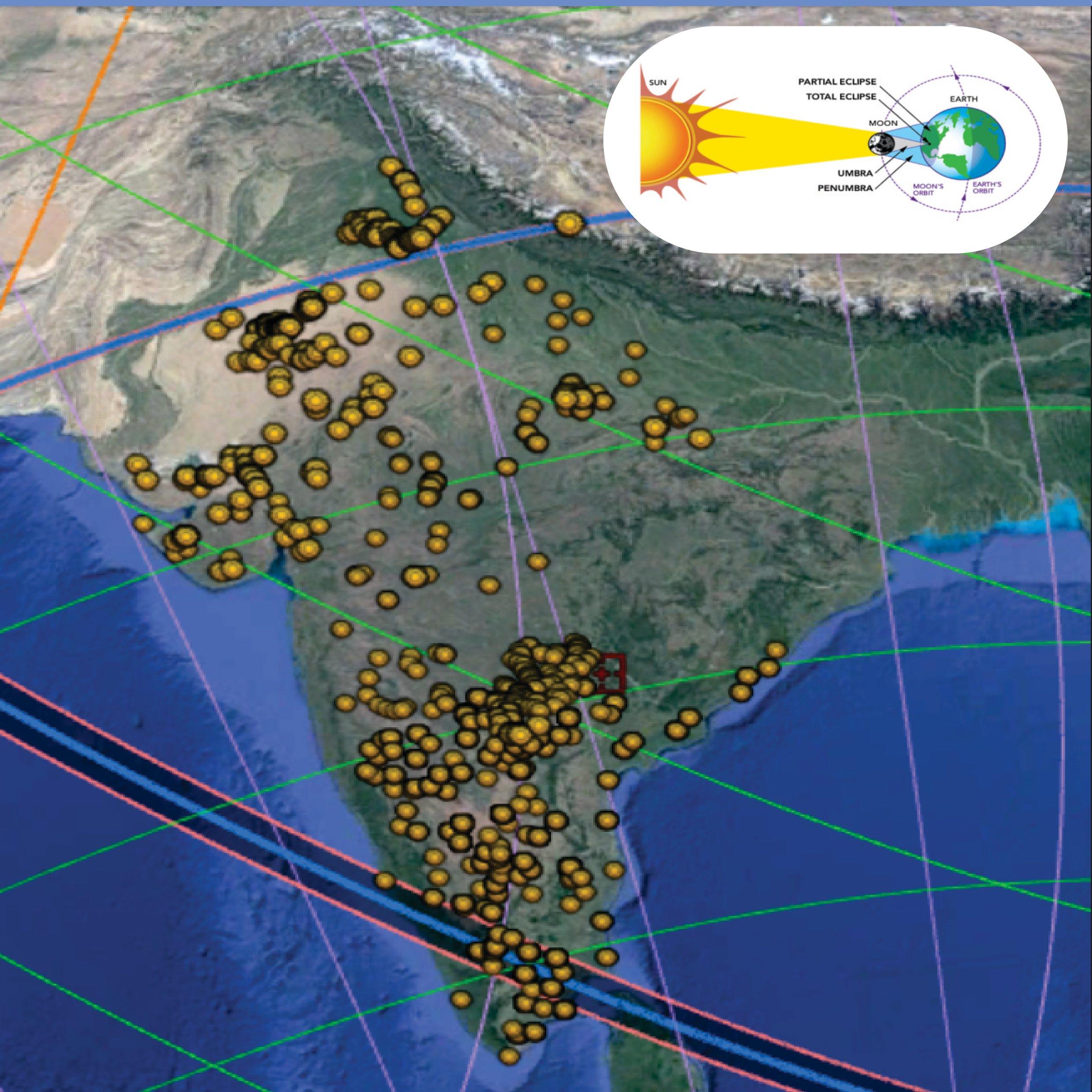
Indian Power System likely impacts and preparedness - A report

November 2019



Power System Operation Corporation Ltd.

(A Government of India Enterprise)

चन्द्रो जलमर्कोऽग्निर्मृद्भूश्छायापि या तमस्तद्धि |
छादयति शशी सूर्यं शशिनं महती च भूच्छाया ||

[आर्यभाटीय, गोलपादः 37]

"Moon is of water, sun is of fire, earth is of soil,

and its shadow is of darkness.

The moon covers the sun, and the great

shadow of the earth covers the moon."

[The book of Aryabhata, Sphere section, #37]

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LIST OF ACRONYMS

ATC: Available Transfer Capability

ACE: Area Control Error

BA: Balancing Authority

CE: Continental Europe Synchronous Area

CGS: Central Generating Station

CAISO: California Independent System Operator

DPV: Distribution-level PV Systems

DSO: Distribution System Operator

ER: Eastern Region

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

LGBR: Load Generation Balance Report

NLDC: National Load Dispatch Centre

NERC: North American Electric Reliability Corporation

NR: Northern Region

NER: North Eastern Region

NTPC: National Thermal Power Corporation Ltd.

POSOCO: Power System Operation Corporation Ltd.

PV: Photovoltaic

PSSE: Power System Simulator for Engineering

RE: Renewable Energy

RSD: Reserve Shutdown

REMC: Renewable Management Centre

RLDC: Regional Load Dispatch Centre

SLDC: State Load Dispatch Centre

SR: Southern Region

SCADA: Supervisory Control and Data Acquisition

TSO: Transmission System Operator

UPV: Utility-Scale PV System

URS: Un-Requisitioned Surplus Power

WECC: Western Electric Coordinating Council

WR: Western Region

EXECUTIVE SUMMARY

India is going to experience two annular solar eclipses, first on 26th December 2019 and second on 21st June 2020. In first case, annularity will be visible mainly in South India i.e. in the states of Kerala, Tamil Nadu and Karnataka while the rest of the country will see partial eclipse of the Sun (even on the northernmost parts of India about 40% of the sun will be covered by the moon) . Secondly, on 21st June 2020, annular eclipse of the sun will be visible in Northern part of India i.e. states of Rajasthan, New Delhi, Punjab, Uttar Pradesh (west) and Uttarakhand will observe annular solar eclipse and other parts of India will observe partial eclipse.

Renewable energy sources are highly dependent on weather parameters such as wind speed & its direction, solar irradiance, temperature and astronomical events such as solar eclipse. By December 2019, the installed capacity of PV in India is slated to reach 34 GW and the eclipse has the potential to cause a large variation in solar generation during clear sky conditions. Solar eclipse poses a challenge for Indian power system having high percentage of solar power integration to grid, as it can cause the solar power in affected region to decrease with very high ramp and later increase quickly.

Objective:

This report has been produced by Power System Operation Corporation Ltd (POSOCO), to evaluate potential reliability consequences of the annular solar eclipse on Indian power system. The report also puts forward the operational preparedness required at state and regional level to mitigate the impact of solar eclipse on the Indian power system.

The main objectives of this report are as follows: -

- Study the potential effect of solar eclipse on Indian power system
- Estimation of total solar generation reduction
- Asses generation reserves requirement for managing the reduced solar generation
- Address ramping and balancing issue in the area of annular solar eclipse and partial solar eclipse
- Asses potential impact on Inter regional transmission corridor
- Coordination requirement between RLDCs, SLDCs, Generating plants and NLDC

- Bring out data requirements for post event analysis

Methodology:

- To enable assessment of the impact of solar eclipse, this report has referred to available literature and mitigation measures taken by ISOs in various parts of the world
- To understand the behaviour of solar irradiance in the event of solar eclipse, solar irradiance data for the month of January 2010 of Trivandrum has been obtained from India Meteorological Department (IMD). Based on the data, the co-relation between the irradiance and obscuration of previous event has been obtained
- The installed solar generation capacity of India has been mapped on Google Earth (map) with solar eclipse trajectory to estimate the impacted solar generation capacity w.r.t obscuration percentage
- In-house forecasting module has been utilised to forecast the demand during Eclipse period

Conclusion & Key Findings:

December 26th, 2019 annular solar eclipse may have a major impact on Southern Region which has highest penetration of solar generation.

- It has been estimated that 12.73 MU of solar generation would be affected during eclipse with a maximum of 7823 MW reduction at 09:30 hrs, out of which 5800 MW pertains to Southern Region
- During eclipse, it is anticipated that from 08:03 hrs to 09:30 hrs solar generation will reduce with an average ramp rate of 13MW/minute and from 09:30 to 11:30 hrs solar generation will increase with an average ramp rate of 122MW/minute
- Based on the past experience, it is anticipated that 2-3% of Southern Region demand may reduce during eclipse w.r.t to a normal day
- Hydro & Gas generation shall be utilized to tackle variation in ramp rates during eclipse

Way Forward:

The post event analysis is required to understand the behaviour of solar eclipse phenomenon on PV plants in India. Such an analysis becomes all the more pertinent in view of approximately 300 GW of solar generation capacity to be installed by year 2029-30 which will account for 36% share in India's energy mix.

1. INDIAN POWER SYSTEM -AN OVERVIEW

Indian electricity grid is one of the largest synchronous grid in the world, The Indian electricity grid has total installed generating capacity of around 360 GW [1]. The installed capacity comprises of 227.64 GW of Thermal, 45.39 GW of Hydro, 80.63 GW of Renewable and 6.78 GW of Nuclear Generation.

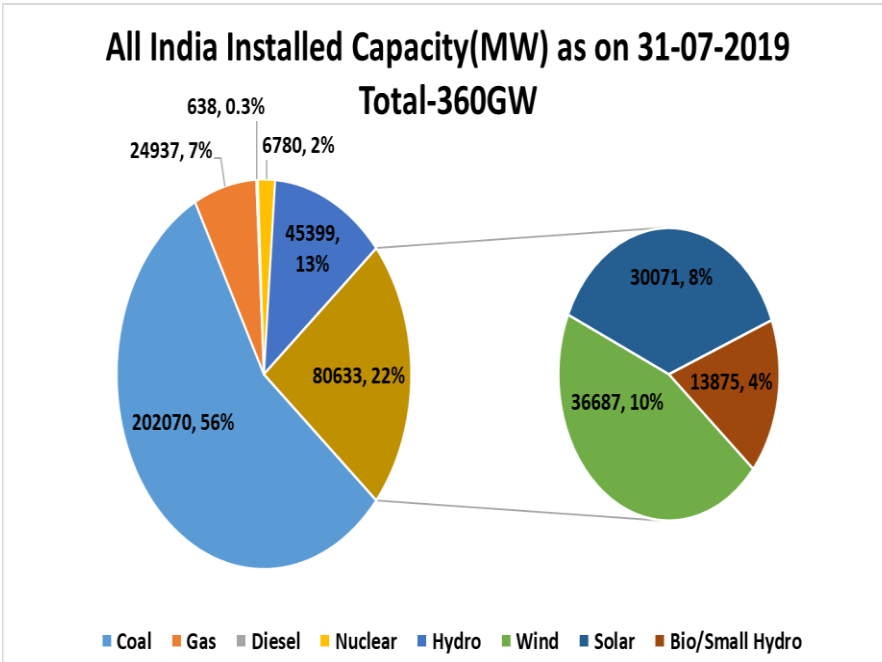


Figure 1: All India Installed Capacity (MW) as on 31.07.2019

The Govt. of India has set a target of achieving 175 GW Renewable Energy integration in the country by year 2022. The Indian grid comprises of not less than 7000 Substations, 4000 Transformers, 11 HVDC Bipole/Back to Back, 180 Nos. of 765 kV lines, 1300 Nos of 400 kV lines, 3200 Nos. of 220 kV lines and downward network. Indian grid is also connected to neighbouring countries Nepal, Bhutan, Bangladesh and Myanmar.

2. INTRODUCTION - SOLAR ECLIPSE

As the earth rotates on its axis, it also revolves around Sun. A solar eclipse occurs when the moon passes directly between the sun and earth, blocking the sun light and casting a shadow on the earth. During the solar eclipse, the moon casts a shadow on earth. The first shadow is called umbra. This shadow gets smaller as it reaches the earth. It is the dark centre of moon's shadow. The second shadow is called the penumbra. The penumbra gets larger as it reaches the earth. Magnitude of a solar eclipse is a function of the season, geographical location and time of the day. The path of totality is the trajectory of moon's shadow across the earth. Figure 2 shows the solar eclipse phenomena.

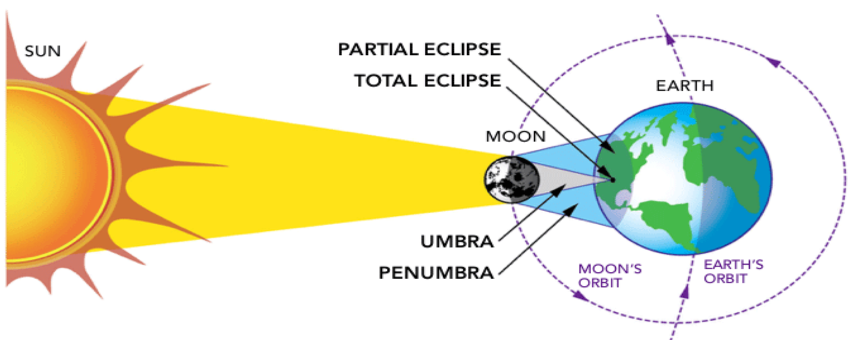


Figure 2: Solar Eclipse Phenomena

There are three types of solar eclipse as described below:

Total Solar Eclipse: Total solar eclipse occurs when the dark silhouette of the moon completely obscures the intensely bright light of the sun, allowing the much fainter solar corona to be visible from earth. During any one eclipse, totality occurs at best only in a narrow track on the surface of earth. This narrow track is called the path of totality.

Partial Solar Eclipse: Partial solar eclipse happens when the moon comes between the sun and earth, but the moon only partially covers the sun's disk.

Annular Solar Eclipse: An annular solar eclipse happens when the moon covers the sun's centre, leaving the sun's visible outer edges to form a "ring of fire" or annulus around the moon. The moon's shadow is not big enough to engulf the entire planet, so the shadow is always limited to a certain area.

Graphical representation of all the three eclipses is given below:

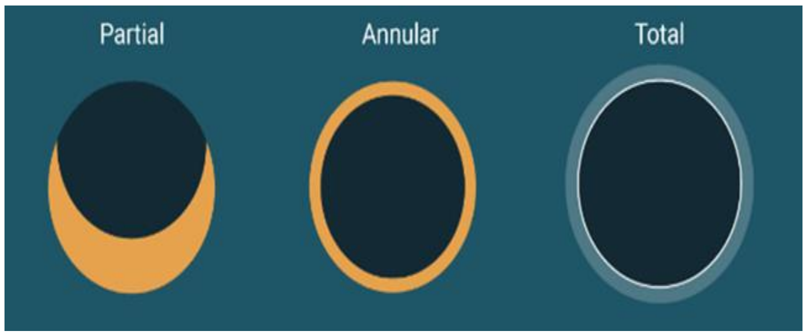


Figure 3: Type of Solar Eclipse

Magnitude: The magnitude of eclipse is the fraction of the angular diameter of a celestial body being eclipsed. This applies to all celestial eclipses. The magnitude of a partial or annular solar eclipse is always between 0.0 and 1.0, while the magnitude of a total solar eclipse is always greater than or equal to 1.0.

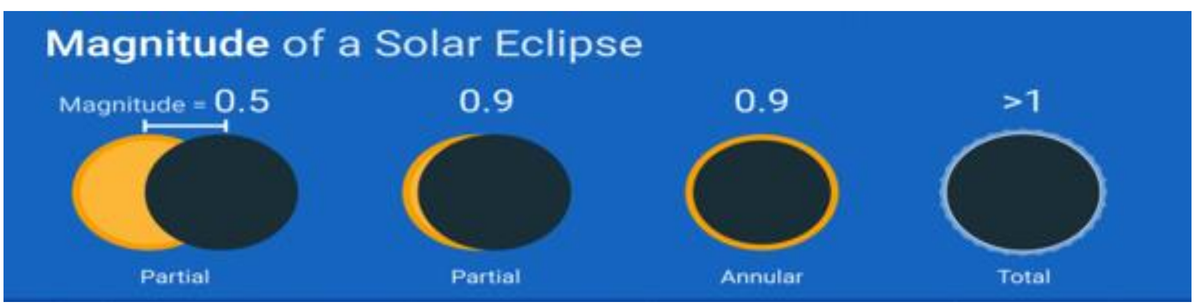


Figure 4: Magnitude of Solar Eclipse

Solar eclipse poses a challenge for power system with high percentage of solar power integration to grid as it can cause the solar power in affected region to decrease with very high ramp and later increase quickly. The advance estimation of effect of solar eclipse on PV power generation is necessary for grid stability and to plan necessary precautions by stakeholders.

1.1. ANNULAR ECLIPSE: 26.12.2019

Annular and partial solar eclipse will be visible in India on 26th December 2019. The large annular eclipse will cover over 93% of the sun, creating a narrow path of 117.9 km wide. It will last for 2 minute 59 seconds at the point of maximum eclipse at Cannanore . Annularity will be visible mainly in South India, in the states of Kerala, Tamil Nadu and Karnataka. The main cities in the annularity path includes Tiruppur, Coimbatore, Dindigul, Mangalore, Trichy (Tiruchirappalli) and Kozhikode. The rest of the country will see partial eclipse of the sun but even on the northernmost parts of India about 40% of the sun will be covered by the moon. Bigger cities, which will experience sun obscuration during solar eclipse, are as follows:

S.No.	City Name	% of Obscuration
1	Bangalore	89.4%
2	Chennai	84.6%
3	Mumbai	78.8%
4	Hyderabad	74.3%
5	Ahmedabad	66.0%
6	Kolkata	45.1%
7	Delhi	44.7%

The annular eclipse will begin at 8:03 AM IST at Dwarka, Gujarat and will end at 12:03 AM IST at Port Blair. Southern Region would be most affected by solar eclipse. Other regions would be partially affected.

The partial and annular eclipse start and end time and the maximum obscuration location are derived from Positional Astronomy Centre, Indian Metrological Department. From this data source, 76 locations for partial eclipse and five locations of annular eclipse are available for the country. For each state, the available location nearest to the geographical centre has been selected. Details of such locations is attached as per Annexure-I. Figure 5 shows the path of annular solar eclipse of 26 December 2019 and figure 6 shows eclipse beginning and ending time across the country.

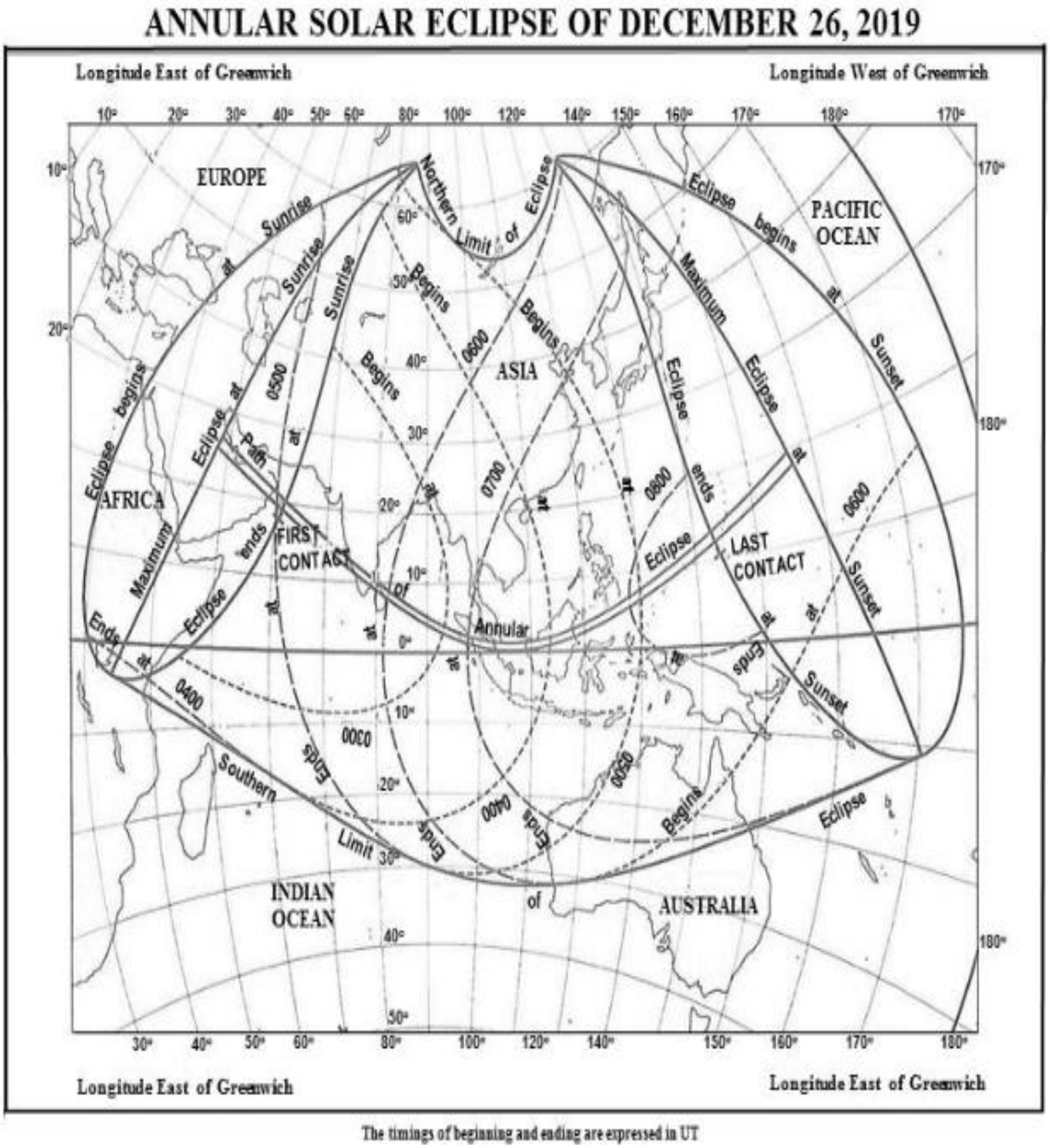
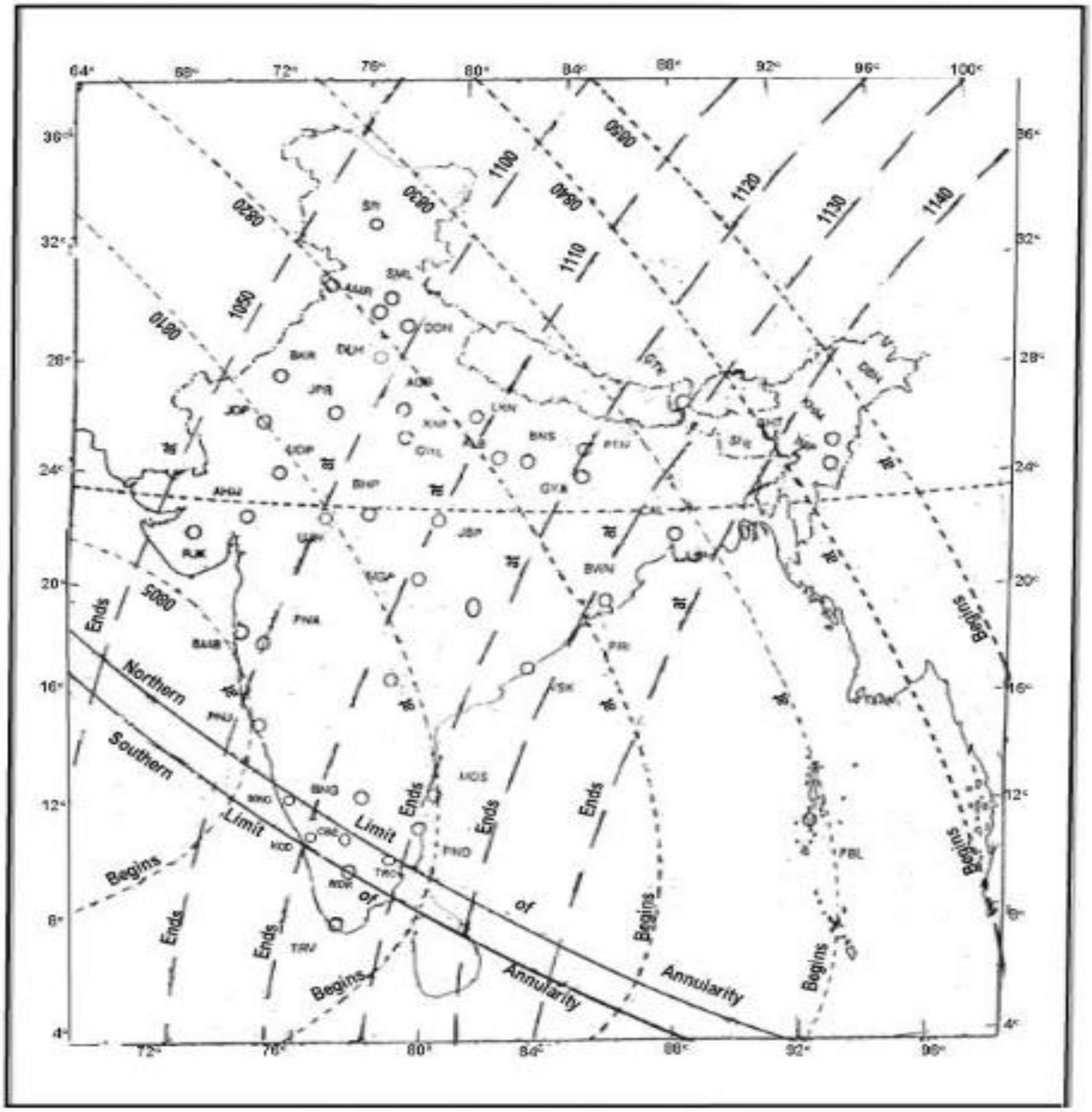


Figure 5: Annular Solar Eclipse of December 26, 2019

SOURCE: http://www.packolkata.gov.in/eclipse.php

ANNULAR SOLAR ECLIPSE OF DECEMBER 26, 2019



The timings of beginning and ending are expressed in IST

Figure 6: Solar Eclipse - Beginning and Ending Time

SOURCE: http://www.packolkata.gov.in/eclipse.php

1.2. ANNULAR ECLIPSE: 21.06.2020

On 21st June 2020, annular eclipse of the sun will be visible in Northern part of India. The annular eclipse will begin at 10:17 AM IST in Western part of India and will end at 14:02 PM IST in Eastern part of India. The states of Rajasthan, New Delhi, Punjab, Western Uttar Pradesh and Uttarakhand will observe annular solar eclipse and other part of India will observe partial eclipse. The large annular eclipse will cover over 99% of the sun, creating a narrow path of 21 km wide. It will last for 38 seconds at the point of maximum eclipse. Figure 7 shows the path of annular solar eclipse of 21st June 2020. The pre and post event analysis of this eclipse will be brought out in a separate report.

Figure 7: Path of Annular Solar Eclipse on June 21, 2020

2. LITERATURE SURVEY

Literature survey has been carried out to study the impact of solar eclipse on power system in various parts of the world. Following reports available on solar eclipse have been referred:

(i) Solar Eclipse 2015 – Impact Analysis - A report published by Regional Group Continental Europe and Synchronous Area Great Britain
(ii) 2017 Solar Eclipse report, May 1, 2017 – Report published by CAISO
(iii) Solar Eclipse Report - Evaluating the impact of the 2017 Solar Eclipse on US Western Interconnection Operations
(iv) A Wide-Area Perspective on the August 21,2017 Total Solar Eclipse - A report published by North American Electric Reliability Corporation (NERC)

2.1. SOLAR ECLIPSE 2015 –IMPACT ANALYSIS : A report published by Regional Group Continental Europe and Synchronous Area Great Britain

On March 20, 2015, a solar eclipse affected Continental Europe. The eclipse started at 8:01 AM UTC in the western part of Portugal and ended at 11:58 AM UTC in the eastern part of Romania. The timing of this solar eclipse is similar to the forthcoming solar eclipse on 26th December 2019. For the first time, the eclipse had a significant impact on the operation of the European power system because of the fast growth in PV in the recent past.

The report address the following issues for Continental Europe related to Solar Eclipse

(i) Estimation of installed PV capacity on 20th March 2015 per country
(ii) Estimation of PV infeed on 20th March by combining capacity and coincidence factors for each country with radiation data with and without the solar eclipse
(iii) Inventory of potential mitigation measures

The National Grid has put in an analysis for Great Britain addressing the following issues

(i) Model for eclipse effect
(ii) Model for residual demand

The assessment is based on the following input per country

a) Installed PV capacity
b) Coincidence factor during the hour of the year with maximum radiation (75% assumed)
c) Maximum radiation factor for the year during clear sky conditions (average) Imax
d) Radiation factor on March 20 during clear sky conditions (average) (I(t))
e) Beginning of eclipse, end of eclipse and maximum solar obscuration (average)

The PV infeed during clear sky conditions is then calculated by combining a) to d)

$P_{clear\ sky}(t) = P_{installed}*0.75* I(t)/I_{max}$

Similarly, the PV infeed considering the solar eclipse is calculated by correcting the normal infeed by .

$P_{eclipse}(t) = P_{clear\ sky}(t) * [1 - \text{obscuration factor}(t)]$

The formula for the obscuration factor is calculated as per Annexure- II.

The following assumptions have been considered:

- Proportional relation between radiation and PV infeed,
- Average data for each country,
- Affect of eclipse on consumer demand is ignored. The study focuses only on PV variation due to solar eclipse.

The estimated installed capacity of PV in synchronous region of Europe was about 89 GW in 2015. Further, it was anticipated that eclipse might cause potential reduction of PV feed-in by more than 34GW in case of clear sky condition in Continental Europe. Collaboration with weather experts, it was further anticipated that power gradient would be higher than normal PV daily ramping. This condition might have posed serious challenges to the regulating capability of the inter-connected grid in terms of available generation capacity, regulation speed and geographical location of the reserves. Beyond the lower PV generation during the eclipse, the most important expected challenge was the decrease of generation by 20 GW within 1 hour, and the increase of generation by almost 40 GW after the maximum impact of the eclipse.

Figure 8 shows a comparison of expected feed-in from solar on 20th March in case of clear sky conditions, with and without solar eclipse.

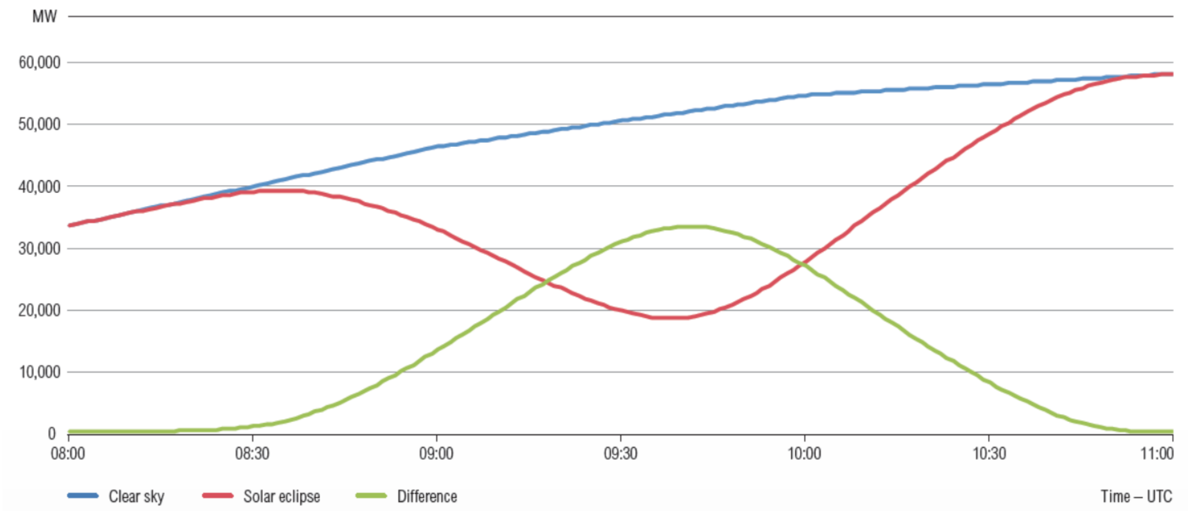


Figure 8: Comparison of Expected feed-in from Solar on 20 March during Clear Sky Conditions with and without Solar Eclipse.

Following measures were taken by the various TSOs of Europe to control the various parameter of the synchronously connected European power system:

- TSOs regulated their amount of primary, secondary and tertiary control reserves to improve their Area Control Error (ACE) close to zero
- Strategic use of pumped storage power plants to have more control during the eclipse for changes in the grid due to the change in PV
- The German TSOs had specially procured approximately double the amount of reserves in comparison to normal operation to meet any exigency in real time operation. Further, they have established special concept for activation of reserves and emergency reserves during the solar eclipse
- All TSOs had agreed to have as little as possible planned outages in their grid during the time of solar eclipse to have a strong and well-meshed system to cover possible load flow deviations
- Capacity on the HVDC cables was reduced by between 18 % and 50 % for the Nordic, UK and CE regions. This ensured synchronous areas to be more independent of each other

- TSOs raised awareness and informed market players, i.e. balancing responsible parties and Distribution System Operators (DSOs) on the responsibility they had during the eclipse

LESSON LEARNT

The weather conditions during the solar eclipse for the western part of Continental Europe were cloudier than the hypothesis, which resulted in less severe impact than predicted. For Germany and Italy, the conditions were still clear sky and the eclipse impact was strong.

The main lessons learned are as follows:

- A detailed and clear description of PV capacity installed and their capabilities is required for the accuracy of forecast studies (technical data, retrofitting campaign, disconnection /reconnection settings and logics, etc.).
- Real time measurement of the dispersed PV generation is the key for adapting the operational strategy in real-time.
- Keep always amount of reserves on higher side to meeting any exigency during real time operation.
- Strong coordination and transparency in preparation for and during the event, all the TSOs were aware of the risks and the existing remedial actions.

2.2. 2017 SOLAR ECLIPSE REPORT, MAY 1, 2017 - Report published by CAISO

On 21st August 2017, it was anticipated that solar eclipse will impact the California power system. California system operator has commercially operational utility-scale PV (UPV) within the balancing area of nearly 10000 MW. It was also anticipated that more that 5800MW rooftop solar would be installed in CAISO by August 2017, which may impact the grid security and reliability during the eclipse. In view of that, CAISO envisioned that a partial eclipse between 9:02 a.m. and 11:54 p.m. would affect it. As per the study, it was predicted that Southern California to Northern California may be obscuring by 62% to 76% respectively. To maintain grid stability, CAISO identified the eclipse trajectory; estimated UPV and DPV installed capacities, and developed mitigation strategies to minimize risk.

Initial estimates showed that at the peak of the eclipse, UPV solar production within CAISO would be reduced from an estimated 8,754 MW to 3,143 MW before returning to 9,046 MW. The solar ramping-down rate was estimated at -70 MW/ minute and ramping-up rate at 98 MW/minute (see Figure 9). By comparison, the estimated ramping-up rate during a similar period was 12.6 MW/minute on a normal clear day; however, DPV was expected to have a smaller effect. Assuming a clear sky during the eclipse, a total net load increase of around 1,365 MW was expected because of the loss of DPV generation. CAISO developed a net load forecast model that considered rooftop solar generation.

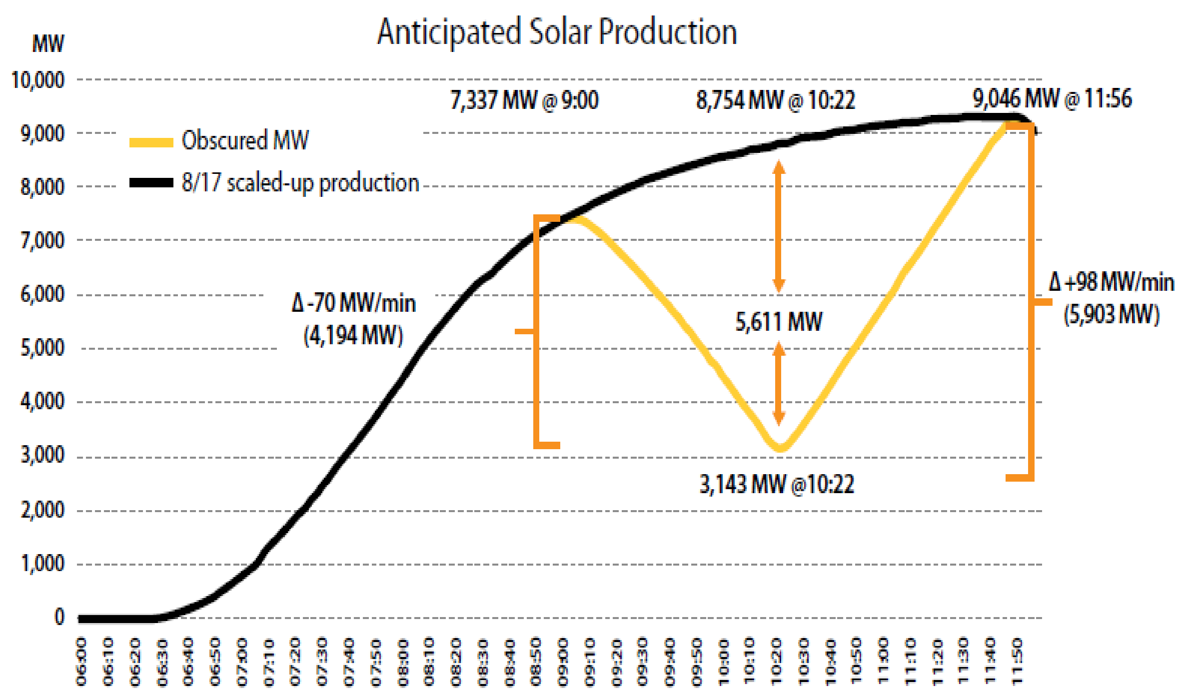


Figure 9: CAISO Forecast of Grid-Connected Solar Production for the August 21, 2017, Eclipse

Similar to the 2015 European total eclipse, the challenges for CAISO were potentially large ramping rates and energy imbalance. As it was predicted that ramping would be faster after the eclipse and may increase the burden on other generator, having a direct impact on CAISO's regulation capability in terms of available regulation capacity, speed, and location of reserves.

As per the 2015 European total eclipse and analysis, CAISO proposed a contingency handling and grid protection plan to maintain grid reliability and encouraged coordination across the Western

Electricity Coordinating Council (WECC). Table 1 summarizes the proposed mitigation measures.

TABLE 1: PROPOSED MITIGATION MEASURES

Reserves procurement	Gas supply needs co-ordination
Flex-ramp usage	Scheduling co-ordinator interaction
Special operating procedures	WECC/Peak reliability coordination
Use of energy imbalance market transfer capability	Hydro generation regulation
Internal market simulation	Potential use of flex alert
Day+2 conference bridge	Market participant coordination

2.3. A WIDE-AREA PERSPECTIVE ON THE AUGUST 21,2017 TOTAL SOLAR ECLIPSE

During the study, NERC (North Electric Reliability Corporation) combined region-specific hourly load estimates, generating unit capacity, and solar data from various sources. NERC also used Solar Market Insight 2016 Q3 report to estimate the impact of the August 21, 2017, eclipse on grid-connected PV capacity across North America and Southern America.

From 2013 – 2015, the reported load for each Monday in August was used as the set of possible hourly data points. For PV generation, an assumption was made to use the aggregated capacity of a facility and three representative hourly generation percentages to map the general shape of PV production.

The report found that the top four states that would require advanced system coordination for operations prior to the eclipse, during the eclipse, and after the eclipse were Utah, California, Nevada, and North Carolina. In some parts of each of these states, a 0.9 obscuration would be observed (Utah had a maximum obscuration of 0.95, and Nevada and North Carolina would experience a total eclipse).

Where peak eclipse and peak demand coincided, the ramping-up and ramping-down rates required Balancing Authorities (BAs) with minimal standby energy storage to be regulated in maintaining grid stability. Following Germany's response to the 2015 eclipse, it was learnt that

disconnecting UPV generators from the grid would mitigate instability caused by extreme ramping for the 2017 eclipse.

