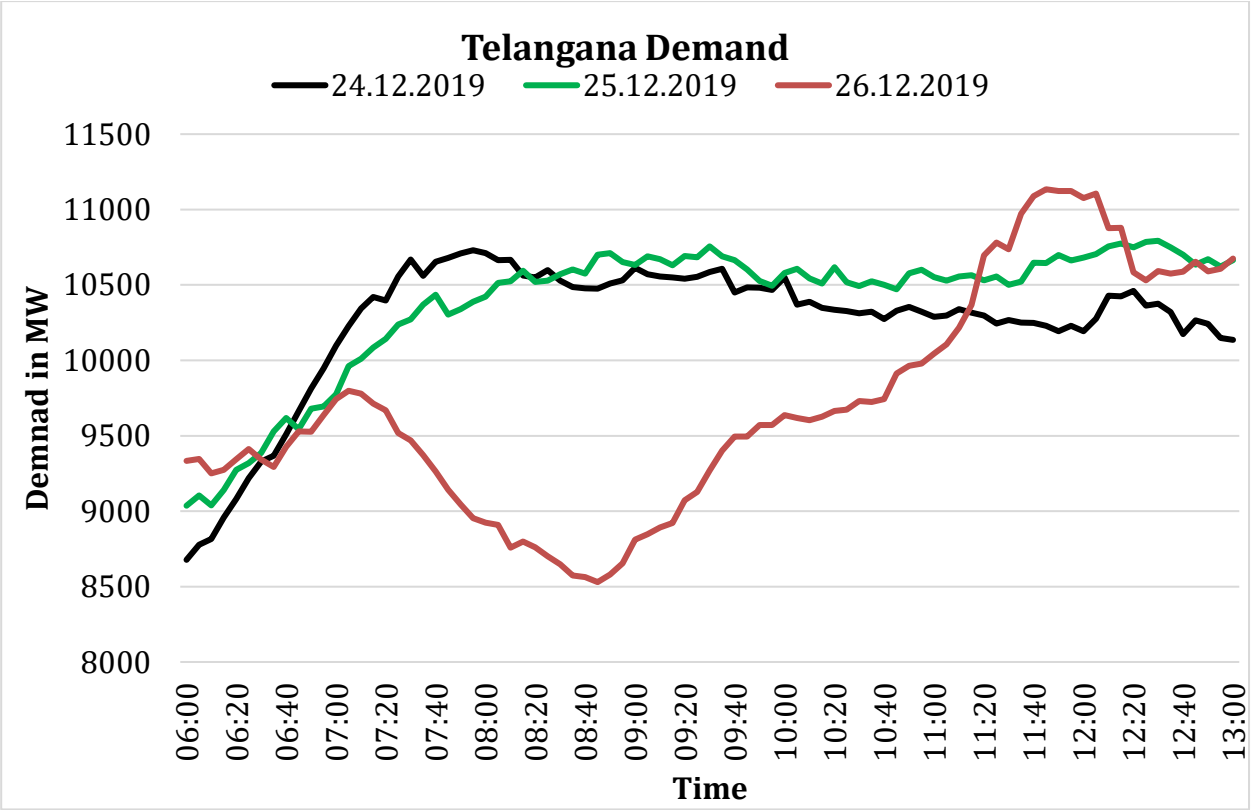


Figure 101: Telangana Demand

Western states demand comparison for 25th and 26th December 2019

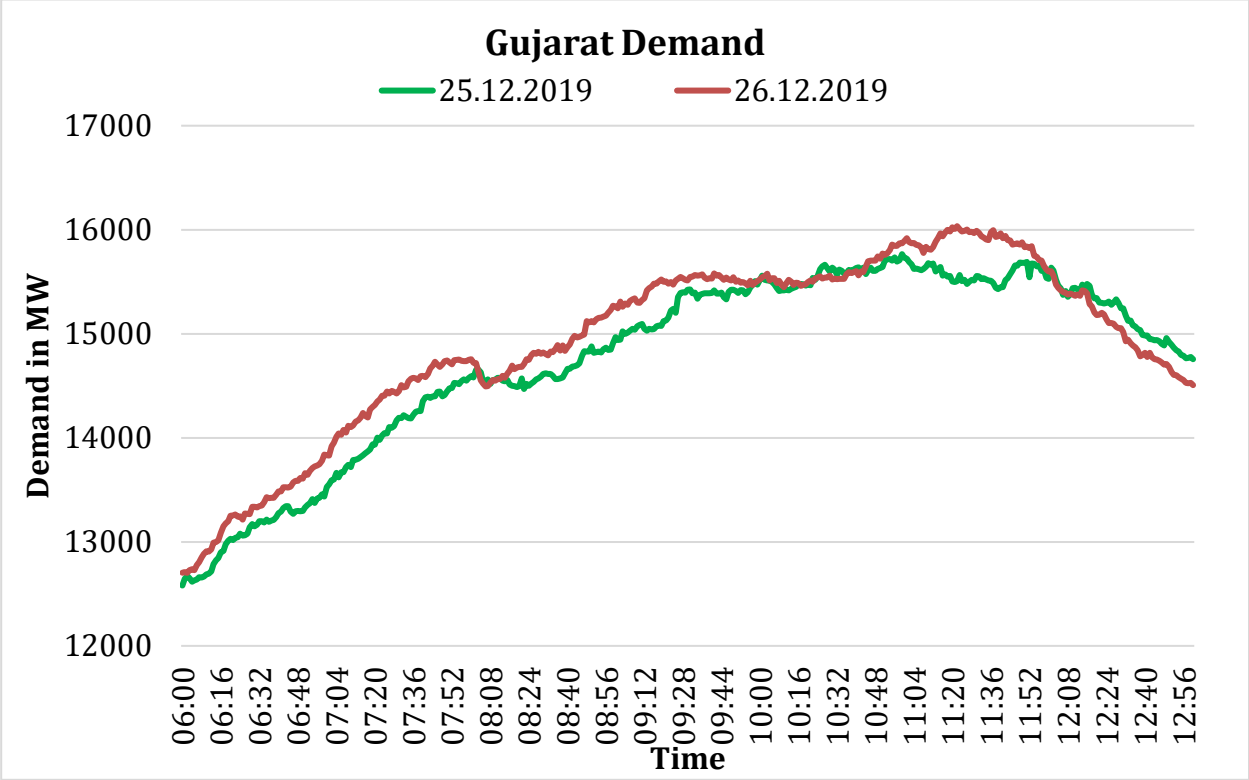


Figure 102: Gujarat Demand

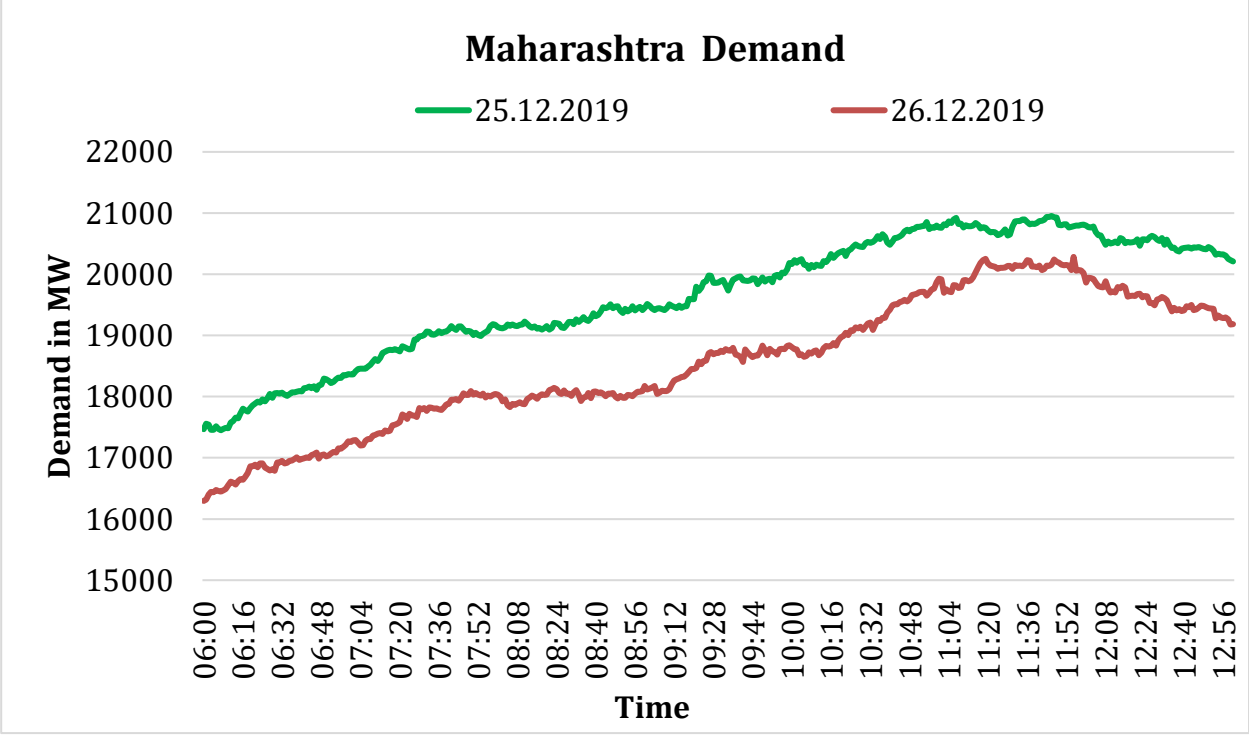


Figure 103: Maharashtra Demand

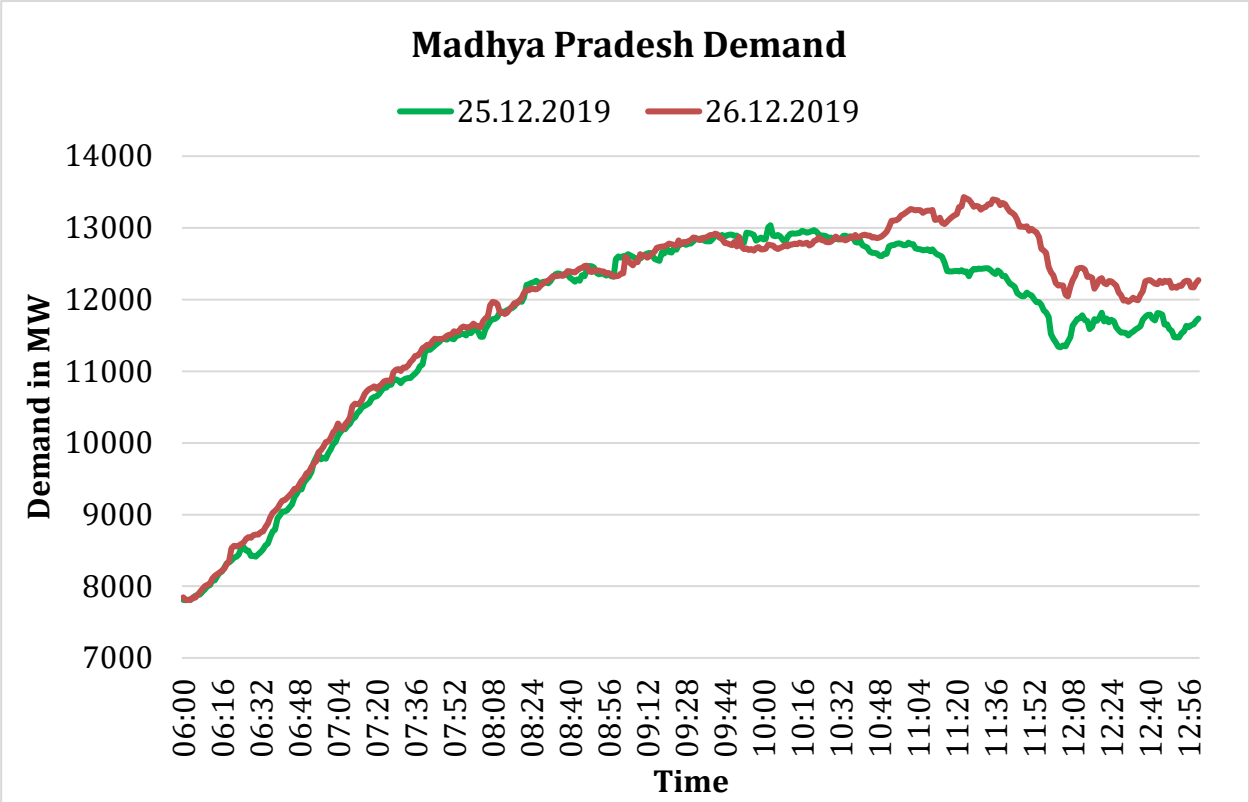


Figure 104: Madhya Pradesh Demand

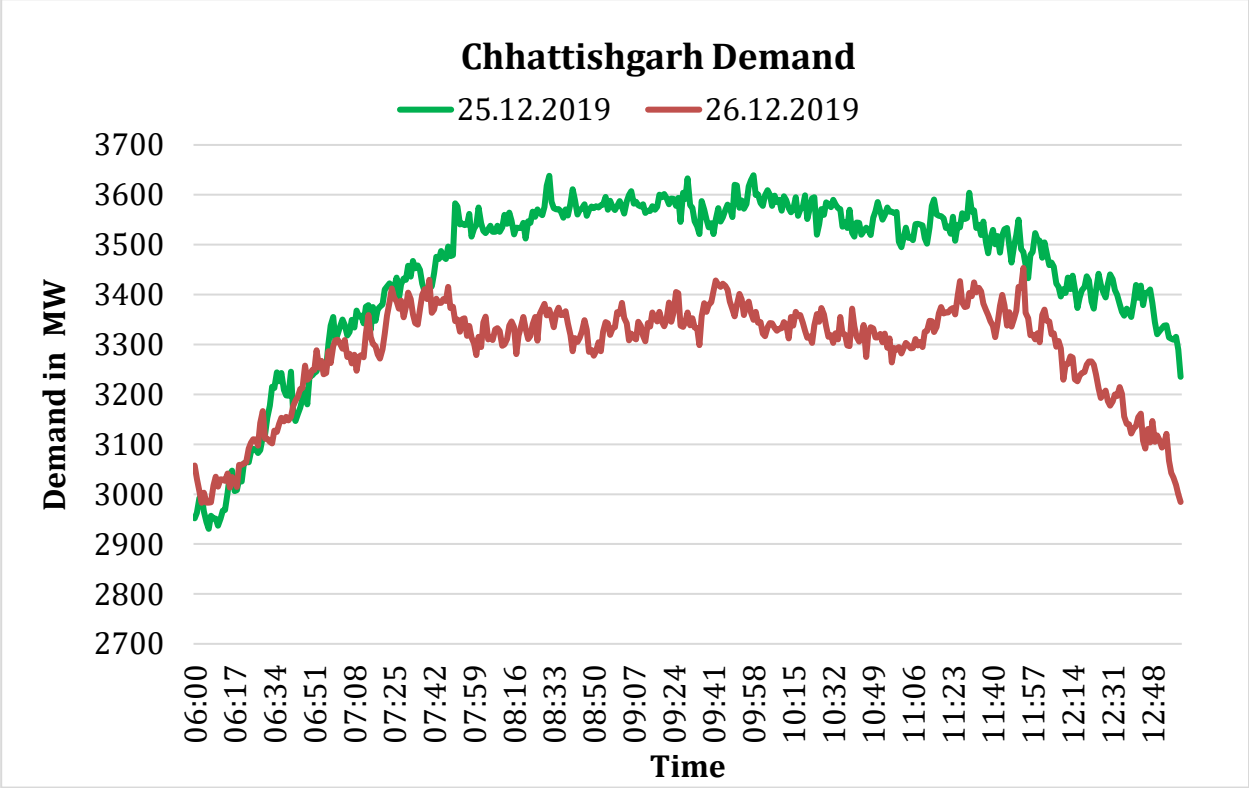