Peak eclipse obscuration occurred around 10:00 am for CAISO, many hours before peak demand and peak generation typically occurs in the late afternoon, therefore mitigating the ramping and balancing concerns. California and North Carolina, however, were identified as states that would require advanced planning and operating coordination for the August 21, 2017, eclipse because of their large PV installation capacity. NERC highlighted the need to coordinate the distributed energy resources for system protection and perform advanced planning and operating coordination.

2.4. SUMMARY

Although, CAISO and NERC relied on simple assumptions and simulations based on physical energy balance, but it is important to note that both suggested significant changes to generation and load profiles in high PV areas during the eclipse event. To maintain grid stability, coordinated pre-event planning with tightly coupled cross-region communications during the event was required and proved beneficial by the response to the 2015 eclipse.

3 PRE EVENT ANALYSIS OF ANNULAR SOLAR ECLIPSE ON 26.12.2019

3.1 STATE WISE INSTALLED CAPACITY OF SOLAR GENERATION

The state wise total Installed capacity of solar power plant as on 31.03.2019 is 28180 MW, which comprises of 26384 MW ground mounted and 1796 MW rooftop. Table 2 shows breakup of state wise installed PV capacity as on 31.03.2019.

TABLE 2: State wise distribution of installed PV capacity

State-wise installed capacity of grid interactive solar power as on 31.03.2019				
S. No	STATE/ UTs	Solar Power		
		Ground mounted (MW)	Roof top (MW)	Total (MW)
1.	Andhra Pradesh	3027.15	58.53	3085.68
2.	Arunachal Pradesh	1.27	4.12	5.39
3.	Assam	10.67	11.73	22.40
4.	Bihar	138.93	3.52	142.45
5.	Chhattisgarh	215.83	15.52	231.35
6.	Goa	0.95	2.97	3.92
7.	Gujarat	2113.46	326.67	2440.13
8.	Haryana	130.80	93.72	224.52
9.	Himachal Pradesh	17.00	5.68	22.68
10.	Jammu & Kashmir	8.49	6.34	14.83
11.	Jharkhand	19.05	15.90	34.95
12.	Karnataka	5936.06	159.5	6095.56
13.	Kerala	100.00	38.59	138.59
14.	Madhya Pradesh	1806.53	33.63	1840.16
15.	Maharashtra	1447.30	186.24	1633.54
16.	Manipur	0.00	3.44	3.44
17.	Meghalaya	0.00	0.12	0.12
18.	Mizoram	0.10	0.40	0.50

State-wise installed capacity of grid interactive solar power as on 31.03.2019				
S. No	STATE/ UTs	Solar Power		
		Ground mounted (MW)	Roof top (MW)	Total (MW)
19.	Nagaland	0.00	1.00	1.00
20.	Odisha	383.56	11.17	394.73
21.	Punjab	828.1	77.52	905.62
22.	Rajasthan	3072.43	154.36	3226.79
23.	Sikkim	0.00	0.01	0.01
24.	Tamil Nadu	2432.27	142.95	2575.22
25.	Telangana	3519.27	72.82	3592.09
26.	Tripura	5.00	0.09	5.09
27.	Uttar Pradesh	844.00	116.10	960.10
28.	Uttarakhand	239.78	66.97	306.75
29.	West Bengal	50.00	25.95	75.95
30.	Andaman & Nicobar	7.60	4.13	11.73
31.	Chandigarh	6.34	28.37	34.71
32.	Dadar & Nagar Haveli	2.49	2.97	5.46
33.	Daman & Diu	10.15	4.32	14.47
34.	Delhi	8.96	117.93	126.89
35.	Lakshadweep	0.75	0.00	0.75
36.	Pondicherry	0.03	3.11	3.14
	Total (MW)	26384.32	1796.39	28180.71

The country has seen average 36% growth in PV installed capacity in the last 3 years. It is expected that by December 2019, the total installed capacity would be around 34 GW.

As per the telemetry available at National Load Despatch Centre (NLDC), maximum solar generation recorded on all India basis is around 16100 MW in May 2019. REMC (Renewable

Energy Monitoring Centre) project is being implemented to further improve the telemetry form solar power plant. The development of solar power installed capacity over the year is shown below:

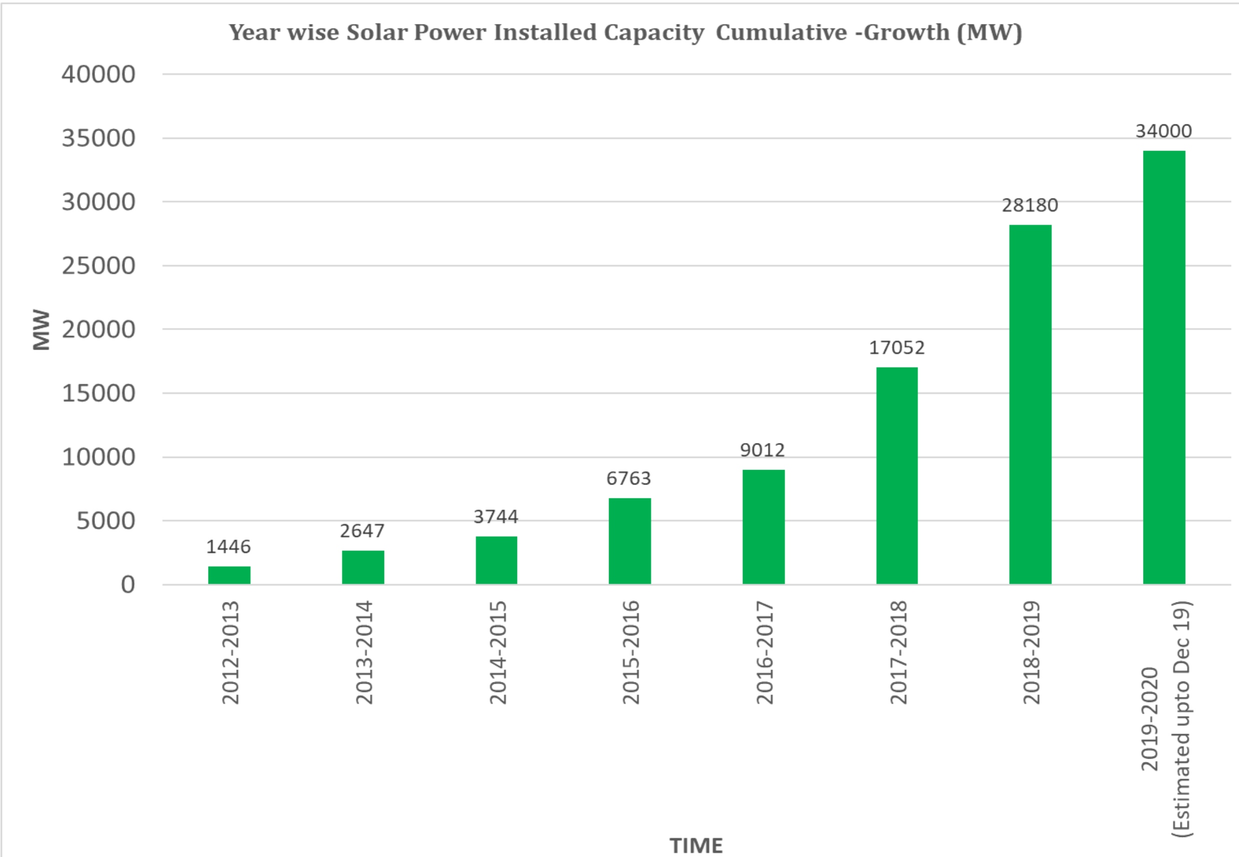


Figure 10: Year wise Solar Power Installed Capacity

3.2 PROJECTED TRAJECTORY OF THE SOLAR ECLIPSE

With the help of Google Earth and Geo Coordinates, the path of the solar eclipse has been drawn and major solar power plants have been geographically located on Indian map [Figure 11]. Based on the above mapping, it is estimated that about 7235 MW solar PV of generation will fall in more than 85 % of obscuration zone, 10520 MW will fall in 60-85 % of obscuration zone and 10251 MW will fall in 35-60% of obscuration zone.

Roof top Solar: Total installed capacity of roof top solar is 481.5 MW in Southern region, 534.73 MW in Western region and 666.9 MW in Northern region. At present penetration of roof top solar is low. Approximately 500-600 MW increase in drawl from the grid may be expected due to loss

of generation from the rooftop solar in Southern and Western Region and partial in Northern Region. Rooftop solar is not observable therefore with increase in capacity over time it will have to be better estimated through various techniques.

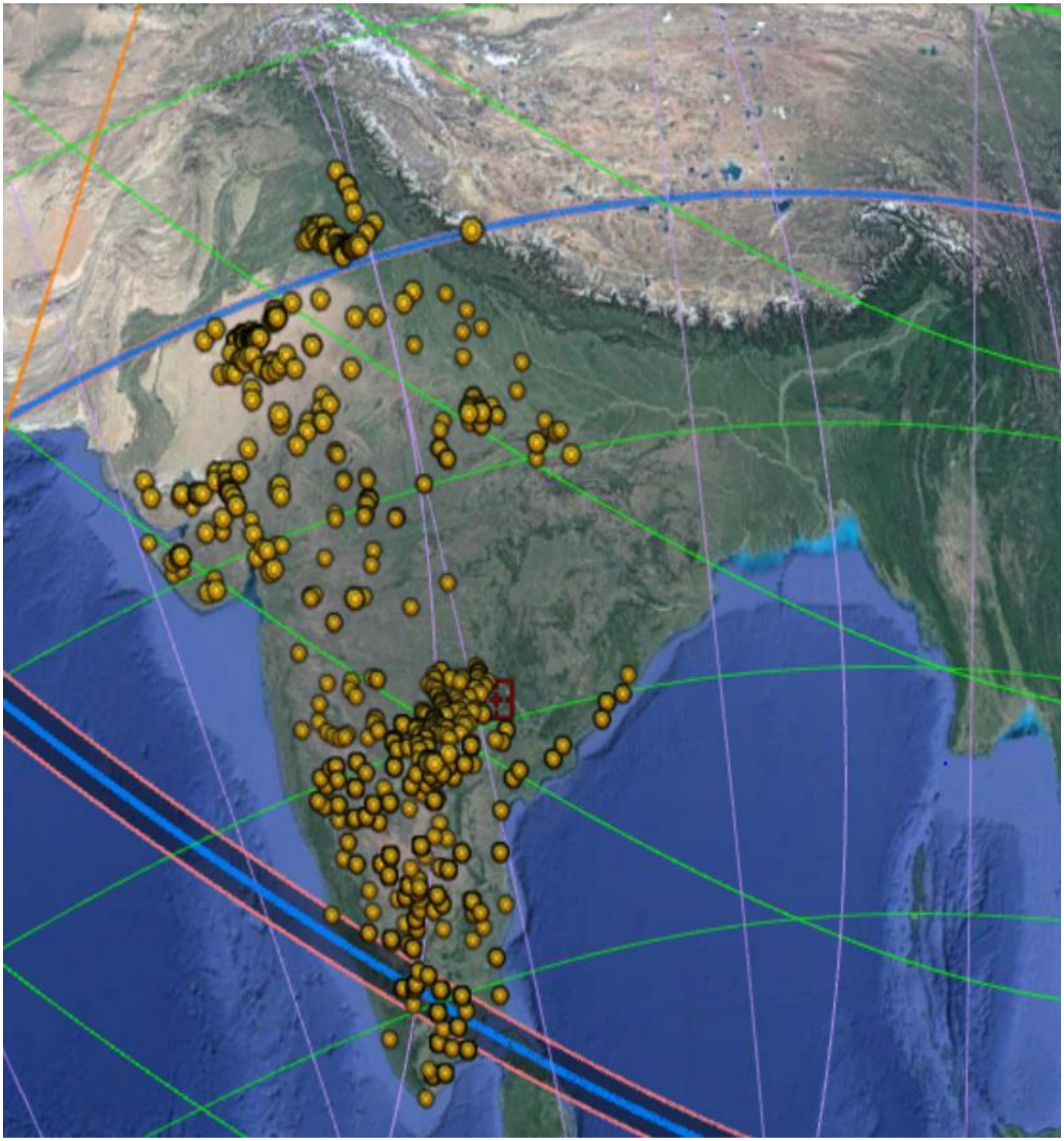


Figure 11: Path of the Solar Eclipse with Solar Power Installed Capacity

3.3 FORECASTING OF PHOTO VOLTAIC GENERATION AND RAMP RATE

In the near past, India has observed annular solar eclipse on 15th January 2010. The solar eclipse started at 11:00 hrs (IST) and traversed through southern part of Kerala and Tamil Nadu and ended at 15:00 hrs (IST). The maximum eclipse was observed at 13:15 hrs. To understand the behaviour of solar radiation in the event of solar eclipse, solar radiation data for the month of January 2010 of Trivandrum has been obtained from India Meteorological Department (IMD). Figure 11 shows the solar radiation (GHI) graph of Trivandrum from 13.01.2010 to 17.01.2010.

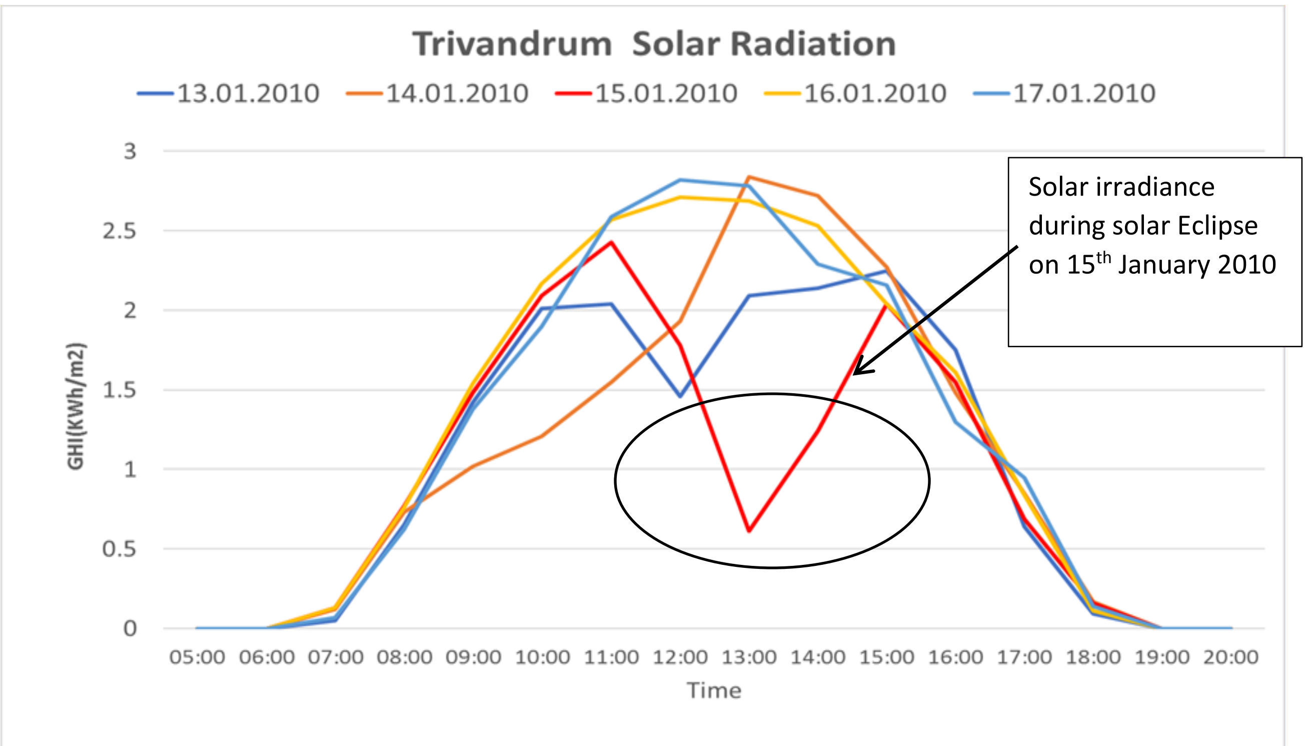


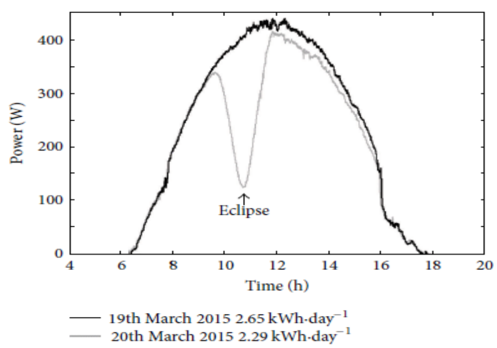
Figure 12: Solar Radiation during Solar Eclipse on 15.01.2010 at Trivandrum

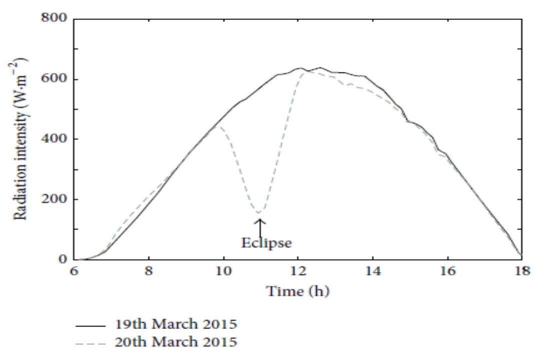
From the above graph, it can be observed that the reduction in solar irradiance started when solar eclipse began at 11:00 hrs at Trivandrum. The maximum reduction in solar irradiance took place at the time of maximum obscuration. As the solar obscuration started declining then solar irradiance started increasing. Based on above, it is inferred that during solar eclipse the solar irradiance varies linearly (Correlation Coeff: 0.88) with percentage obscuration. Further, based on various other research and experiments carried out {Ref 9, 10}, it has been observed that during solar eclipse, reduction in total solar irradiance level is directly proportional to

magnitude of solar eclipse. One of the research article on' Behaviour of Photovoltaic System during Solar Eclipse in Prague' (Ref Martin Libra, Pavel Kourim and Vladislav Poulak) has concluded that decrease of the instantaneous output power of PV system during the solar eclipse corresponds with the relative shading of the solar disc which leads to decrease of solar radiation intensity. Below graphs depict time series instantaneous output power and the amount of generated electric energy and time series of solar radiation intensity on a horizontal plane during two sunny days (19th and 20th March 2015)

TABLE 2: Selected values of important variables during the solar eclipse on March 20, 2015.

Eclipse phase	Time (h)	Solar radiation intensity on horizontal plane ($W \cdot m^{-2}$)	Solar radiation intensity on perpendicular plane ($W \cdot m^{-2}$)	Solar radiation intensity on PV panels ($W \cdot m^{-2}$)	Temperature of PV panels (°C)	Instantaneous output power (W)
Start	9:37	437	874	679	31	340
Maximum	10:46	155	258	241	14	124
Finish	11:58	612	952	948	43	415





METHODOLOGY ADOPTED TO FORECAST SOLAR GENERATION DURING ECLIPSE

In the backdrop of above inferences, reduction in solar generation for each state has been calculated as follows:

1) The state wise average solar generation of March 2019 of 5 minutes duration has been considered from SCADA and has been time shifted for the month of December (As per sunrise and sunset timings).
2) The solar generation for March 2019 has been considered to capture maximum telemetered capacity and the generation has been scaled up by 15% to factor new generation addition upto 26th December 2019.
3) Generation of solar plant in each state has been reduced linearly based on solar eclipse obscuration & timings available as per the table no. 3. At the time of maximum obscuration of eclipse, the generation has been considered minimum and in proportion to obscuration.

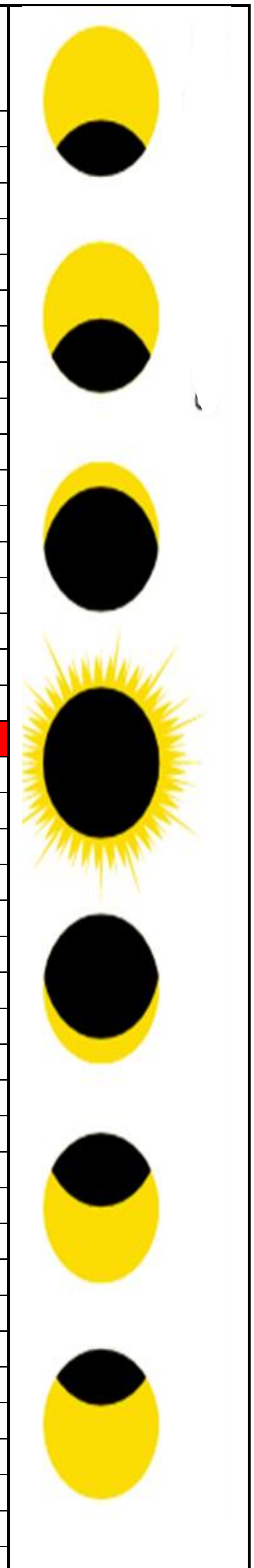
4) Again, generation from solar plants have been increased linearly based on solar eclipse magnitude and time.

TABLE 3: State wise mean obscuration considered for calculation of solar generation reduction on 26th December 2019

State	% of Mean Obscuration
Tamil Nadu	95%
Karnataka	90 %
Andhra Pradesh	85%
Telangana	75%
Maharashtra	70%
Gujarat	65%
Madhya Pradesh	55 %
Rajasthan	50%
Punjab	50%
Uttar Pradesh	50%

For Example: Calculation of anticipated solar generation for state of Andhra Pradesh

Time	Average Solar MW	Mean Obscuration Factor	Anticipated Generation (MW)
8:05	534	0.95	509
8:10	585	0.91	530
8:15	636	0.86	546
8:20	688	0.81	558
8:25	734	0.76	561
8:30	784	0.72	562
8:35	834	0.67	559
8:40	883	0.62	549
8:45	931	0.58	535
8:50	978	0.53	516
8:55	1026	0.48	493
9:00	1070	0.43	463
9:05	1116	0.39	431
9:10	1161	0.34	393
9:15	1206	0.29	352
9:20	1254	0.24	306
9:25	1292	0.20	255
9:30	1331	0.15	200
9:35	1367	0.19	260
9:40	1408	0.23	325
9:45	1443	0.27	392
9:50	1486	0.31	464
9:55	1550	0.35	546
10:00	1603	0.39	630
10:05	1637	0.43	709
10:10	1678	0.47	795
10:15	1717	0.51	883
10:20	1753	0.55	972
10:25	1775	0.60	1056
10:30	1797	0.64	1142
10:35	1825	0.68	1234
10:40	1853	0.72	1328
10:45	1873	0.76	1418
10:50	1902	0.80	1517
10:55	1924	0.84	1612
11:00	1943	0.88	1707
11:05	1960	0.92	1801
11:10	1982	0.96	1901
11:15	2001	1.00	2001
11:20	2018	1.00	2018
11:25	2034	1.00	2034



The above table, maximum obscuration of solar eclipse will occur at 09:30 AM. Therefore, anticipated generation at 09:30 AM will be 200 MW (15% of 1331 MW).

Figure 13 shows expected feed-in from solar on 26th December 2019 in case of clear sky conditions, with and without solar eclipse.

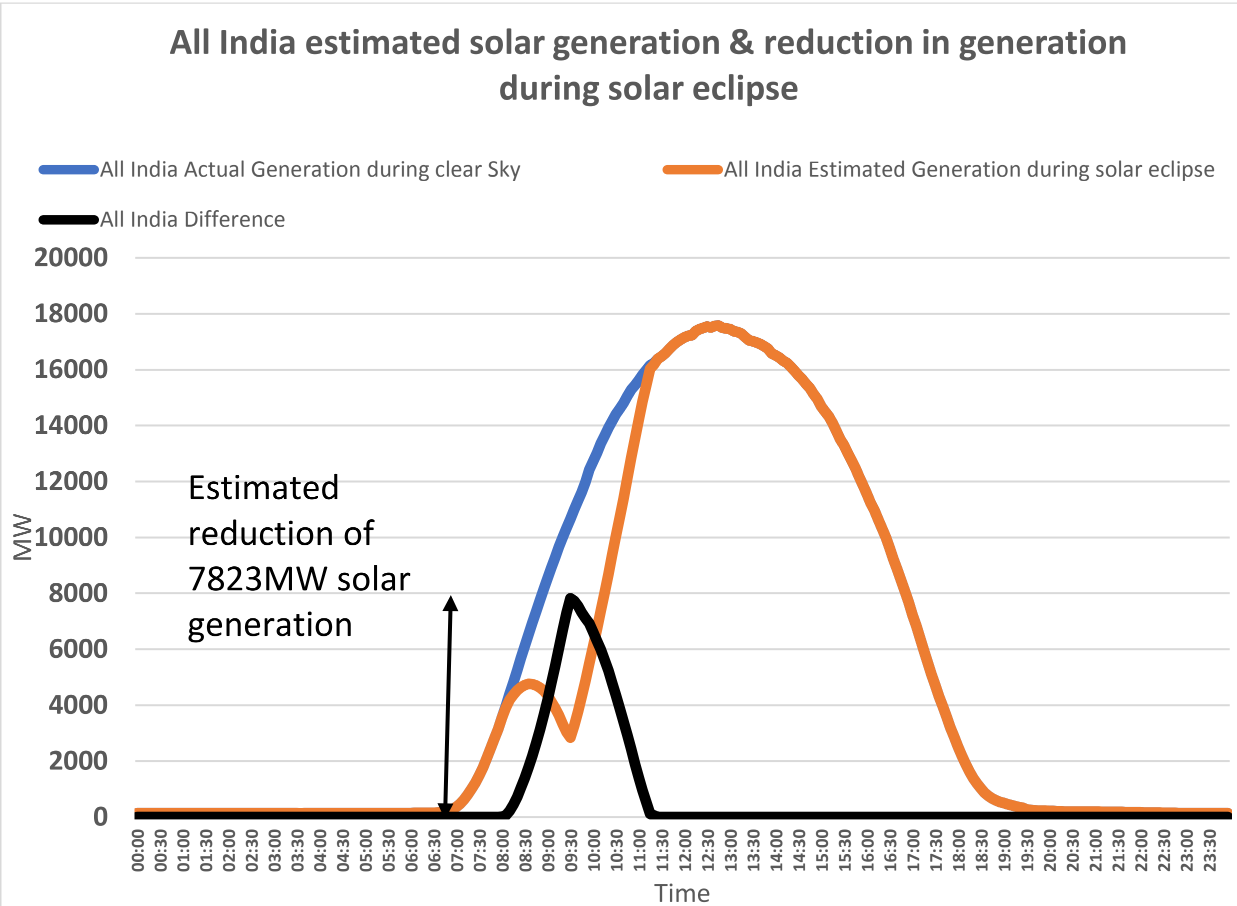


Figure 13: All India Estimated Solar Generation & Reduction in Generation during Solar Eclipse on 26.12.2019

It is estimated that eclipse would lead to reduction of PV generation by approximately 7823 MW at maximum obscuration time i.e. 09:30 AM and total estimated reduction in energy would be 12.7MU. During initial period of eclipse, the generation is likely to reduce by 1124 MW in 1:25 hrs. However, after maximum obscuration of the solar eclipse, the generation from the solar PV plant is likely to increase by 13344 MW in 1:50 hrs.

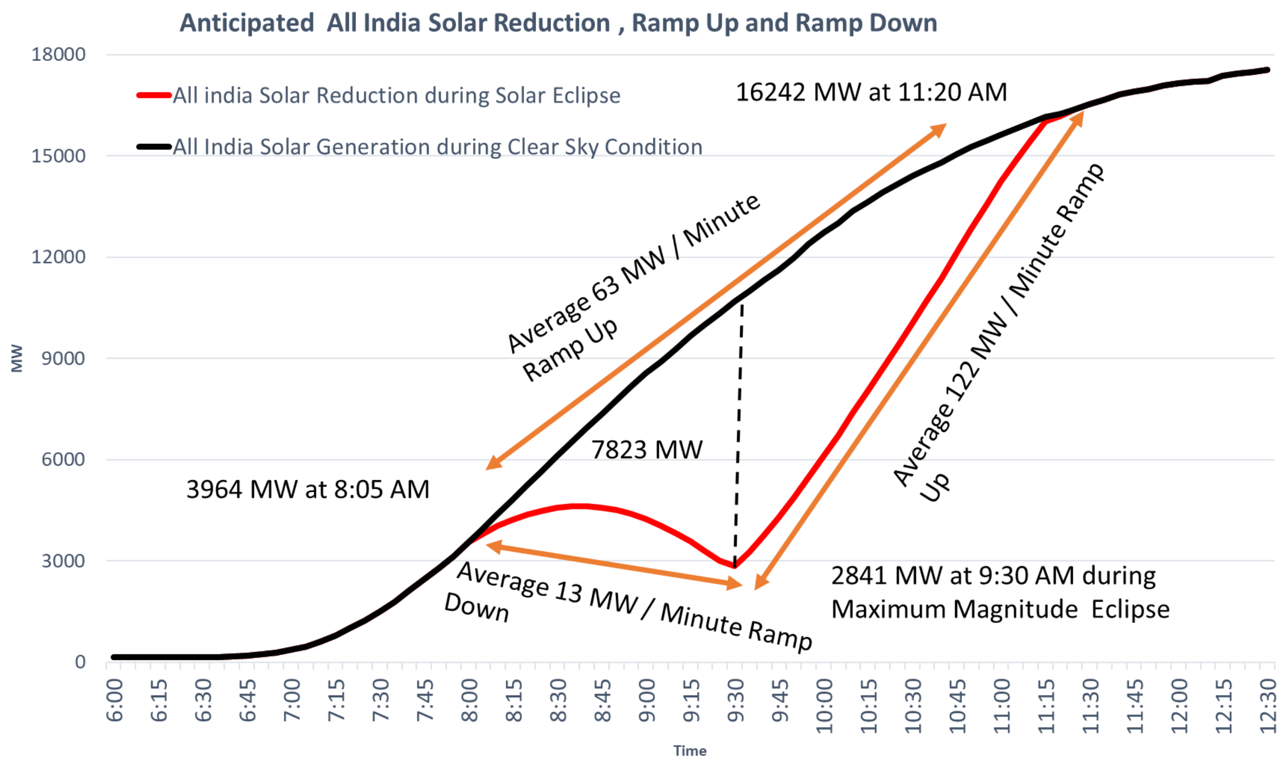


Figure 14: Estimated all India Solar Reduction and Ramp Up and Ramp Down Rate of Solar Generation during Solar Eclipse on 26.12.2019

As shown in Fig. 14, All India estimated solar generation average ramp up rate is 122 MW/ minute (13344 MW in 1:50 hrs) and average ramp down rate is 13 MW/ minute (1124 MW in 1:25 hrs).

This condition will pose serious challenge to system operators to maintain load and generation balance during the eclipse period i.e. 08:03 AM to 12:03 PM (Port Blair).

To maintain the load generation balance due to reduction in PV generation during solar eclipse, around 7823 MW generation from other sources (i.e. Thermal, Hydro, and Gas) is required within a short duration of time as detailed below:

a) From (8:05 to 09:30 Hrs): average 76 MW/ minute (63+13) ramp-up required during reduction of solar generation. (63MW/minute normal day ramp up & 13 MW/minute ramp down during eclipse)

b) From 09:30 to 11:20 hrs: average 49 MW/ minute (122-63) ramp-down required during increase of solar generation. (63MW/minute normal day ramp up & 122 MW/minute ramp up during eclipse)

The average generation required with ramp rate (MW) every 5 minute from other source is given as per Annexure-III

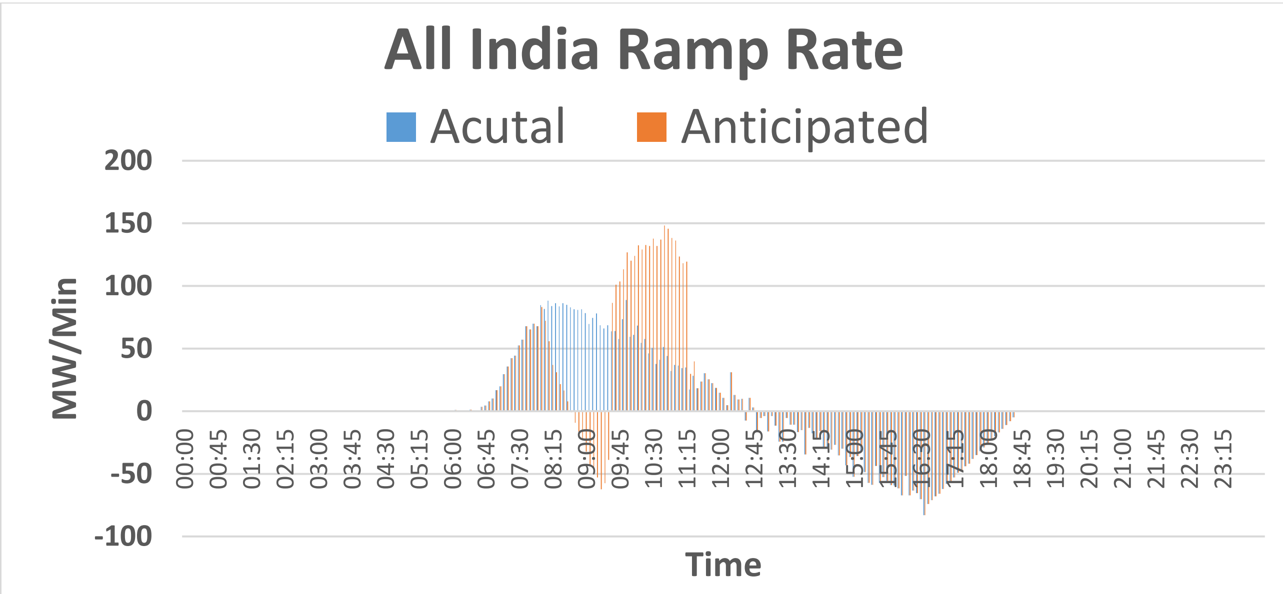


Figure 15: All India Normal Ramp Rate Vs Forecasted Ramp Rate during Solar Eclipse on 26.12.2019

State wise solar generation ramp rate is summarised in table 4.

TABLE 4 : STATE WISE SOLAR GENERATION AVERAGE RAMP RATE

State	Ramp down rate MW/ minute	Ramp up rate MW/Minute
Andhra Pradesh	4 MW	17 MW
Karnataka	8 MW	31 MW
Tamil Nadu	5 MW	13 MW
Telangana	3 MW	21 MW
Gujarat	0.26 MW	11 MW
Madhya Pradesh	0.25 MW	8 MW
Maharashtra	0.61 MW	5 MW
Rajasthan	0.51 MW	21 MW
Punjab	0.07 MW	03 MW
Uttar Pradesh	0.21 MW	02 MW

State wise solar generation ramp rate for every 5 minutes is given as per Annexure-IV

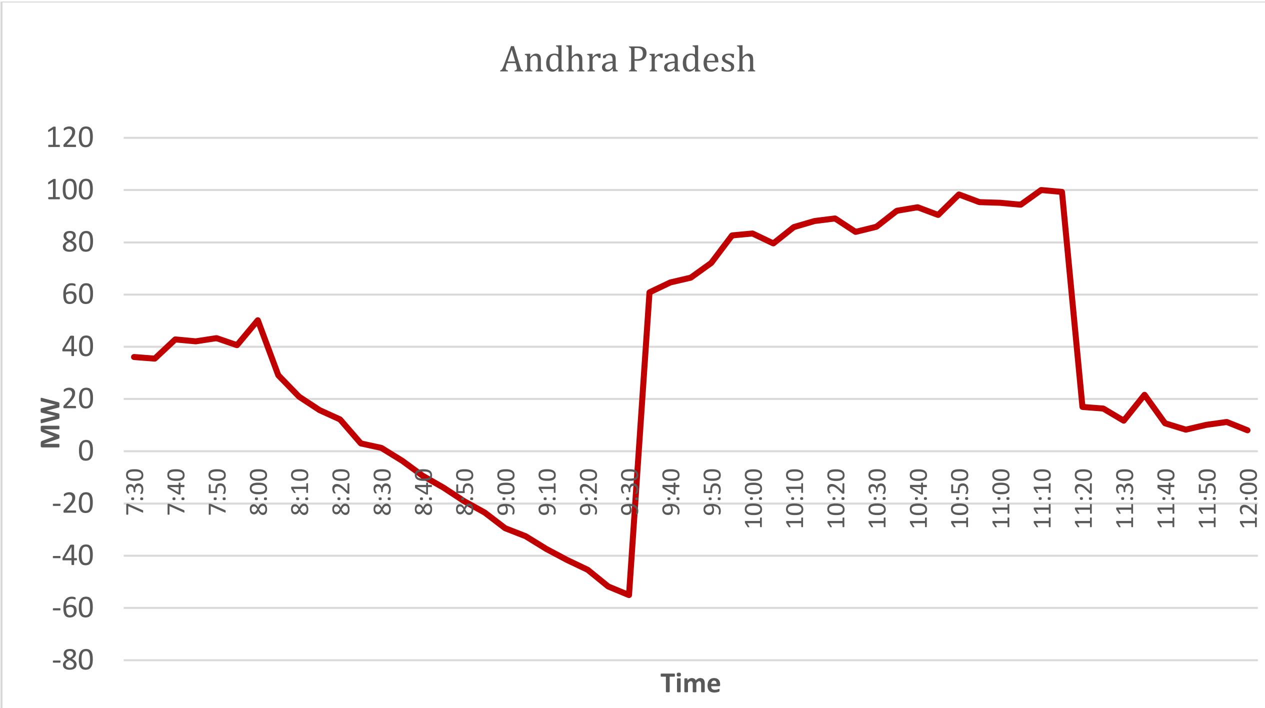


Figure 16: Andhra Pradesh Estimated Solar Generation Ramp Rate during Solar Eclipse on 26.12.2019

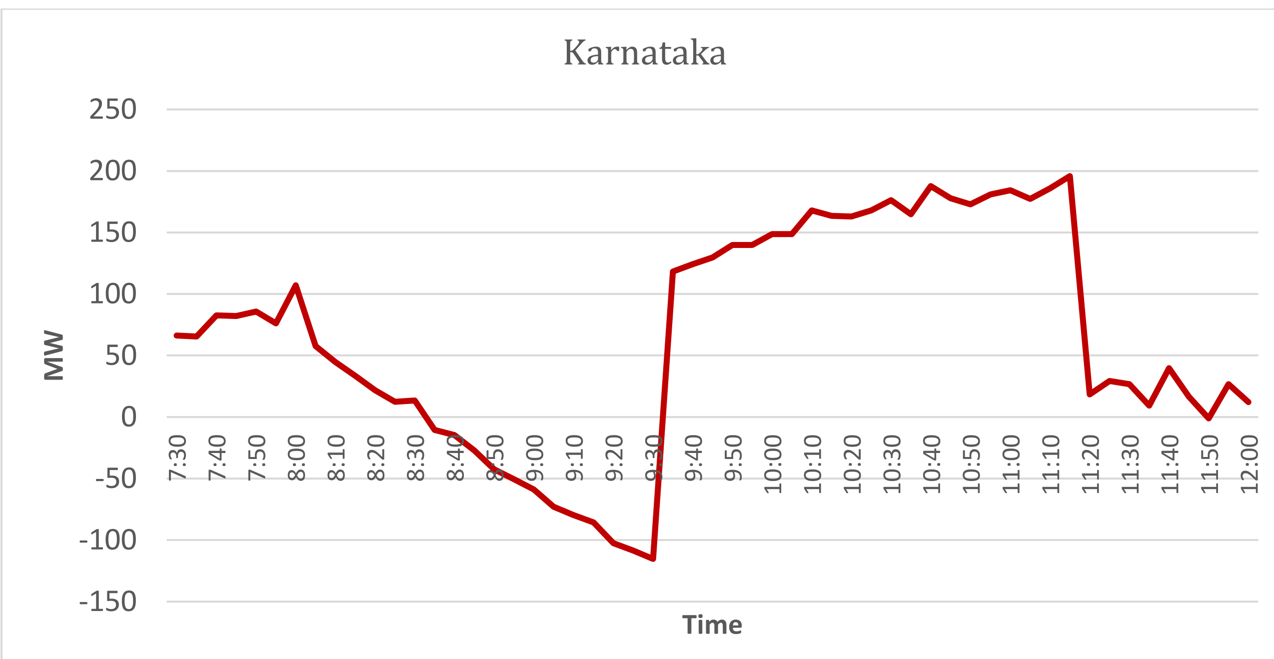


Figure 17: Karnataka Estimated Solar Generation Ramp Rate during Solar Eclipse on 26.12.2019