Figure 105: Chhattisgarh Demand

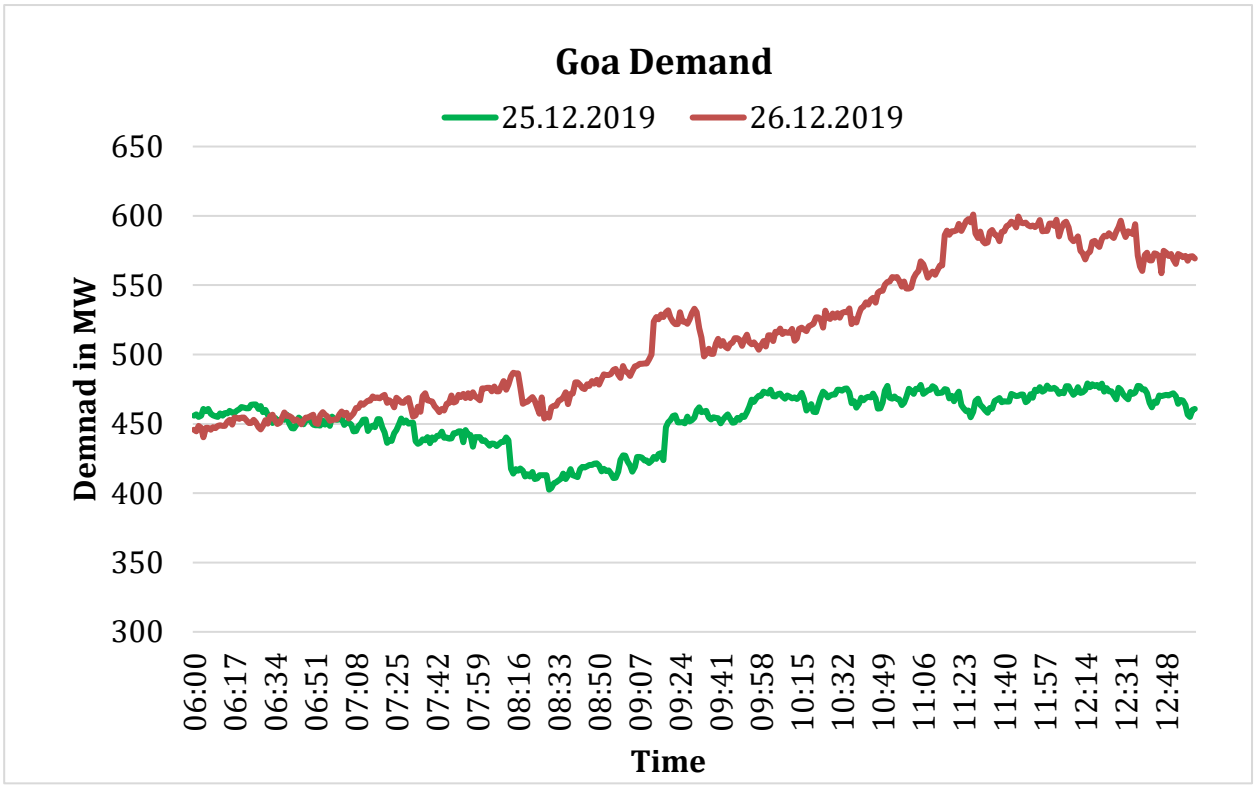


Figure 106: Goa Demand

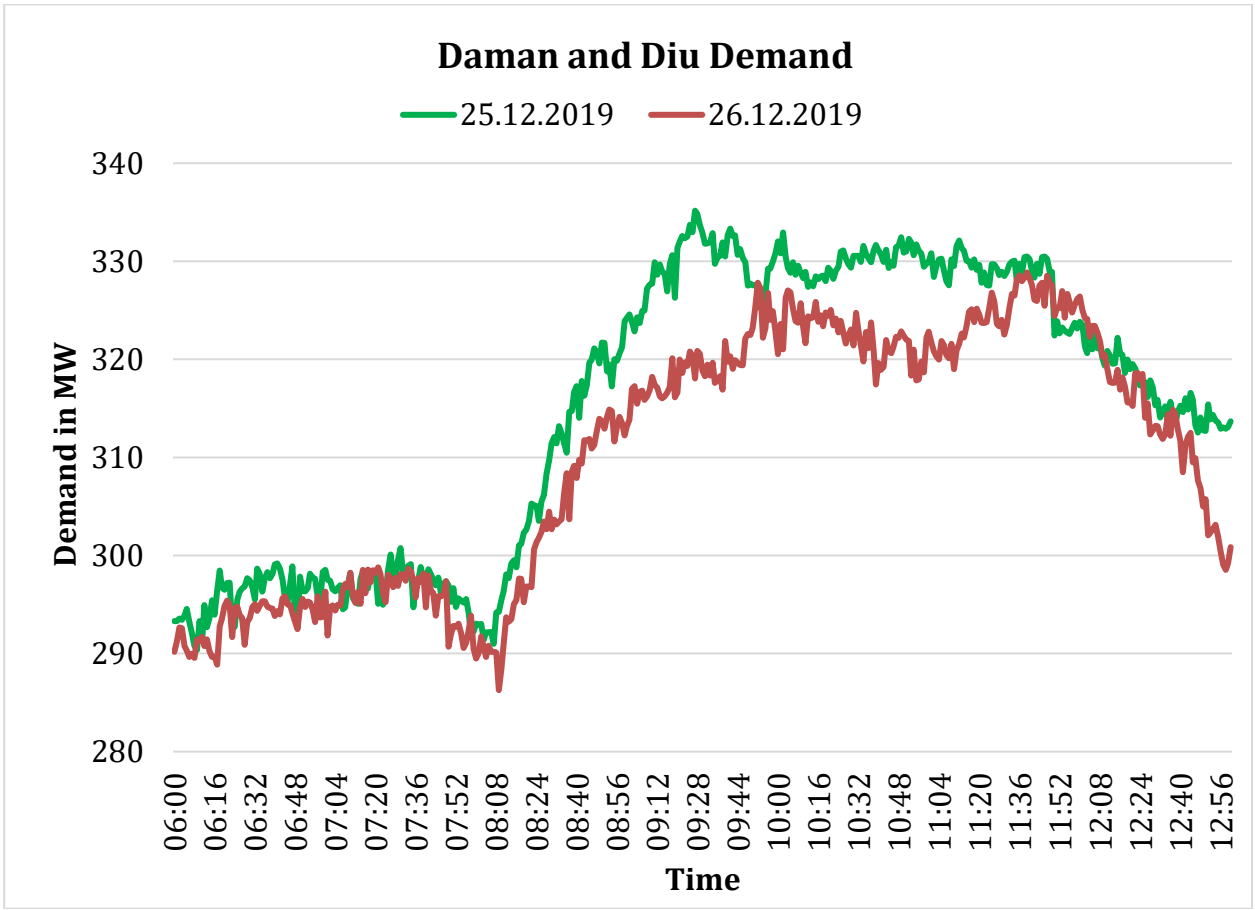


Figure 107: Daman and Diu Demand

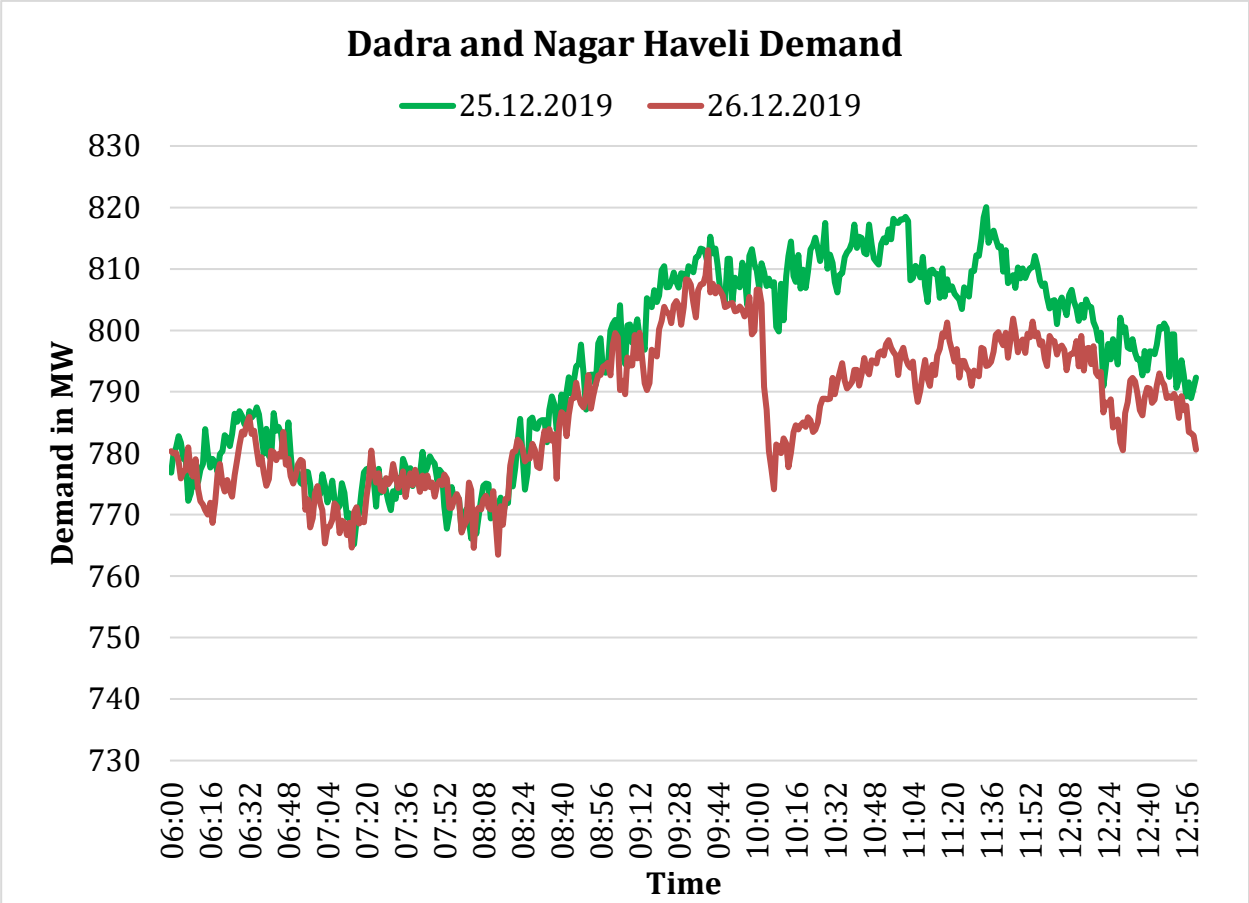


Figure 108: Dadra and Nagar Haveli Demand

Annexure- VIII

Northern Region States demand comparison for 25th and 26th December 2019

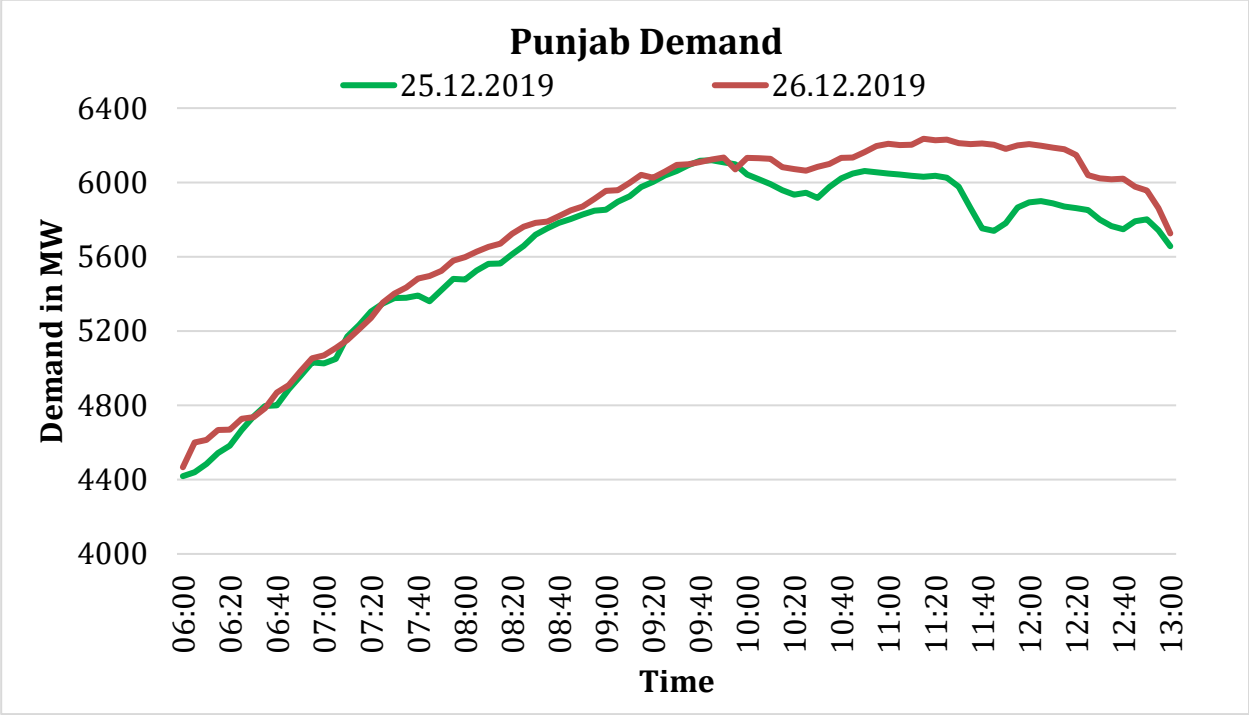


Figure 109: Punjab Demand

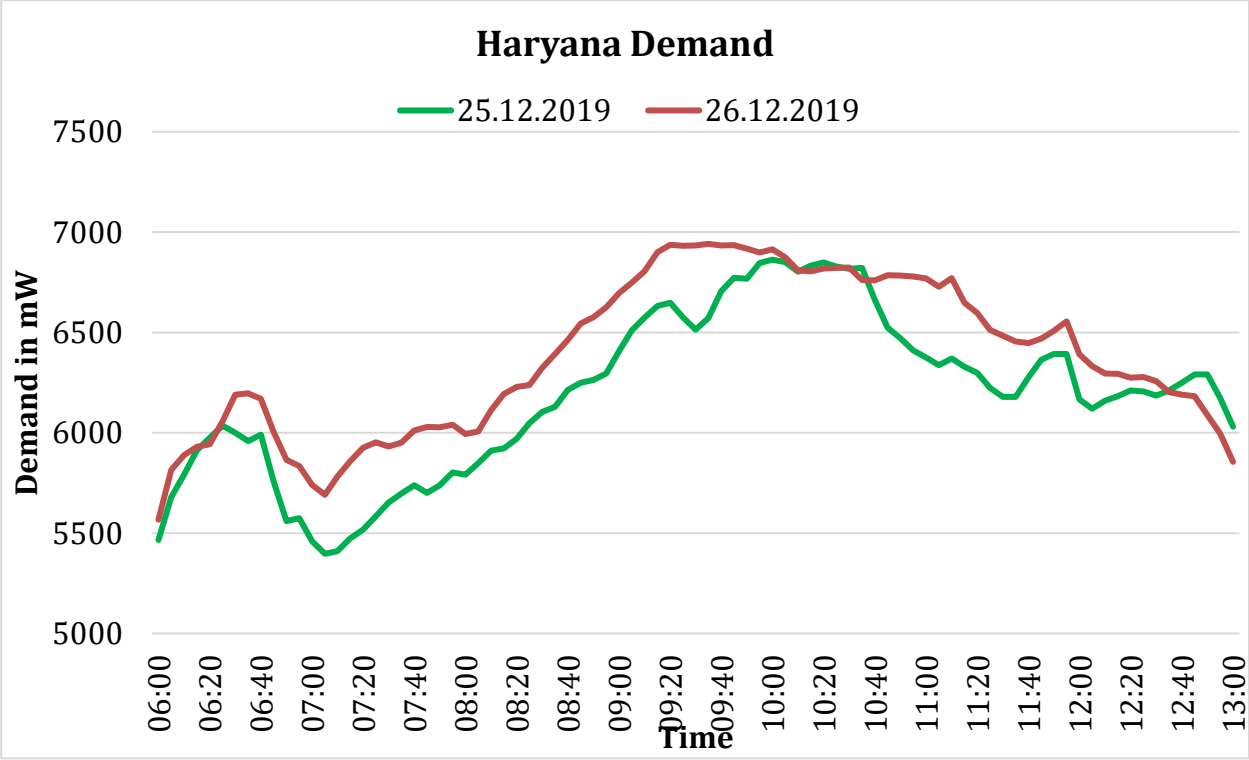


Figure 110: Haryana Demand

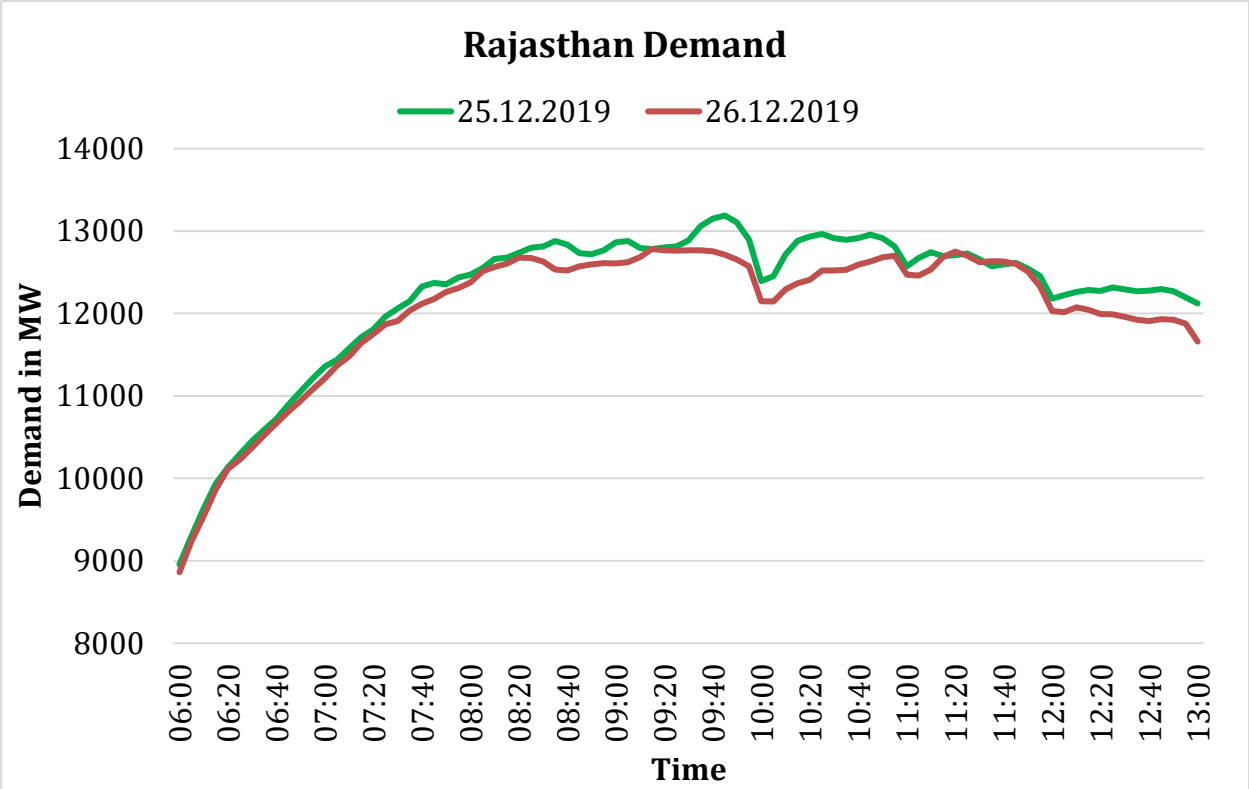


Figure 111: Rajasthan Demand

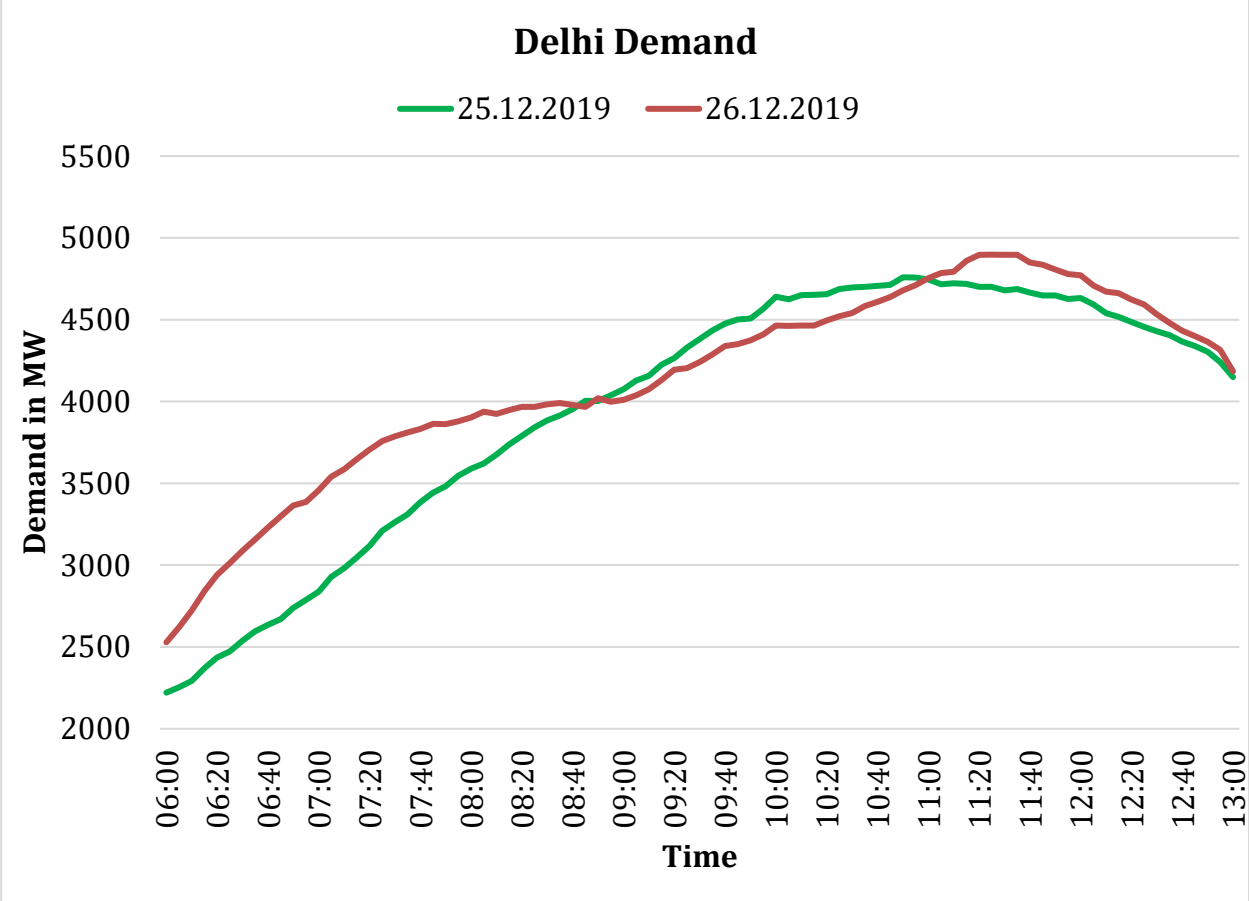


Figure 112: Delhi Demand

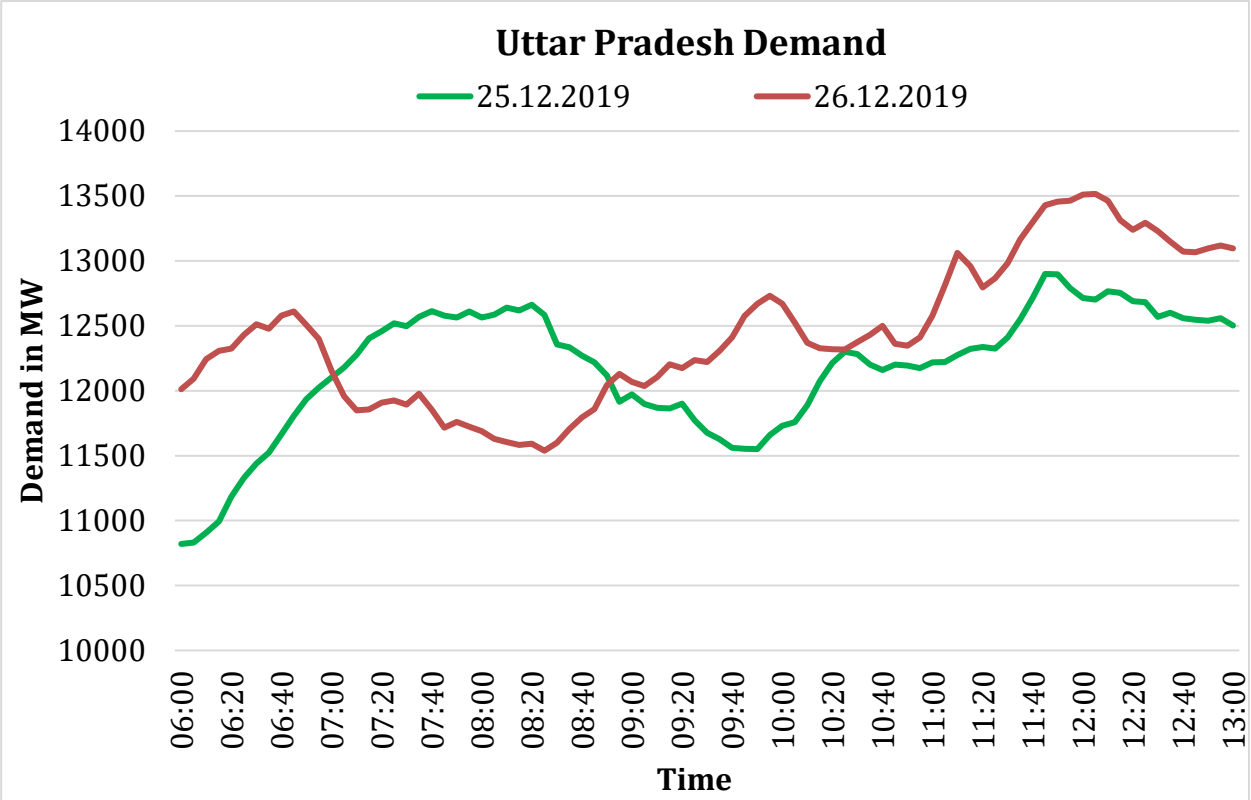


Figure 113: Uttar Pradesh Demand

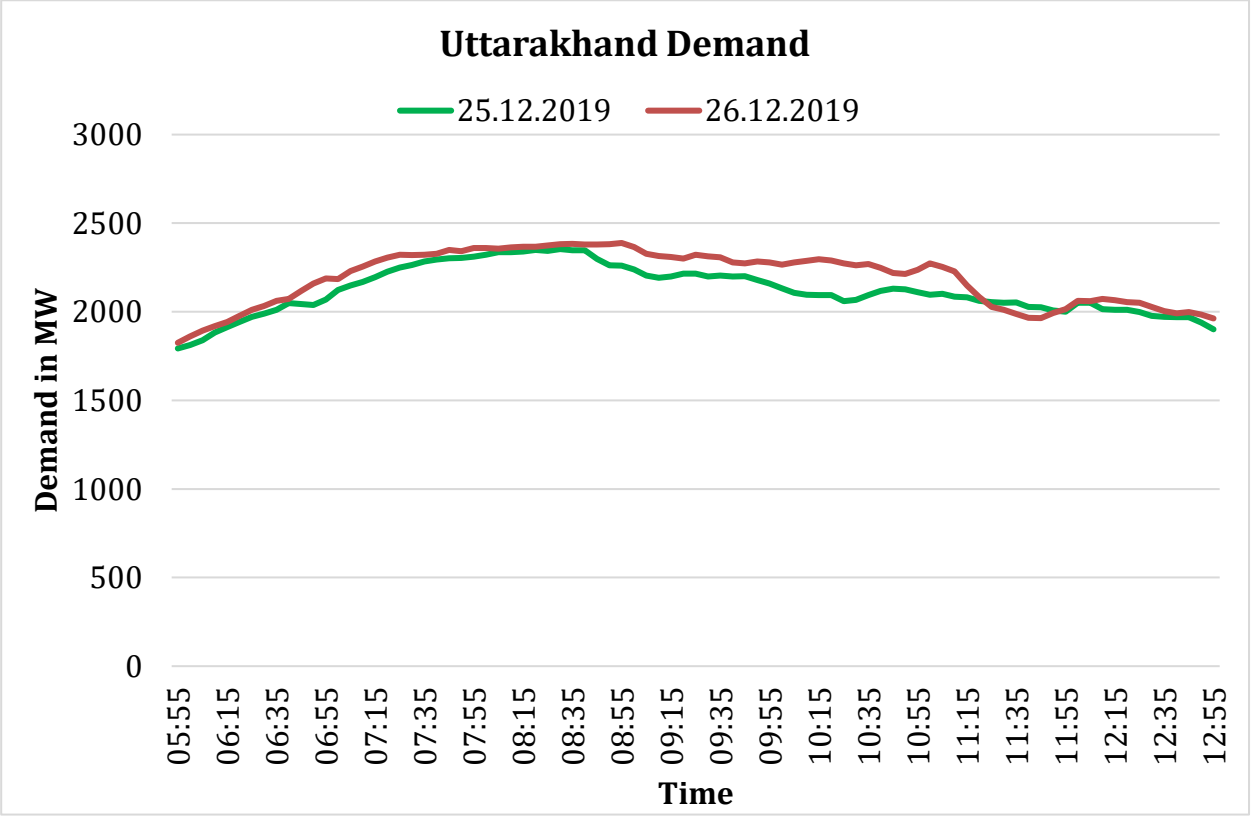