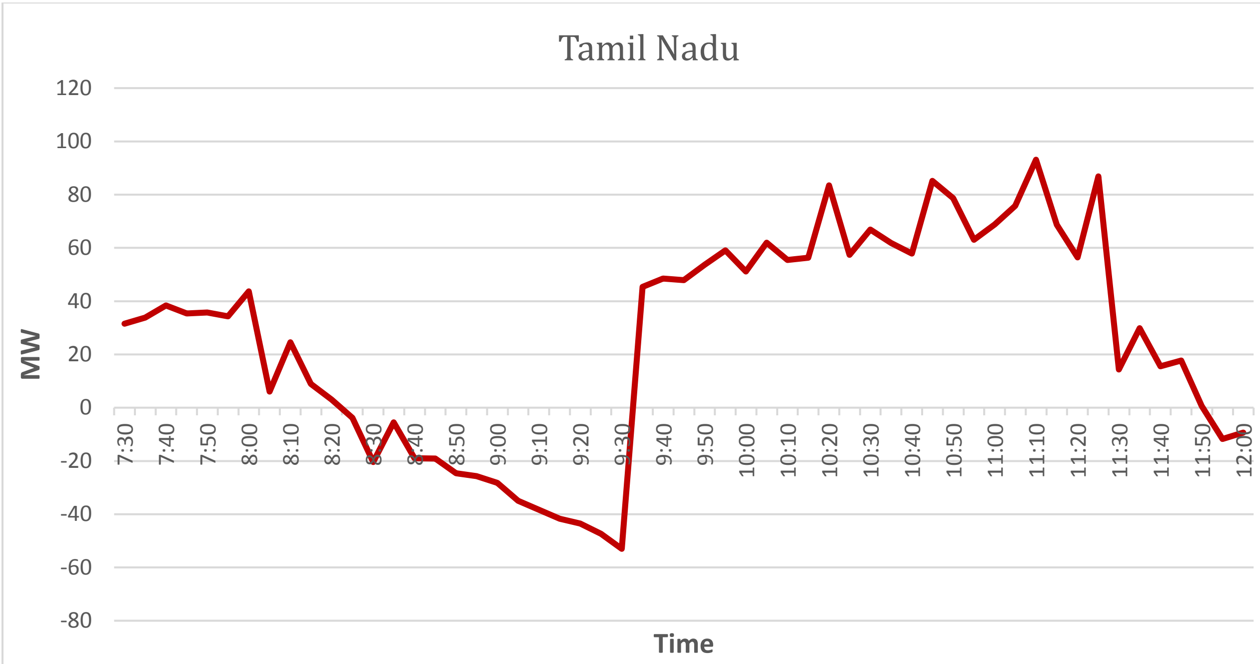


Figure 18: Tamil Nadu Estimated Solar Generation Ramp Rate during Solar Eclipse on 26.12.2019

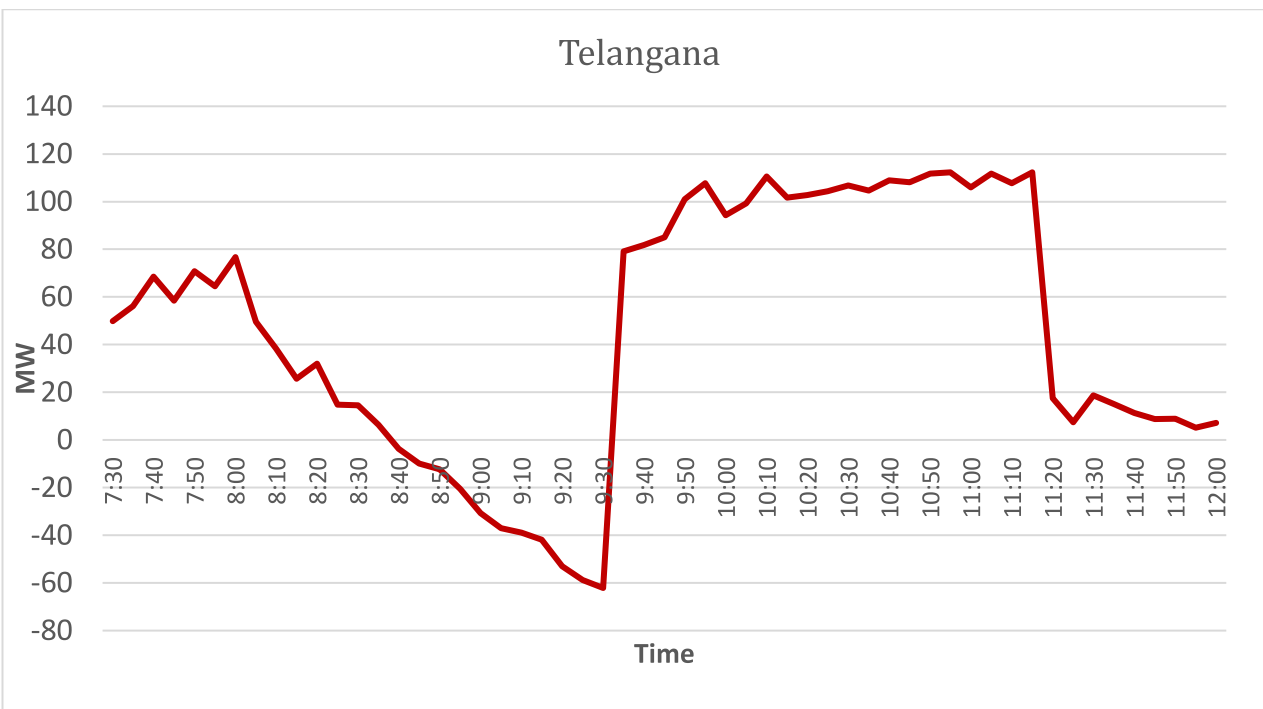


Figure 19: Telangana Estimated Solar Generation Ramp Rate during Solar Eclipse on 26.12.2019

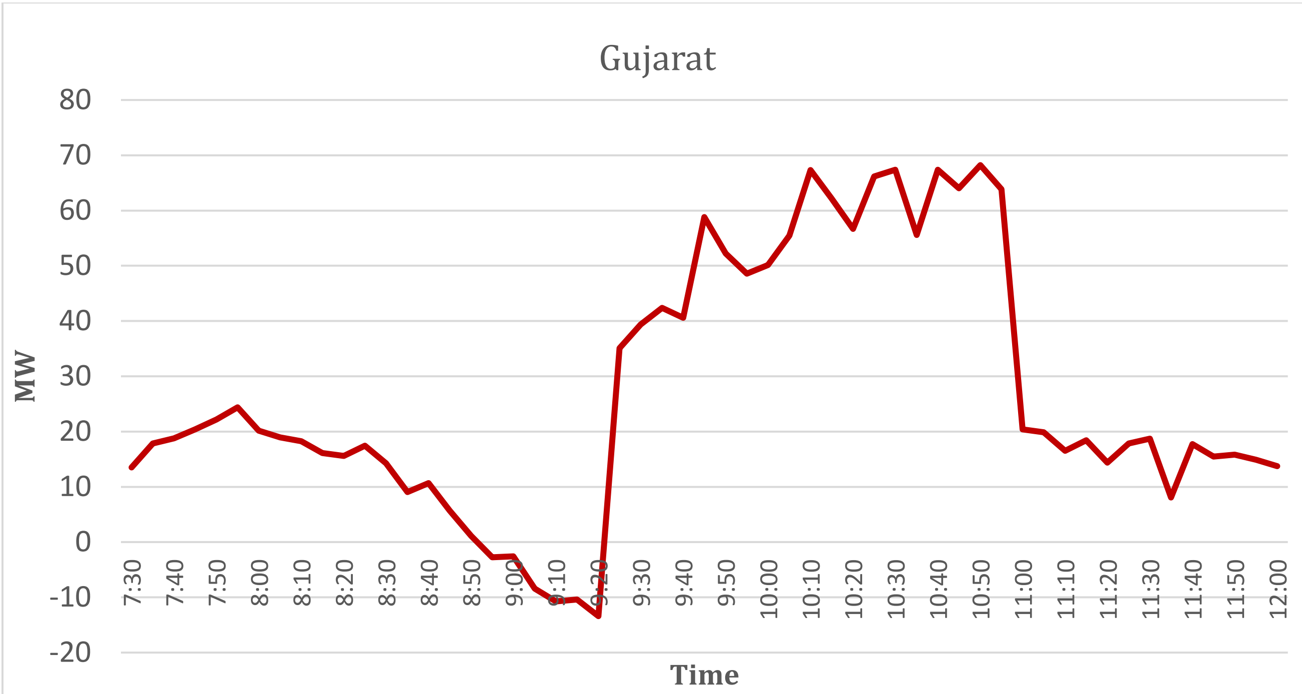


Figure 20: Gujarat Estimated Solar Generation Ramp Rate during Solar Eclipse on 26.12.2019

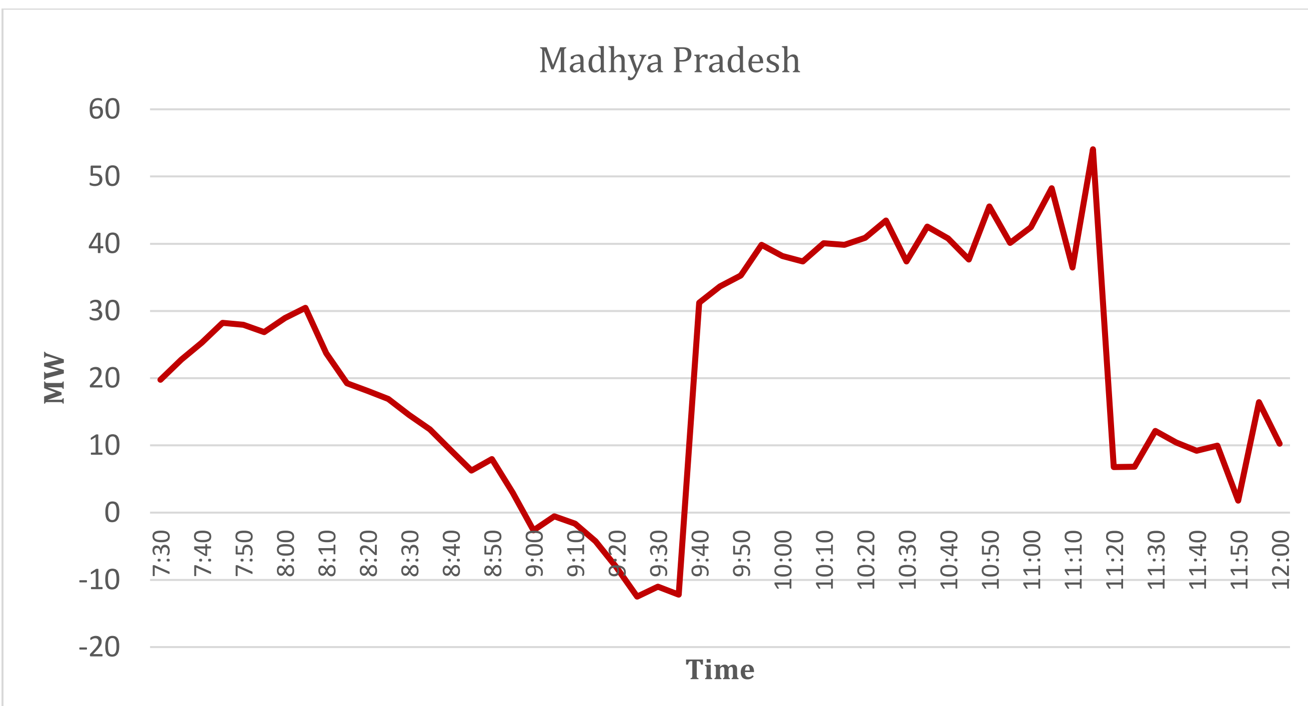


Figure 21: Madhya Pradesh Estimated Solar Generation Ramp Rate during Solar Eclipse on 26.12.2019

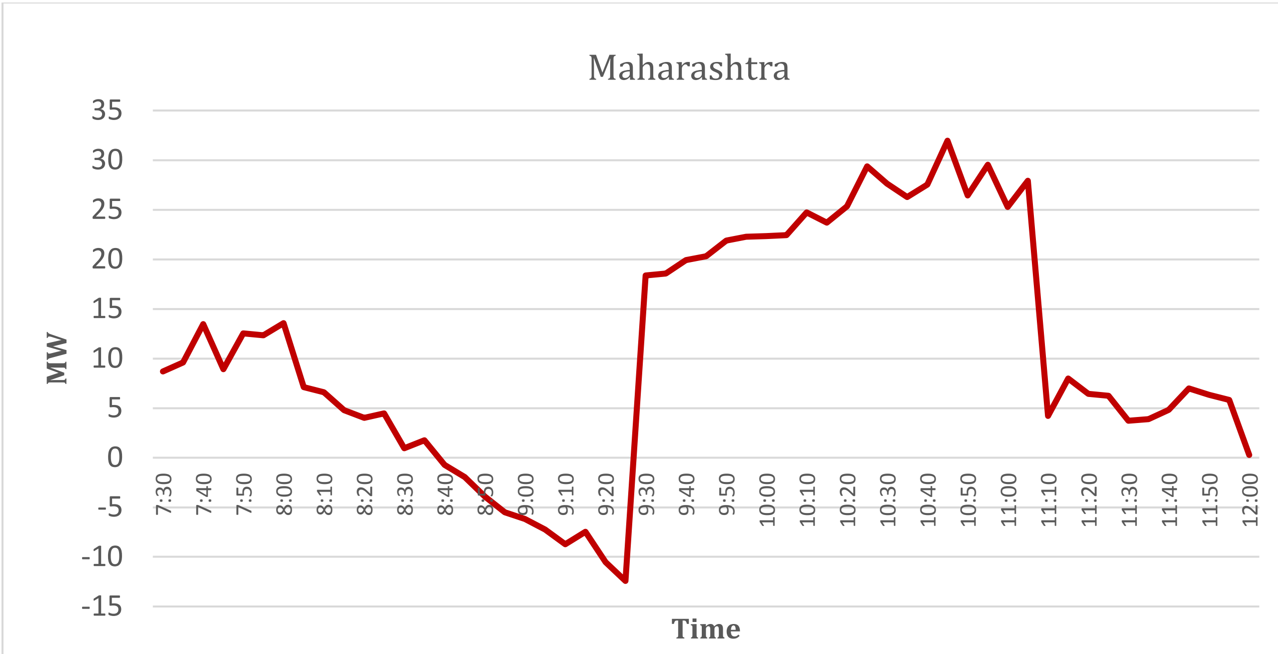


Figure 22: Maharashtra Estimated Solar Generation Ramp Rate during Solar Eclipse on 26.12.2019

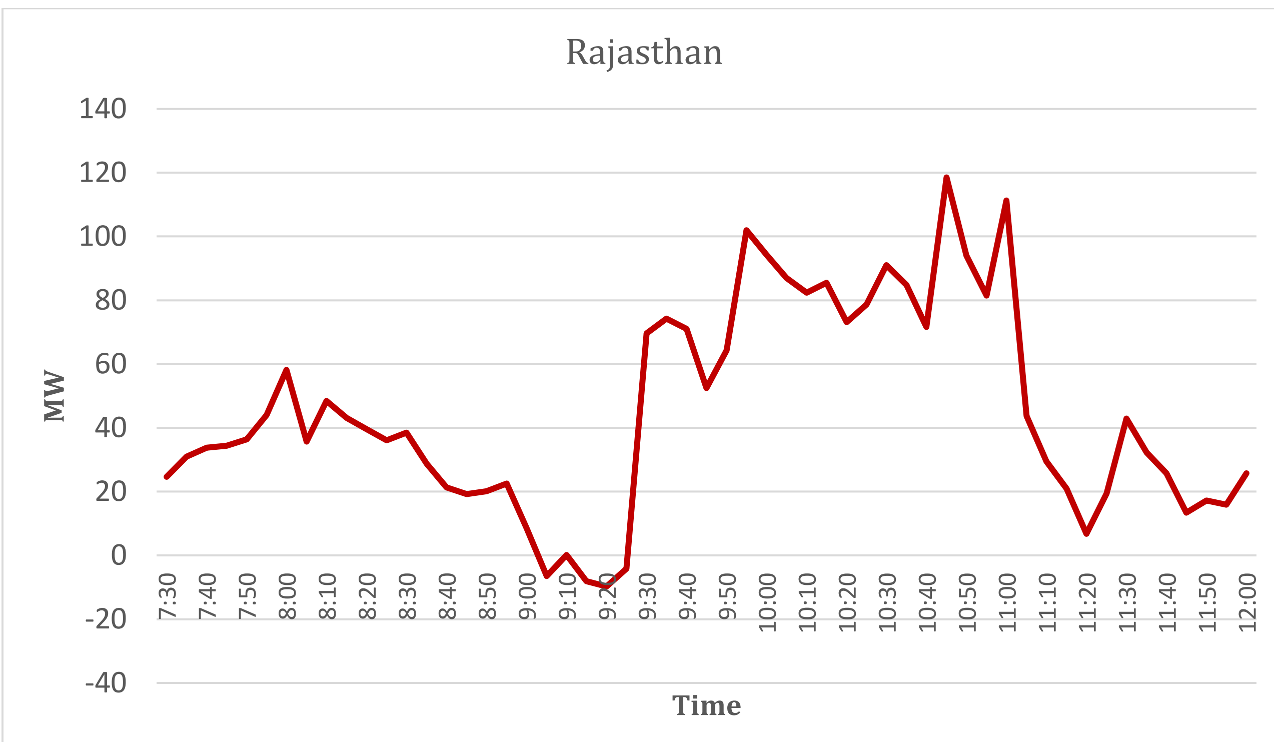


Figure 23: Rajasthan Estimated Solar Generation Ramp Rate during Solar Eclipse on 26.12.2019

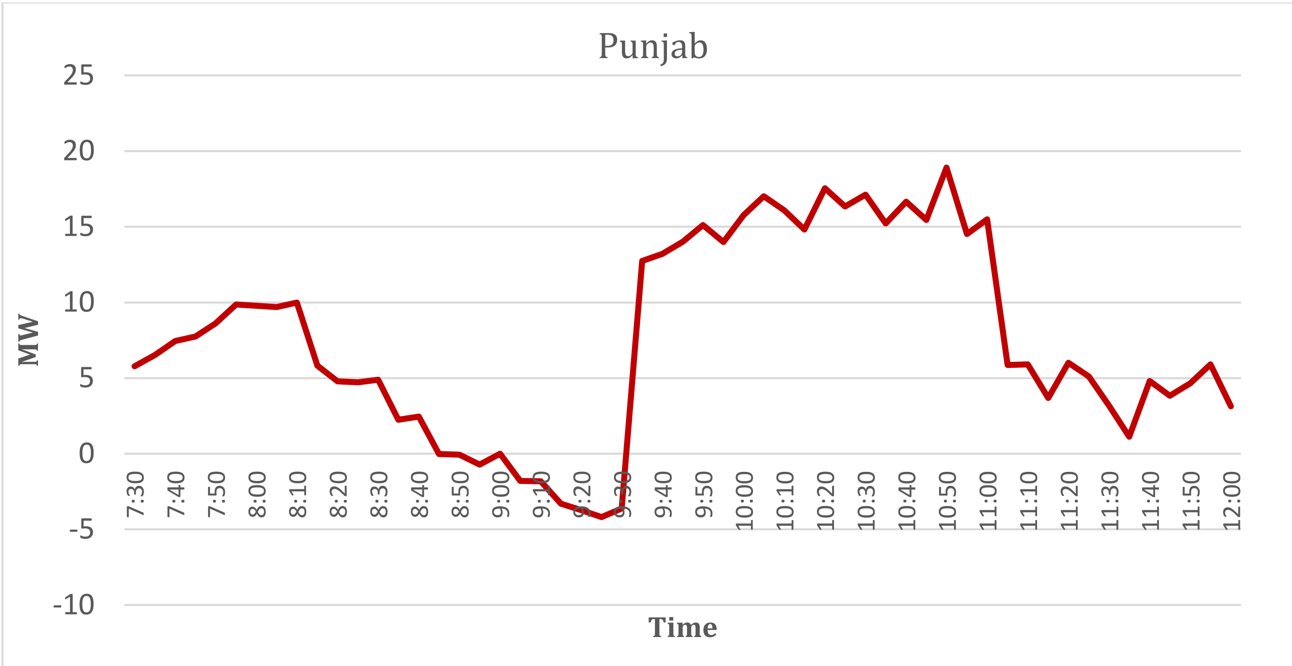


Figure 24: Punjab Estimated Solar Generation Ramp Rate during Solar Eclipse on 26.12.2019

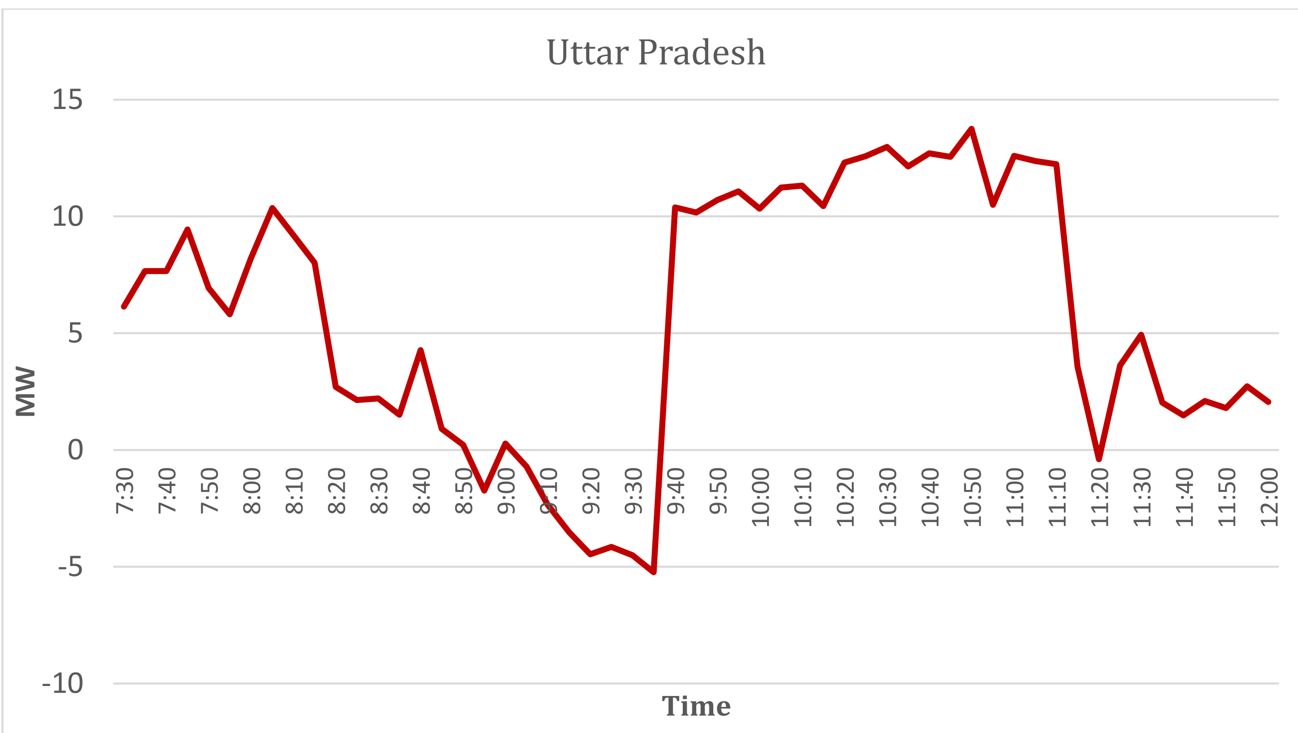


Figure 25: Uttar Pradesh Estimated Solar Generation Ramp Rate during Solar Eclipse on 26.12.2019

The Region and State wise expected feed-in from solar on 26th December 2019 in case of clear sky conditions, with and without solar eclipse is detailed below-

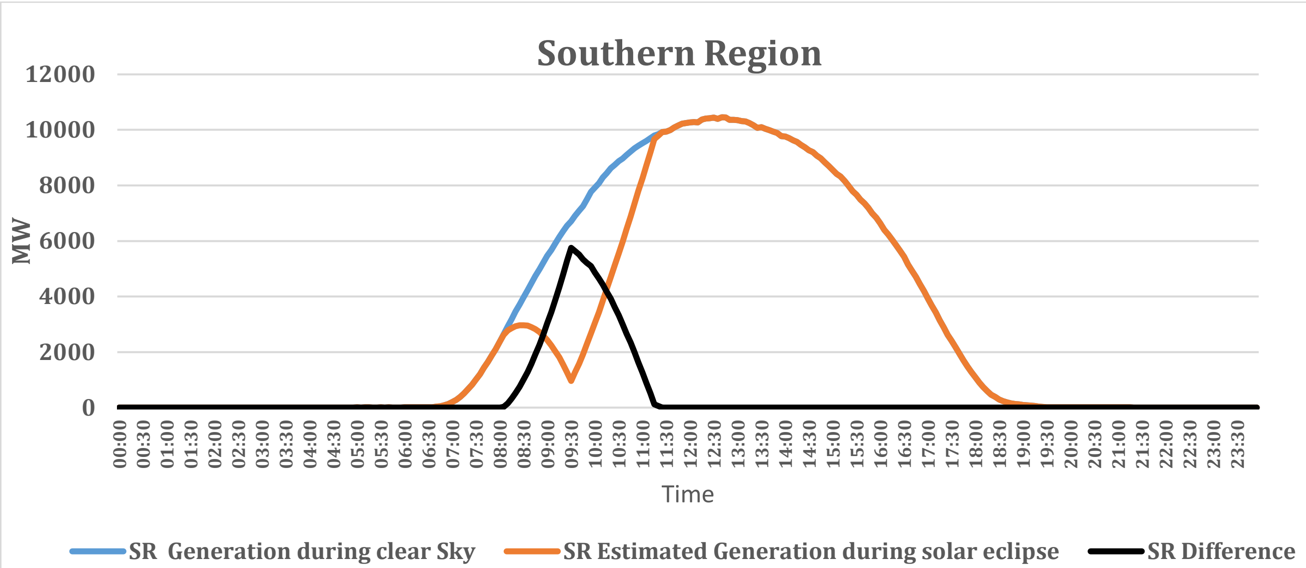


Figure 26: Southern Region Estimated Solar Generation on a Clear Sky day vis-à-vis during Solar Eclipse on 26.12.2019

It is estimated that Southern Region solar generation would decrease by 1.68 GW within 1:25 hour from start of eclipse and would increase by almost 9.85 GW within 1:50 hrs after the maximum impact of the eclipse.

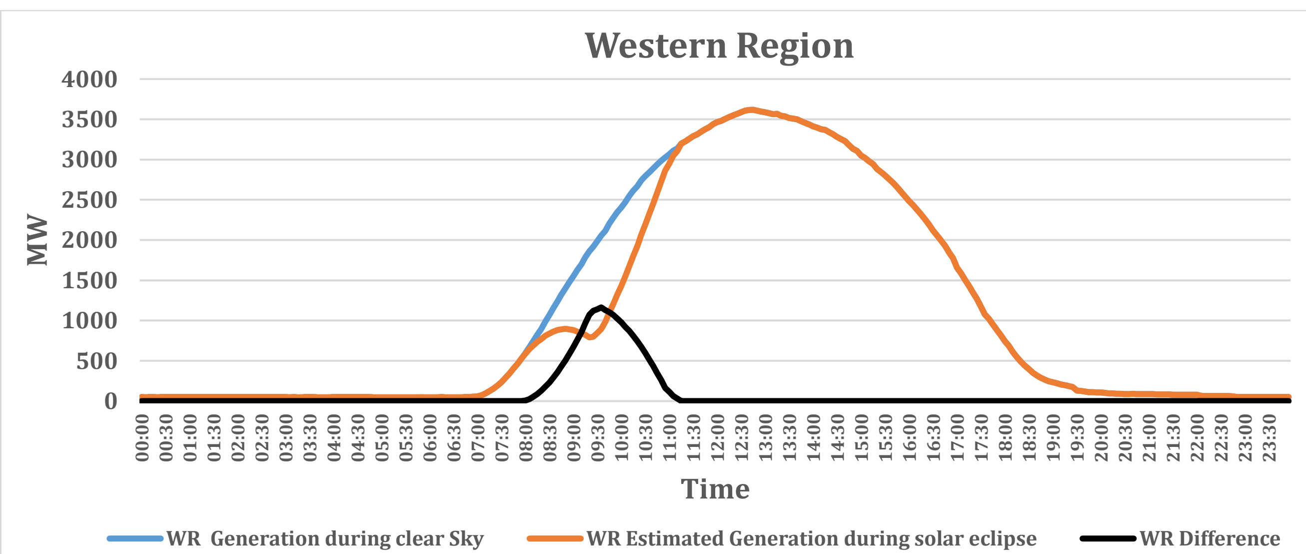


Figure 27: Western Region Estimated Solar Generation on a Clear Sky day vis- à -vis during Solar Eclipse on 26.12.2019

It is estimated that Western Region solar generation would decrease by 200 MW within 1:00 hour from start of eclipse and would increase by almost 2.3 GW within 1:10 hrs after the maximum impact of the eclipse.

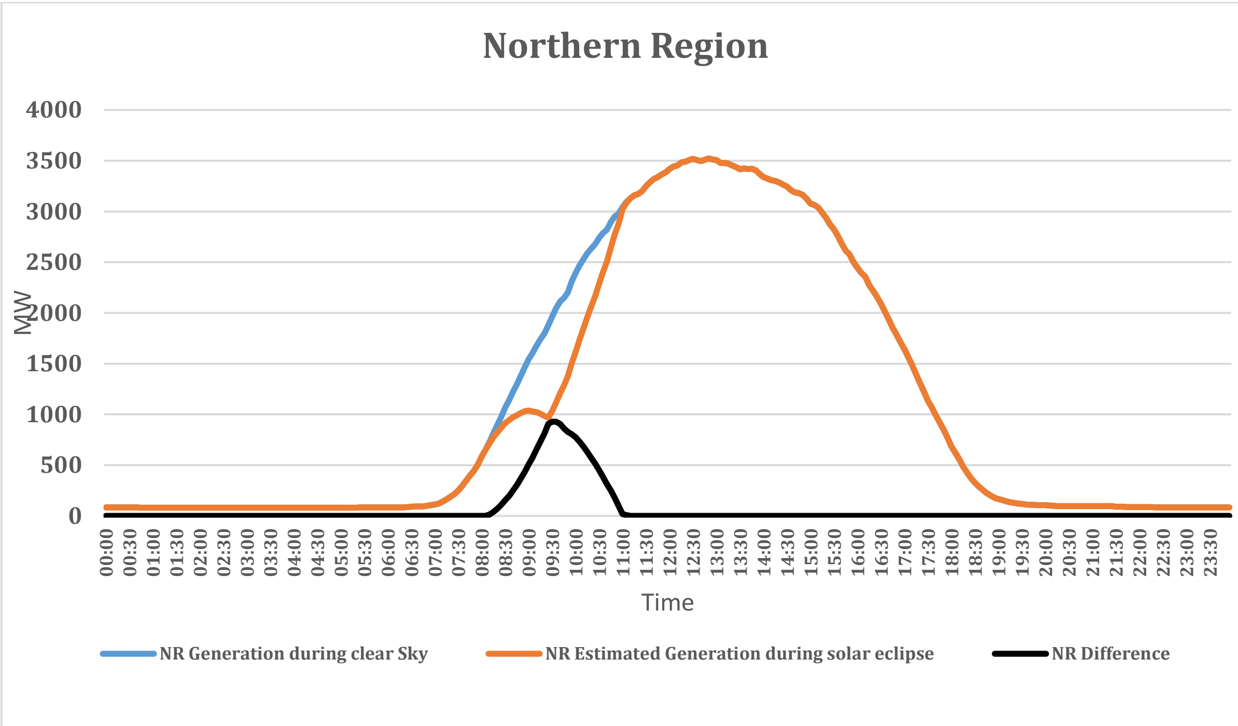


Figure 28: Northern Region Estimated Solar Generation on a Clear Sky day vis- à -vis during Solar Eclipse on 26.12.2019

It is estimated that Northern Region solar generation would decrease by 100MW within 1.00 hour from start of eclipse and would increase by almost 2.1 GW within 1:45 hrs after the maximum impact of the eclipse.

3.4 ESTIMATED STATE-WISE SOLAR GENERATION DURING SOLAR ECLIPSE

The estimated solar generation during solar eclipse with respect to generation during clear sky condition of renewable rich states are given below:

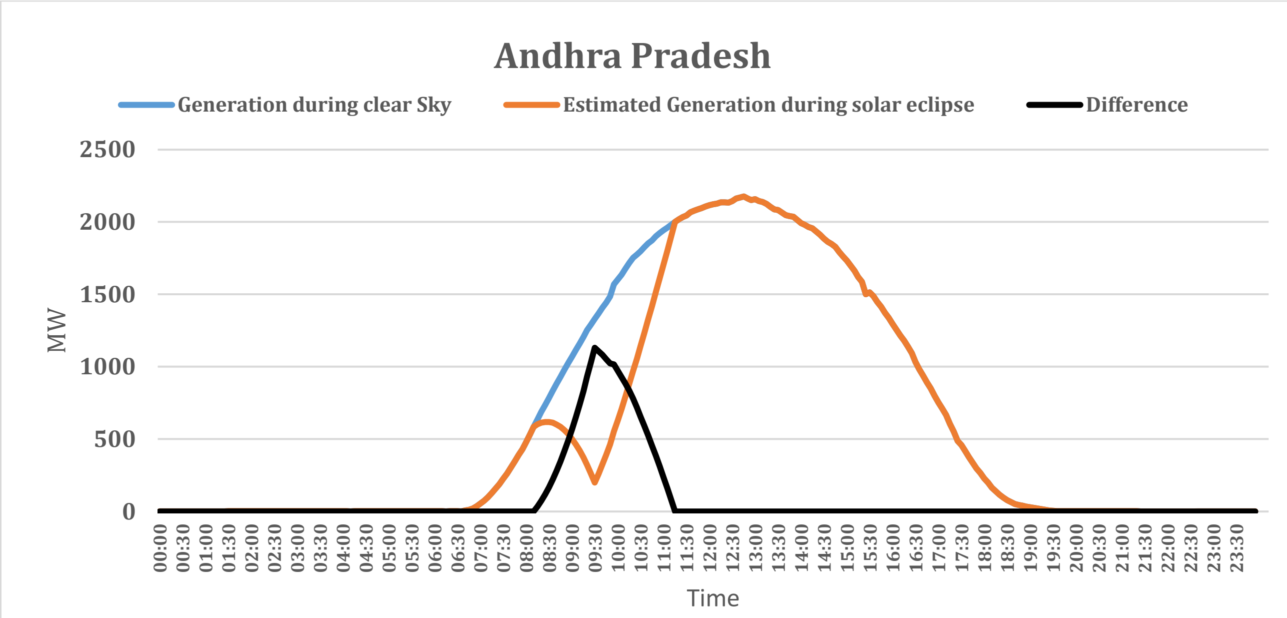


Figure 29: Andhra Pradesh Estimated Solar Generation on a Clear Sky day vis- à -vis during Solar Eclipse on 26.12.2019

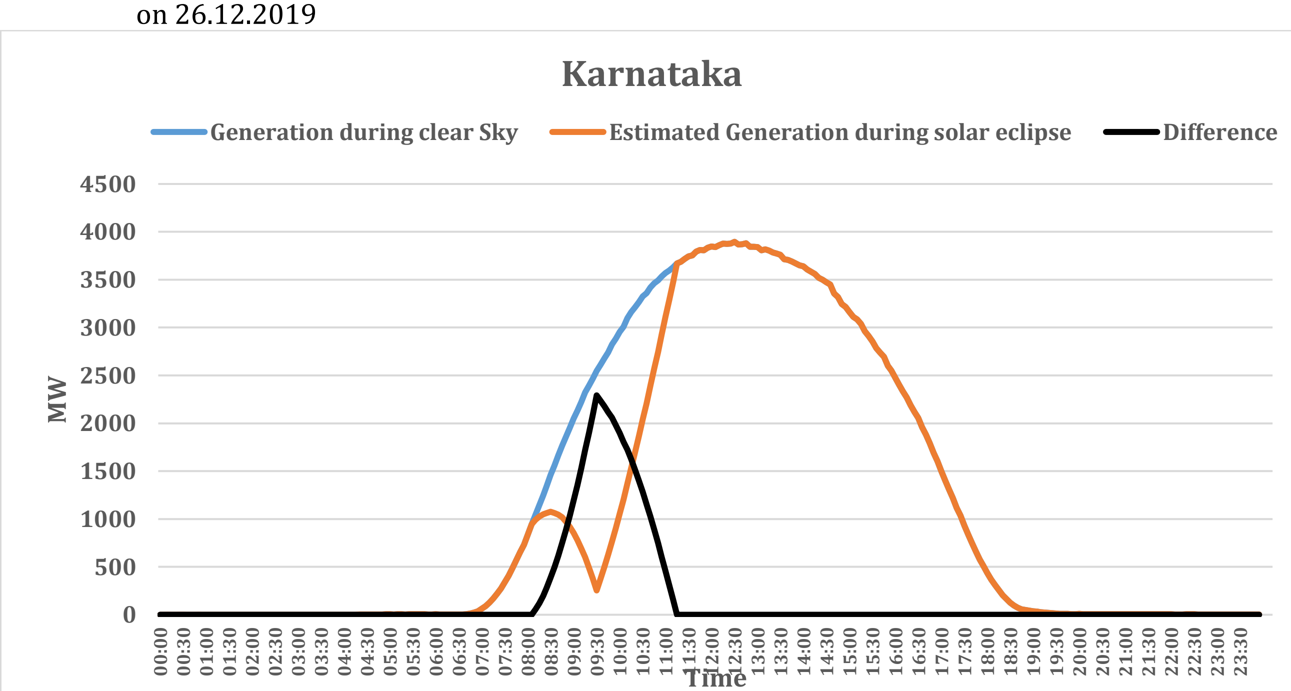


Figure 30: Karnataka Estimated Solar Generation on a Clear Sky day vis- à -vis during Solar Eclipse on 26.12.2019

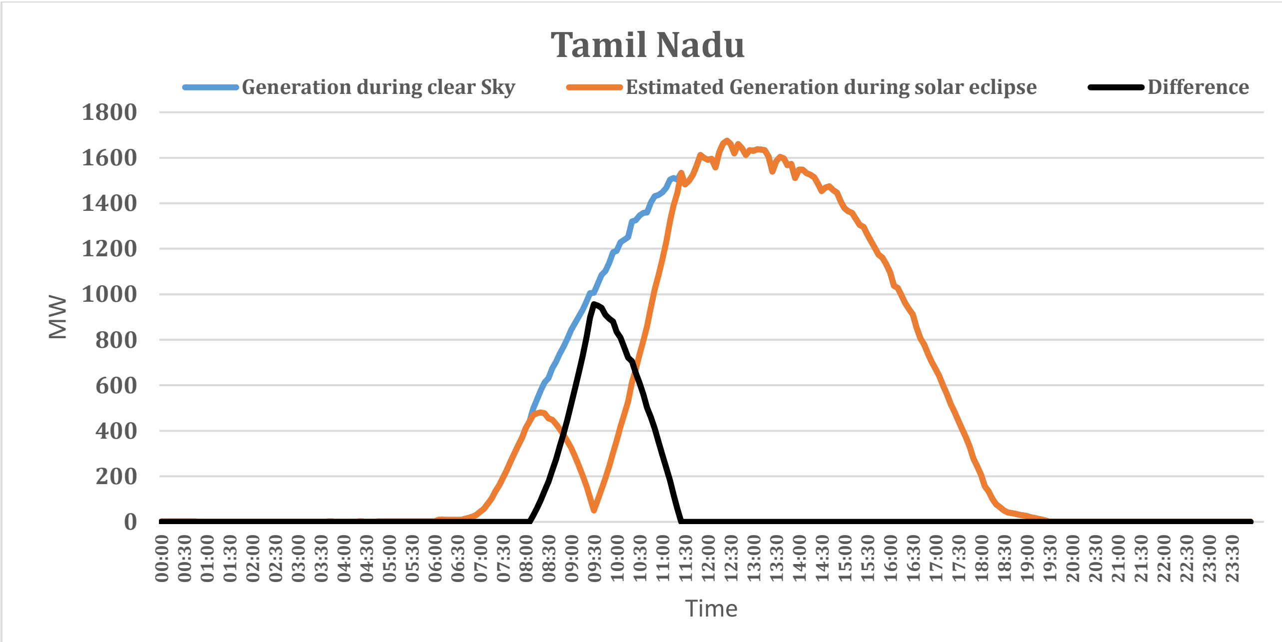


Figure 31: Tamil Nadu Estimated Solar Generation on a Clear Sky day vis- à -vis during Solar Eclipse on 26.12.2019