Figure 114: Uttarakhand Demand

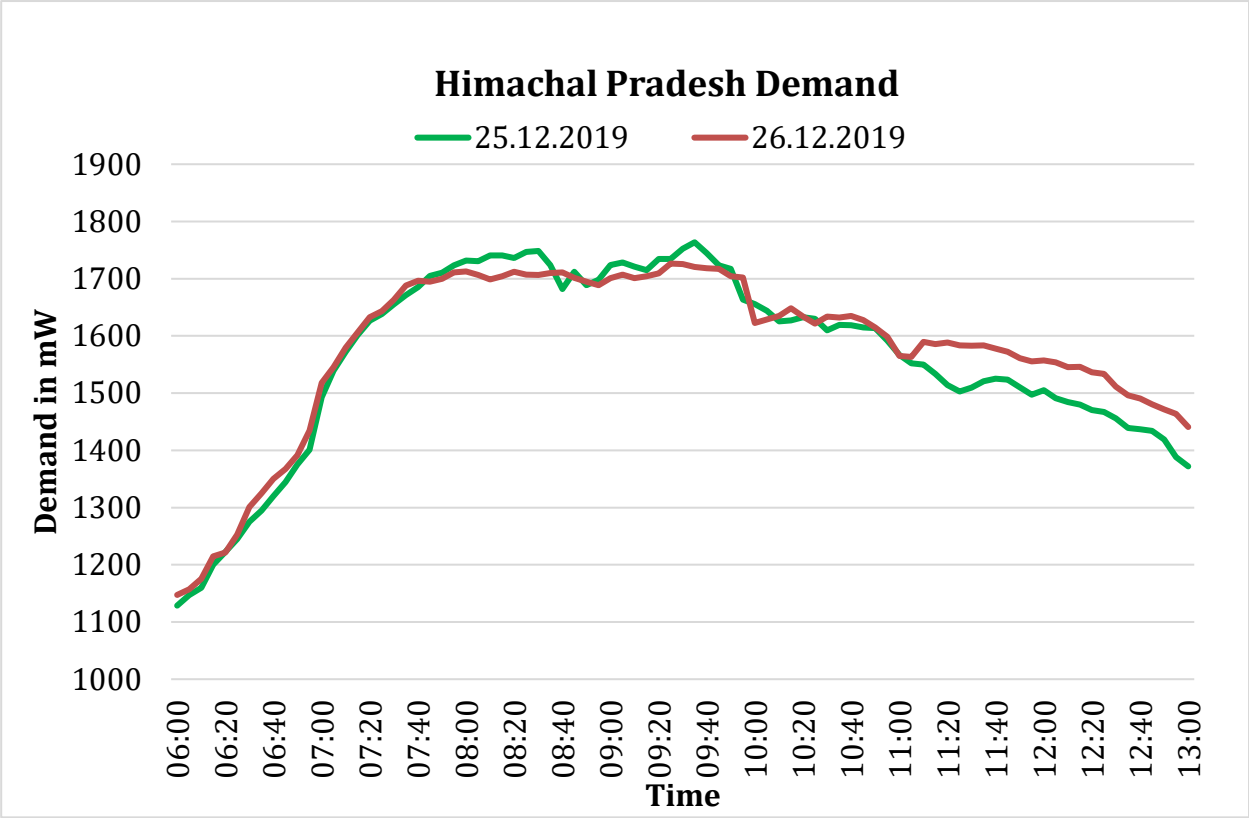


Figure 115: Himachal Pradesh Demand

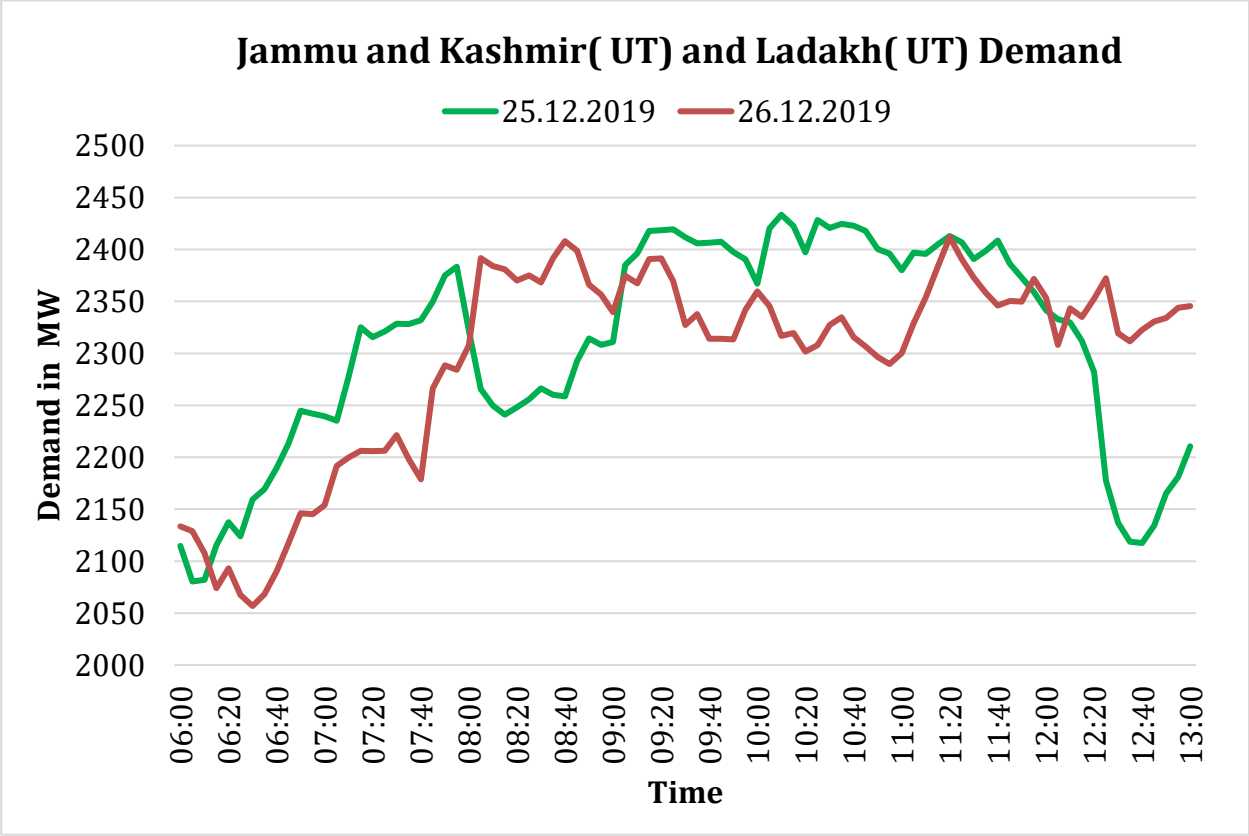


Figure 116: Jammu and Kashmir (UT) and Ladakh (UT) Demand

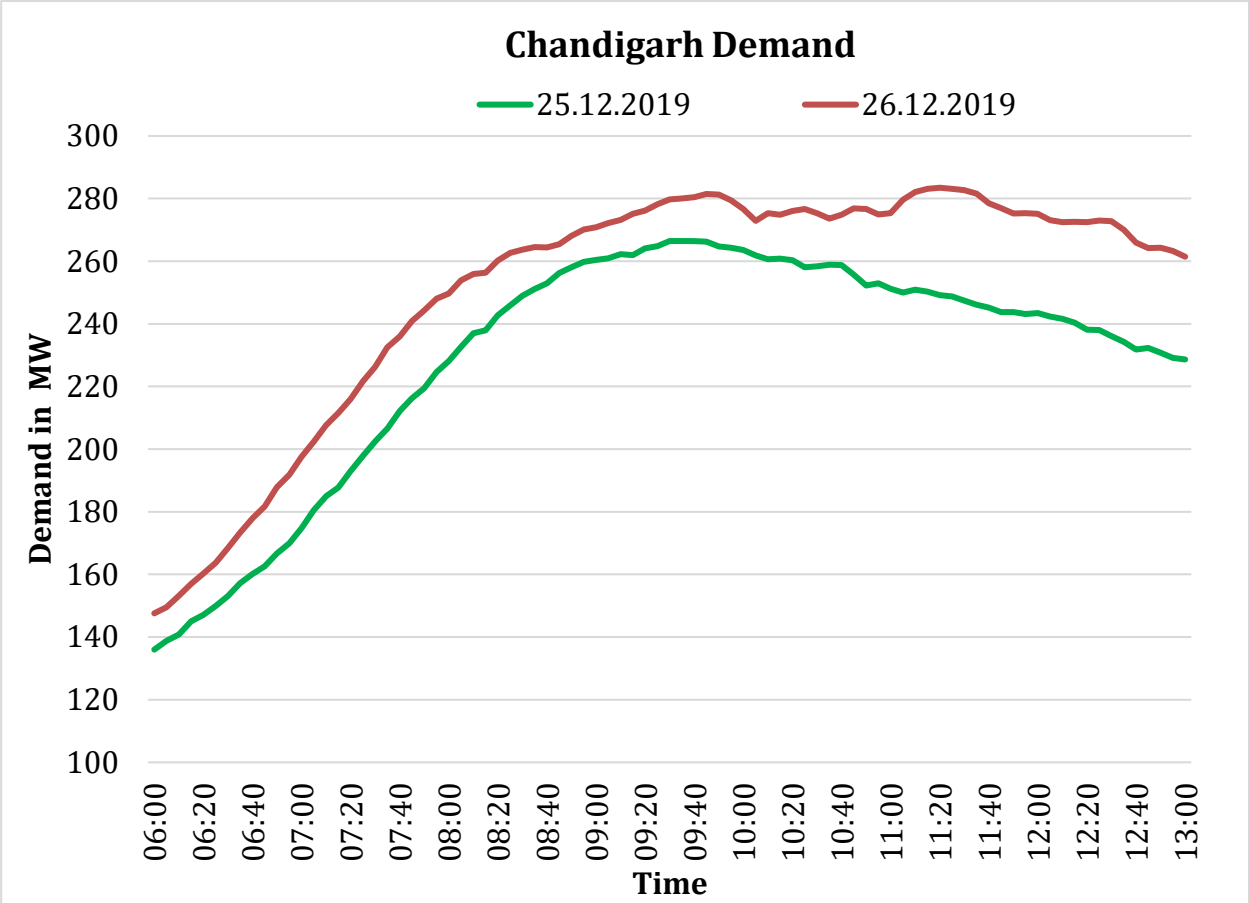


Figure 117: Chandigarh Demand

Annexure- IX

Eastern Region States demand comparison for 25th and 26th December 2019

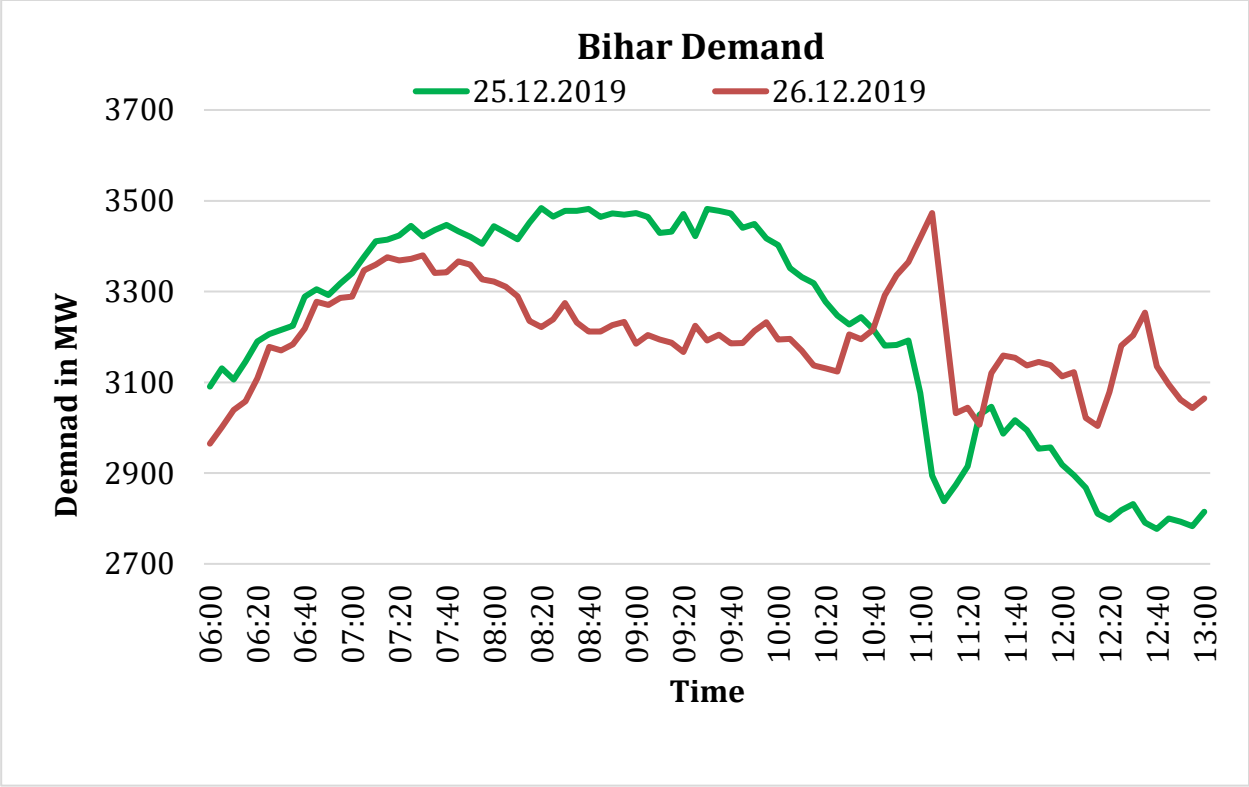