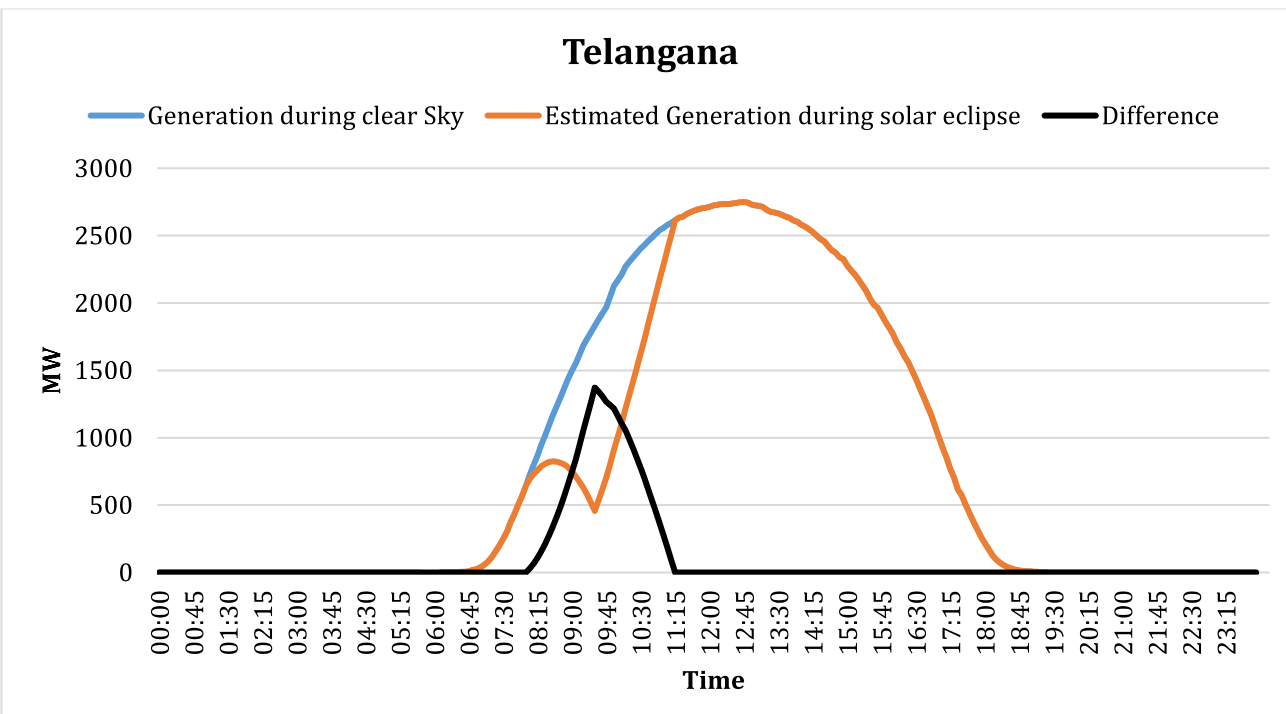


Figure 32: Telangana Estimated Solar Generation on a Clear Sky day vis- à -vis during Solar Eclipse on 26.12.2019

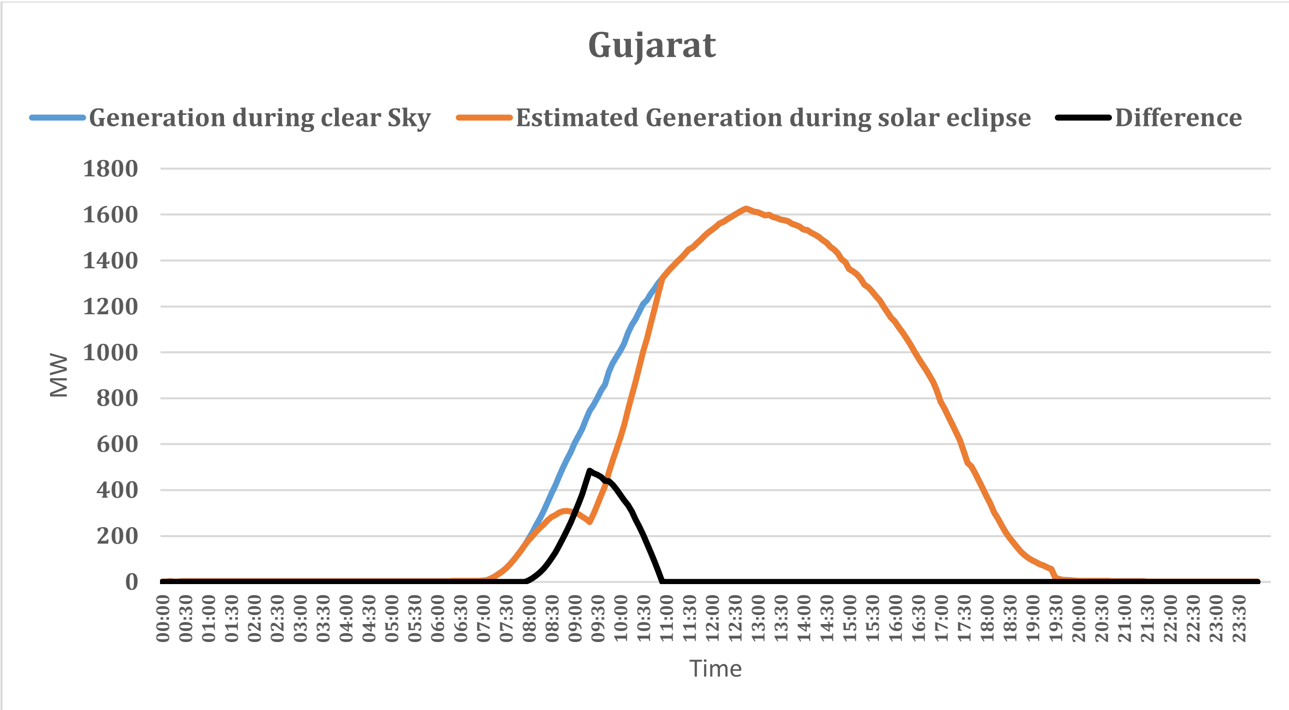


Figure 33: Gujarat Estimated Solar Generation on a Clear Sky day vis- à -vis during Solar Eclipse on 26.12.2019

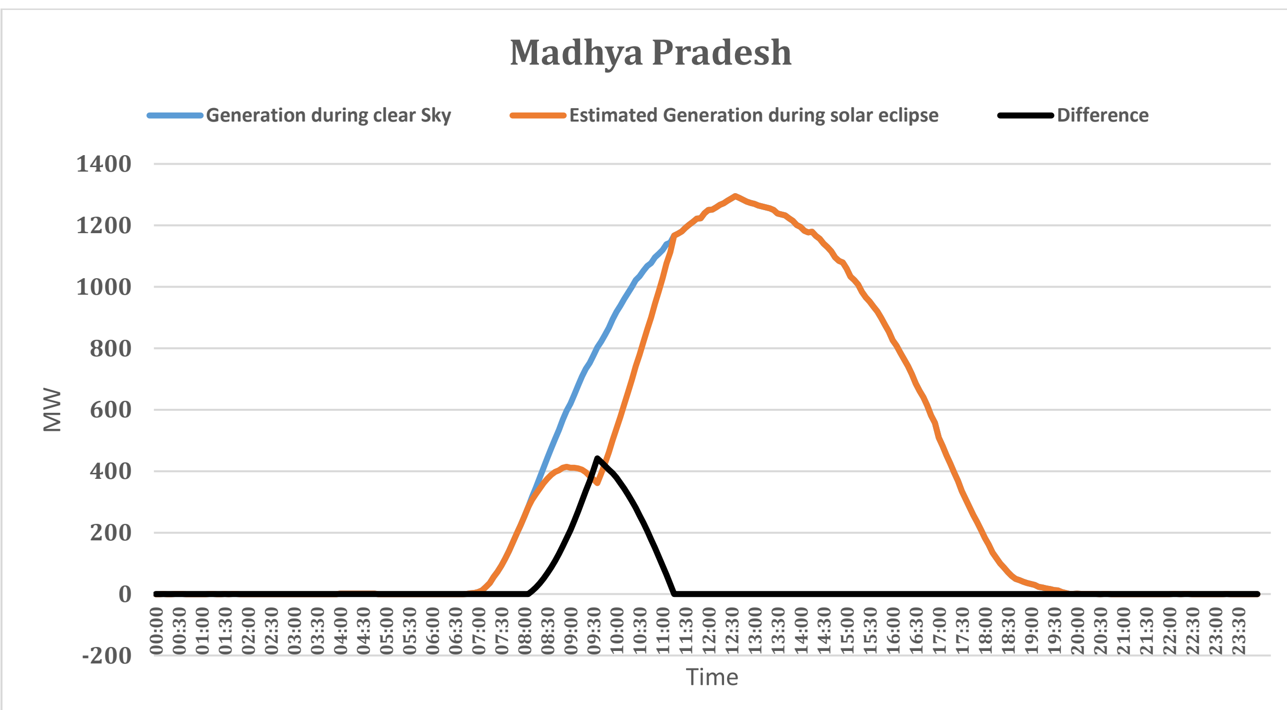


Figure 34: Madhya Pradesh Estimated Solar Generation on a Clear Sky day vis- à -vis during Solar Eclipse on 26.12.2019

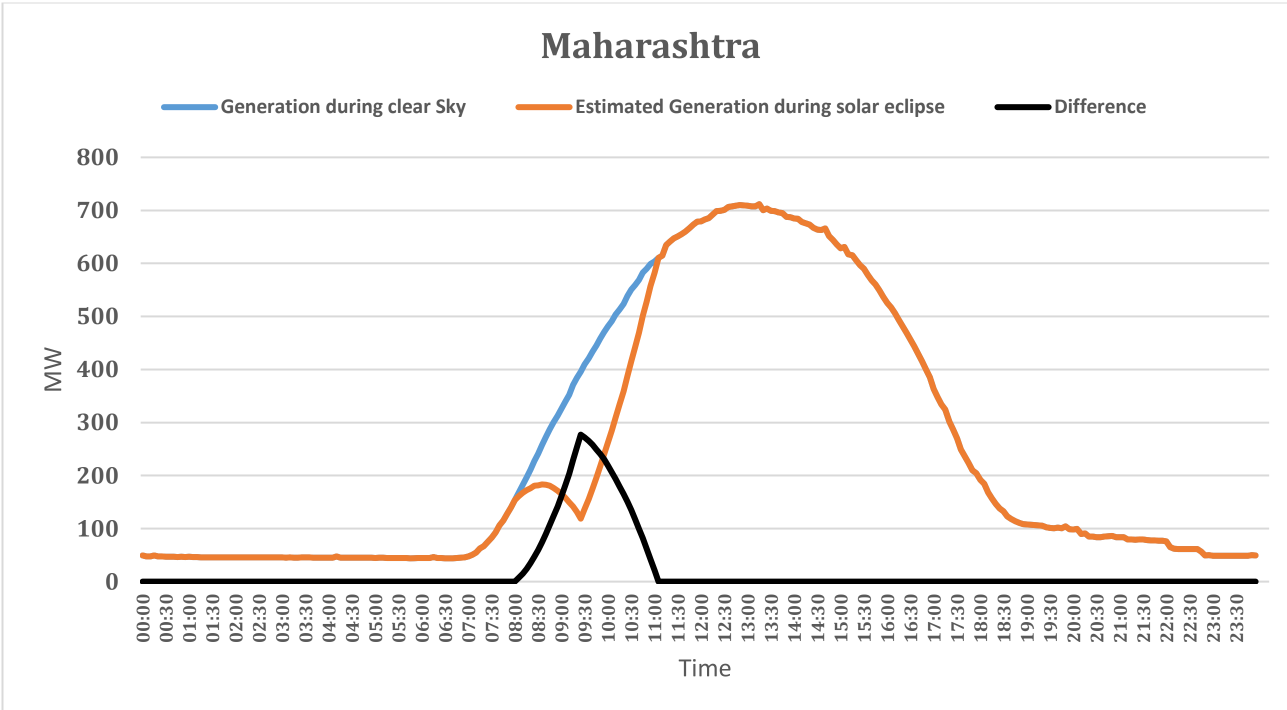


Figure 35: Maharashtra Estimated Solar Generation on a Clear Sky day vis- à -vis during Solar Eclipse on 26.12.2019

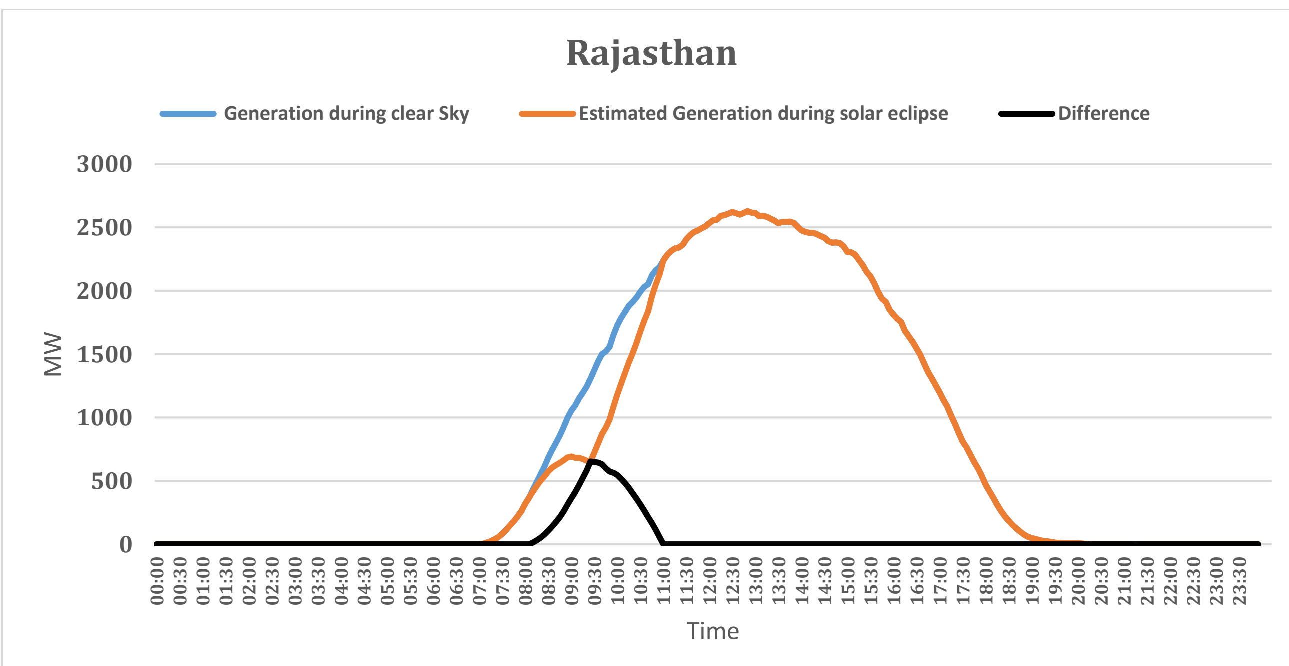


Figure 36: Rajasthan Estimated Solar Generation on a Clear Sky day vis- à -vis during Solar Eclipse on 26.12.2019

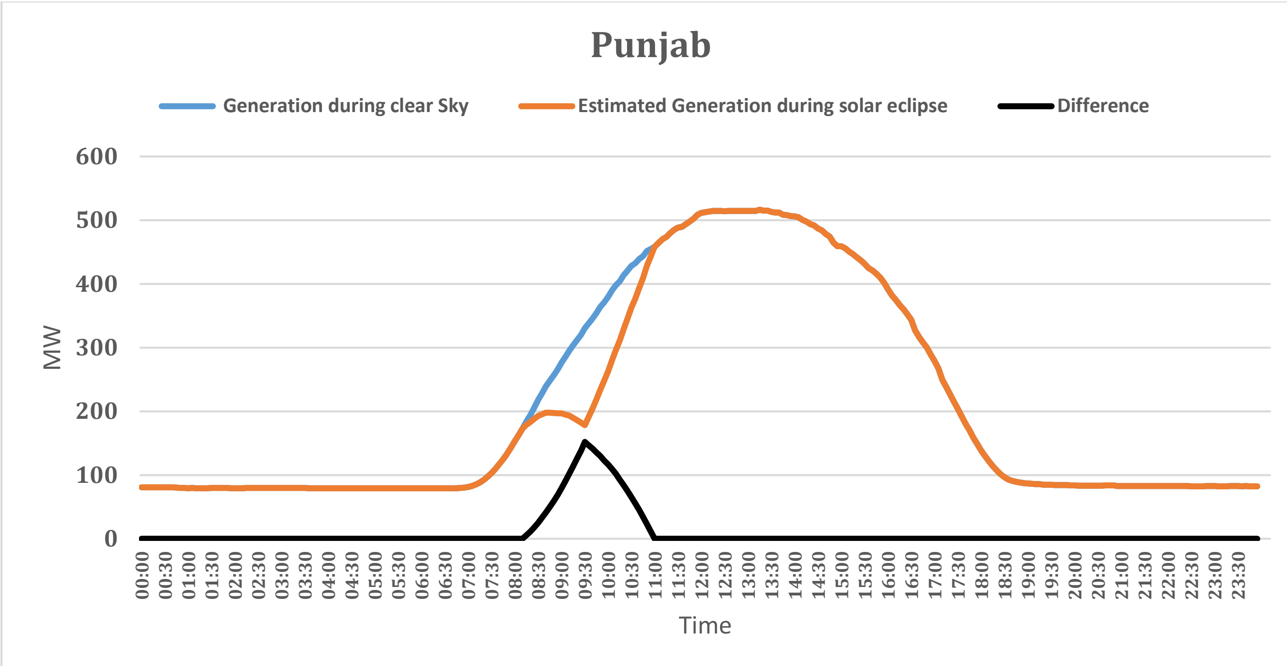


Figure 37: Punjab Estimated Solar Generation on a Clear Sky day vis- à -vis during Solar Eclipse on 26.12.2019

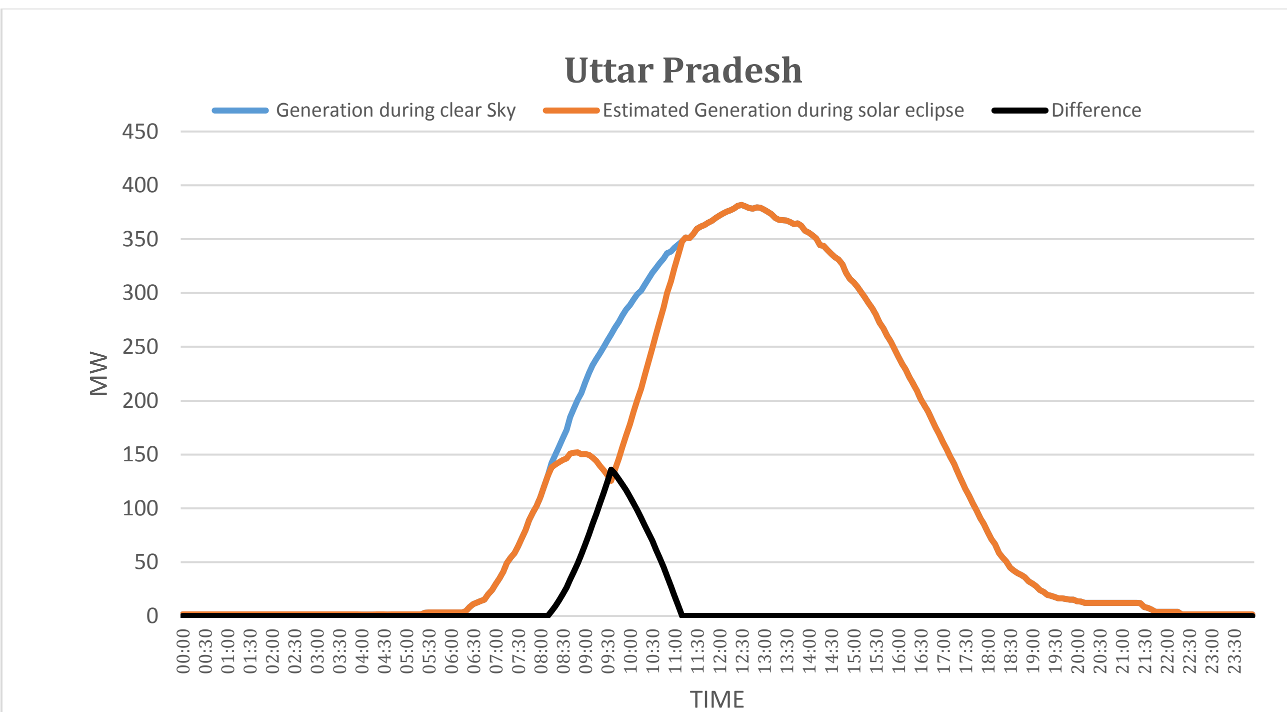


Figure 38: Uttar Pradesh Estimated Solar Generation on a Clear Sky day vis- à -vis during Solar Eclipse on 26.12.2019

3.5 FORECASTED ALL INDIA AND REGIONAL DEMAND

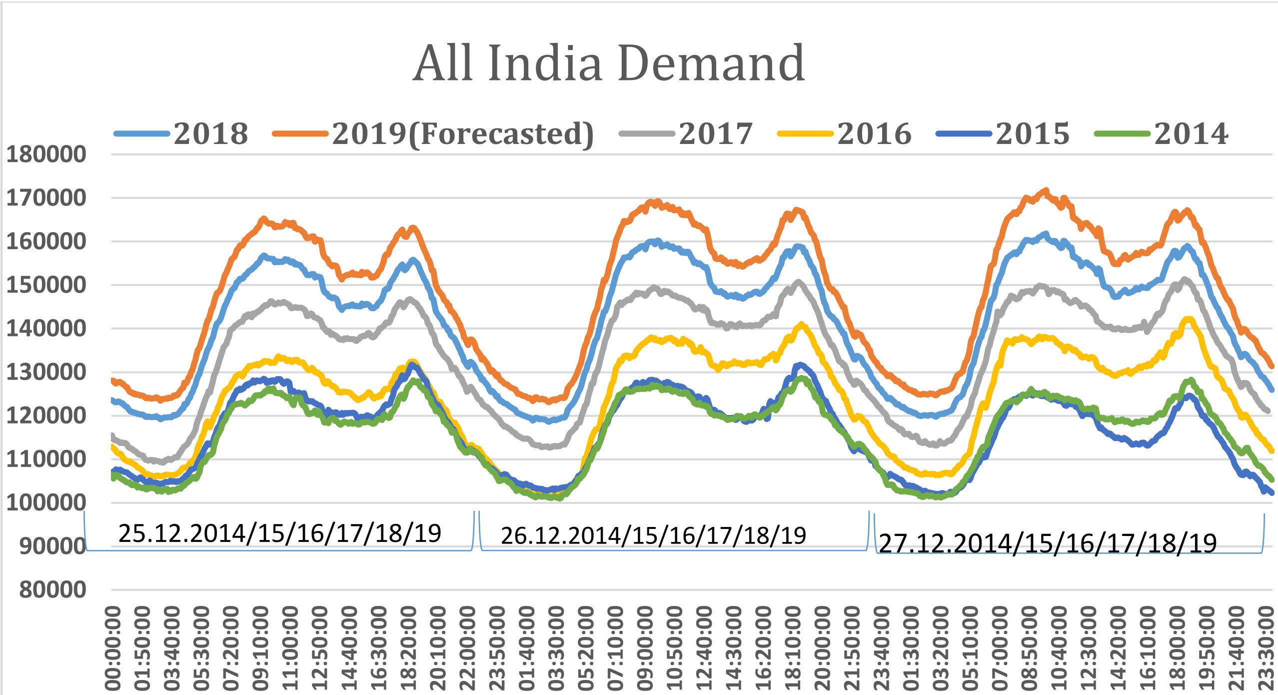


Figure 39: All India Forecasted Demand during Solar Eclipse on 26.12.2019

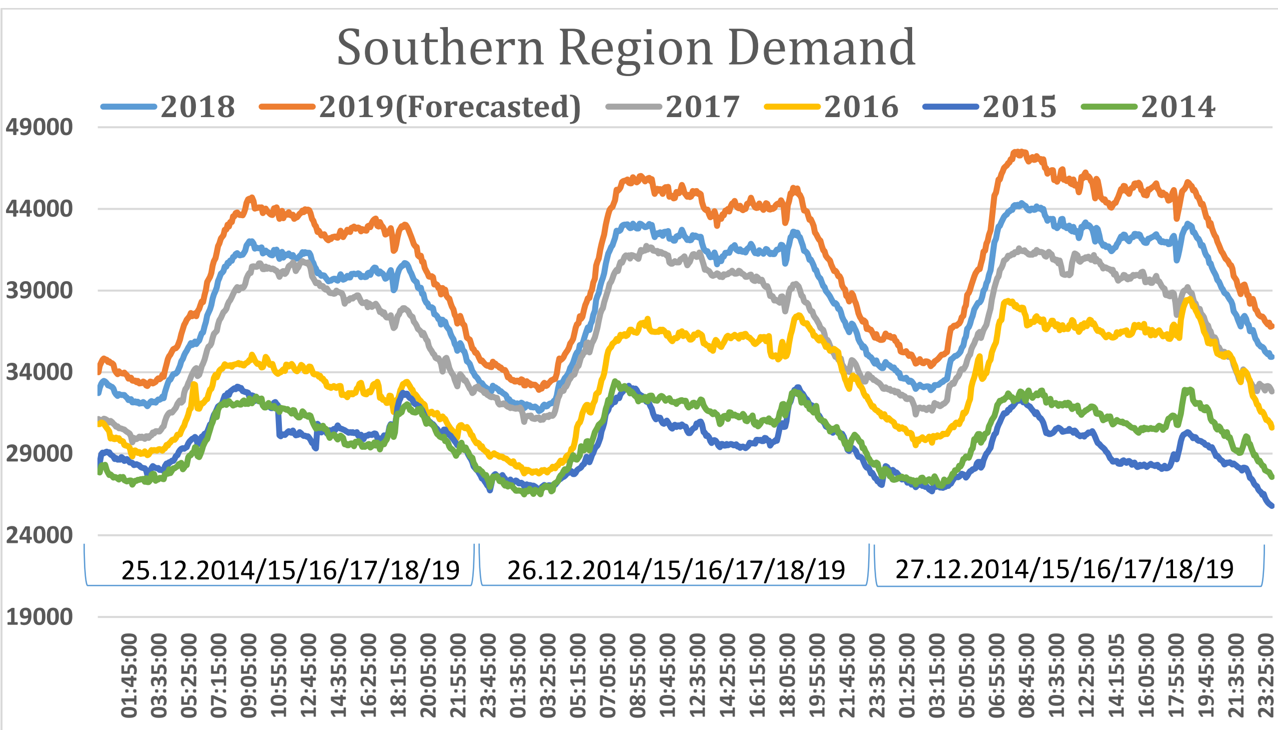


Figure 40: Southern Region Forecasted Demand during Solar Eclipse on 26.12.2019

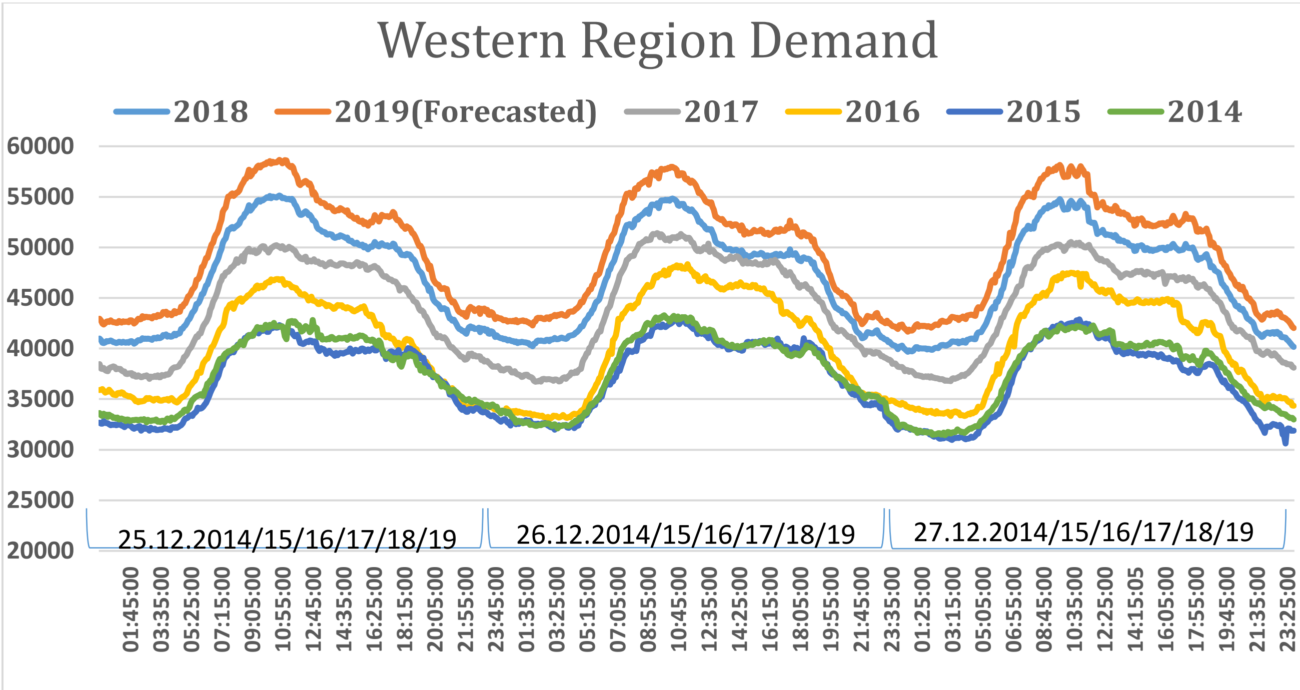


Figure 41: Western Region Forecasted Demand during Solar Eclipse on 26.12.2019

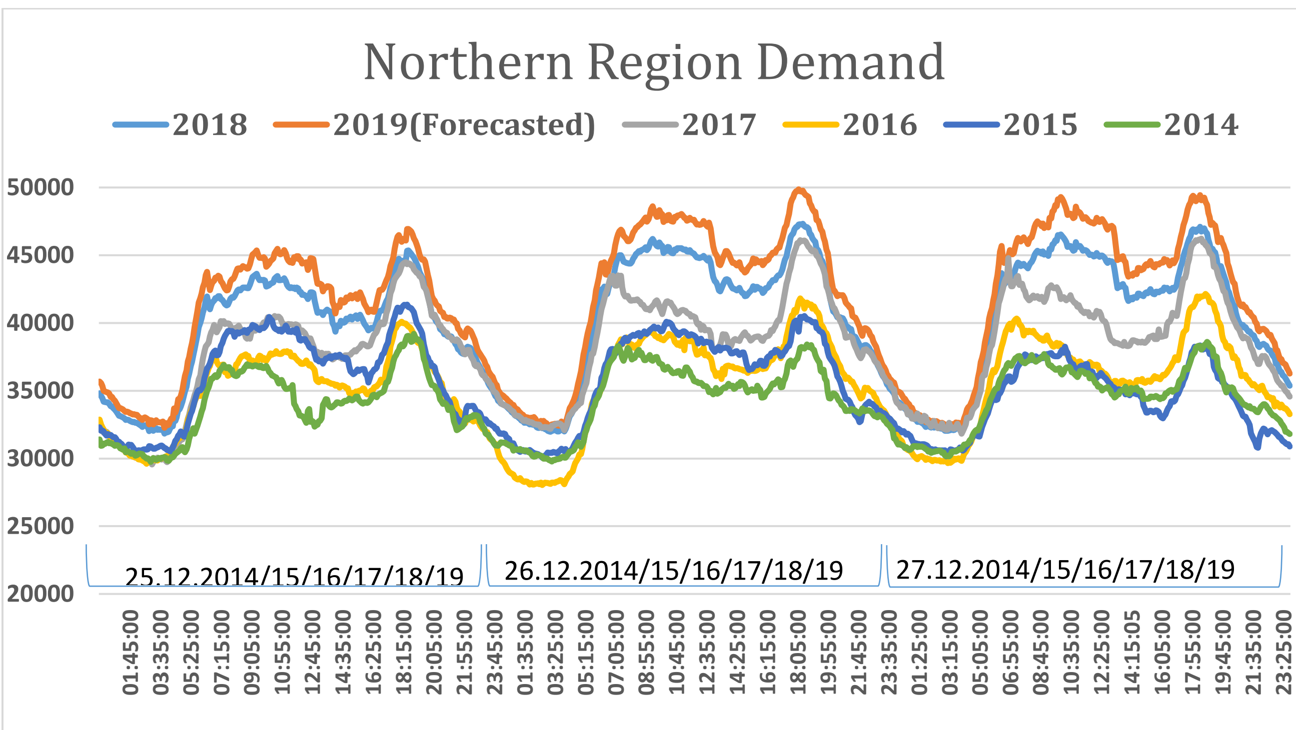


Figure 42: Northern Region Forecasted Demand during Solar Eclipse on 26.12.2019

4. IMPACT OF PSYCHOLOGICAL BEHAVIOUR ON POWER SYSTEM

4.1 EFFECT ON DEMAND DUE TO HUMAN BEHAVIOUR

As per the literature survey of Europe's Eclipse, based on evidence from the 1999 eclipse, it was expected a depression in demand around the time of maximum obscuration due to human causes such as people stopping work and going to look at the phenomenon. From 1999 solar eclipse report, it was expected that the demand effect would dominate the PV effect.

Further as per WECC report on solar eclipse 2017, similar to the Europe's eclipse, effect on energy demand partially depends on human behaviour, e.g., halting normal activities to observe the eclipse and the transient cooling effect. These two effects lower the actual energy demand. When distributed PV is present, an eclipse reduces the output from these sources, leading to an apparent increase in energy demand. Thus, these two counteract each other during an eclipse

In Indian Context, two most prominent solar eclipses have been observed in past ten years.

1) Total eclipse on 22.07.2009
2) Annular eclipse on 15.01.2010

On 22nd July 2009 from 06:25 hrs (IST) to 06:29 hrs (IST)), a total eclipse of the sun was visible from within a narrow corridor that traversed half of earth. The path of the moon's umbral shadow began in India and crossed through Nepal, Bangladesh, Bhutan, Myanmar and China. After leaving mainland Asia, the path crossed Japan's Ryukyu Islands and curved southeast through the Pacific Ocean where the maximum duration of totality reached for 6 minutes and 39 seconds. A partial eclipse was observed within the much broader path of the moon's penumbral shadow, which included most of eastern Asia, Indonesia, and the Pacific Ocean.

In India, it passed through south of Gujarat, Maharashtra, Madhya Pradesh, Jharkhand, Bihar, West Bengal and some parts of Chhattisgarh. The Path of the eclipse is given in figure below:

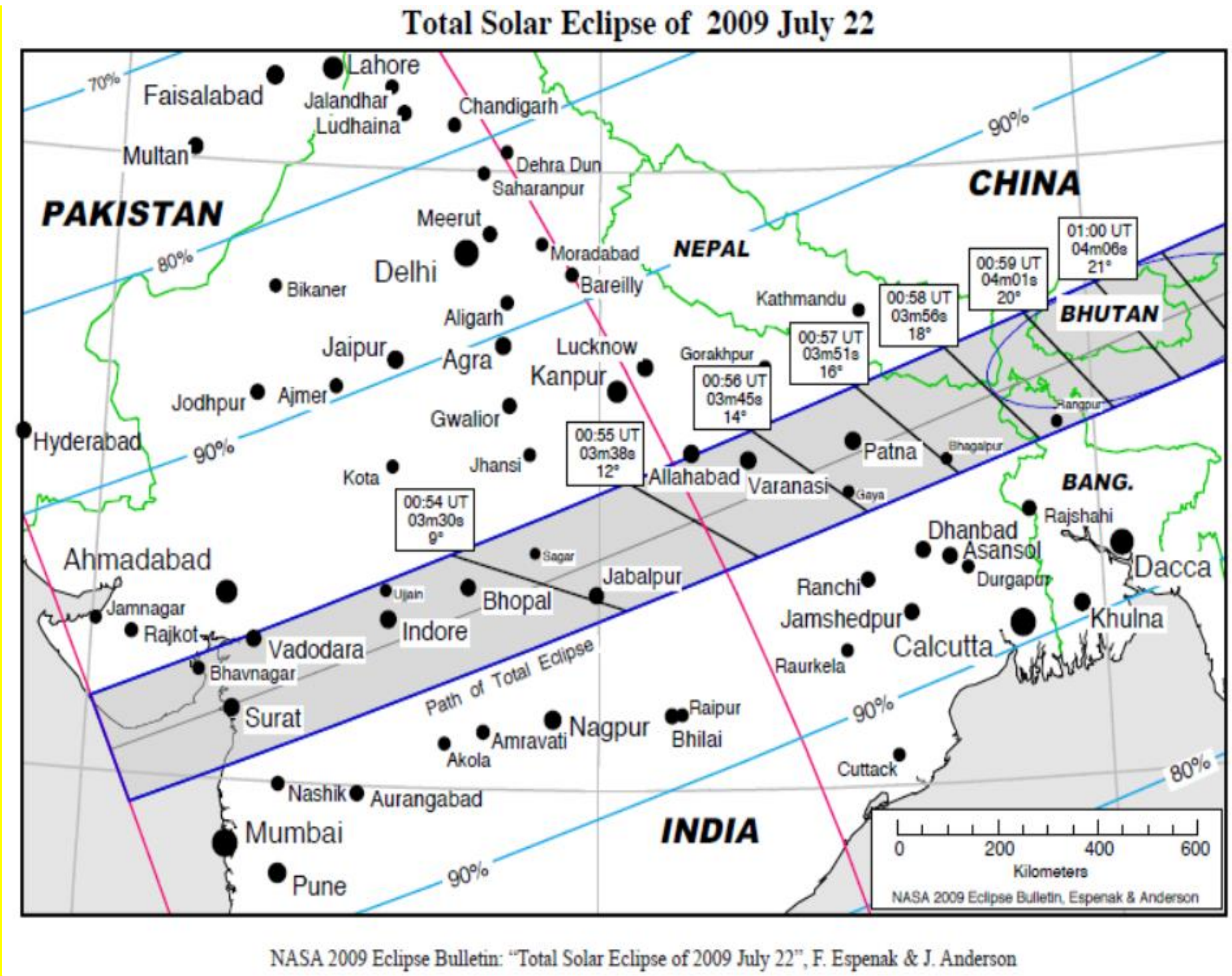


Figure 43: Path of Total Solar Eclipse on 22 July 2009

Solar eclipse in India started at 06:25 hrs (IST) from Southern Gujarat and at 06:29 hrs (IST), it crossed the territory of India and entered into Bhutan. During the eclipse, slight reduction in demand of Northern and Eastern Region was observed. The change in demand of Western Region could not be ascertained due to non-availability of data during the period of eclipse. Plot of demand met for Western Region, Eastern Region, Southern Region, Northern Region and all India from 21st July 2019 to 23rd July 2019 is shown below.

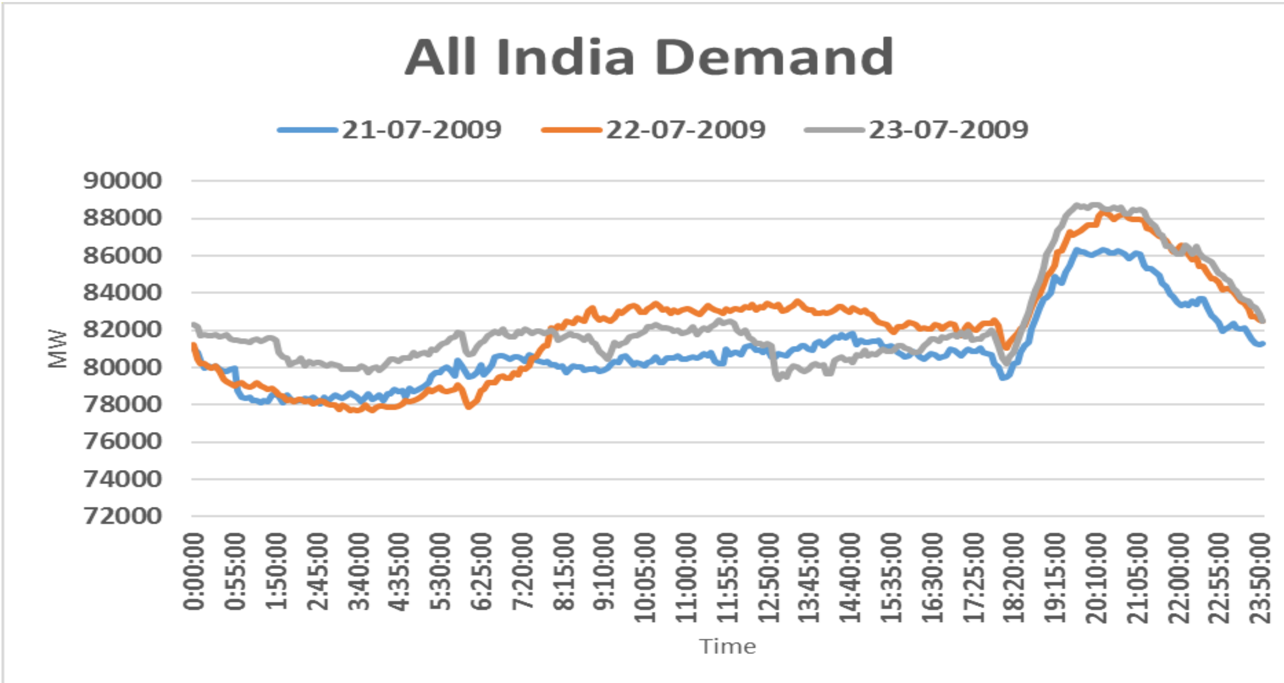


Figure 44: All India Demand Pattern for 21-23 July 2009

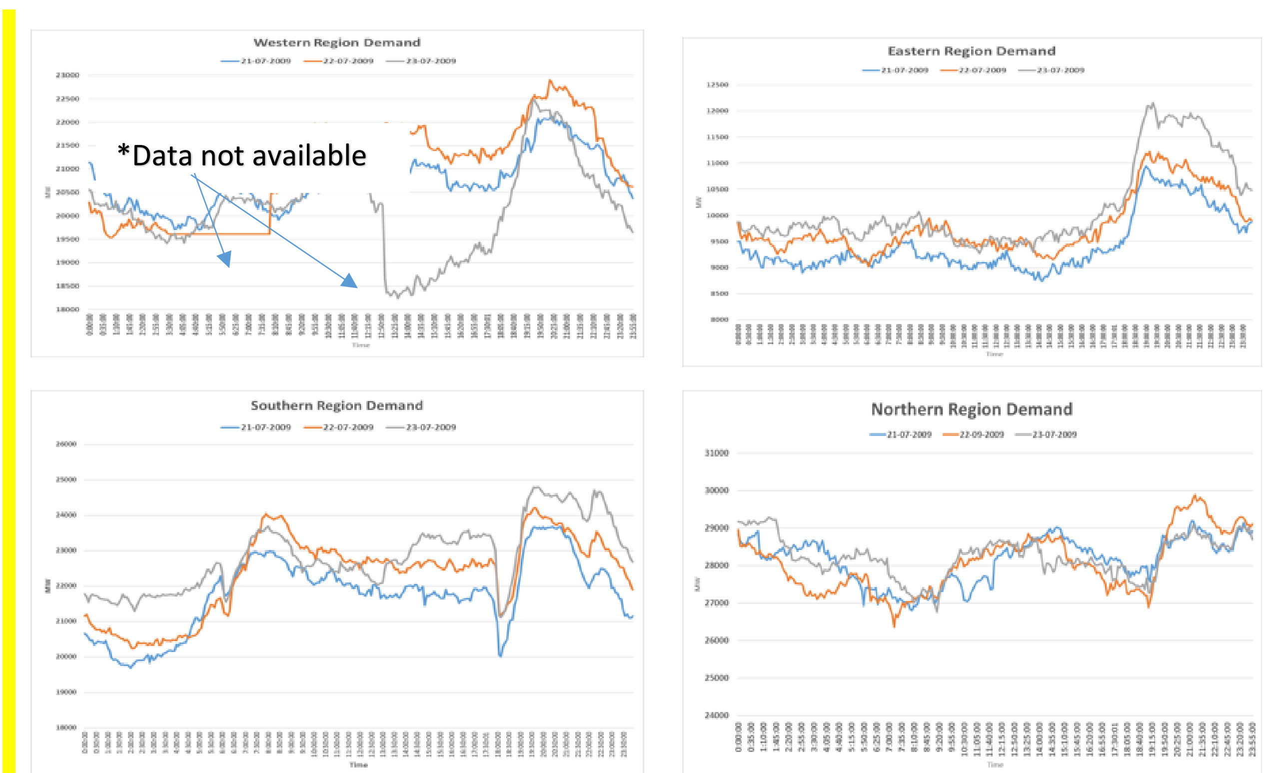


Figure 45: Region Wise Demand Pattern for 21-23 July 2009

Annular Eclipse on 15.01.2010: On 15th January 2010 from 13:15 hrs (IST) to 13:25 hrs (IST)), an annular eclipse of the sun was visible from within a 300-km-wide track that traversed half of earth. The path of the moon's antumbral shadow began in Africa and crossed the Indian Ocean where the maximum duration of annularity reached for 11 minutes and 08 seconds. The central path then continued into Asia through India, Bangladesh, Myanmar, and China. A partial eclipse was also observed in the European countries.

In India, it mainly passed through eastern part of Tamil Nadu and Southern part of Kerala. Path of the solar eclipse is given below:

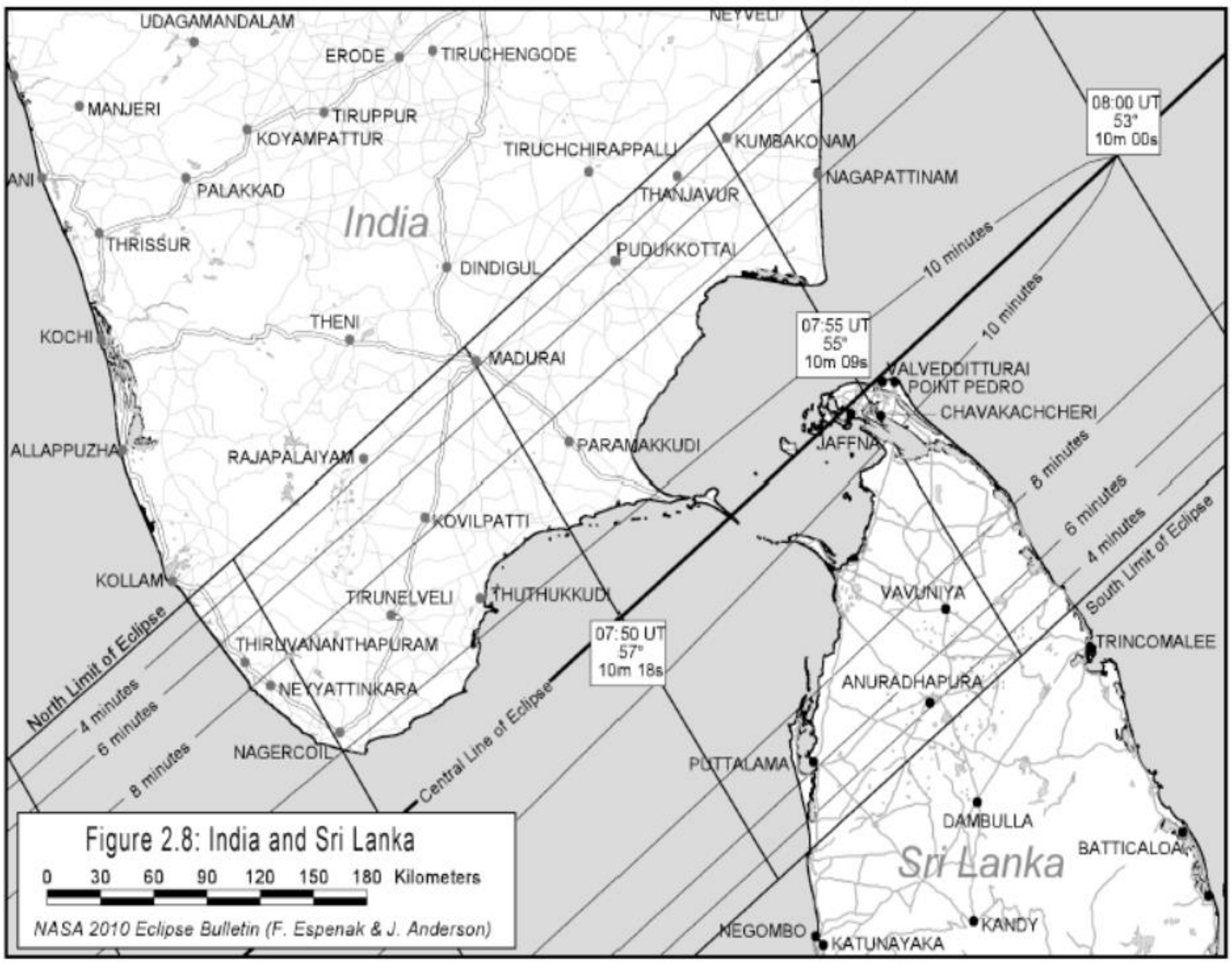


Figure 46: Annular Solar Eclipse Path on 15 January 2010

In India, Annular solar eclipse started at 11:00 hrs (IST), traversed through Southern part of Kerala and Tamil Nadu and ended at 15:00 hrs (IST). During the eclipse, it has been observed

that Southern Region demand reduced by an average of 576MW (around 2.5% of previous day demand) with maximum reduction of 1200MW (around 5% of previous day demand).

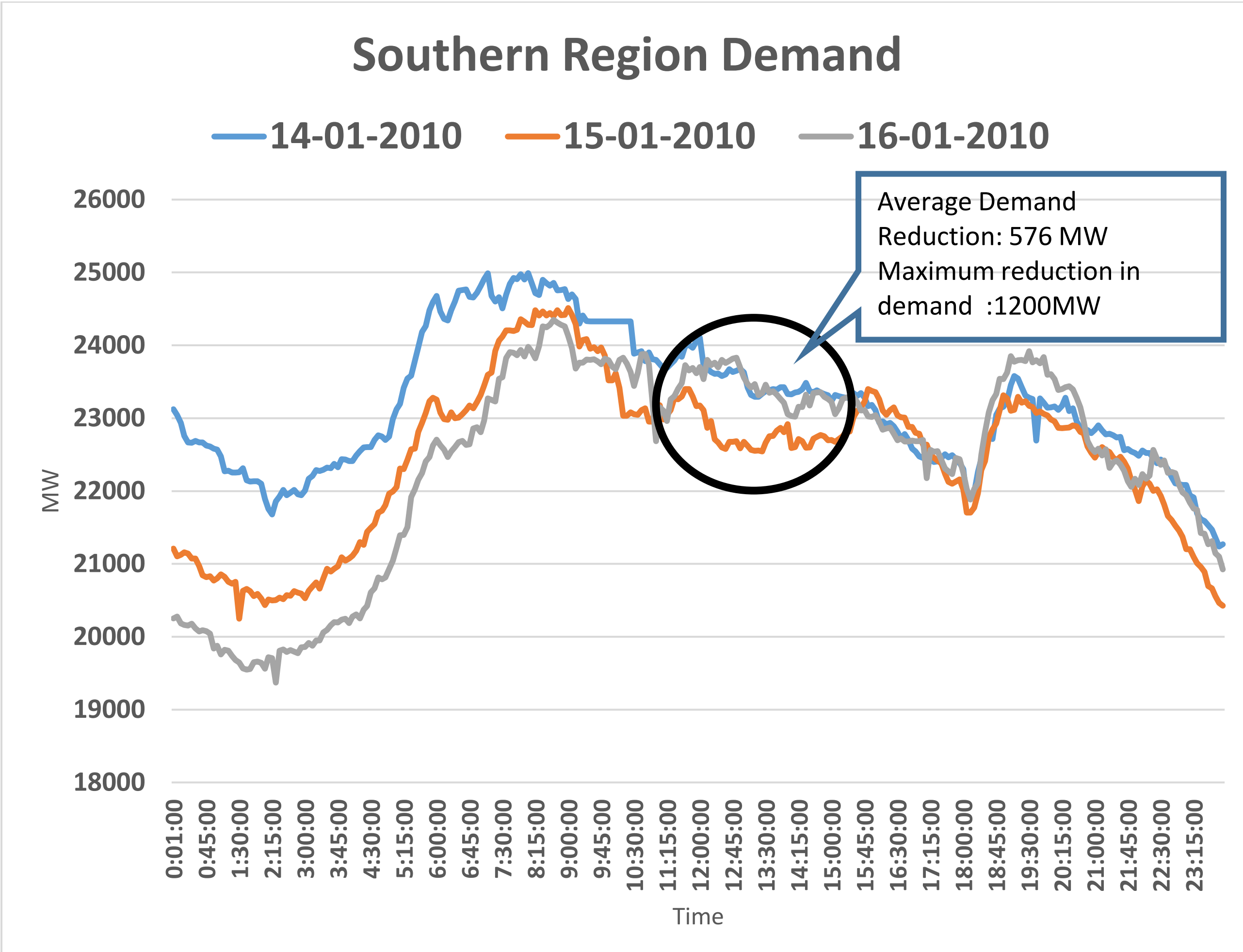


Figure 47: Southern Region Demand Pattern on 15 January 2010

Similar phenomena has been also observed during lunar eclipse on 31.01. 2018. There was reduction of approximately 3500MW in demand compared to the previous day during the period of lunar eclipse.

It is expected that during eclipse on 26th December 2019, there would be depression in demand due to human behaviour. It has been observed that during eclipse temples are closed, small commercial shops postpone their activities, cooking activity is postponed and people generally confine themselves indoor. This human behaviour leads to decrease in power consumption by a small amount.

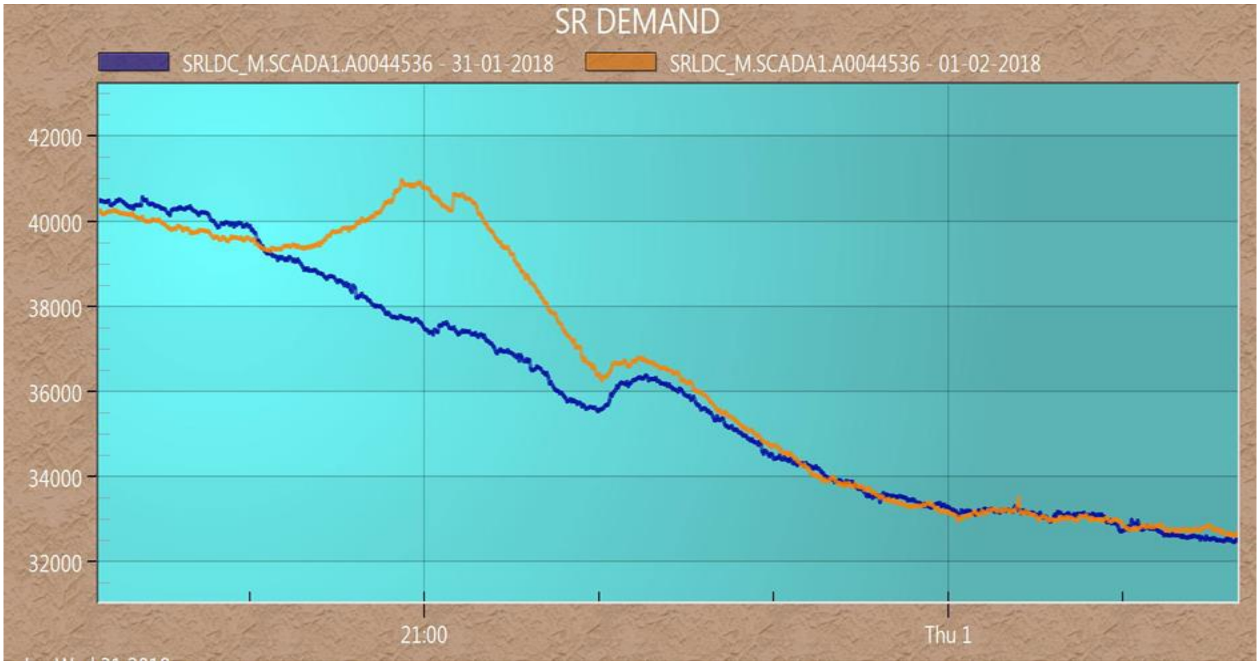


Figure 48: Southern Region Demand during Lunar Eclipse on 31.01.18 & Normal day 01.02.18.

State wise demand of Southern Region during lunar eclipse on 31st January 2018 is given below:

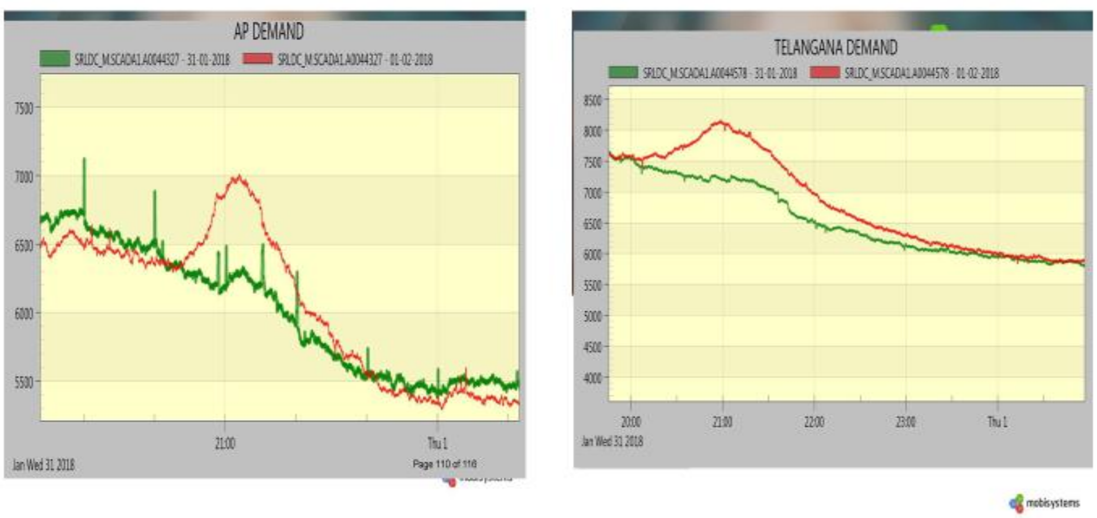


Figure 49: Demand of Andhra Pradesh & Telangana during Lunar Eclipse on 31.01.18 & Normal Day 01.02.18.

Figure 50: Demand of Karnataka & Tamil Nadu during Lunar Eclipse on 31.01.18 & Normal day 01.02.18.

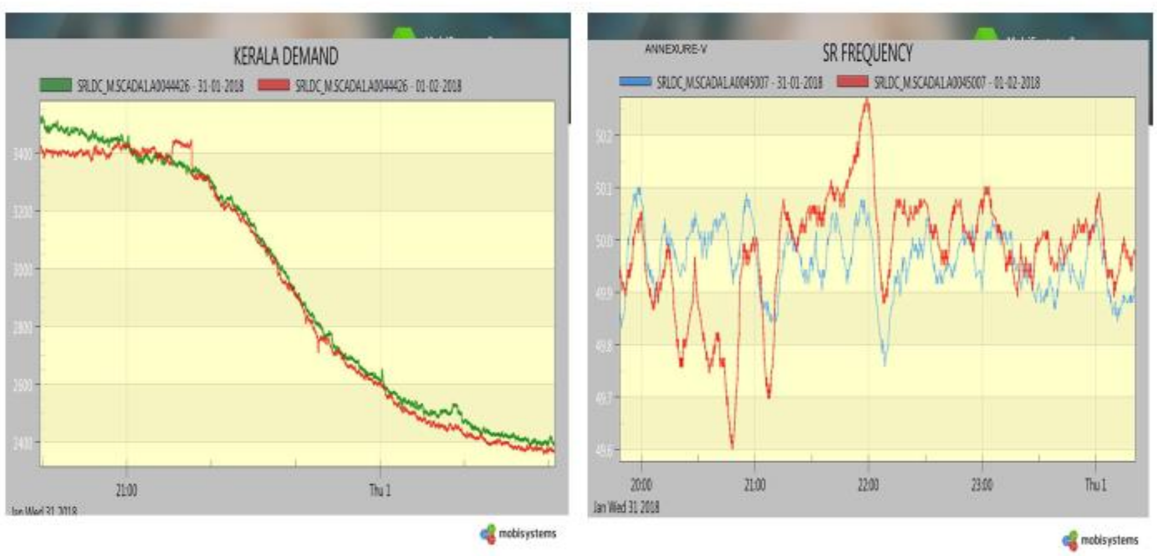


Figure 51: Demand of Kerala & Frequency during Lunar Eclipse on 31.01.18 & Normal day 01.02.18.

5. SYSTEM RELIABILITY STUDY FOR 26th DECEMBER 2019 SOLAR ECLIPSE SCENARIO

During the month of December-January, the demand has a rising trend in Southern Region due to upcoming summer season. All India anticipated demand for 26 Dec 2019 is ~170000 MW from 09:00 to 10:00 hrs. During this period effect of solar eclipse would be highest. It is anticipated that the maximum reduction in solar generation could be upto 7.8 GW. Thus, there would be requirement of 7.8 GW in 1:25 hrs (08:05 am to 09:30 am) from conventional sources and then this 7.8 GW being injected would have to be reduced to 0 in 1:50 hrs (09:30 am to 11:20 am). Out of this 7.8 GW generation, ~5.7GW, ~1.1 GW and ~1GW would be required in Southern Region, Western Region and Northern Region respectively. The availability of margin on inter regional corridor for 26th December 2019 is calculated based on 26 Dec 2018 inter-regional drawls.

The table 5 shows the Inter-regional drawl on 26 December 2018.

TABLE 5 : INTER-REGIONAL DRAWL ON 26 DECEMBER 2018

Exporting region	Importing region	Present ATC	Dec 2018 Max	Margin	26 Dec 2018 (09:30 AM)	Margin
WR	NR	12750	6600	6150	6000	6750
ER	NR	4950	4100	850	2500	2450
WR	SR	5050	4800	250	3000	2050
ER	SR	4700	5000	-300	1000	3700
Simultaneous NR		17150	8900	8250	8000	9150
Simultaneous SR		9250	9200	50	4000	5250

From the above table, it is clear that margin in SR import is around 5.25 GW whereas requirement is of nearly 5.7 GW, thus there needs to be increase in internal generation of around 0.45 GW in SR in 1:25 hrs and has to reduce by 0.5 GW in next 1:50 hrs provided generation is available in other regions. Sufficient margin is available in Northern Region import capability.

Power flow study for the scenario of total solar power reduction during eclipse time is carried out using PSS/E software. The following assumptions made while doing the study.

1. LGBR of 5th April 12:00 Hrs. (with suitable adjustments considering December 2018 scenario) is considered
2. April & December are lean wind generation months in Southern Region, hence similar wind generation considered
3. Solar generation of NPKUNTA (1500 MW), PAVAGADA (2000 MW) and Kamuthi (648 MW) solar parks considered as zero, and overall SR 8000 MW solar generation reduction is considered.
4. All possible measures to be taken to keep maximum thermal generators on bar.
   Following generators would be offline during 26th December 2019 as per Outage plan.

Unit Name:	Capacity	Outage Date	Revival Date	Reason	In PSSE Case
RSTPS-4	500	26-Dec-19	29-Jan-20	COH: Boiler+LPT+Gen	**On bar**
NLC TS II - 4	210	01-Dec-19	25-Dec-19	Boiler Ins, Fur+Coil Clng, RSD Duct Refr Rectification	**Off Bar**
North Chennai-1 (Stage - I)	210	11-Dec-19	25-Dec-19	COH	**Off Bar**
Raichur TPS U-6	210	14-Dec-19	03-Jan-20	AOH	**Off Bar**
Kudgi Unit – 1	800	01-Dec-19	30-Dec-19	Boiler OH + TG (Valves, Bearings) + Gen Ins. +Ele Testing	**Off Bar**

Generating stations which are under shutdown as on 12.07.2019 and not expected to be on bar on 26.12.2019 are kept offline in the case. 15% reduction in thermal generation is considered to factor any unforeseen outage of generators.

5. Hydro generation of 4000 MW maximum is considered.

5.1 STUDY RESULTS

(i) All Line loadings are within limits, maximum line loading observed to be 61% on each of 400kV Ramagundam- Bhadrawathi D/C and other loaded line details as follows:

Top Line Loading	% Loading
400 kV RSTPS NTPC-- BHADRAWATHI--T2	61
400 kV RSTPS NTPC--BHADRAWATHI--T1	61
400 kV RSTPS NTPC--MALKARAM--T2	56
400 kV GHANAPUR--GAJWEL--T1	53
400 kV GOOTY--GTYNLM--T1	53

(ii) There will not much issue of voltages in the grid, maximum voltage of 425kV is observed at 400kV Thappagundu and minimum voltage of 385kV observed at 400kV Hoody substation. Top 5 high voltage and low voltage substation details are given here high voltages observed at following nodes

High Bus Voltage	Voltage(kV)
400 kV THAPPUGUNDU	425
400 kV ANIKADV4	422
400 kV RASIPALYAM	422
400 kV PALAVADI	416
765 kV CUDDAPAH-PG	792

Low Bus Voltage	Voltage(kV)
400 kV HOODY	385
400 kV YELAHANKA	386
400 kV NELAMANGALA	389
400 kV SOMANHALLI	391
400 kV KOLAR	391

(iii) Contingency analysis is carried out for solar eclipse scenario loading of 400kV RSTPS NTPC- Bhadrawathi and 400/220kV Vemagiri ICTs are violating N-1

Lines with N-1 Violation	Max Loaded branch	% Loading
400 kV RSTPS NTPC-BHADRAWATHI-T2	400 kV RSTPS NTPC-BHADRAWATHI-T2	121
400 kV RSTPS NTPC-BHADRAWATHI-T1	400 kV RSTPS NTPC--BHADRAWATHI-T1	121
400/220 kV VEMAGIRI-1	400/220 kV VEMAGIRI--1	106
400/220 kV VEMAGIRI-2	400/220 kV VEMAGIRI--2	106
400/220 kV VEMAGIRI-3	400/220 kV VEMAGIRI--3	106

The detailed study report is enclosed as Annexure-V

5.2 HVDC SET POINTS TOWARDS SOUTHERN REGION DURING SOLAR ECLIPSE

Southern Region would be the most affected region followed by Western and Northern Region.it has been envisaged during studies that around 5.7GW of solar generation would be reduced in Southern Region alone viz. Andhra Pradesh 1131 MW , Karnataka 2292 MW, Tamil Nadu 956 MW, Telangana-1372 MW.

During the eclipse, it is anticipated that drawl from the grid would be maintained by the respective states as per the their schedules and any mismatch or solar reduction would be tackle by the internal hydro generation of respective states to avoid high loading on Inter-regional corridor viz. WR-SR and ER-SR.

Details of AC transmission lines in corridor towards SR are as follows:

Sl.No.	**Name of the Transmission line**	**Corridor**
1	765kV Sholapur-Raichur-1 and 2	WR-SR
2	765kV Wardha-Nizamabad-1 and 2	WR-SR
3	765kV Angul-Srikakulam 1 and 2	ER-SR
4	400kV Kolhapur-Kudgi-1 and 2	WR-SR

Notwithstanding above, following HVDCs are also present in corridor towards SR to control loading on any of the above mentioned line. Details is as below:

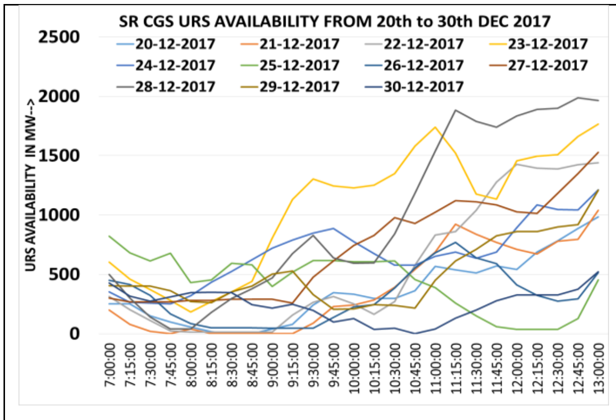
Sl. No.	**Name of the HVDC**	**Continuous Rating**	**Remarks**
1	HVDC Talcher-Kolar Bipole	2000MW	It may be increased upto 2500MW for 10hrs
2	Back to back HVDC Gazuwaka pole-1 and 2	1000MW	It is restricted to 650MW only due to low voltage issue at east bus of Gazuwaka. STATCOM at Jeypore must be in service
3	Back to back HVDC Bhadravathi pole-1 and 2	1000MW	

In view of highest solar reduction in Southern region, HVDC set points may be kept such that adequate margin is available to tackle any contingency during solar reduction or major over drawl by southern states from inter-regional corridor.

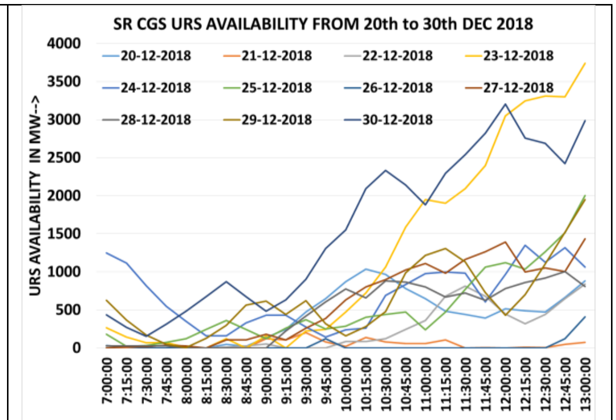
Further, it may also advised that during post eclipse scenario, HVDC set points may be kept judicially to avoid low loading /high voltage scenario on inter regional nodes.

6. RESERVE

To understand the availability of spinning reserves on 26th December 2019 during solar eclipse time, URS availability from 20th Dec to 30th Dec of last two years (2017 & 2018) analysed and plotted below:



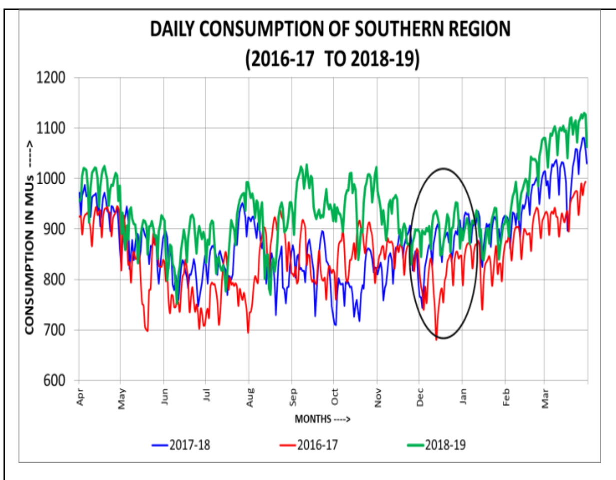
URS availability 20th to 30th Dec-2017



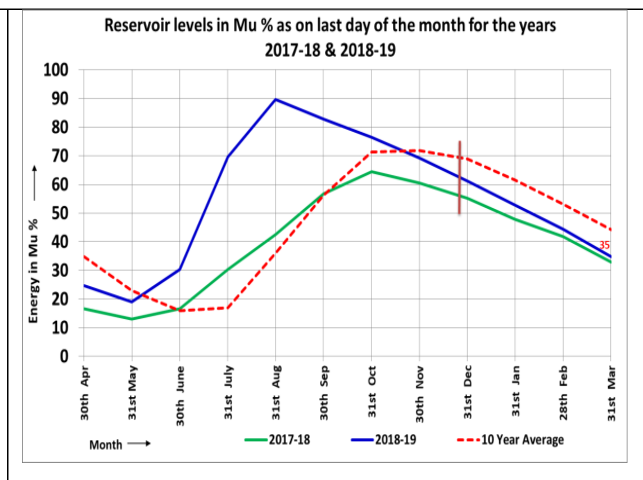
URS availability 20th to 30th Dec-2018

Figure 52: URS Availability 20th to 30th Dec-2017 and 2018

From the above plots it can be seen that URS availability is increasing as solar generation is picking up and it is in the range of 500 MW to 1000 MW most of the time. Maximum URS of 3500 MW is available on weekends.



SR Daily consumption 2016-17 to 2018-19



SR Reservoir levels in MU % of designed energy

Figure 53: SR Daily Consumption and Reservoir Levels 2016-17 to 2018-19

It was observed that during Feb-19 to May-19 period even on peak demand days one or two units of NTPC Kudgi station (3x800 MW) were kept under reserve shut down. December month

being average demand period for Southern Region, one or two units of NTPC Kudgi station are expected to be under reserve shut down, the same can be brought on bar before 26th December 2019 to have more reserves in the system. Similarly other generating units which are kept under reserve shut down may be brought back to increase availability. Any planned outage of thermal stations starting or ending near to 26th December 2019 may be planned such a way that maximum availability of thermal units is ensured on the day of eclipse.

Reservoir position also would be good during December, based on previous reservoir levels data it can be seen that around 60 to 70% of reservoir designed energy will be available. Hence, some flexibility from hydro also will be available to constituents. Based on December 2017& 2018 Hydro generation data, and good monsoon this year, it can be expected that during December last week around 4500 - 5500 MW of maximum Hydro generation is available in Southern region.

As per the past hydro generation trends in regions, it has been observed that at the time of maximum obscuration during solar eclipse, around 2500MW, 700MW and 4300MW hydro reserves would be available in Southern Region, Western Region and Northern Region respectively with respect to evening peak. As per the reserves available in previous year, it has been expected that solar reduction would be taken care by available hydro and gas generation in Western and Northern Region but reserves available in Southern Region would not be sufficient to meet the solar reduction. Therefore, states of Southern Region may be advised to arrange remaining power to address solar reduction and ramp rates during the eclipse.

In addition to the above, around 10500MW average hydro generation reserves would be available with respect to evening peak on All India basis (during 24.12.18 to 29.12.18). Therefore, if margins are available on inter-regional corridor towards Southern Region, then solar reduction may easily be taken care off.