Figure 118: Bihar Demand

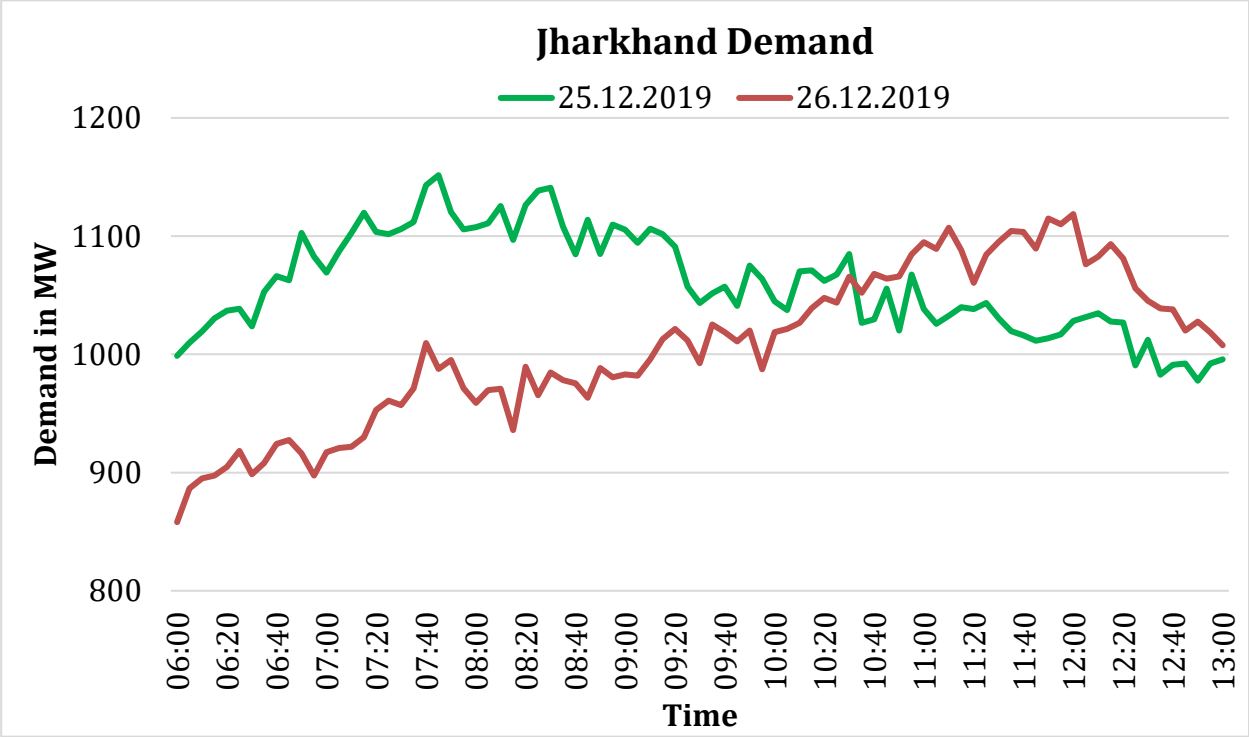


Figure 119: Jharkhand Demand

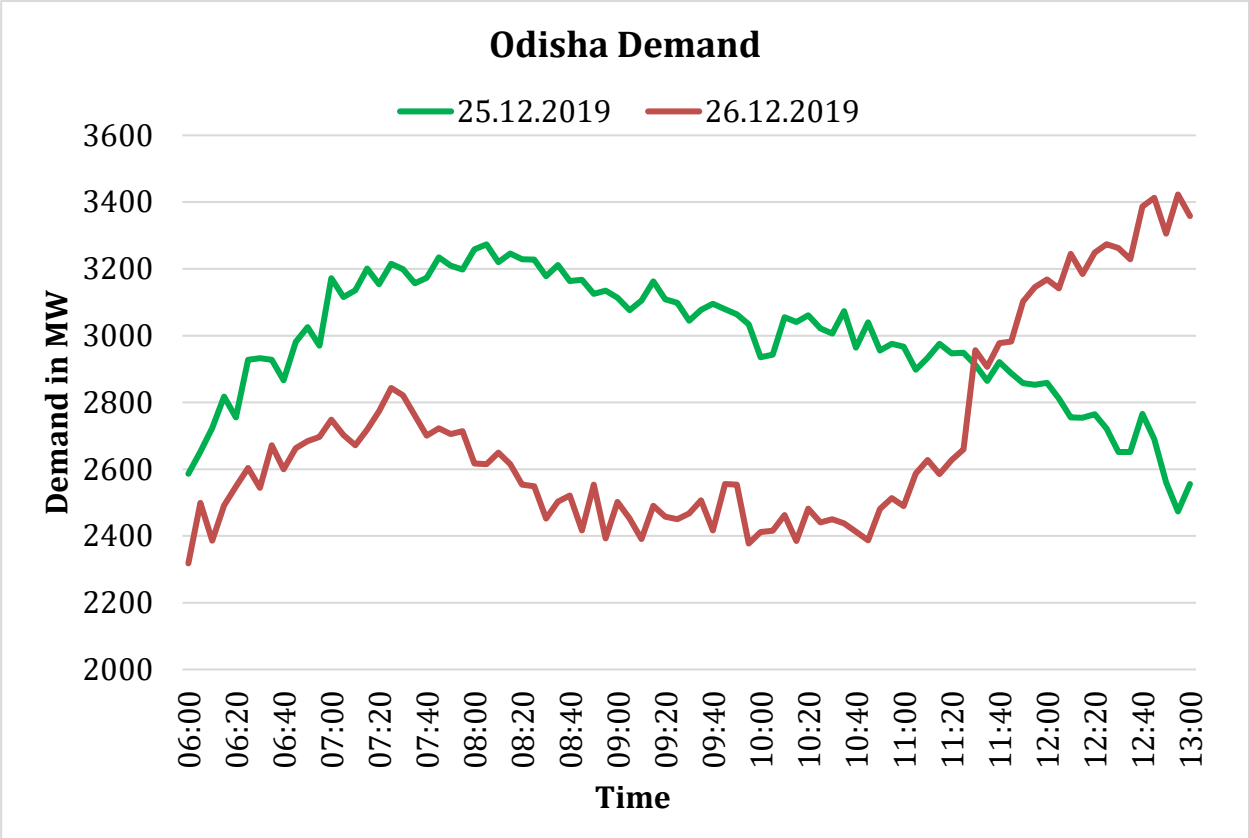


Figure 120: Odisha Demand

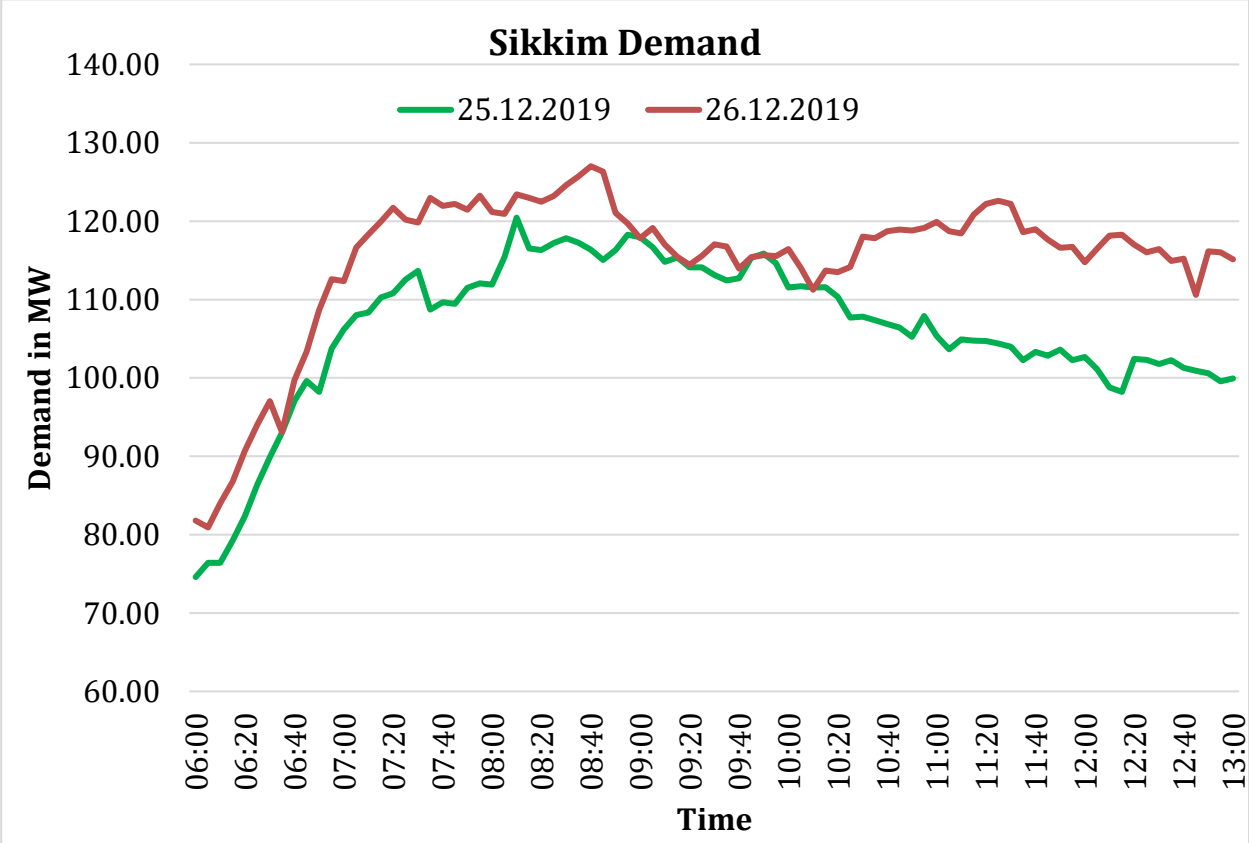


Figure 121: Sikkim Demand

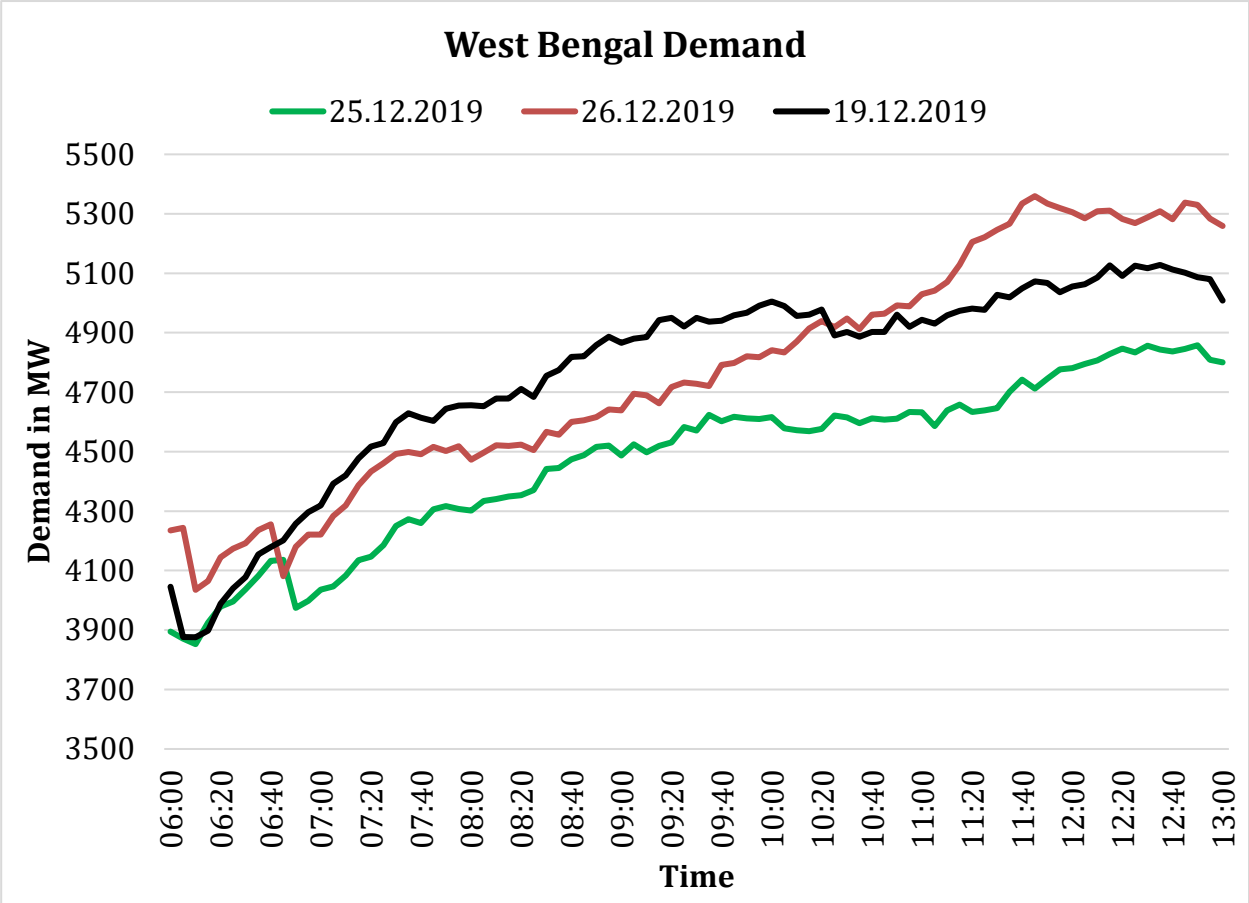


Figure 122: West Bengal Demand

Annexure- X

States Schedule vs Actual drawl

Southern Region:

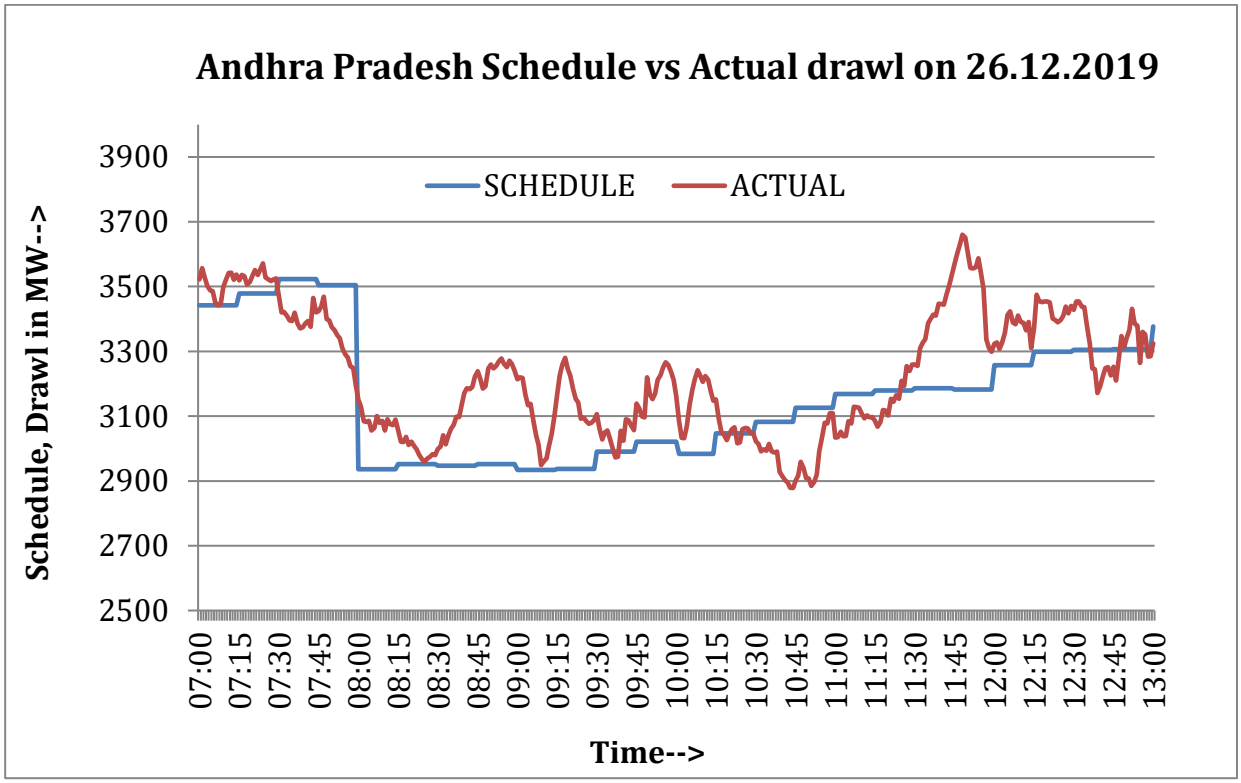


Figure 123: Andhra Pradesh Schedule vs Actual drawl on 26.12.2019

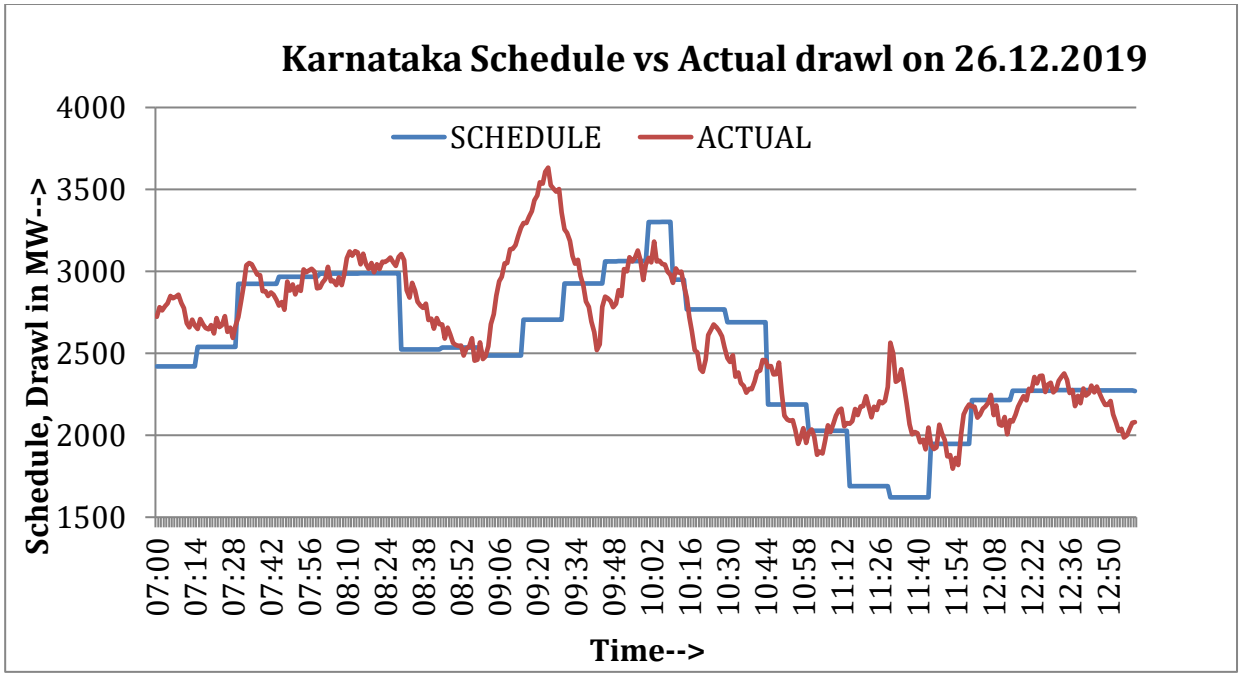


Figure 124: Karnataka Schedule vs Actual drawl on 26.12.2019

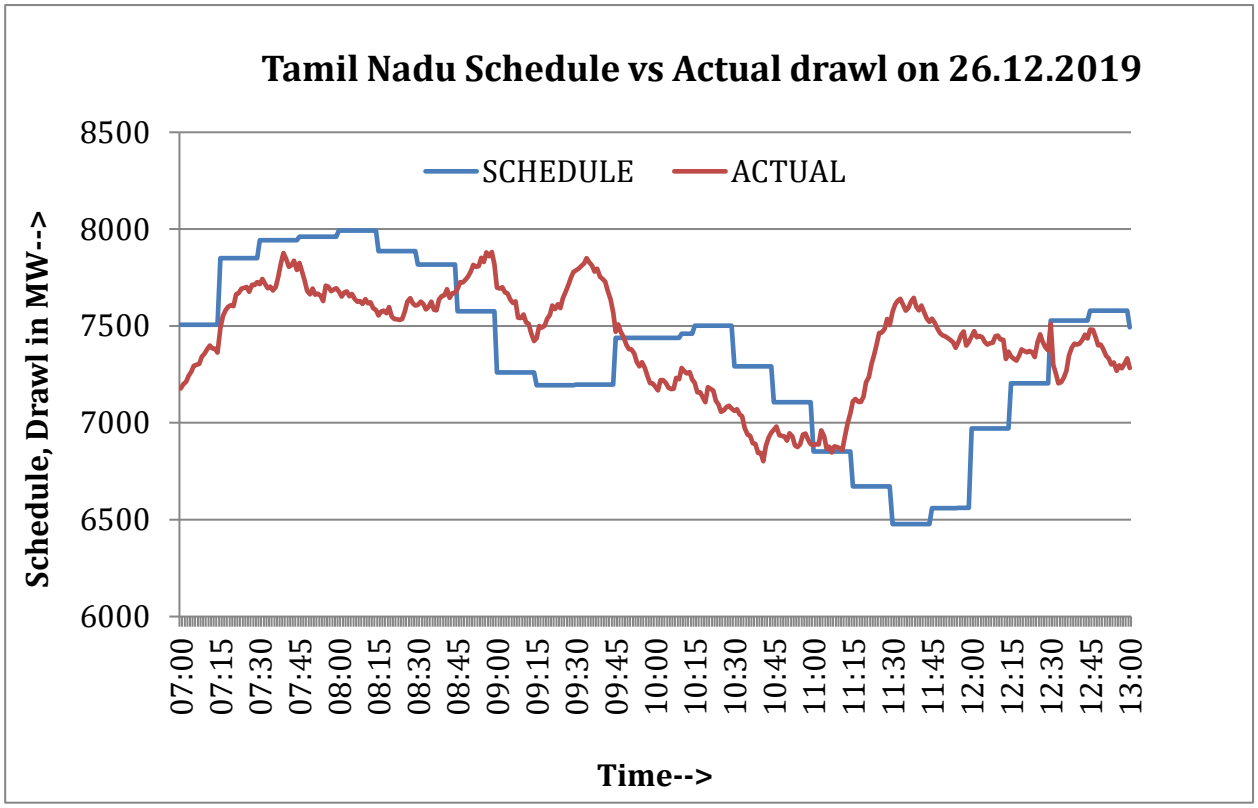


Figure 125: Tamil Nadu Schedule vs Actual drawl on 26.12.2019

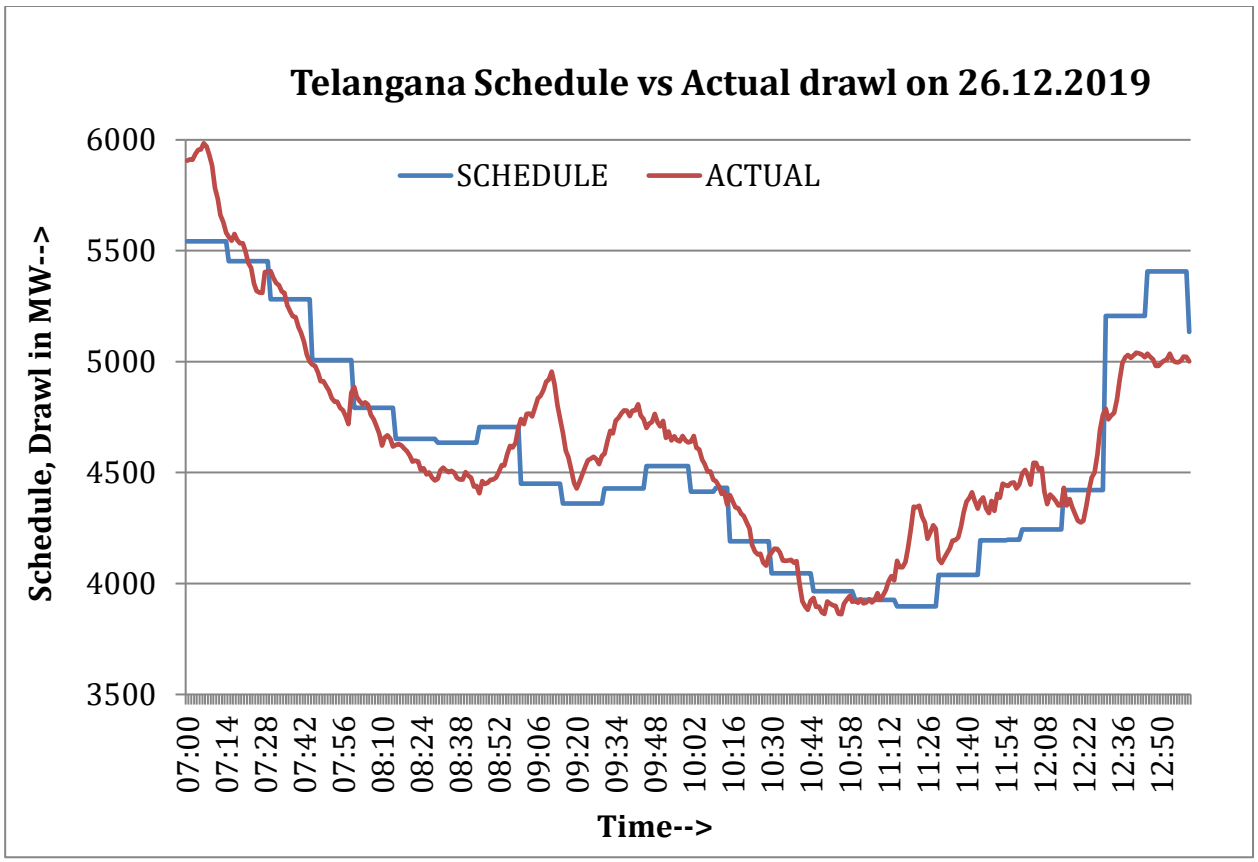


Figure 126: Telangana Schedule vs Actual drawl on 26.12.2019

Western Region

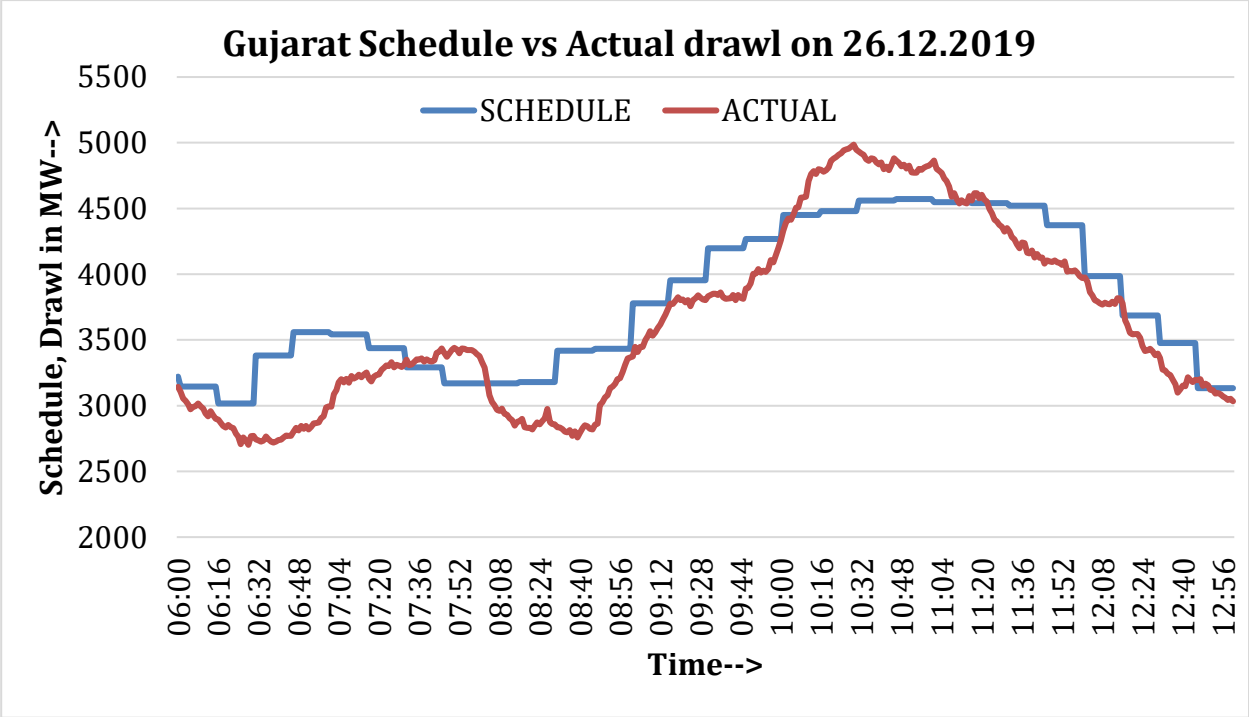


Figure 127: Gujarat Schedule vs Actual drawl on 26.12.2019

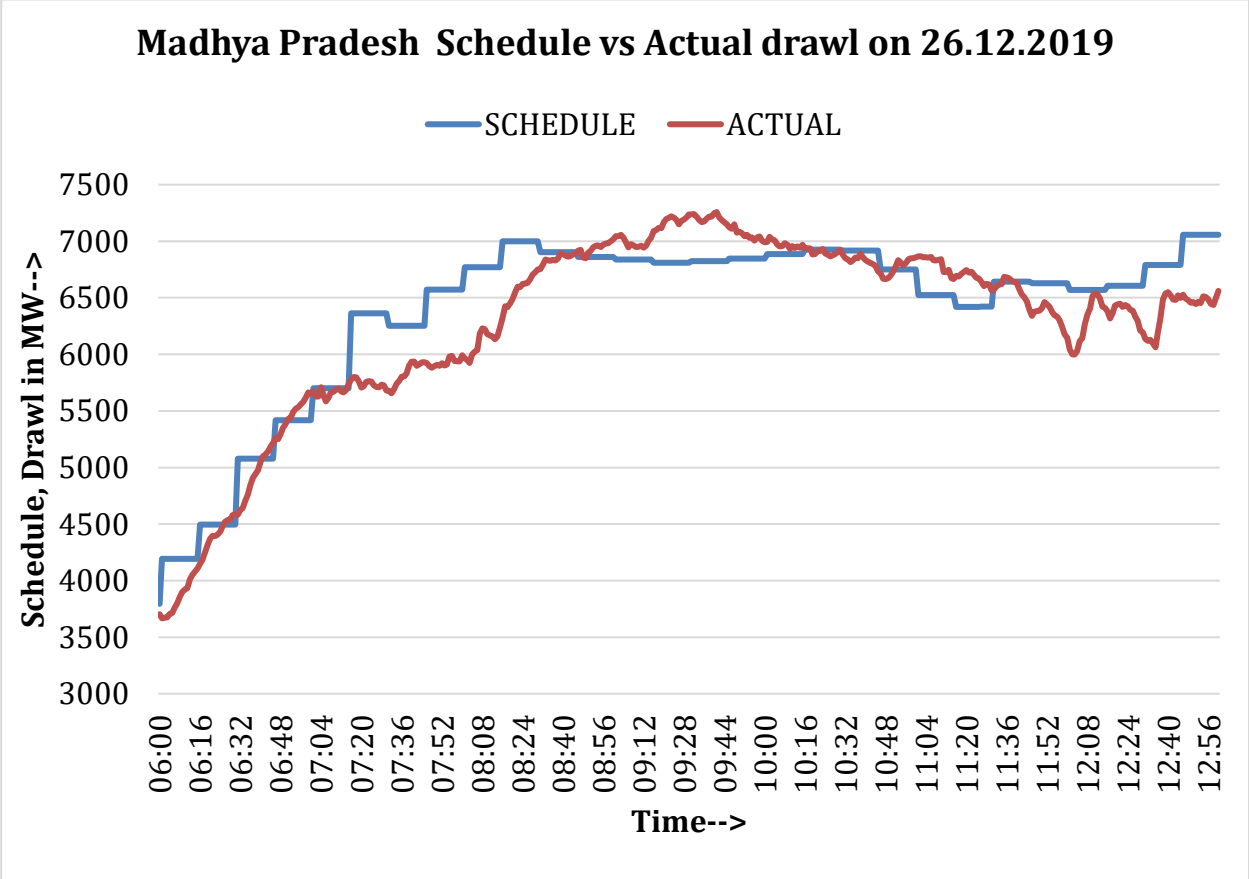


Figure 128: Madhya Pradesh Schedule vs Actual drawl on 26.12.2019

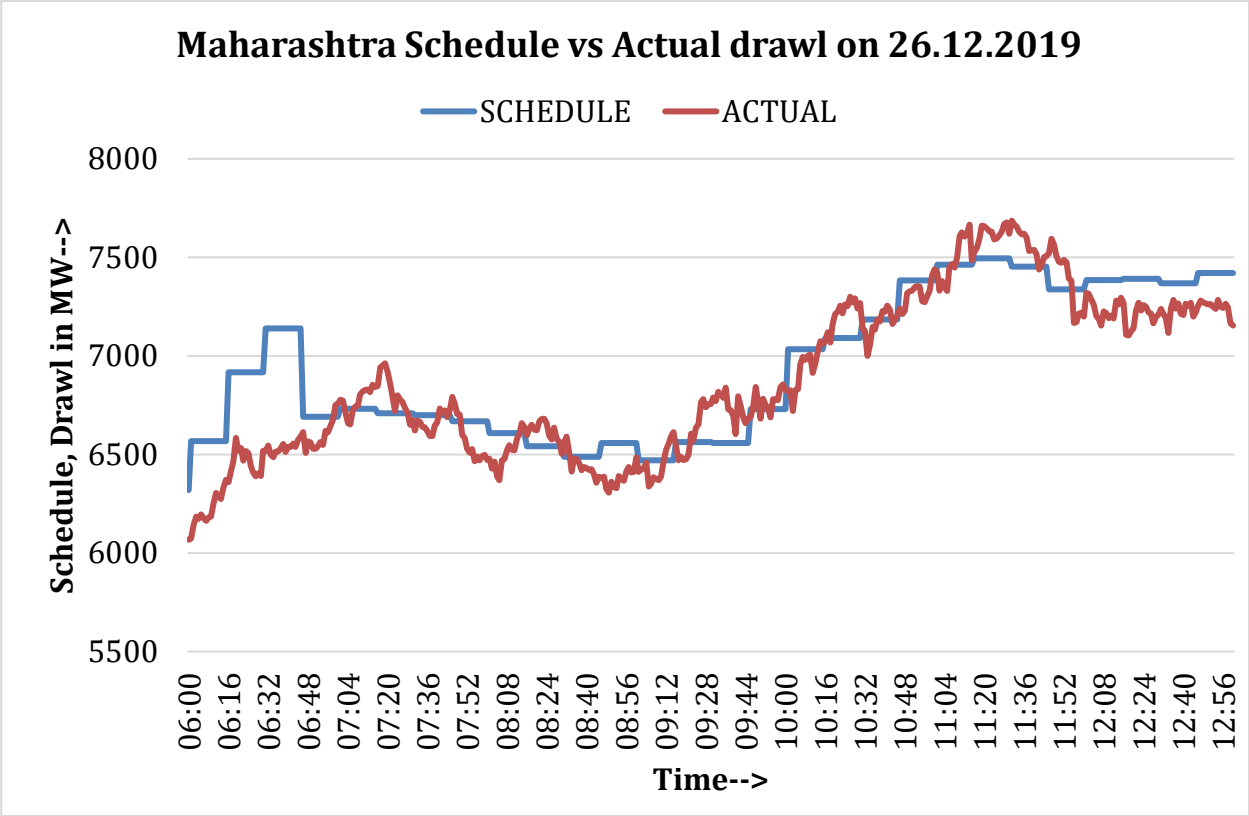


Figure 129: Maharashtra Schedule vs Actual drawl on 26.12.2019

Northern Region

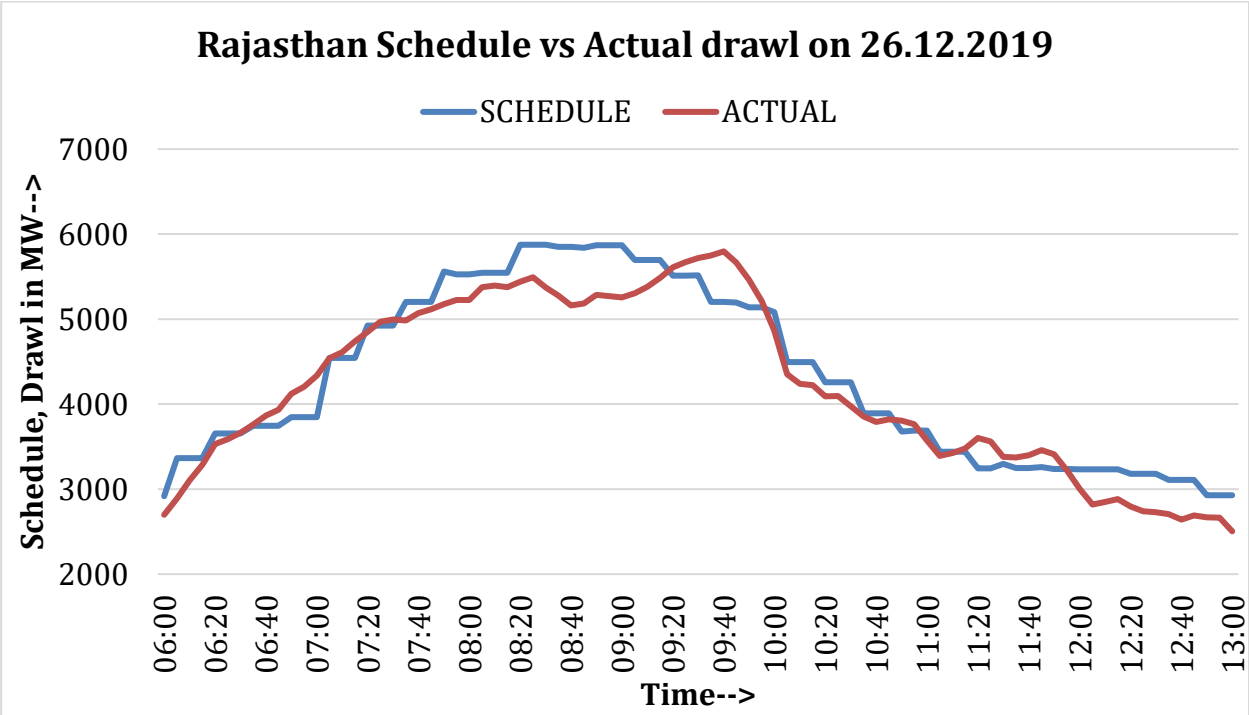


Figure 130: Rajasthan Schedule vs Actual on 26.12.2019

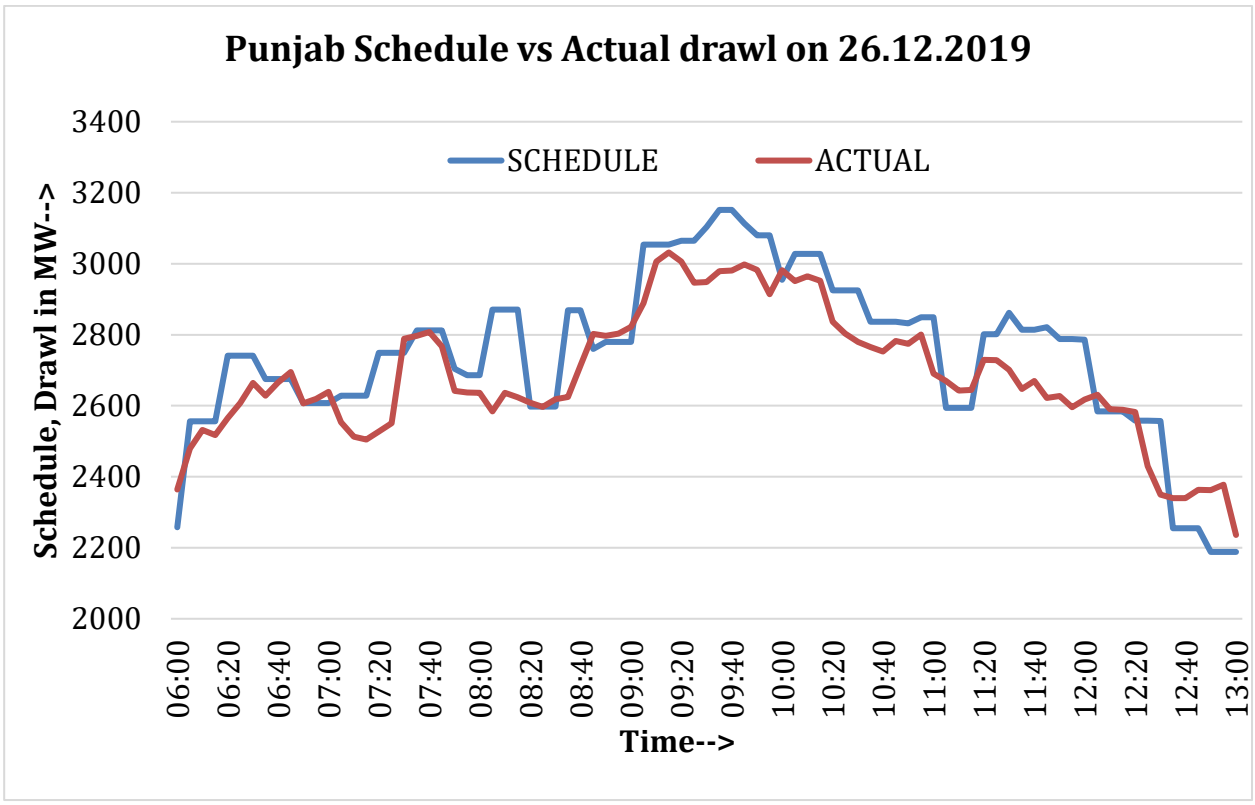


Figure 131: Punjab Schedule vs Actual on 26.12.2019

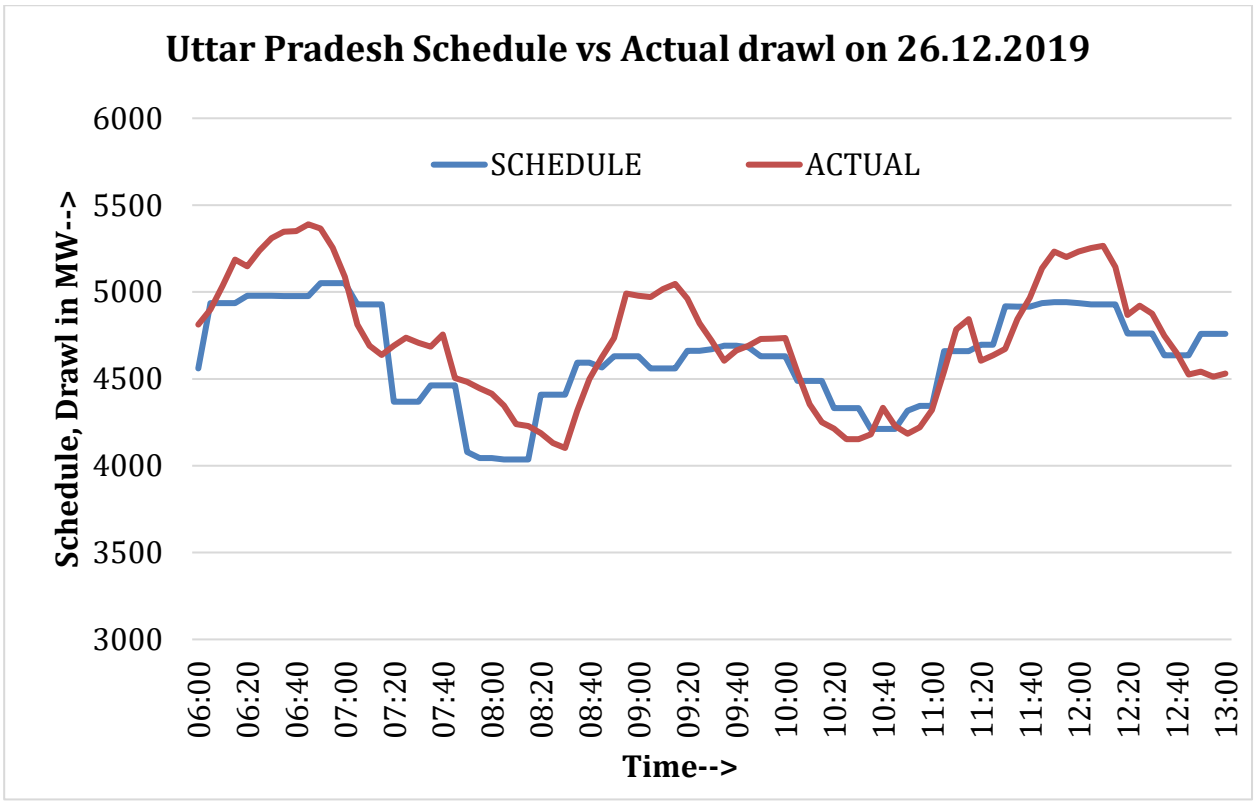


Figure 132: Uttar Pradesh Schedule vs Actual on 26.12.2019

Annexure- XI

State wise Area Control Error

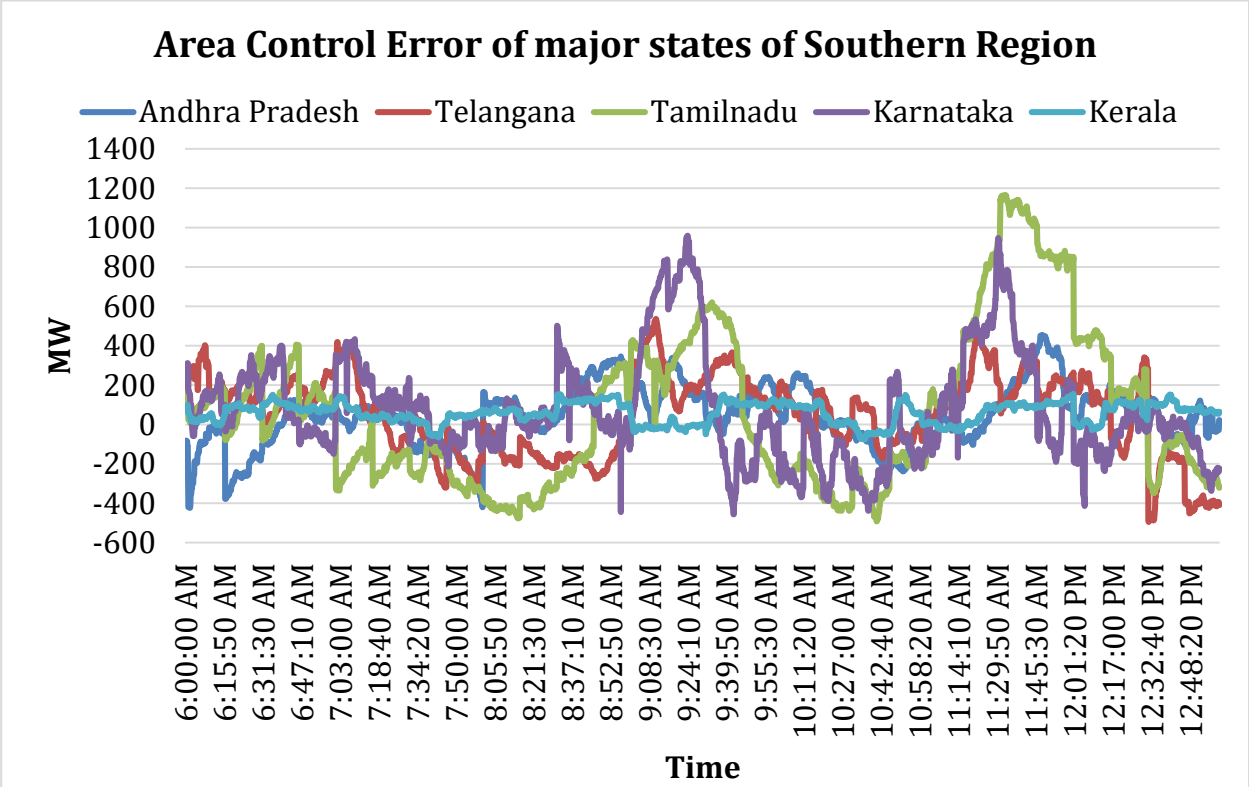


Figure 133: Area Control Error of major states of Southern Region

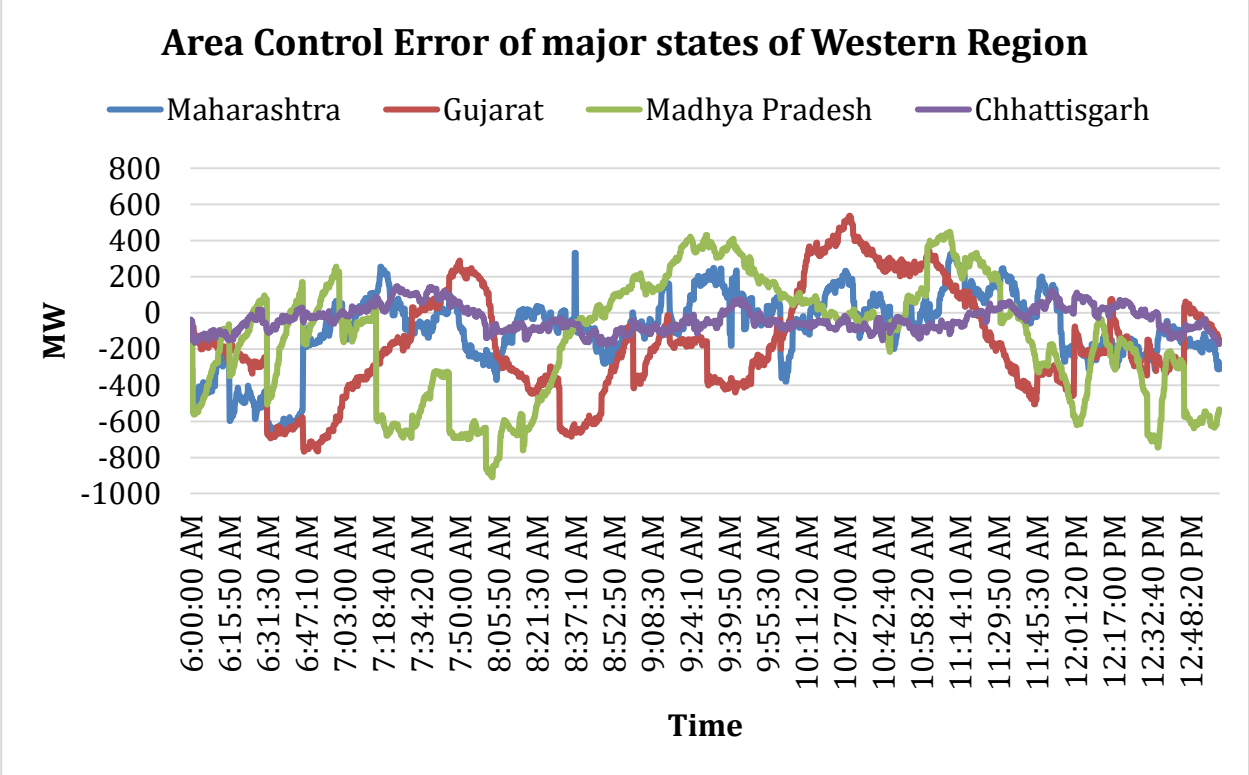


Figure 134: Area Control Error of major states of Western Region

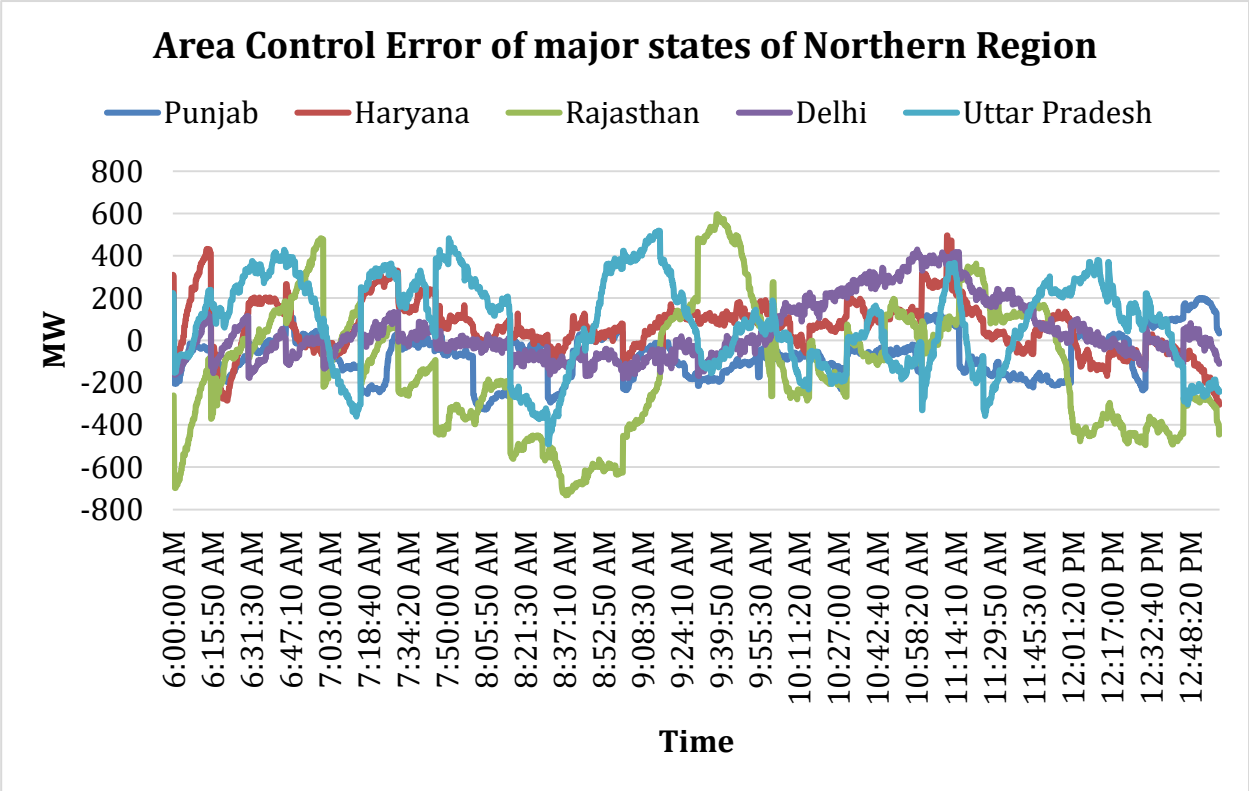