Regionwise graphs of average hydro generation from 24.12.18 to 29.12.18 and anticipated solar reduction on 26.12.19 are given below:

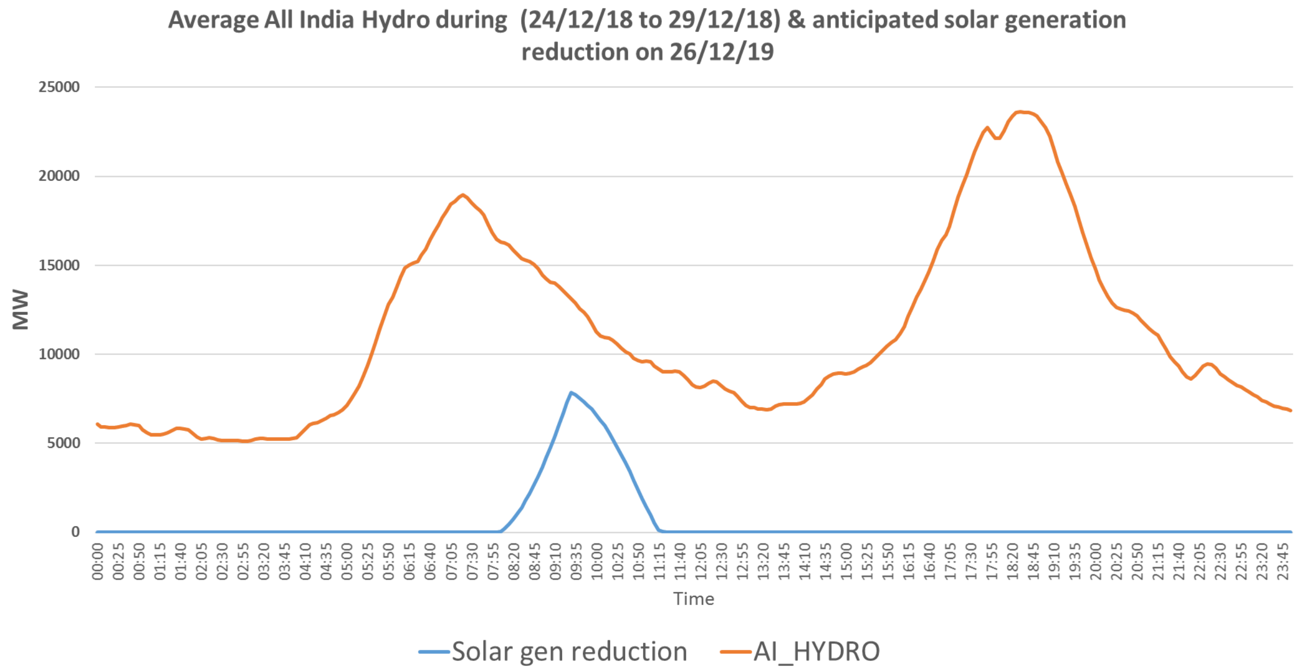


Figure 54: Average all India Hydro and Anticipated Solar Generation

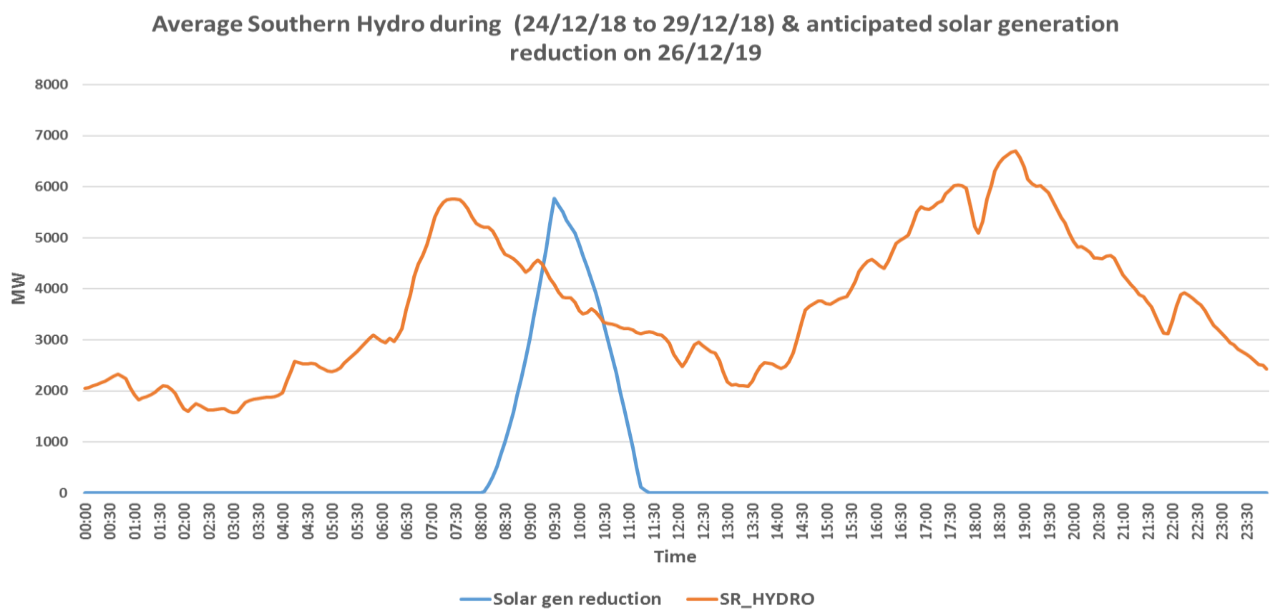


Figure 55: Average Southern Region Hydro and Anticipated Solar Reduction

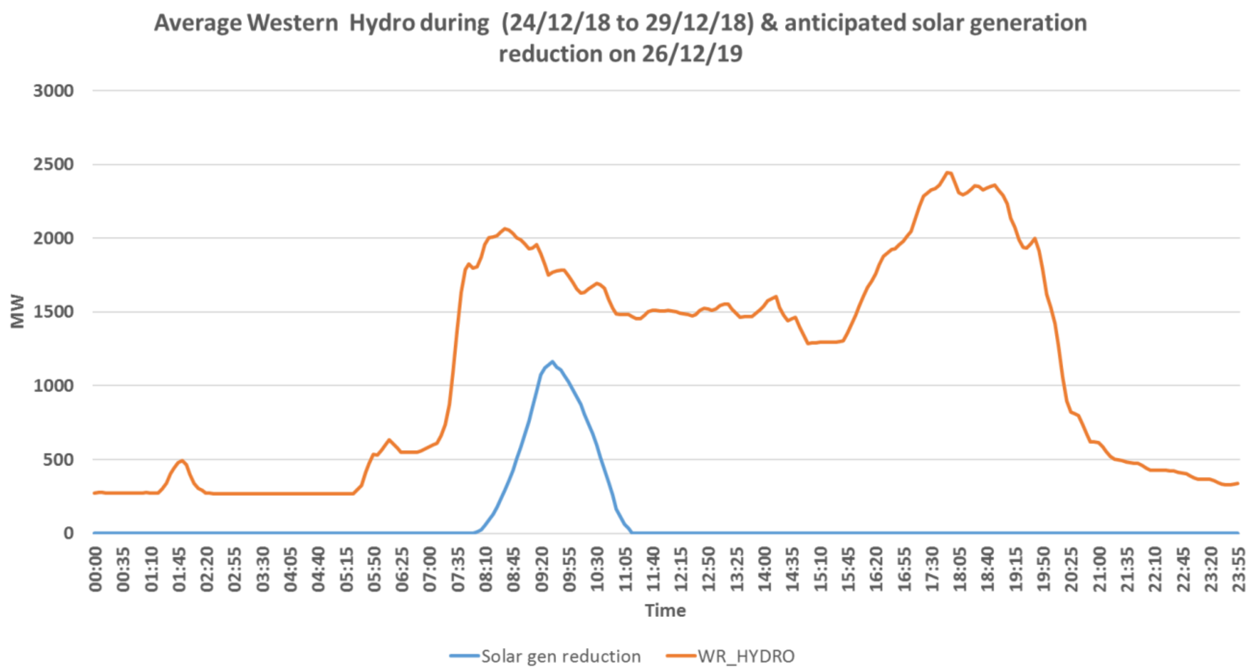


Figure 56: Average Western Region Hydro and Anticipated Solar Reduction

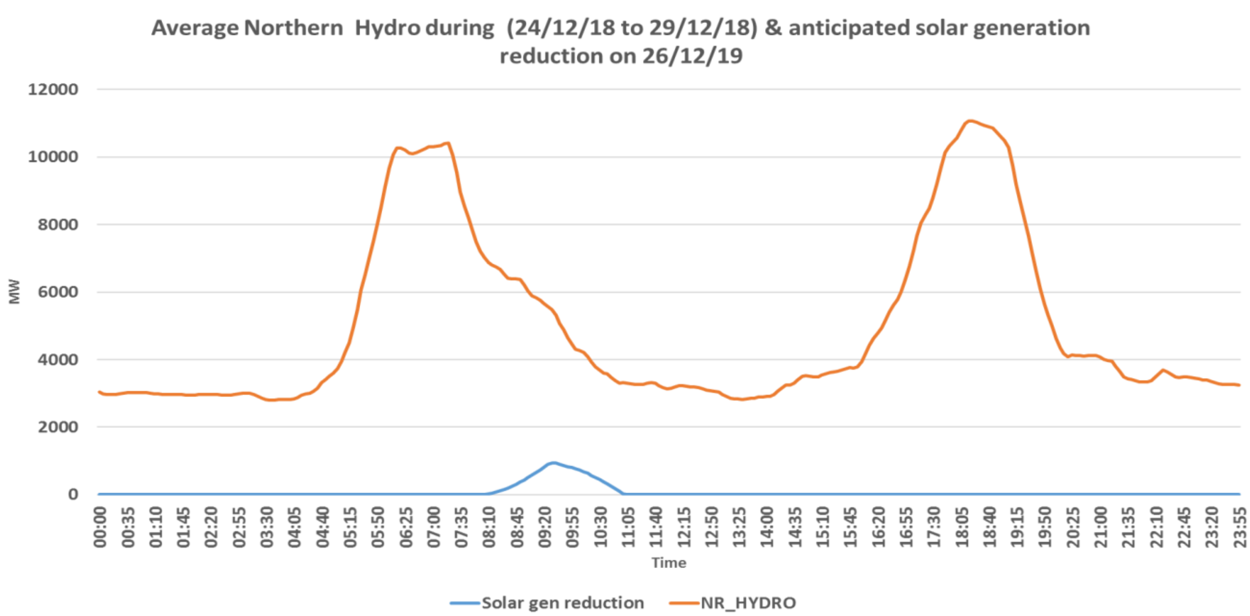


Figure 57: Average Northern Region Hydro and Anticipated Solar Reduction

7. UTILITY SCALE SOLAR POWER PLANT CONTROLLER

Power plant controller is utility scale solar power controller that consolidates management of photovoltaic (PV) power plants, providing a single point of integrated control and monitoring. A PV plant requires many inverters to process the output of multiple arrays. Each inverter is capable of individual control functions but must coordinate, as a unified regiment, to appear as a single source at the Point of Interconnect (POI). This becomes the fundamental role of the plant controller. A power plant controller receives input from authorised users, sensory devices, and feedback applying this constant stream of data to established system directives. The controller commands the regiment of inverters as well as supporting capacitive and inductive devices to maintain the most stable and useful output possible.

Power Plant Controller manages all parameters, which are necessary for a constant stability of the grids. PV plant appears to the grid as a single unified source of power while maximizing active power output and providing grid support. This is accomplished by balancing two modes of operation: Active Power Control (APC), and Automatic Voltage Regulation (AVR).

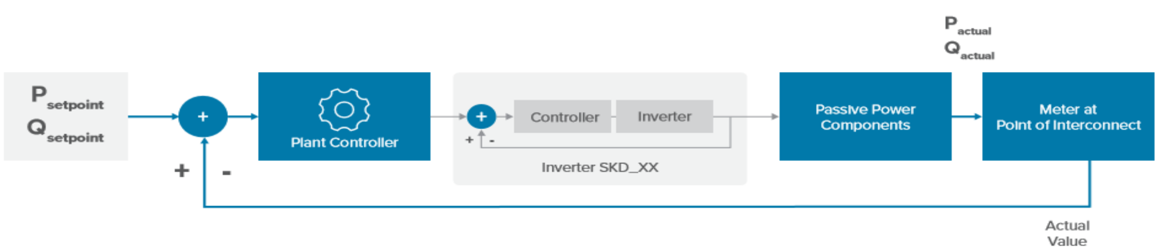


Figure 58: Utility Scale Solar Power Plant Controller

Active power control: Active Power Control (APC) is the ability for the controller to manage active power (MW) to maintain load and generation balance. Accurate and dynamic control of production is achieved using a closed-loop feedback. A meter at the POI tracks the plant's contribution as it is seen on the grid. If there is more irradiance potential than needed to maintain a set point, the inverters must be commanded to limit themselves. Purposeful limitation of production is called "curtailment".

The duties of Active Power Controller of the power plant:

1) Manage active power (MW) to maintain load and generation balance
2) The power plant Start up/Shutdown in controlled manner.
3) The Power plant Curtailment
4) Power Ramp Rate Control

Automatic Voltage Regulation (AVR): Automatic Voltage Regulation (AVR) provides grid support by means controlling of reactive power. It is like as APC (Active Power Control), a closed-loop feedback from the POI (Point of Interconnect) drives the changes to each inverter to reach a collective ideal, but unlike APC, only reactive power is adjusted to meet demands. The controller imposes upper and lower limits on the system, as well as specific ramp-up rates, all for reactive power.

There are three modes of operation which fall under AVR. Each mode regulates reactive power based on a different driving control parameter.

1. Reactive Power Control – The plant tracks a specific reactive power setpoint regardless of active power output
2. Power Factor Control - A power factor setpoint (-0.95 to +0.95) is the controller's priority; adjusting reactive power output to meet that ratio
3. Voltage Control – Based online voltage at the point of regulation, a reactive power compensation is calculated and tracked by the controller

The solar plants having 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. This ramp control of solar plants along with ramp capability of hydro and gas generation could be used for meeting the necessary ramp requirements. As per clause no.4(iv) CEA's Technical standards for connectivity to the Grid(Amendment) regulation 2019, '*The generating station with installed capacity more than 10MW connected at a voltage level of 33kV and above shall be equipped with the facility for controlling the rate of change of power output at a rate not more than +/-10% per minute*'

Since major target area of eclipse is Southern Region, thus PPC control of Northern Region may not be that much useful. However, in future for solar eclipse on 21st June 2020, PPC control installed on Northern Region plants may be useful during ramp up. Therefore, all PPC should test their ramp control mode beforehand so that it could be utilised during need. Standby energy storage systems may be required to control ramp rate in future.

Details of PPC installation at Solar Plants is given below:

Region	Name Of the Plant	Installed Capacity	PPC Status
SR	NTPC NPKUNTA	250	YES
	ACME BHIWADI	50	No
	ACME HISSAR	50	No
	ACME KARNAL	50	No
	TATA	100	No
	AZURE	50	No
	FRV-I	50	No
	FRV-II	50	No
WR	ACME JAIPUR SOLAR POWER PVT LTD	250	NO
	ARINSUN CLEAN ENERGY PVT. LTD.	250	No
	Mahindra Renewables Pvt Ltd	250	NO
	WELSPUN (RATANGARH (NEEMUCH)	105	YES
	M/s. Fermi Solarfarms Pvt Ltd	80	Details Not available
	M/s. Fermi Solarfarms Pvt Ltd	60	Details Not available
	M/s. Gale Solar farms Ltd (Saltek)	50	Details Not available
	M/s. Tornado Solar farms Ltd. (Saltek)	20	Details Not available
	JBM SOLAR ENERGY MAHARASHTRA PVT. LTD.	100	Details Not available
	M/s. NVR Mahasolar Pvt. Ltd.	54	Details Not available
	M/s. Parampujya Solar Energy Pvt. Ltd.	20	Details Not available
	M/s. Osmanabad Solar Energy Ltd.	20	Details Not available
	M/s. Fourth Dimension Infra & Power Ltd	18.25	Details Not available

Region	Name Of the Plant	Installed Capacity	PPC Status
	M/s TATA POWER RENEWABLE ENERGY LTD	55	Details Not available
	M/s CLEAN SUISTAINABLE SOLAR ENERGY PVT LTD	50.33	Details Not available
	MAHAGENCO	125	Details Not available
	M/s. Orange Renewable Power Pvt. Ltd.	100	Details Not available
	M/s. Solar Edge Power & Energy Pvt Ltd	130	Details Not available
	M/s. Talettutayi Solar Projects Four Pvt. Ltd	50	Details Not available
NR	Azure Power India Pvt. India Ltd.	200	Yes
	SB Energy Four Pvt. Ltd	200	Yes
	MAHOBA SOLAR (UP) PRIVATE LTD(1 * 250)	250	yes
	RENEW SOLAR POWER PVT LTD(50)	50	yes
	TATA POWER RENEWABLE ENERGY LTD(1 * 150)	150	Yes
	AZURE POWER THIRTY FOUR PRIVATE LTD(1 * 130)	130	Yes
	Godawari Green Energy Ltd	50	Yes
	Yarrow Infrastructure Pvt. Ltd.	70	YES at Inverter level through SCADA
	NTPC Ltd - Bhadla Solar Power Project	260	YES

8. POST EVENT ANALYSIS (TO BE UPDATED AFTER EVENT)

The purpose of post event analysis is to know the behaviour of solar eclipse phenomenon of PV plant in India. The data would also highlight the drop in mean temperature in transient eclipse zone and any change in wind speed due to change in temperature associated with the Eclipse.

Three type of PV plant may be chosen for post event analysis based on geographical location

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 %

Plant Name	Installed capacity	Partial eclipse start time H: MM	Greatest eclipse H: MM	Magnitude	Partial eclipse end time H: MM	Duration	Obscuration
Adani Solar Park, Kamuthi	648	08:07	09:32	0.95	11:16	03:08	92.40%
Charnka Solar Park, Gujarat	590	08:05	09:20	0.74	10:48	02:42	66:52 %
SB Energy four Power Ltd, Bhadla	200	08:10	09:22	0.65	10:45	02:35	55.09%

Following data on per minute basis (on even higher resolution) may be collected from the above plant site for further analysis.

i. Solar irradiance

ii. Power generation

iii. Cloud cover

iv. Temperature

v. Wind speed and direction

9. OPERATIONAL PLANNING

Annular solar eclipse would occur on 26th Dec 2019. The Annular eclipse will begin few minutes past 8:03 AM (IST - Indian Standard Time = UTC+5:30) and will end at about 12:03 PM (at Port Blair). The Annular eclipse on the west coast and east coast shall begin at 9:24 IST and 9:31 IST respectively. Annularity will end at 9:27 AM on the west coast and 9:35AM on the east coast. Full obscuration shall remain for 2-3 minutes. Darkness due to penumbra would last for one & half hour before and after the peak time of annularity. It is estimated that 12.73 MU of solar generation would be affected during eclipse with a maximum of 7823 MW reduction at 09:30 hrs, out of which 5800 MW pertains to Southern Region. During eclipse, it is anticipated that from 08:03 hrs to 09:30 hrs solar generation will reduce with an average ramp rate of 13MW/minute and from 09:30 to 11:30 hrs solar generation will increase with an average ramp rate of 122MW/minute.

In view of the above, an operation planning has been prepared for affected region i.e. Southern, Western and Northern Region for load generation balance during eclipse on 26 December 2019.

(a) Operational planning for Southern Region

25th December being Holiday it would impact 26th December demand and it is expected that the impact will be similar to year 2018 (As 25th & 26th are week days and falling in middle of the week in both the years 2018 & 2019). There could be average demand reduction of 2.5 to 3% during the solar eclipse compared to a normal day. Estimated SR demand for 26th December 2019 is as follows,

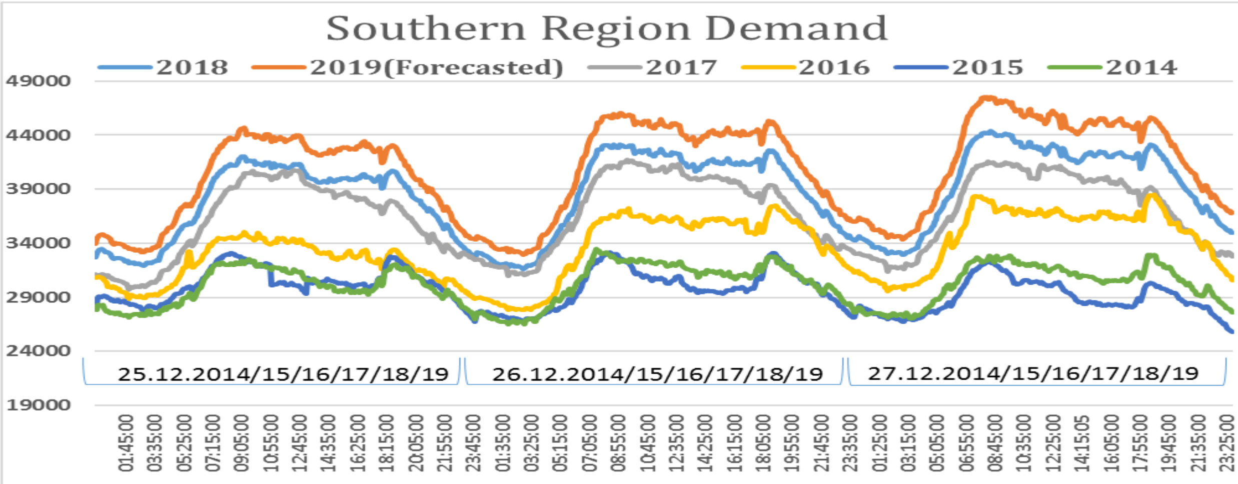


Figure 59: Estimated Southern Region Demand

Expected solar generation variation state wise and management plan:

Three things to be managed here which are illustrated with the below diagram

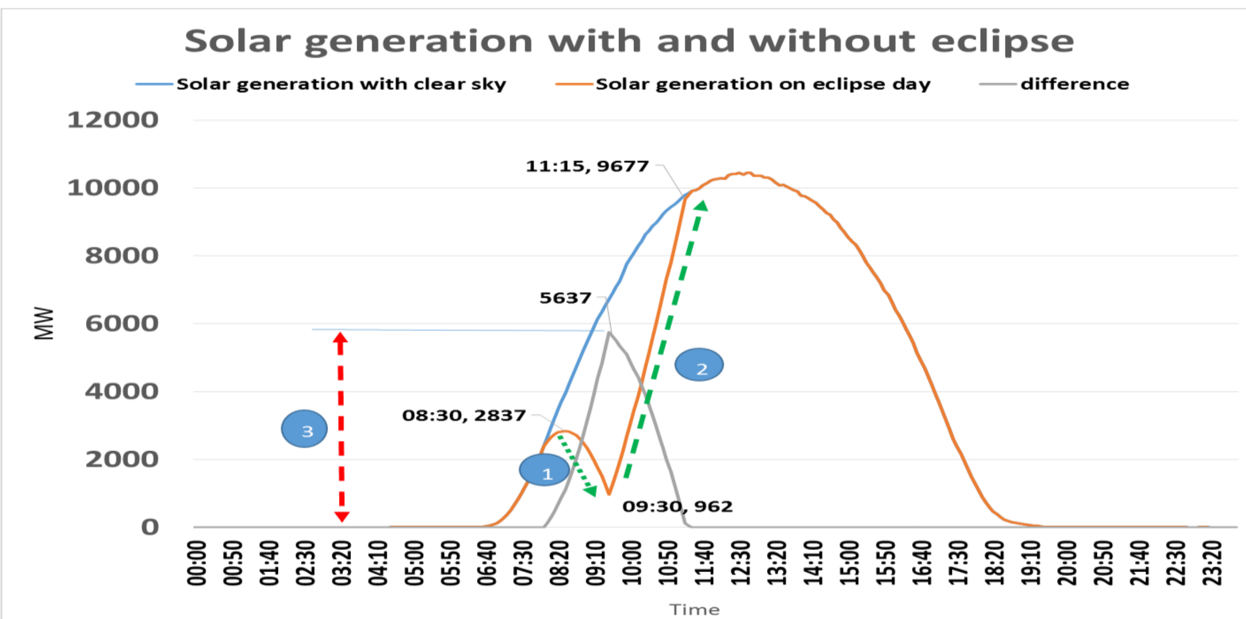


Figure 60: Estimated Solar Generation with and without Solar Eclipse

1. Managing solar generation reduction & associated ramps from eclipse start to maximum eclipse time.
2. Managing solar generation increase & associated ramps from maximum eclipse to end of eclipse.

3. Arranging power from alternate sources for meeting the demand which was generally met from solar power.

Andhra Pradesh:

Expected solar reduction is 361 MW i.e from 561 to 200 MW, the same can be managed with available hydro station like Srisailam Right bank (7x110=770 MW) and Lower sileru and other stations. After maximum eclipse solar generation ramps up sharply 1800 MW increment in just 1hr 45 Min, which has to be managed by ramping down hydro and thermal stations. Andhra Pradesh has to arrange power from other sources to the tune of 1100 MW maximum to meet the demand.

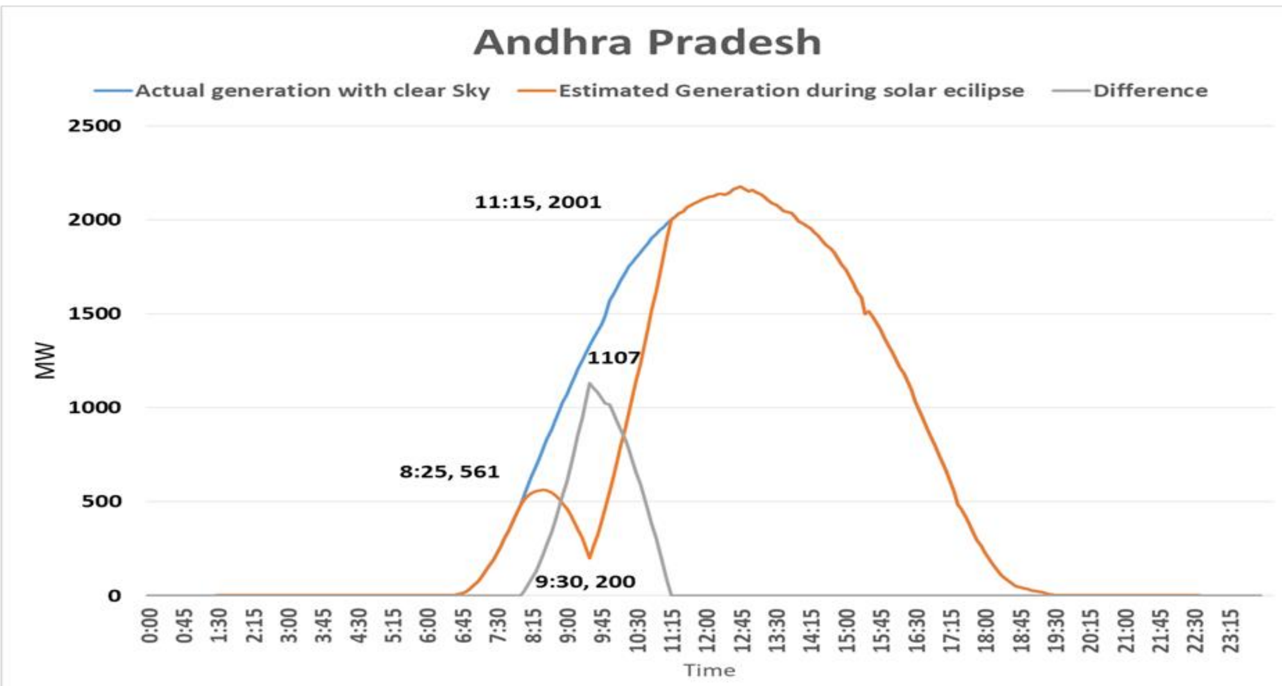


Figure 61: Estimated Andhra Pradesh Solar Generation during Solar Eclipse

SL.NO.	STATION	EFFECTIVE INSTALLED CAPACITY (MW)			Station Available/Not	Max expected Generation	Type of plant (Run of River, Storage...)
1	UPPER SILERU	4x60	=	240.00			
2	DONKARAYI	1x25	=	25.00			
3	LOWER SILERU	4x115	=	460.00			
4	SRISAILAM RBPH	7x110	=	770.00			
5	NSR RT.CANAL.P.H	3x30	=	90.00			
	TOTAL			**1585.00**			

Karnataka:

Expected solar reduction is 755 MW i.e from 1010 to 255 MW, this can be managed with available hydro station like Sharavathi (10x103.5=1035 MW) and Varahi itself. At the peak of eclipse all hydro stations generation to be maximized and thermal generation needs to be ramped down so that maximum fast ramping hydro generation would be available for managing solar generation rise after eclipse. After maximum eclipse solar generation ramps up sharply, 3400 MW increment in just 1hr 45 Min, which has to be managed by ramping down hydro and thermal also can be planned to support hydro. Karnataka has to arrange power from other sources to the tune of 2180 MW (maximum) to meet the demand.

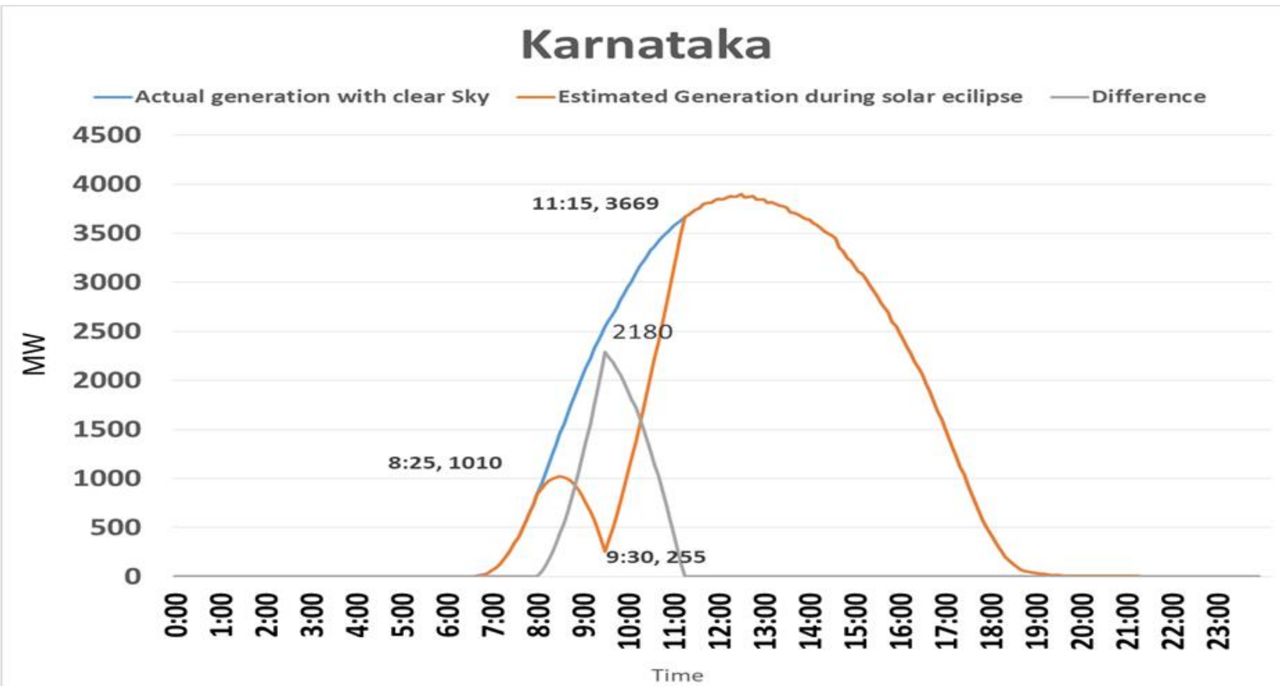


Figure 62: Estimated Karnataka Solar Generation during Solar Eclipse

SL.NO.	STATION	EFFECTIVE INSTALLED CAPACITY (MW)			Station Available/Not	Max expected Generation	Type of plant (Run of River, Storage…)
1	SHARAVATHY	10x103.5	=	1035.0	Available	960	Storage
2	LINGANAMAKKI.P.H.	2x27.5	=	55.0	Available	55	Storage
3	JOG (MGHES)	4x21.6+4x13.2	=	139.2	Available	50	Storage
4	NAGJHERI	6x150	=	900.0	Available	850	Storage
5	SUPA	2x50	=	100.0	Available	98	Storage
6	VARAHI	4x115	=	460.0	Available	450	Storage
7	KADRA	3x50	=	150.0	Available	146	Storage
8	KODASALLI	3x40	=	120.0	Available	118	Storage
9	SHARAVATHI TAIL RACE	4x60	=	240.0	Available	230	Storage
10	ALMATTI	1x15+5x55	=	290.0	Not Available	0	Run of river
	TOTAL			**3489.2**		**2957**	

Telangana:

Expected solar generation reduction is 347 MW i.e from 791 to 458 MW, this can be managed with available hydro station like Srisailam Left Bank (6x150=900 MW) and Nagarjuna Sagar (1x110+7x100.8=815.6 MW) itself. At the peak of eclipse all hydro stations generation to be maximized and thermal generation needs to be ramped down so that maximum fast ramping hydro generation would be available for managing solar generation rise after eclipse. After maximum eclipse solar generation ramps up sharply, 3400 MW increment in just 1hr 45 Min, which has to be managed by ramping down hydro and thermal also can be planned to support hydro. Both Nagarjuna sagar and Srisailam Left bank are have pump operation facility, if required pump mode operation also can be utilized. Telangana has to arrange power from other sources to the tune of 1340 MW (maximum) to meet the demand.

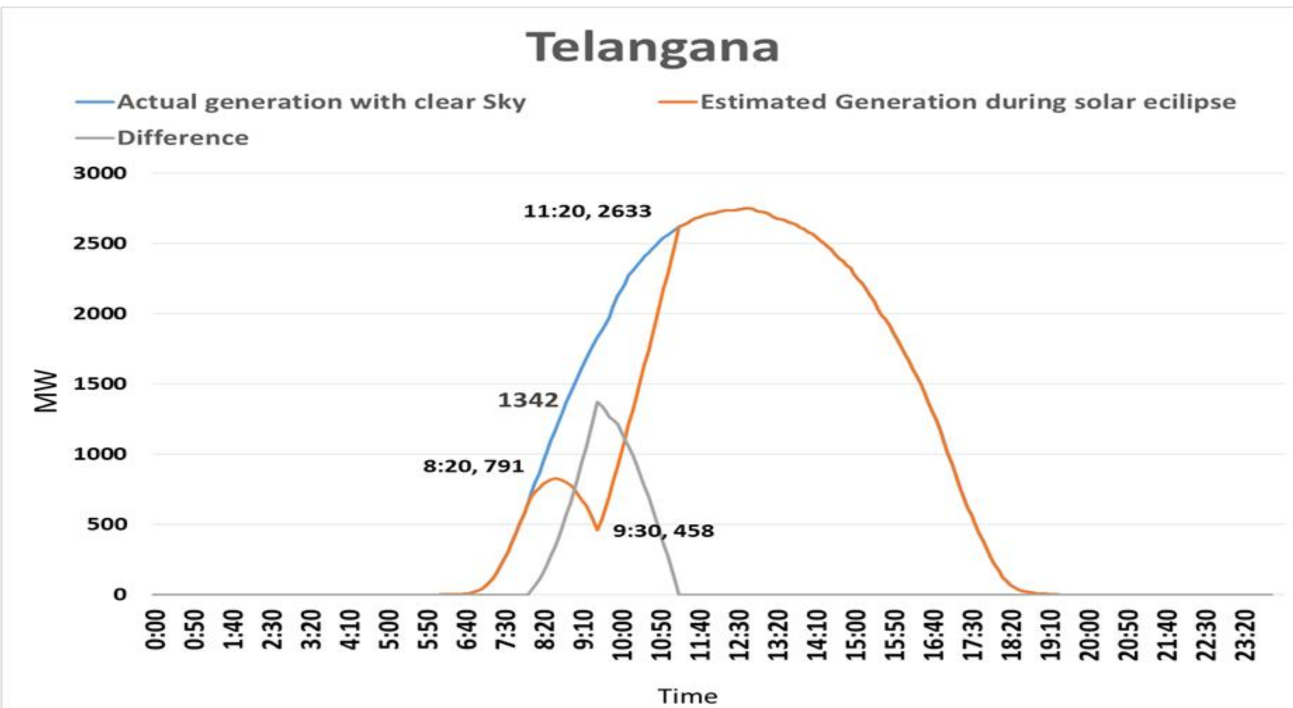


Figure 63: Estimated Telangana Solar Generation during Solar Eclipse

SL.NO.	STATION	EFFECTIVE INSTALLED CAPACITY (MW)			Max expected Generation	Type of plant (Run of River, Storage...)
1	SRISAILAM LBPH	6x150	=	900.00	900.00	storage
2	N'SAGAR	1x110+7x100.8	=	815.60	815.60	storage
3	NSR LT.CANAL.P.H	2x30	=	60.00	0.00	storage
4	JURALA	6x39	=	234.00	0.00	Run of River
5	LOWER JURALA	6x40	=	240.00	0.00	Run of River
6	PULICHINTALA	4x30	=	120.00	0.00	Run of River
	TOTAL			**2369.60**		

Tamil Nadu:

Expected solar generation reduction is 400 MW i.e from 456 to 50 MW, this can be managed with available hydro station like Kadamparai (4x100=400 MW) and Kundah complex (~510 MW). At the peak of eclipse all hydro stations generation to be maximized and thermal generation needs to be ramped down so that maximum fast ramping hydro generation would be available for managing solar generation rise after eclipse. After maximum eclipse solar generation ramps up sharply, 1433 MW increment in 1hr 45 Min, which has to be managed by ramping down hydro and thermal also can be planned to support hydro. Tamil Nadu has to arrange power from other sources to the tune of 940 MW (maximum) to meet the demand. Pump mode operation Kadamparai can be utilized during solar generation rise time after eclipse.

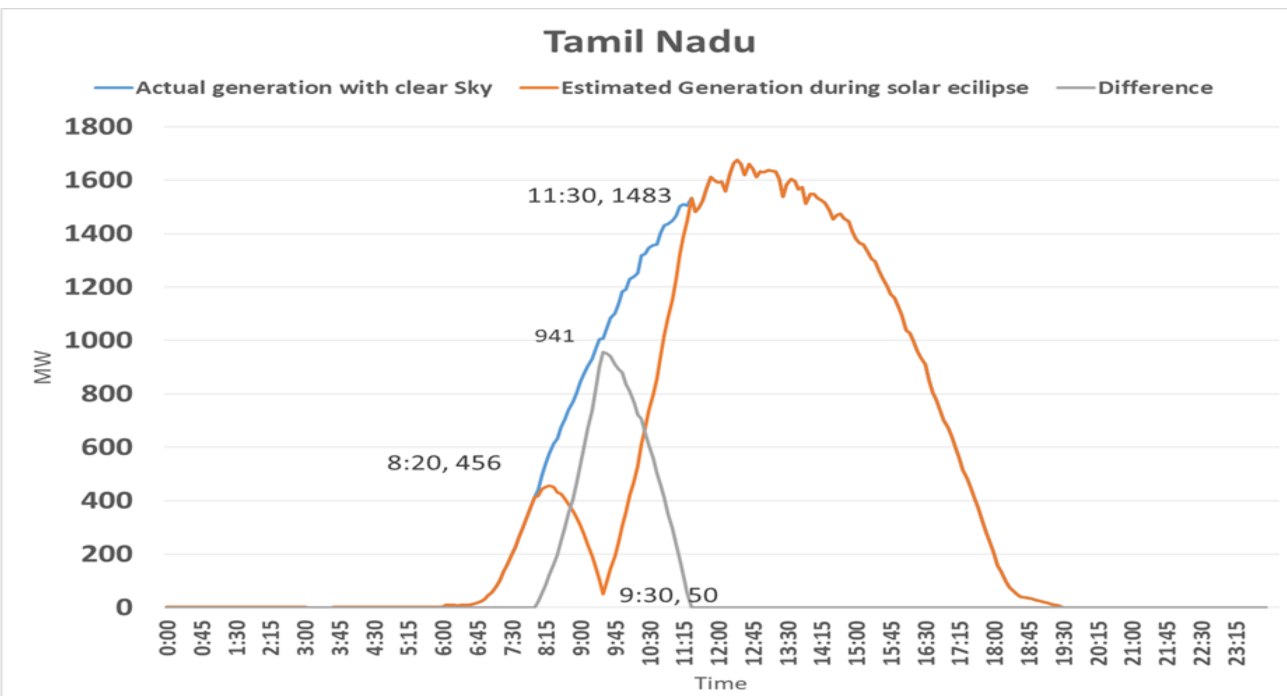


Figure 64: Estimated Tamil Nadu Solar Generation during Solar Eclipse

SL.NO.	STATION	EFFECTIVE INSTALLED CAPACITY (MW)		Station Available/Not	Max expected Generation	Type of plant (Run of River, Storage…)
1	PYKARA	3x6.65+1x11+2x14	= 58.95			
2	PYKARA ULTIMATE (PUSHEP)	3x50	= 150.00			
3	KUNDAH-I	3x20	= 60.00			
4	KUNDAH-II	5x35	= 175.00			
5	KUNDAH-III	3x60	= 180.00			
6	KUNDAH-IV	2x50	= 100.00			
7	KADAMPARAI	4x100	= 400.00			
8	ALIYAR	1x60	= 60.00			
9	METTUR DAM	4x12.5	= 50.00			
10	METTUR TUNNEL	4x50	= 200.00			
11	LOWER METTUR BARRIAGE - 1 TO 4	8x15	= 120.00			
12	PERIYAR	4x35	= 140.00			
13	SHOLAYAR	2x35+25	= 95.00			
14	KODAYAR	1x60+1x40	= 100.00			
15	BHAVANI KATTALAI BARRAGE - I & I	4x15	= 60.00			
	TOTAL		**1948.95**			

State thermal generation also need to be planned in coordination with State Hydro generation so that additional support from thermal can be utilized.

Kudgi units shall be brought on bar from Reserve shut down and kept as reserve, for compensating regional entity solar generation reduction.

Inter-regional margin to the tune 1000-1500 may be kept for getting support from other regions.

RRAS instructions: NLDC may give suitable RRAS instructions of RRAS UP during solar generation reduction and RRAS DOWN during solar generation rise.

Solar generation reduction/increase during eclipse time can easily be managed with available hydro generation of Southern Region (as this year reservoir positions are good). Pump mode operation, thermal generation support, Keeping reserves, keeping margin in inter regional corridor would be helpful in better managing the situation.

(b) Operational Planning for Western Region

Percentage of Mean Sun obscuration in WR is given below-

State	% of Mean Obscuration
Maharashtra	70%
Gujarat	65%
Madhya Pradesh	55 %

The State wise average solar generation with resolution of 5 minutes SCADA data has been forecasted and compared with generation during clear sky. The same are given as below-

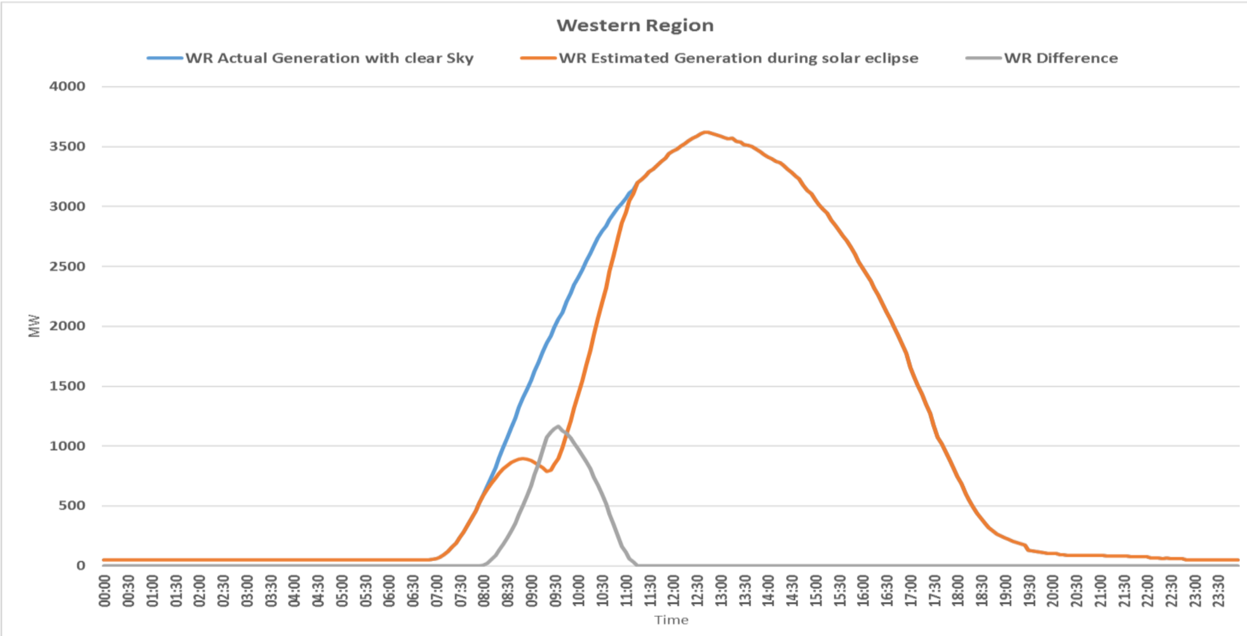


Figure 65: Estimated Western Region Solar Generation during Solar Eclipse

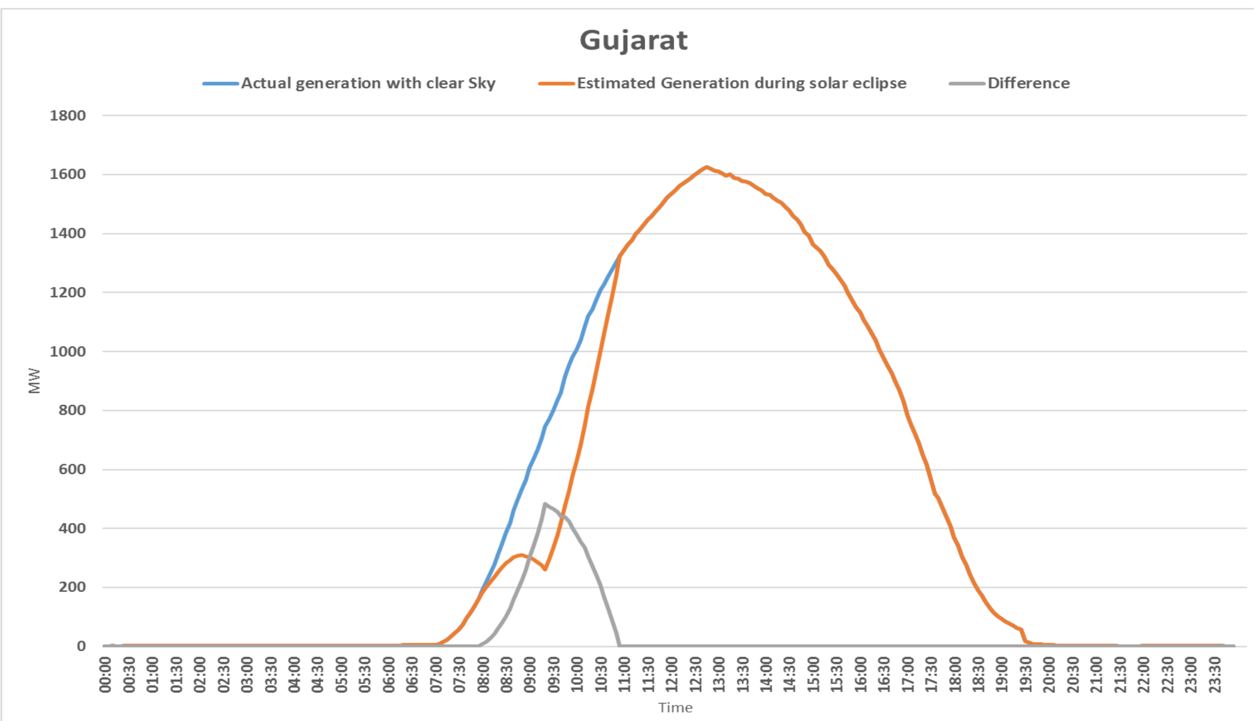


Figure 66: Estimated Gujarat Solar Generation during Solar Eclipse

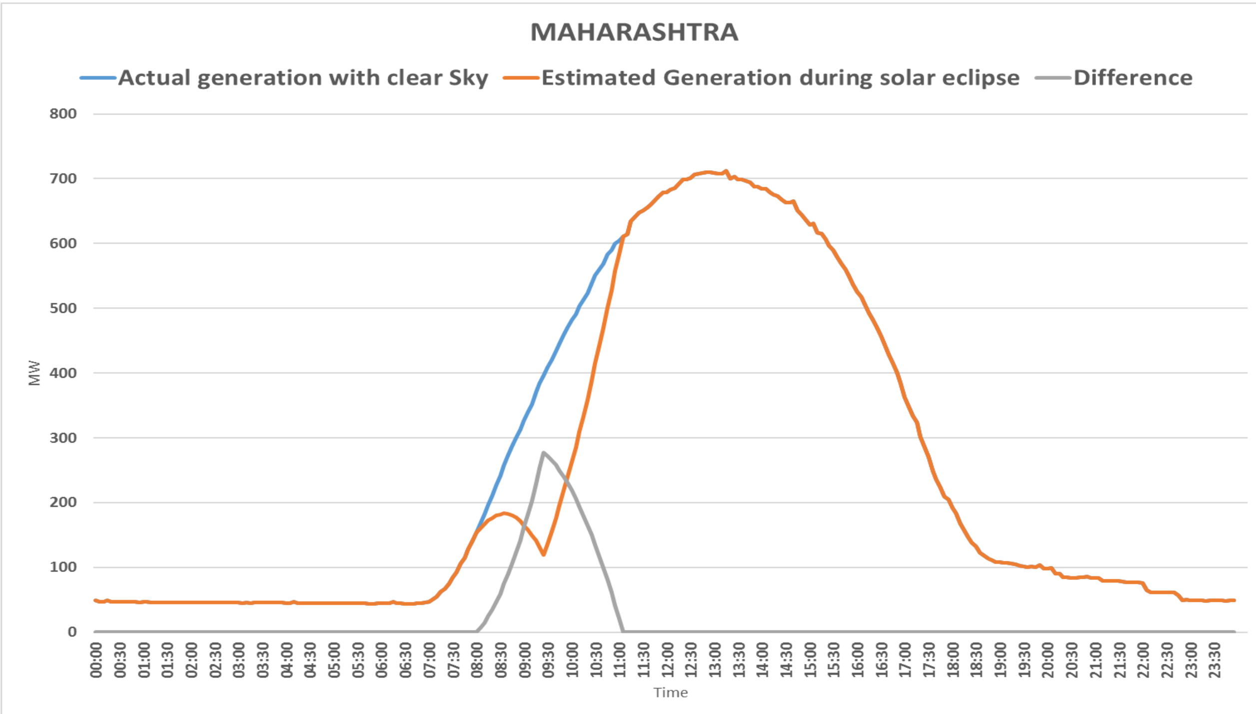


Figure 67: Estimated Maharashtra Solar Generation during Solar Eclipse

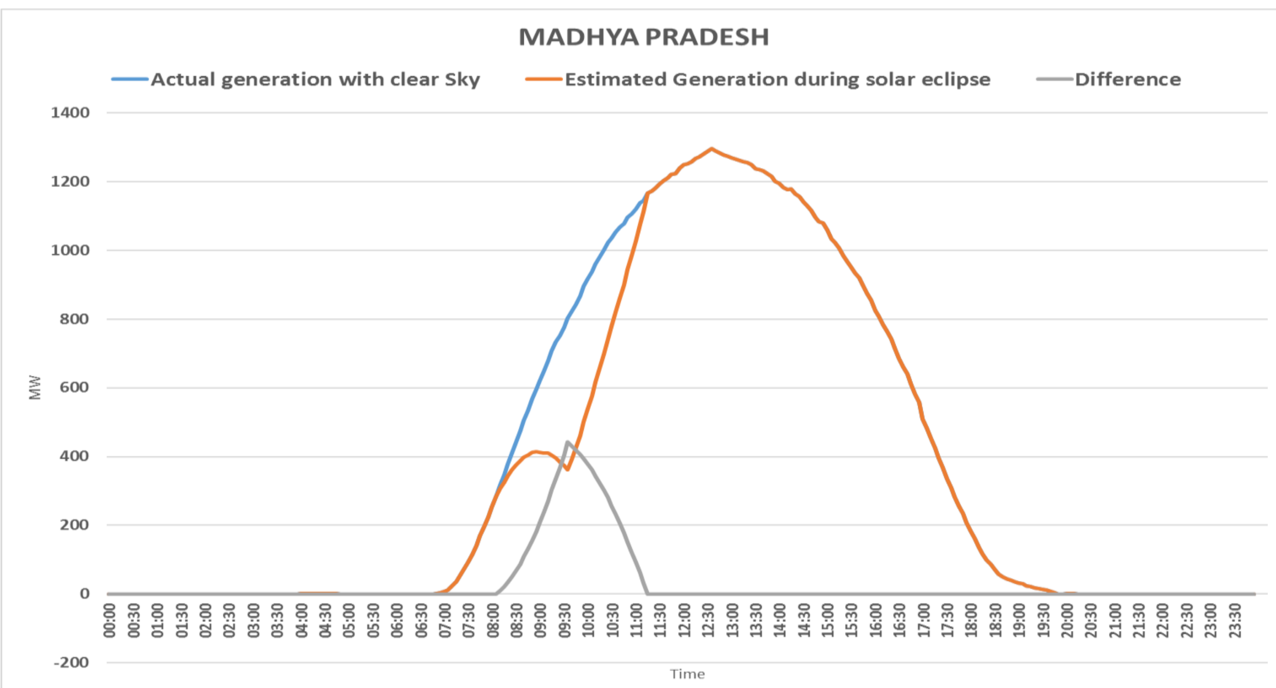


Figure 68: Estimated Madhya Pradesh Solar Generation during Solar Eclipse

Load has also been forecasted for 26th Dec 2019, It is observed that there will not be major drop in demand but we can expect a 1% drop in demand may occur during the solar eclipse due to human behaviour. The Forecast of the WR load is shown below-

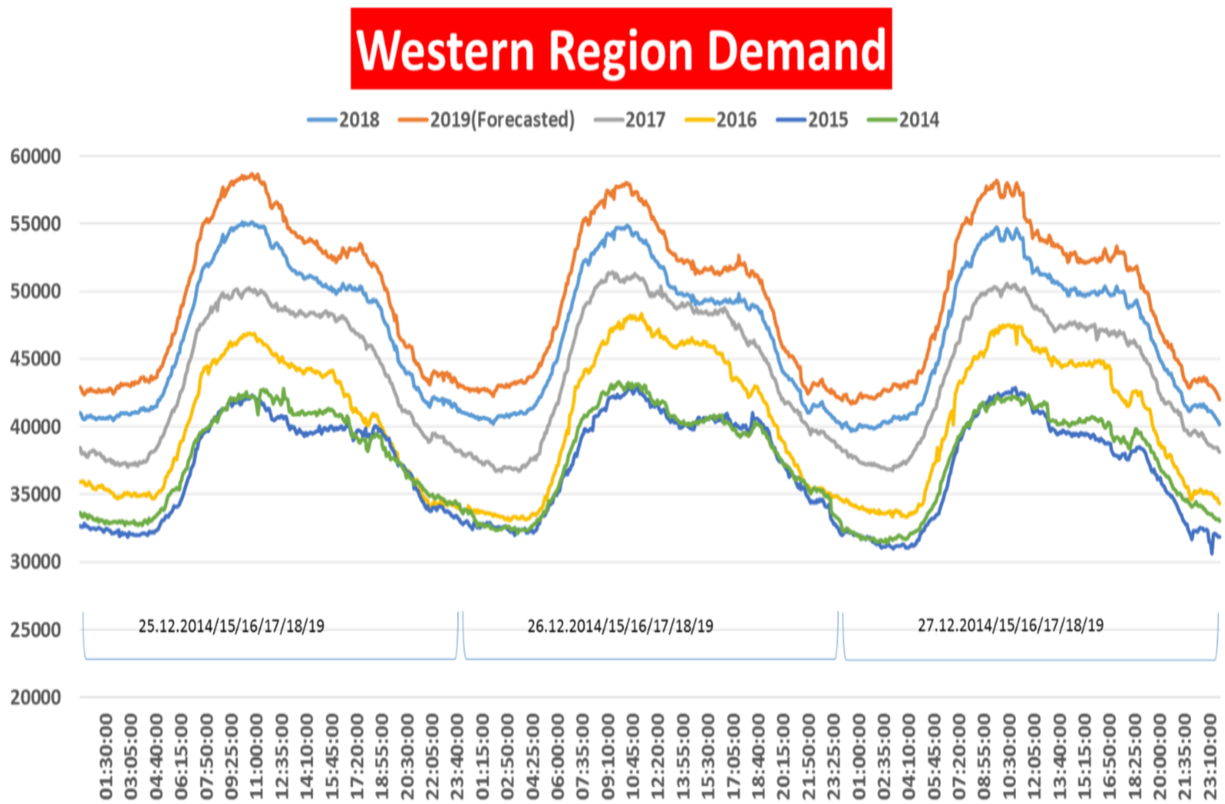


Figure 69: Estimated Western Region Demand during Solar Eclipse

Following operations may be planned to balance the load and generation to maintain the compliance in the grid during solar eclipse-

1. Scheduling of all conventional reserves in Western region

As per forecast of solar generation during solar eclipse, the reserves requirement is as follows-

Time	WR Reserves requirement(MW) during solar eclipse period	Time	WR Reserves requirement(MW) during solar eclipse period	Time	WR Reserves requirement(MW) during solar eclipse period
08:00	7	09:25	1119	10:50	257
08:05	24	09:30	1142	10:55	164
08:10	53	09:35	1164	11:00	114
08:15	88	09:40	1128	11:05	63
08:20	129	09:45	1106	11:10	31
08:25	177	09:50	1070	11:15	0
08:30	231	09:55	1027		
08:35	290	10:00	977		
08:40	356	10:05	923		
08:45	428	10:10	871		
08:50	504	10:15	809		
08:55	584	10:20	741		
09:00	670	10:25	674		
09:05	760	10:30	598		
09:10	856	10:35	517		
09:15	964	10:40	434		
09:20	1074	10:45	347		

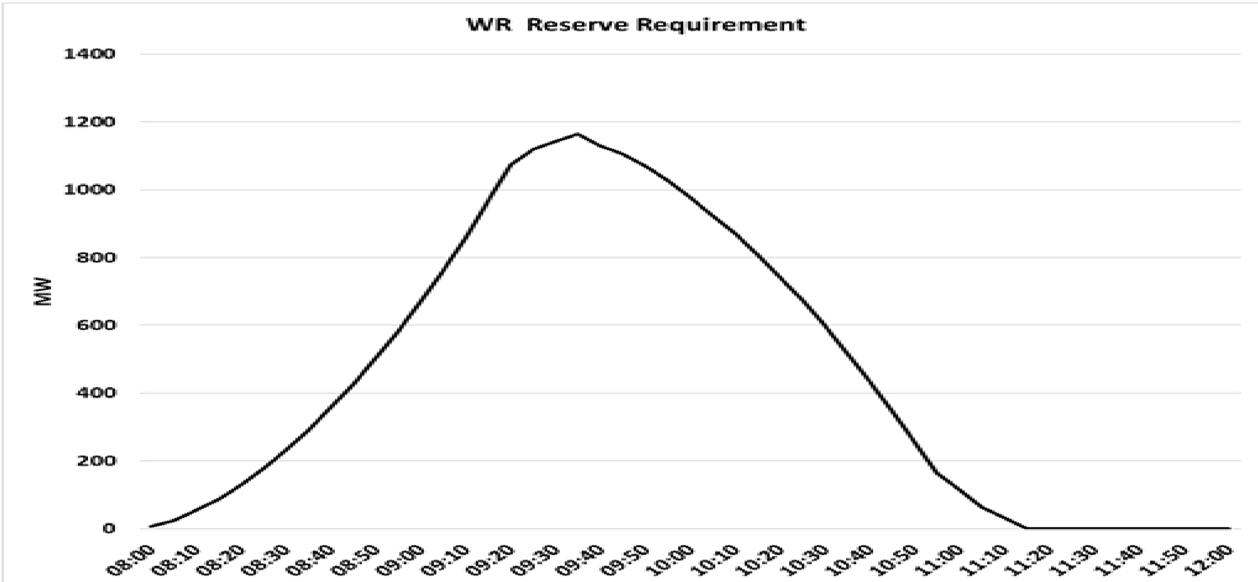


Figure 70: Western Region Reserve Requirement during Solar Eclipse

Maximum reserve required is 1164MW. The data of reserves available during 21-Dec -18 to 31-Dec2018 in WR ISGS station is analysed and average reserves available is shown below-

Time	WR						
	Schedule (MW)	**on Bar DC (MW)**	**Reserves Available(MW)**	**Time**	**Schedule (MW)**	**on Bar DC (MW)**	**Reserves Available(MW)**
08:00	19590	19828	238	10:00	19553	19796	242
08:15	19565	19837	273	10:15	19538	19792	254
08:30	19590	19837	247	10:30	19531	19788	258
08:45	19578	19816	239	10:45	19509	19771	262
09:00	19550	19830	280	11:00	19501	19720	219
09:15	19569	19822	253	11:15	19492	19719	227
09:30	19579	19822	243	11:30	19466	19722	256
09:45	19593	19823	230				

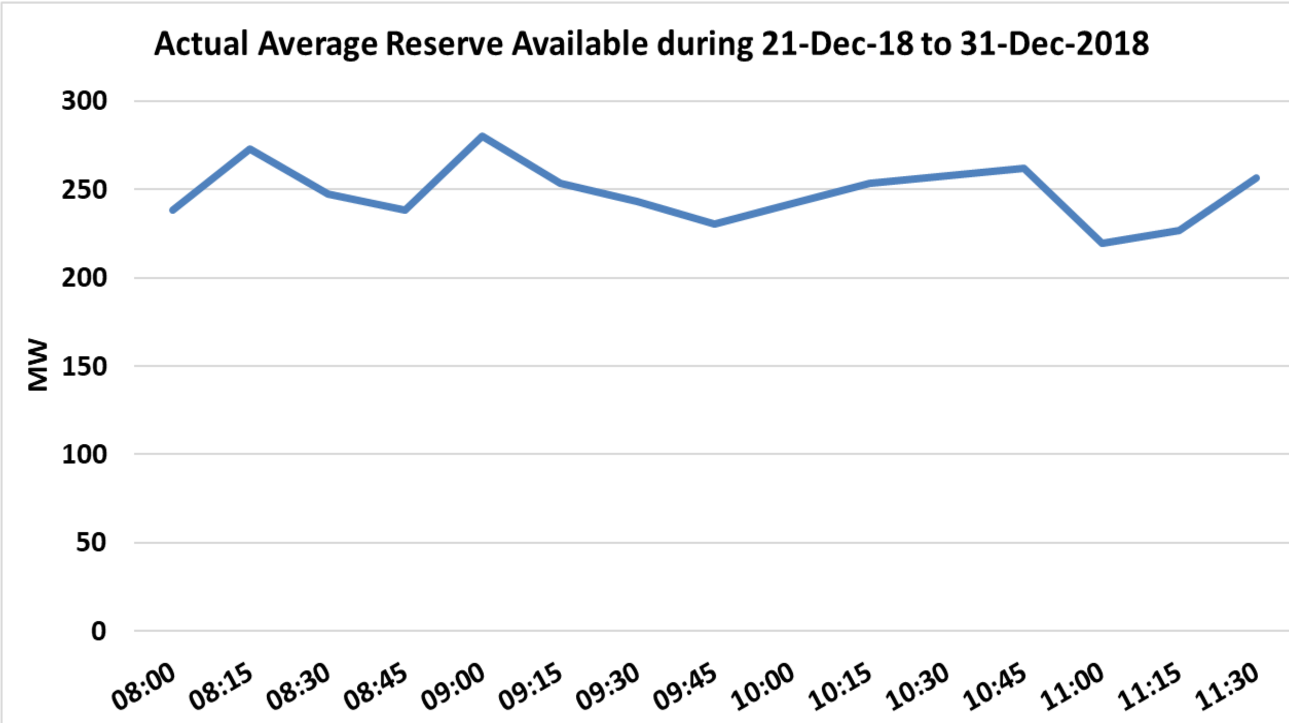


Figure 71: Western Region Actual Average on-bar Reserves Available during 21.12.18 to 31.12.2018

Actual average on-bar reserves available during 08:00 Hrs to 11:30Hrs was in the range of 250MW in ISGS Units at regional level. Lower reserve was available due to outage of Gas Units at KAWAS and Gandhar under reserve shut down (less schedule). During Dec'18, It was also observed that the two units of Mouda (500 & 660MW) and Solapur(660MW) were kept out on reserve shut down. Therefore, to mitigate the requirement of reserves of 1164 MW, proper planning of generating units required for flexibility. Appropriate planning to keep the units (listed below) in service may be done keeping the fast response required during solar eclipse

1. Kawas Gas units
2. Gandhar Gas units
3. Mouda stage I
4. Mouda Stage II
5. Solapur
6. Lara

2. Scheduling of Hydro Generation in Western region

The scheduling of Hydro plant during solar eclipse may be given the priority by the state as the response of hydro generation is very fast compared to other type of generation. Ghatghar(Mahrashtra) is the only pump storage plant in Western Region. It has generated during peak demand and pumped during off peak hours in the month of December 2018. Maharashtra may plan the two units at Ghatghar(2x125MW) each to give the response during solar eclipse 2019. Apart from Gharghar Pump Storage Plant, Following is the list of Hydro generators in WR where generation during December month is observed. Plots of generation and reservoir level is enclosed as **Annexure A.**

Hydro Generator	State-Owned/ISGS	Injected Power during Dec 2018
SSP(1450MW)	ISGS	Yes(CHPH units only)
Koyna(1960MW)	Maharashtra	Yes
Ukai(305MW)	Gujarat	Yes
Kadana(240MW)	Gujarat	Yes
Indirasagar(1000MW)	MP	Yes
Omkareshwar(520MW)	MP	Yes
Tons(315MW)	MP	Yes
Gandhisagar(57.5MW)	MP	No

Therefore, each state of WR may plan their hydro generation during solar eclipse so immediate response can be given during sudden drop and increase in the solar generation in each state.

3. Action required by State as per 524th OCC meeting

Study carried out for solar eclipse by POSOCO has also been discussed during 524th OCC meeting of WRPC (agenda no- 9.4). Following actions required from the states as discussed during OCC meeting-

i. Study the potential effect of solar eclipse on respective control areas
ii. Estimation of total solar power reduction
iii. Need of the reserve requirement for managing the reduced solar generation

iv. Ramping and balancing issue in the area of annular solar eclipse and partial solar eclipse.
v. Potential loading of transmission corridors.
vi. Coordination requirement between RLDCs, SLDCs and RE plants.
vii. Collection of contact details of solar plants having capacity of more than 50 MW and availability of Power Plant Control (PPC) facility.

Therefore, States may study the impact of solar eclipse on weak ahead/day ahead/intraday basis. The same may be intimated to the forecasters from which states are taking forecast services. Weather Forecast (Solar Radiation) also may be asked from the Weather service provider in state so that post event study can be carried out and it may be used in the future. Based on the forecast, state may plan their schedule in Hydro generators as well as in thermal plants. Locations may be identified where voltage balancing is required in the state during solar eclipse. Solar generating stations having PPC may be utilized for voltage balancing. In addition, the switching of B/R may be planned to control the voltage at nearby substations.

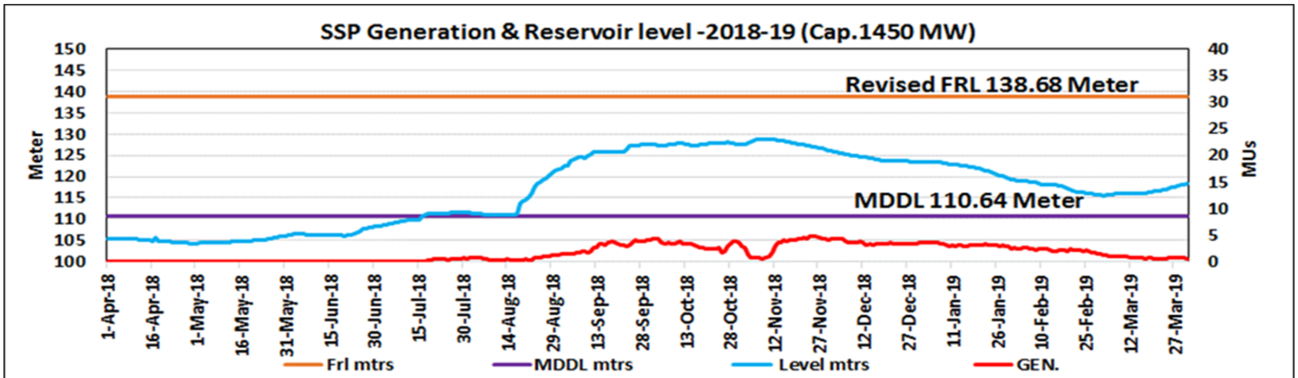
4. Solar plants to be selected for Post Event Analysis

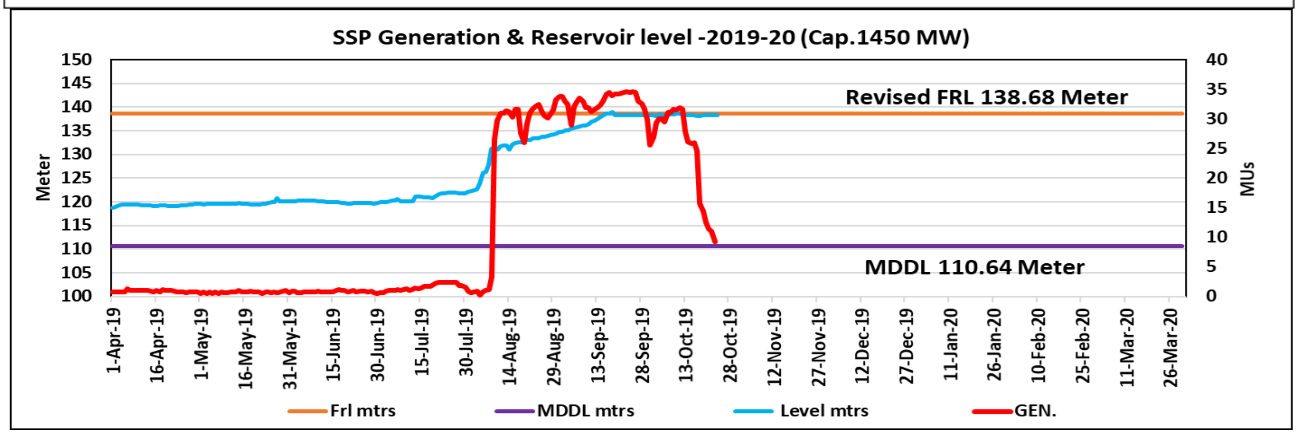
At regional level, solar plant e.g. Mahindra, ACME and Arinsun will be selected for Forecasting of the generation. The post event analysis will also be carried out after the solar eclipse. Solar radiation forecast considering the solar eclipse impact will also be requested by the Weather Service provider in REMC. Based on the forecasted radiation, forecast on day ahead basis will be prepared with In-house models of forecasting at WRLDC. Also there will be 4 Forecasts available given by FSP (Forecast Service Providers). There will be different forecast available to take the decision in real time. Also post event, the comparison of forecast and actual impact of solar eclipse will be carried out.

Similarly, all the states may plan to select the large solar park in the state to study, Forecast and Post event analysis.

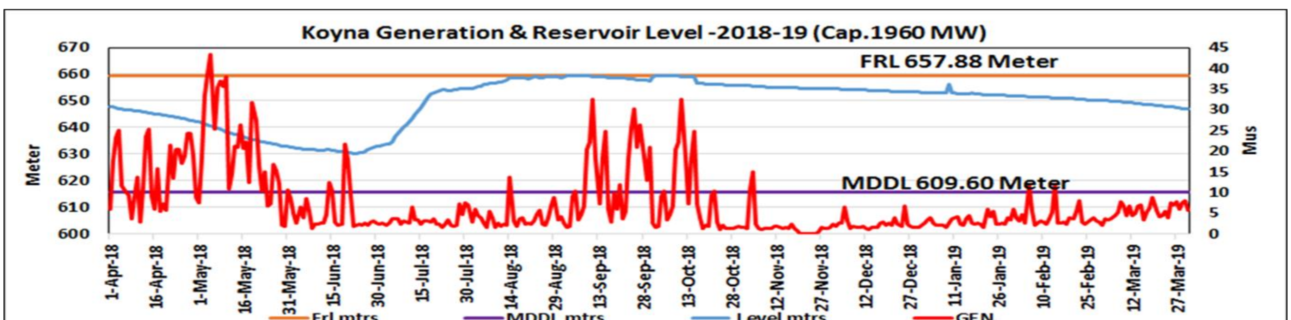
Hydro Generation in WR and Reservoir Level   Annexure A

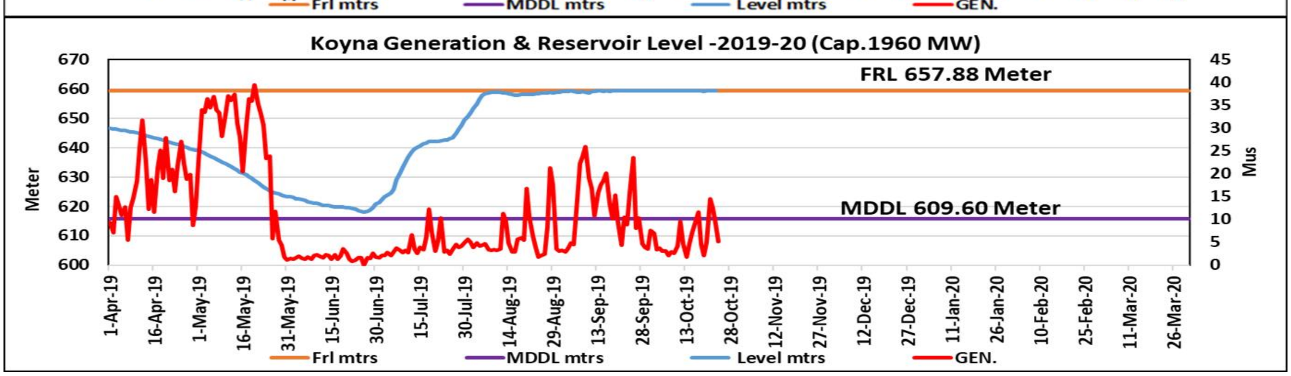
ISGS Hydro Station-



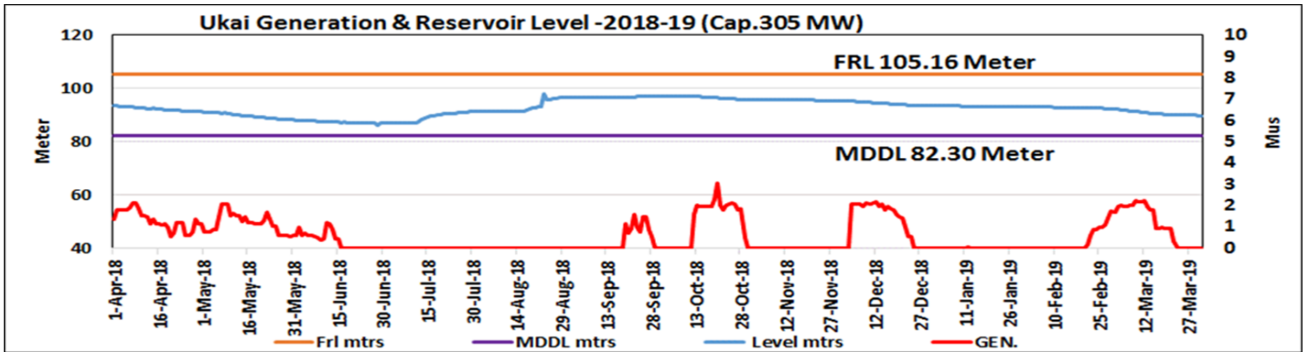


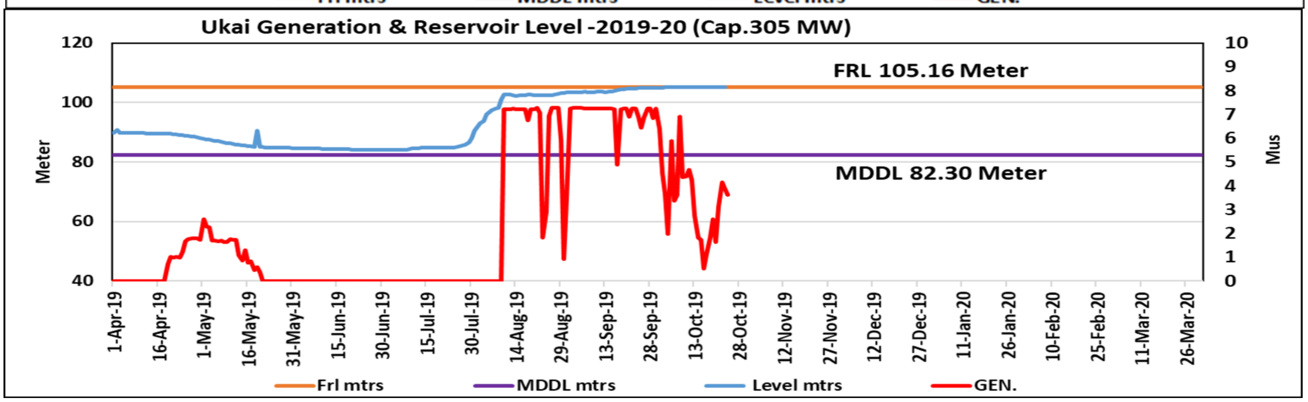
Maharashtra State Hydro Generating Station-