Figure 135: Area Control Error of major states of Northern Region

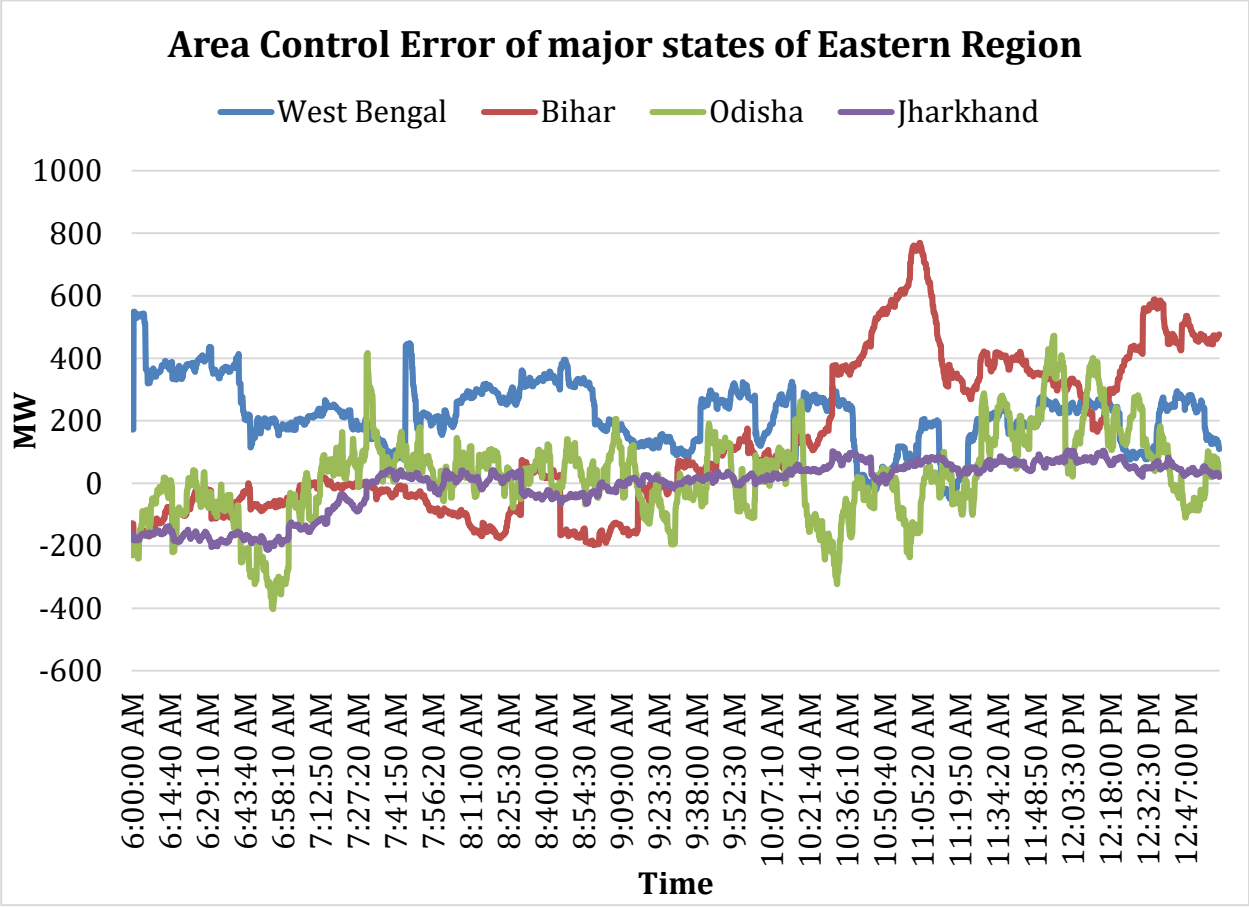


Figure 136: Area Control Error of major states of Eastern Region

Task Force Committee

Overall guidance and supervision: Shri. S R Narasimhan, Director (System Operation)

Task Force Committee Members:

- Shri Alok Kumar (Team leader), Sr. Deputy General Manager, NRLDC
- Shri Sudheer Talluri, Manager, NLDC
- Shri Sunil Kumar Kanaujiya, Manager,NRLDC
- Shri A. Janardhan Reddy, Deputy Manager, SRLDC
- Shri Absar Ahmad, Deputy Manager, WRLDC
- Shri Rohit Anand, Deputy Manager, NLDC

Other Contributors:

- Shri R.S. Abhishek, Assistant Manager, SRLDC
- Shri Gaurav Malviya, Deputy Manager, NRLDC
- Shri Paresh Khandelwal, Chief Manager, NRLDC
- Shri Vivek Pandey, Sr. Deputy General Manager, WRLDC
- Shri Ashok Kumar, Sr. Deputy General Manager, NLDC

Reviewed by:

- Shri Rajiv Porwal, Sr. General Manager, NLDC
- Shri N Nallarasan, Chief General Manager, NLDC
- Shri Debasis De, Executive Director, NLDC
- Shri S.S. Barpanda, Executive Director, NRLDC
- Shri S.K. Soonee, Advisor, POSOCO
- Shri S R Narasimhan,Director (System Operation), POSOCO
- Shri KVS Baba, Chairman and Managing Director, POSOCO

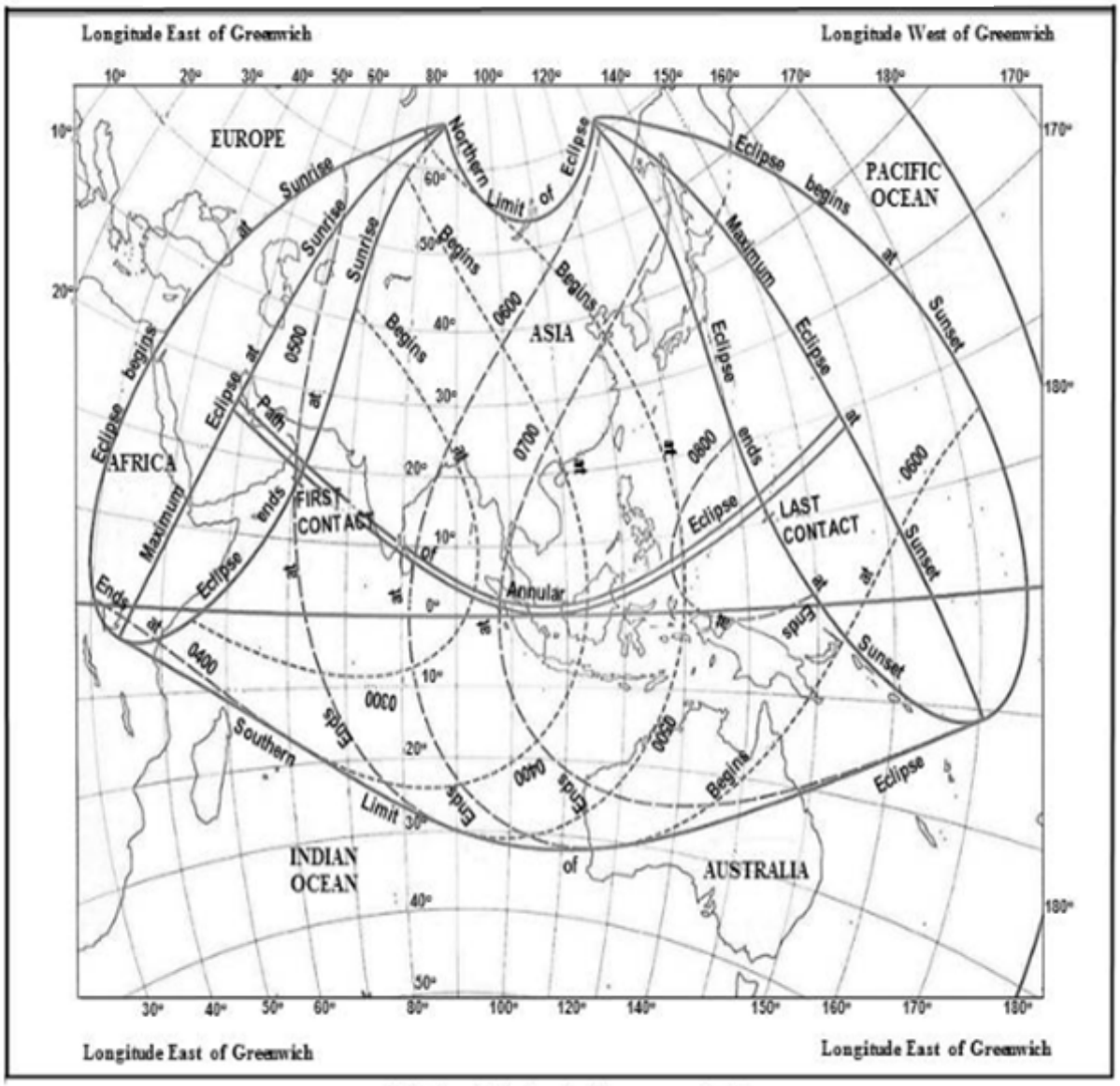
Disclaimer

Precautions have been taken by Power System Operation Corporation (POSOCO) to ensure that the accuracy of data / information in this report is accurate, reliable and complete. However, before relying on the information from this report, users are advised to ensure its accuracy, completeness and relevance for their purposes. POSOCO shall not be responsible for any errors or omissions. All information is provided without warranty of any kind.

POSOCO disclaims all express, implied, and statutory warranties of any kind to user and/or any third party, including warranties as to accuracy, timeliness, completeness, merchantability, or fitness for any particular purpose. POSOCO have no liability in tort, contract, or otherwise to user and/or third party. Further, POSOCO shall, under no circumstances, be liable to user, and/or any third party, for any lost profits or lost opportunity, indirect, special, consequential, incidental, or punitive damages whatsoever, even if POSOCO has been advised of the possibility of such damages.

By reading this report, the users/reader confirm about their awareness and agreement to this disclaimer and associated terms referred elsewhere.

ANNULAR SOLAR ECLIPSE OF 26th DECEMBER 2019



The timings of beginning and ending are expressed in UT

Power System Operation Corporation Ltd.

(A Government of India Enterprise)

Registered Office : B-9, Qutab Institutional Area,
Katwaria Sarai, New Delhi - 110016