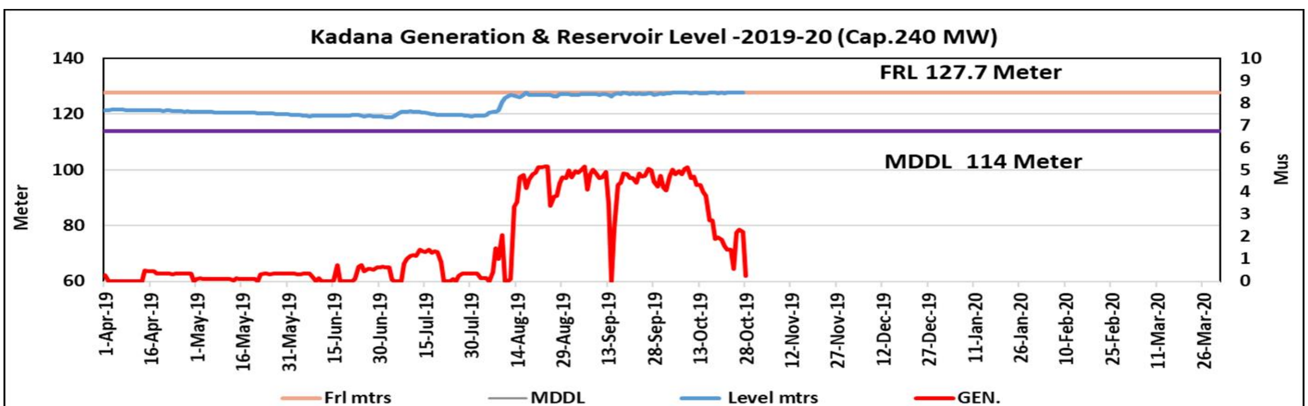


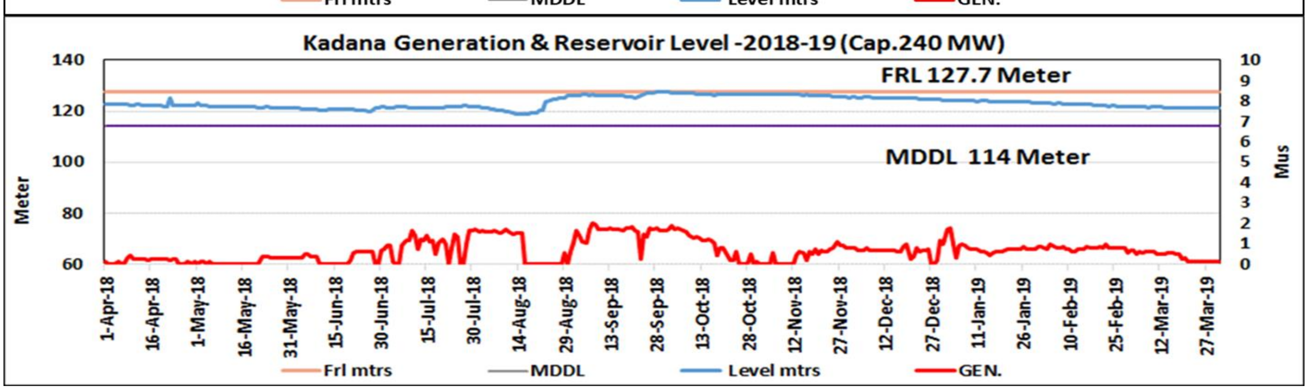


Gujarat State Hydro Generating Station

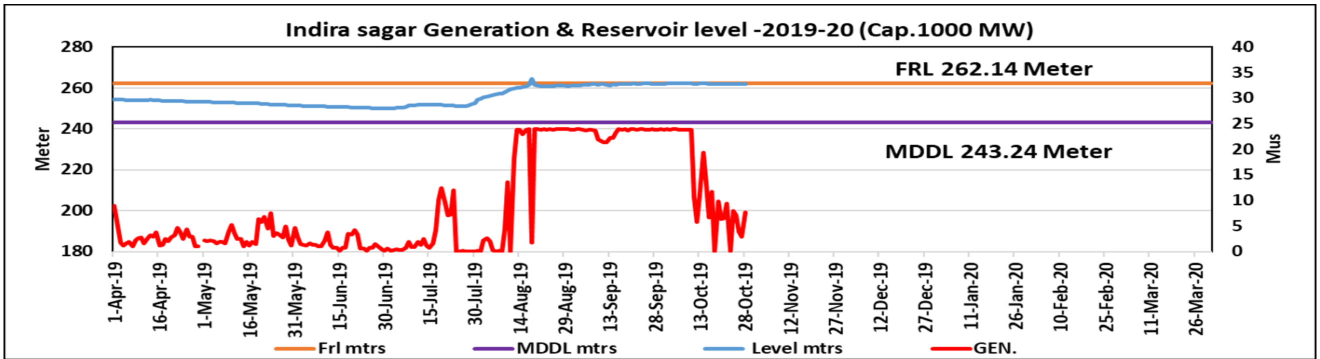


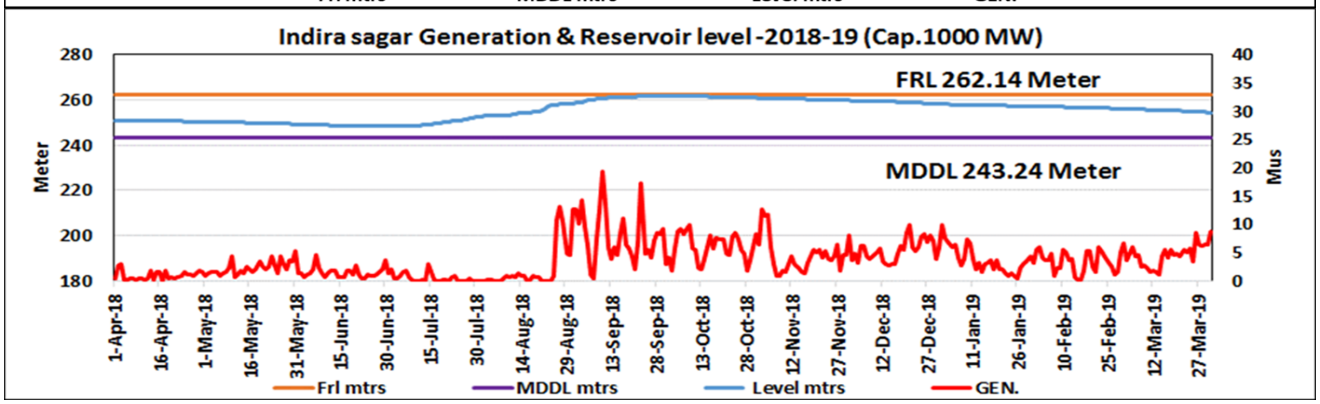


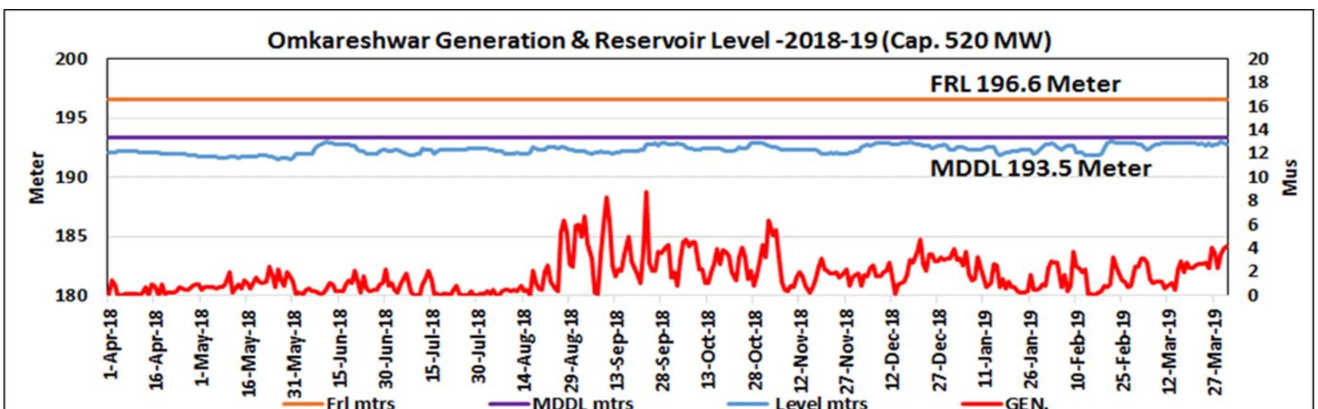


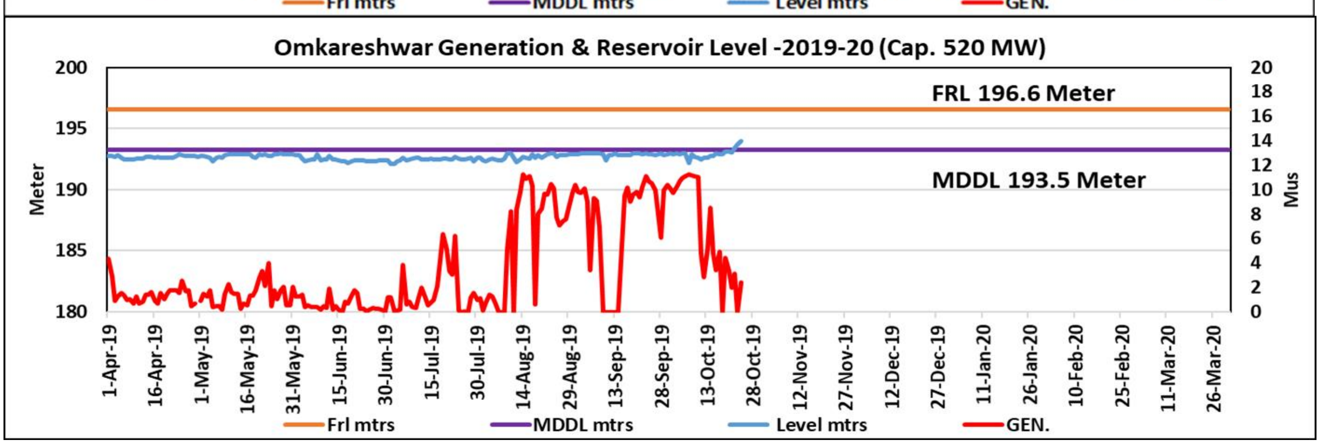


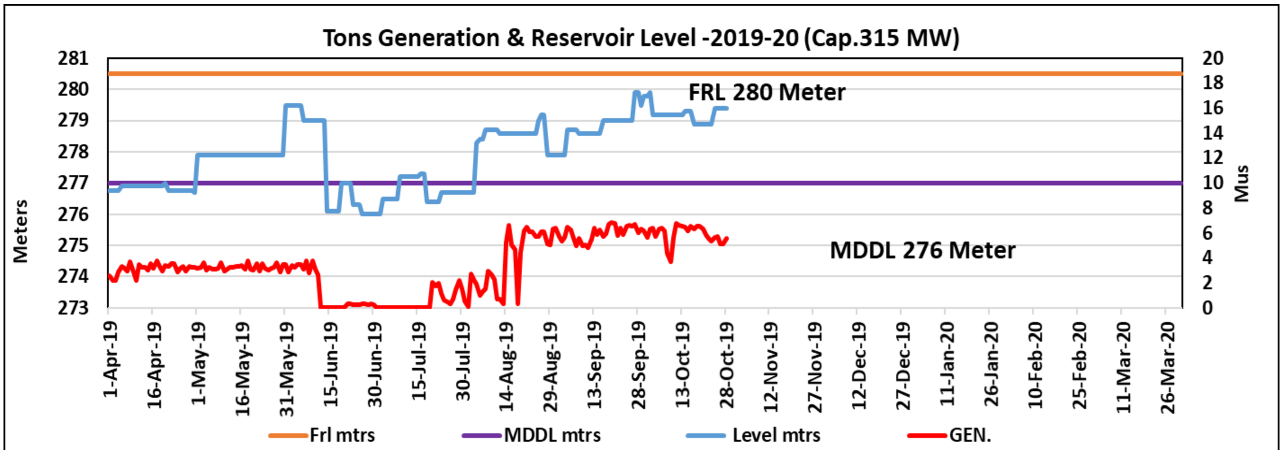
MP State Hydro Generating Station

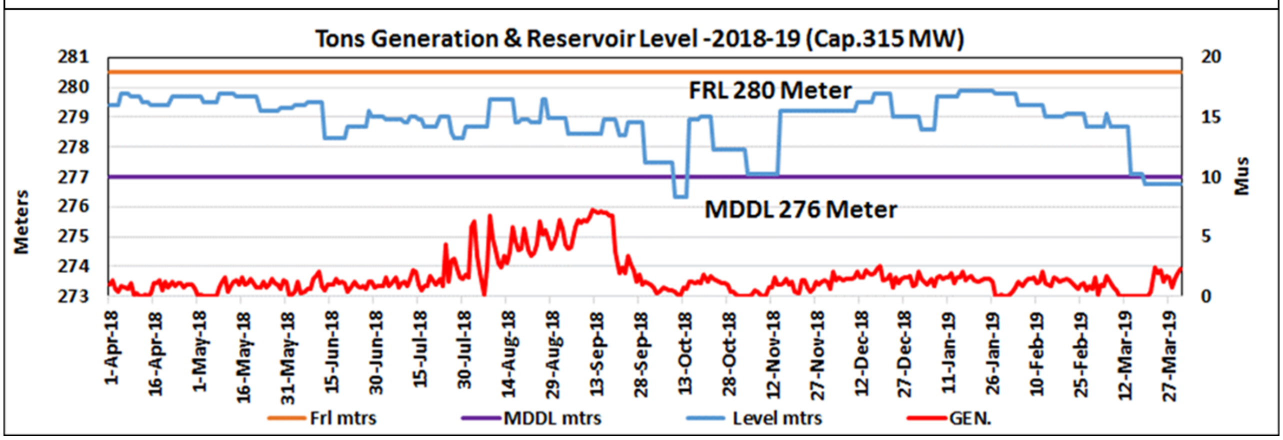


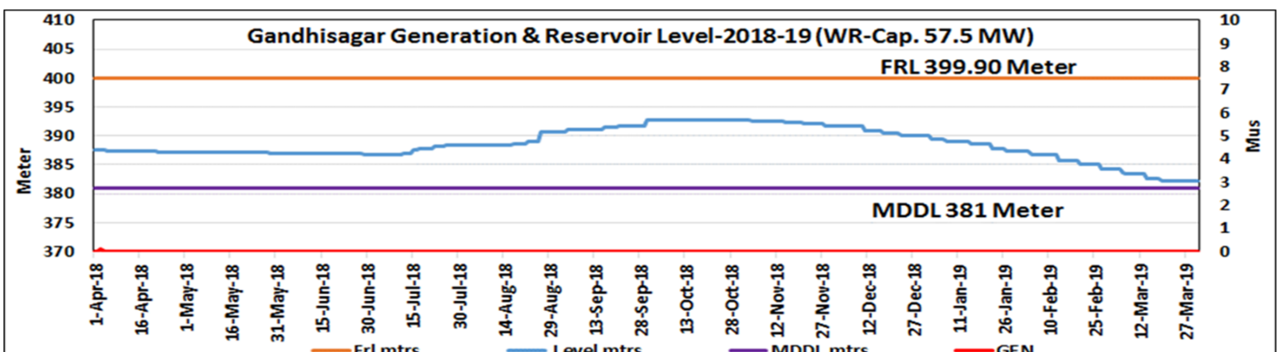


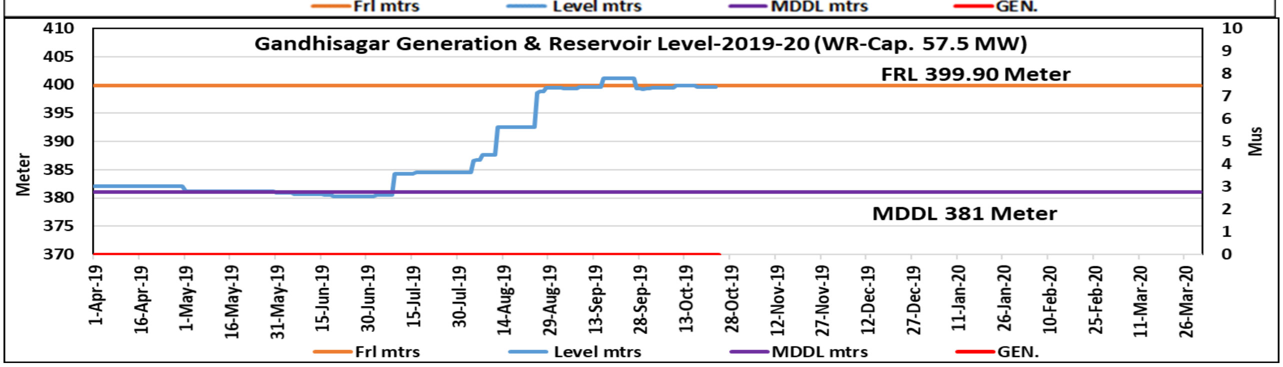





Tons Generation & Reservoir Level -2019-20 (Cap.315 MW)
FRL 280 Meter
MDDL 276 Meter
Meters
Mus
Frl mtrs
MDDL mtrs
Level mtrs
GEN.


Tons Generation & Reservoir Level -2018-19 (Cap.315 MW)
FRL 280 Meter
MDDL 276 Meter
Meters
Mus
Frl mtrs
MDDL mtrs
Level mtrs
GEN.


Gandhisagar Generation & Reservoir Level-2018-19 (WR-Cap. 57.5 MW)
FRL 399.90 Meter
MDDL 381 Meter
Meter
Mus
Frl mtrs
Level mtrs
MDDL mtrs
GEN.


Gandhisagar Generation & Reservoir Level-2019-20 (WR-Cap. 57.5 MW)
FRL 399.90 Meter
MDDL 381 Meter
Meter
Mus
Frl mtrs
Level mtrs
MDDL mtrs
GEN.

(c) Operational Planning for Northern Region

There could be 1 to 2 % average drop in demand during the demand compared to a normal day. The expected Northern Region demand on 26 December 2019 is given below:

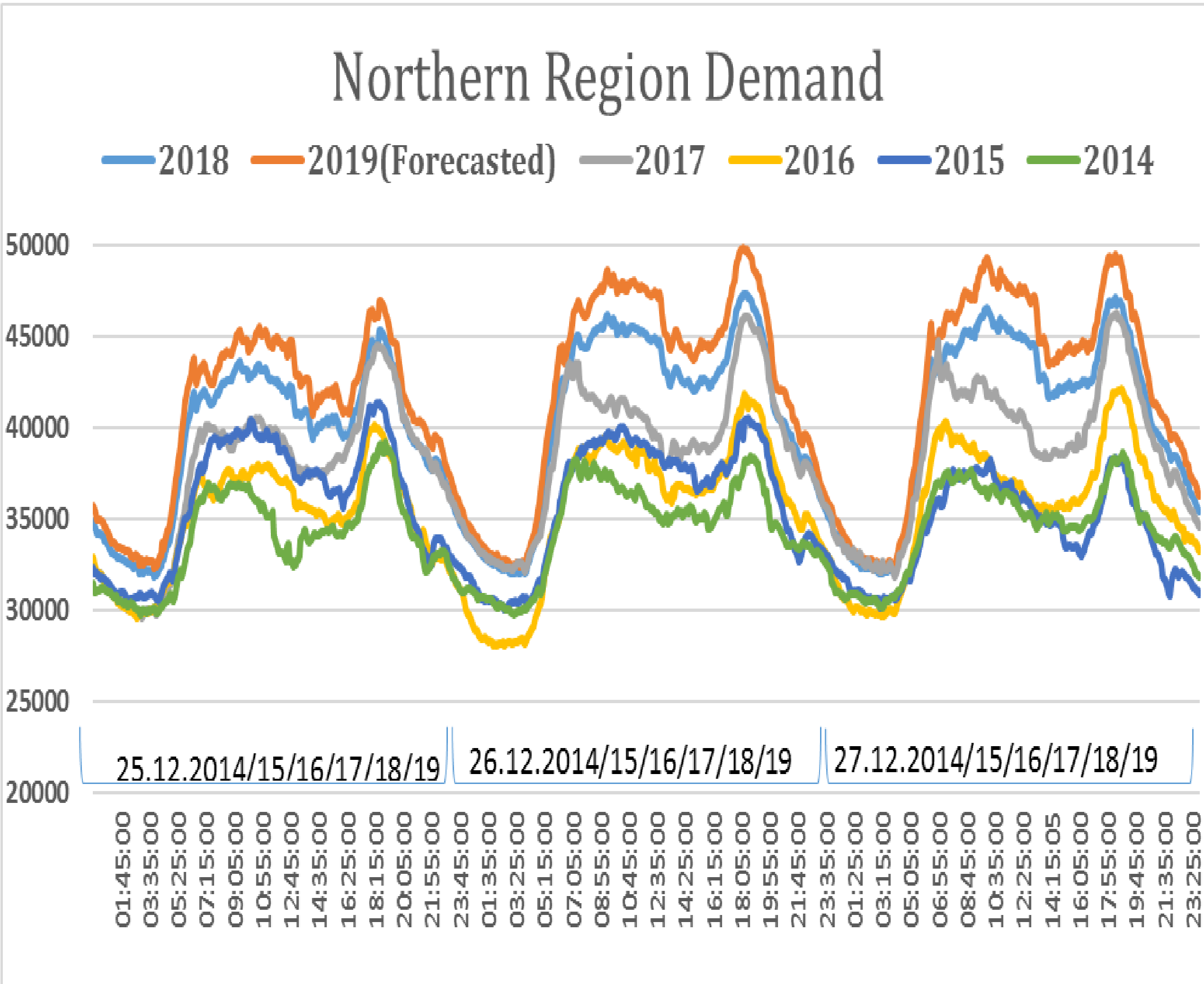


Figure 72: Estimated Northern Region Demand during Solar Eclipse

It is estimated that during solar eclipse, solar generation in Northern region will reduce approximately by 928 MW and after the eclipse is over the solar generation will increase by 2.1 GW within a period of 1:30 Hrs .

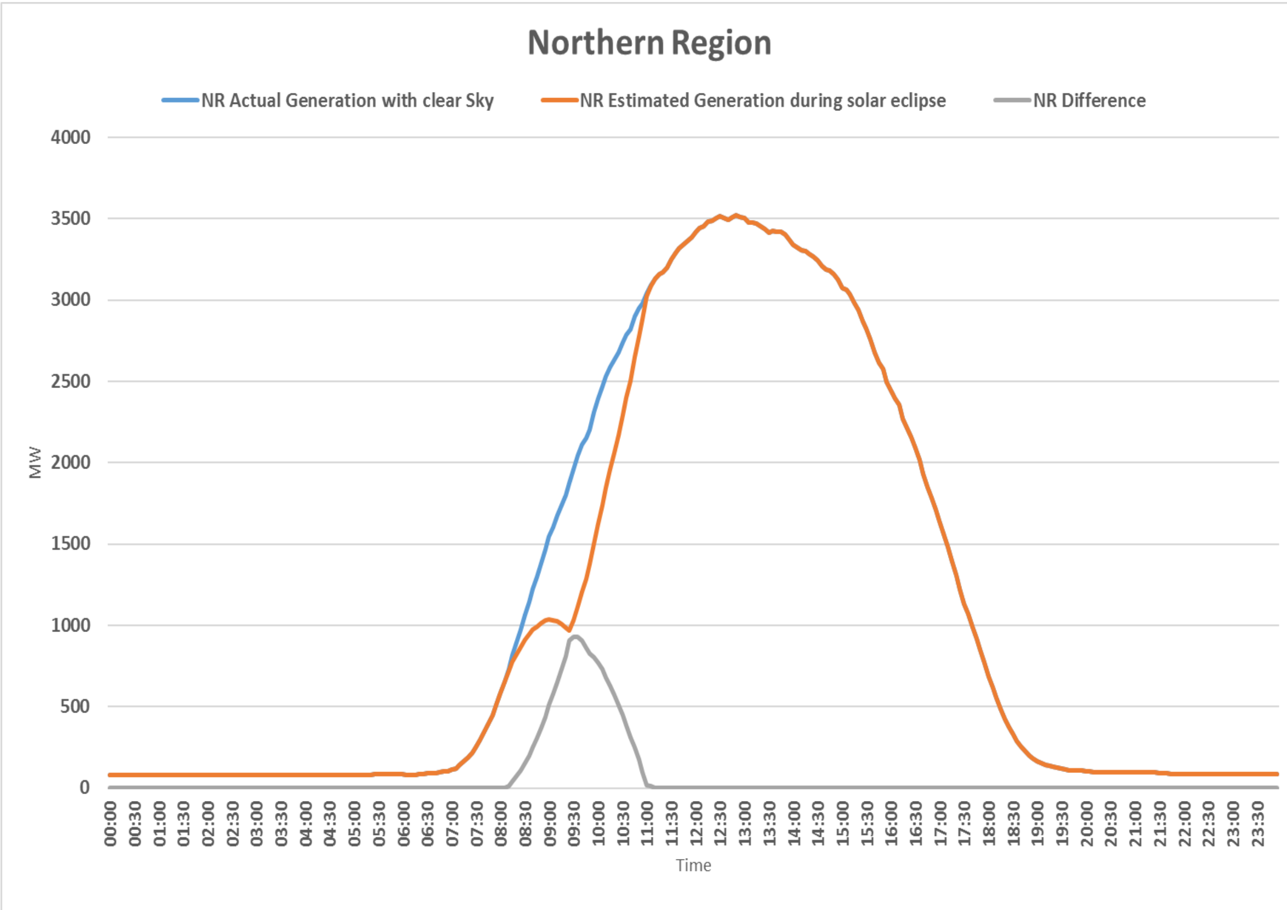


Figure 73: Estimated Northern Region Solar Generation during Solar Eclipse

The Northern Region is required to manage the following during eclipse period

1. Managing solar generation reduction & associated ramps from eclipse start to maximum eclipse time.
2. Managing solar generation increase & associated ramps from maximum eclipse to end of eclipse.
3. Arranging power from alternate sources for meeting the demand which was generally met from solar power

I. Scheduling of all conventional reserves in Northern Region

The maximum reserve requirement in Northern Region is 928 MW. The data of reserves available during 21-Dec -18 to 26-Dec-2018 in NR ISGS station has been analysed and average reserves available is shown below.

Time	NR		
	on bar DC (MW)	Schedule (MW)	Reserves Available (MW)
08:00	14541	14137	405
08:15	14247	13907	340
08:30	13761	13453	308
08:45	13525	13182	343
09:00	12952	12609	343
09:15	12531	12215	316
09:30	11972	11704	268
09:45	11617	11392	225
10:00	11448	11203	245
10:15	11129	10874	256
10:30	10965	10677	288
10:45	10878	10607	271
11:00	10859	10579	280
11:15	10818	10522	296
11:30	14541	14137	405

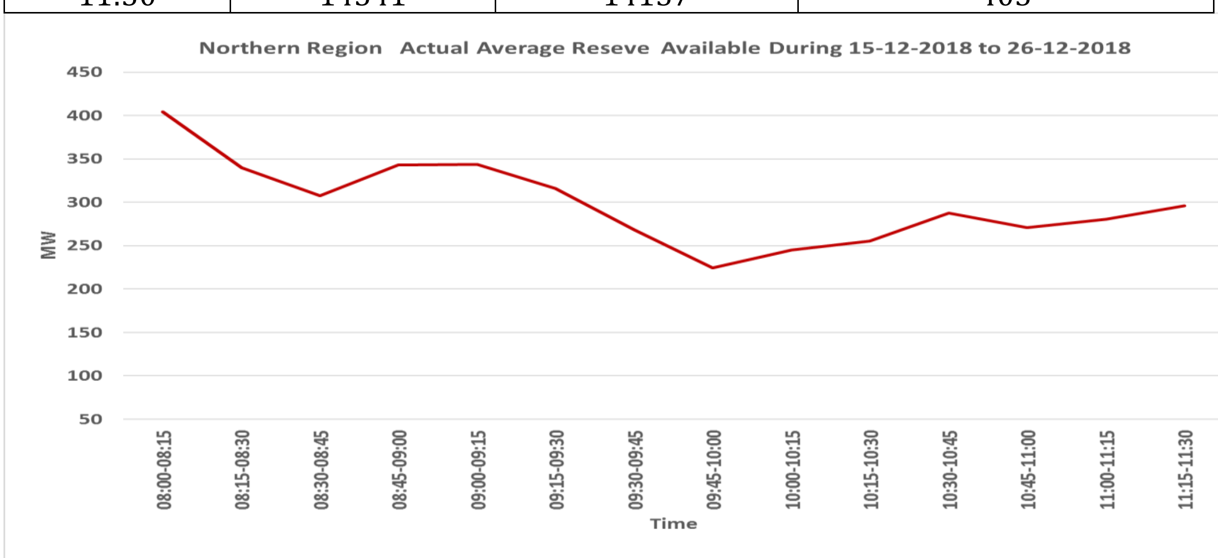


Figure 74: Northern Region Actual Average On-bar Reserves Available during 15.12.18 to 26.12.2018

Actual average on-bar reserves available during 08:00 Hrs to 11:30 Hrs was in the range of 300 MW in ISGS Units at regional level. During 15th -26th December 2018, the Gas power plants Dadri GPS, Faridabad GPS, Auraiya GPS and Anta GPS were kept out on reserve shutdown due to less demand. Therefore, to meet the balance requirement of reserves, following units as listed below may be taken in service for fast response during solar eclipse.

1. Dadri Gas units (2 * 154.51 + 4 * 130.19)= 819 MW
2. Faridabad Gas units (1 * 156.07 + 2 * 137.75)= 432 MW
3. Anta Gas units (1 * 153.2 + 3 * 88.71)= 419 MW
4. Auraiya Gas Units(2 * 109.3 + 4 * 111.19)= 663 MW

II. Scheduling of Hydro Generation in Northern Region

The data of hydro generation available during 15-12 -18 to 31-12-2018 in Northern Region ISGS hydro station has been analysed and average generation is shown below:

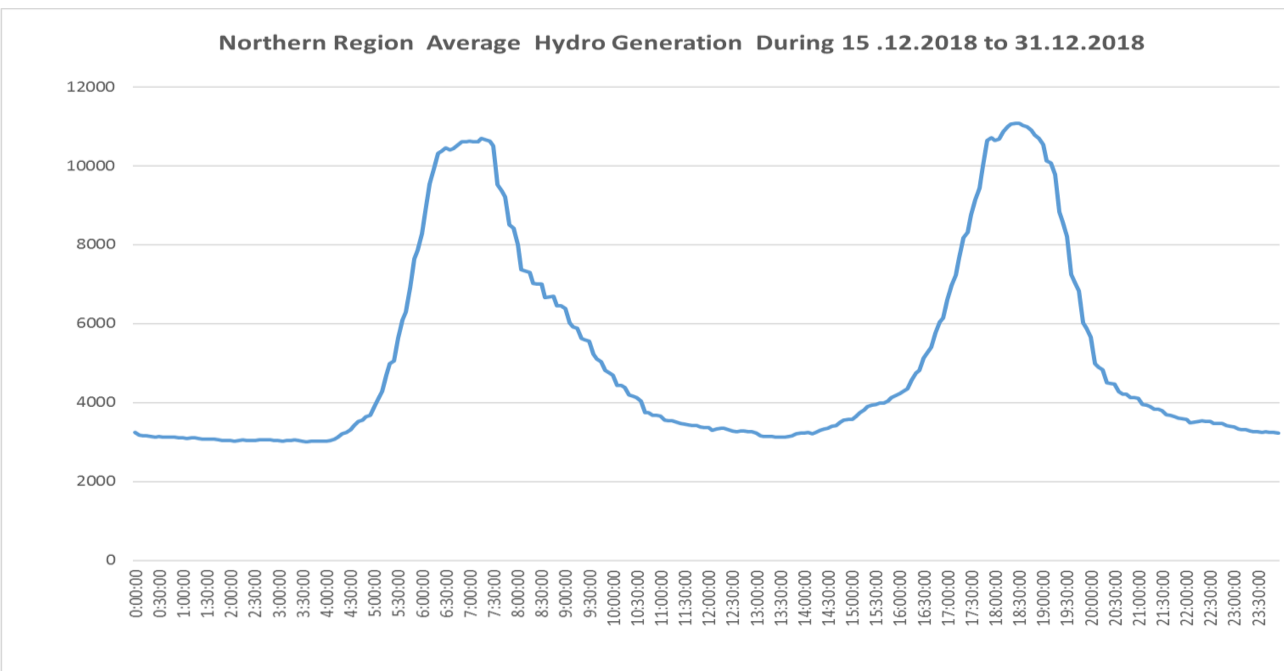


Figure 75: Northern Region Average Hydro Generation during 15.12.2018 to 31.12.2018

During the eclipse period, hydro generator's may be scheduled to tackle solar generation ramp down and ramp up. List of Northern Region hydro which may be scheduled during solar eclipse period is given below:

1. Tehri Hps(4 * 250) = 1,000 MW
2. Koteshwar Hps(4 * 100) =400 MW
3. Koldam Hps(4 * 200)= 800 MW
4. Karcham Wangtoo Hps(4 * 250) = 1,000 MW
5. Dhauliganga Hps(4 * 70) = 280 MW
6. Dulhasti Hps (3 * 130) = 390 MW

Rajasthan

The expected maximum solar generation reduction in Rajasthan is 654 MW during solar eclipse period. Rajasthan has to arrange this power from their available resource. At the peak of eclipse all hydro stations generation may be maximized so that maximum fast ramping hydro generation would be available for managing solar generation rise after eclipse. The generation from wind plants should also be properly forecasted and closely monitored during eclipse period. The Rajasthan have following hydro plant that may be scheduled during solar eclipse period from their available resource to mitigate this effect.

1. Mahi Bajaj Sagar (2x25+2x45) =140 MW
2. Rana Pratap Sagar (RPS) (4x43) = 172 MW
3. Jawahar Sagar (JS) (3x33) =99 MW
4. Gandhi Sagar (5x23) = 115.

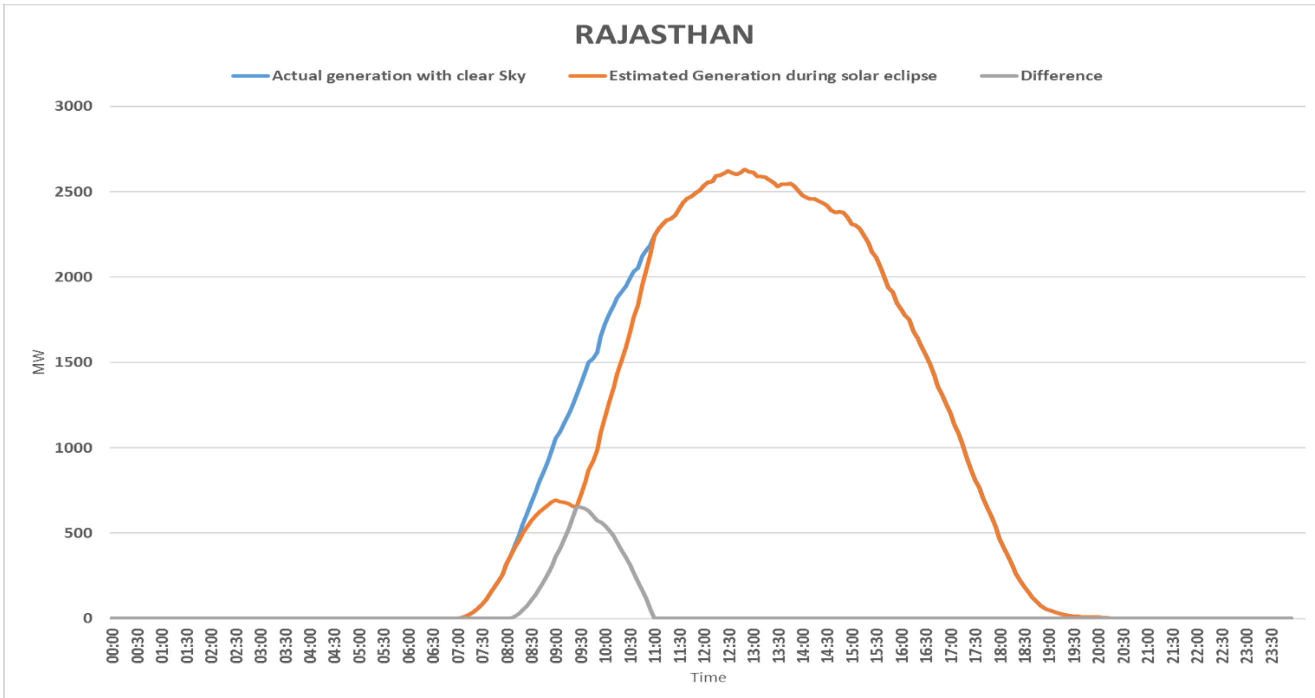


Figure 76: Estimated Rajasthan Solar Generation during Solar Eclipse

Thermal generation of Rajasthan also need to be planned in coordination with hydro generation so that additional support from thermal can be utilized. ISGS Hydro plants may also be scheduled to further optimize the drawal from the grid.

Uttar Pradesh

The expected maximum solar generation reduction in Uttar Pradesh is 136 MW during solar eclipse period. Uttar Pradesh has to arrange this power from their available resource. The list of available Hydro resource from the Uttar Pradesh is given below.

(a) Rihand HPS 6x50 = 300 MW
(b) Obra 3x33 = 99 MW
(c) Matatilla 3x10.2 =30.60 MW
(d) Khara 3x24 =24 MW
(e) Vishnu Prayag IPP 4x110= 440 MW
(f) Alaknanda HPS 4x82.5 330

Uttar Pradesh has to schedule 136 MW power with above available hydro resources. If the above resource will not available that day then required 136 MW to be scheduled from ISGS hydro plant during solar eclipse period.

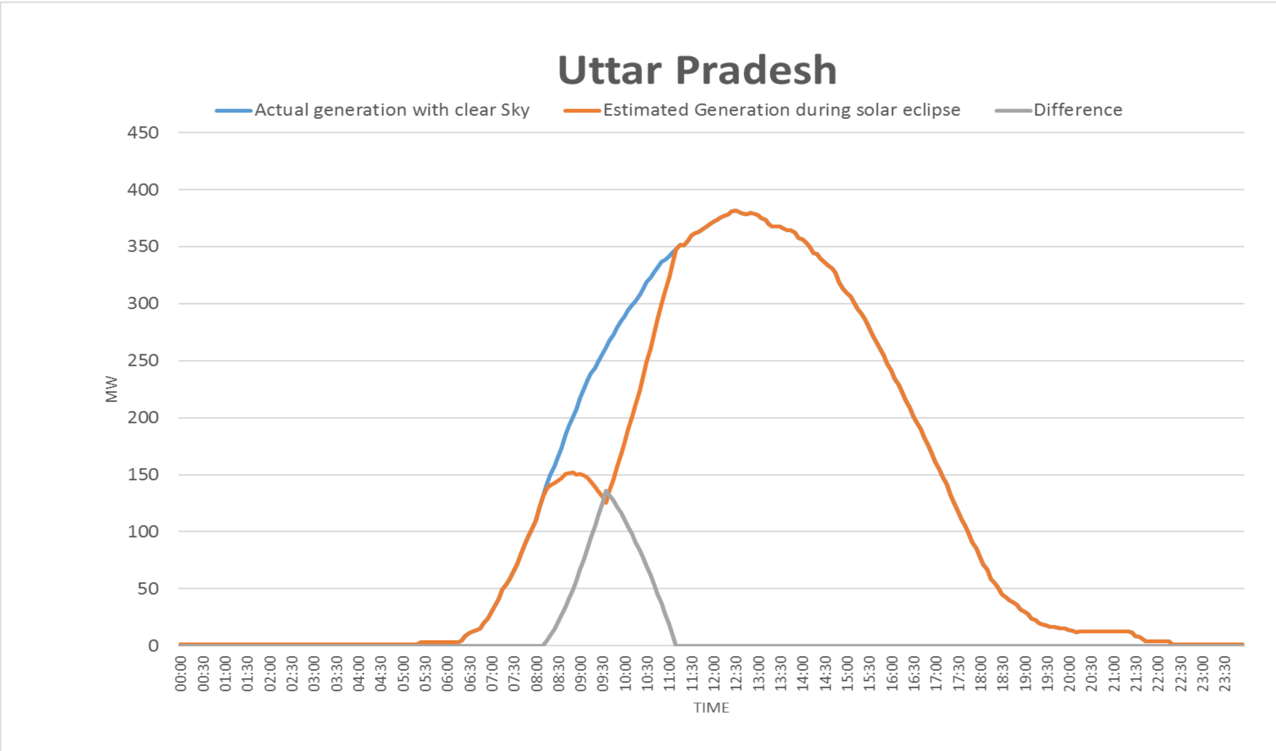


Figure 77: Estimated Uttar Pradesh Solar Generation during Solar Eclipse

Punjab

The expected maximum solar reduction during solar eclipse period in Punjab is 152 MW. The Punjab has to arrange this power from their available resource. The list of available hydro resource of Punjab is given below. Punjab is required to schedule the 152 MW power from available hydro resources and if that day these resources are not available then same quantum may be scheduled from ISGS hydro plants.

(a) Shanan (4x15+1x50) = 110 MW
(b) UBDC Canal (3x15+3x15.45) =91.35 MW
(c) Mukerian (6x15+6x19.5 +2x19) = 225 MW
(d) Anandpur Sahib (APS) (4x33.5) = 134 MW
(e) Ranjit Sagar HPS (4x150)=600 MW

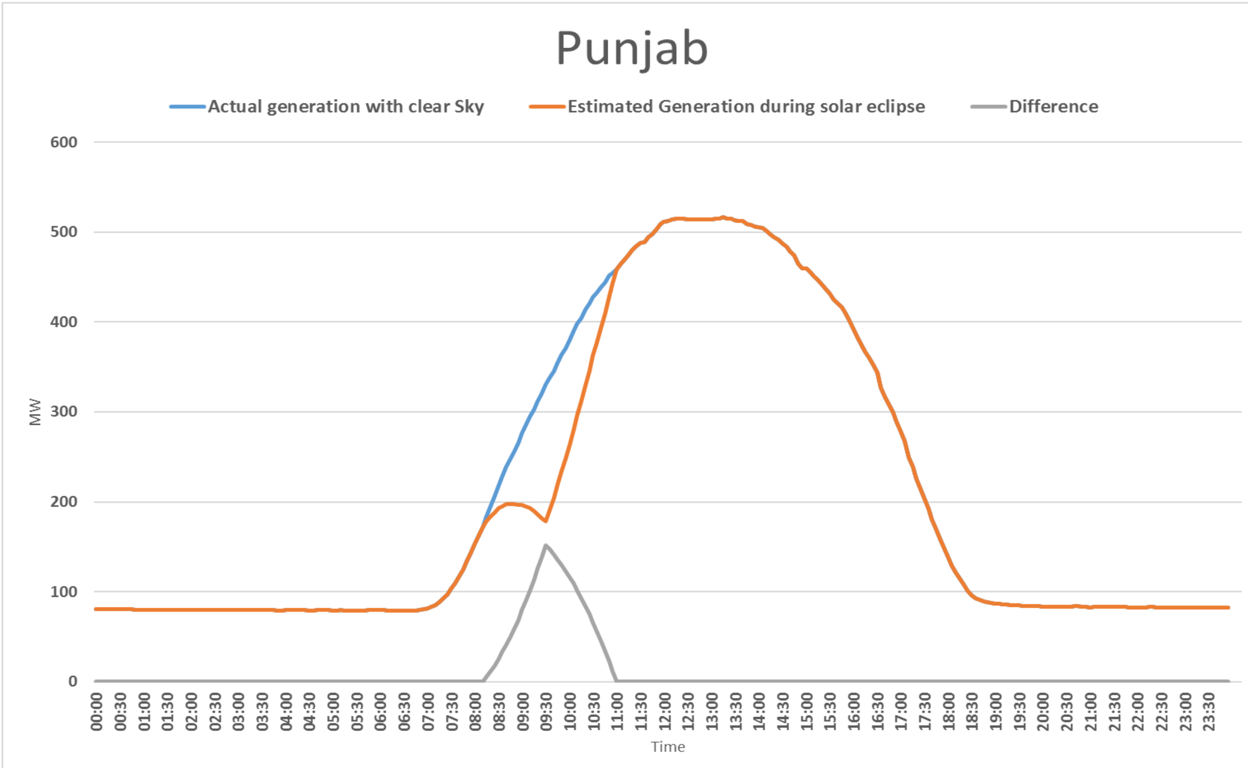


Figure 78: Estimated Punjab Solar Generation during Solar Eclipse

10. SUMMARY AND RECOMMENDATIONS

The Solar Eclipse is a Predictable event where the generation is impacted for a known period of time. With the present level of solar generation penetration , there is no reliability issue but with increase in the penetration of distributed solar generation in future, there would be reliability issues.

(i) Power output from PV plants is highly dependent on obscuration due to solar eclipse. Day ahead forecast of solar generation is very important for 26th December 2019 for all the plants/states/regions. Solar generation scheduling shall be done as per the forecasted variation in generation due to solar eclipse.

(ii) Advance coordination between SLDCs /RLDCs and NLDC is required to address ramp issues.

(iii) Resources must be identified and kept on bar to meet the changes in generation from PV plants and solar rooftops.

(iv) Planned Shutdown of Conventional Power Stations / Transmission lines may be avoided in SR on 26th December 2019

(v) The solar plants having PPC would be of great help for system operators to manage the ramp rate. The PPC active power control mode of operation can help in managing load and generation balance.

(vi) In order to cater the fast ramping down/up demanded by solar eclipse start/ end the following procedure needs be followed by all the constituents

a) Keeping all Hydro units on bar and maintaining generation at minimum possible levels before start of the eclipse and picking the Hydro once solar eclipse starts at 8.03hrs. It is to be noted that during December 2018, all India hydro was used for ramp up from 04:30 AM to 07:30 AM and started receding thereafter.

b) Maintaining full generation at all the Hydro stations during eclipse peak at 9.30hrs and start ramp down after completion of annularity of eclipse to tackle ramping of solar generation.

c) Thermal generation, being slow ramping compared to Hydro, can also be planned in similar manner to aid the support provided by Hydro stations in catering the

ramping requirements. If required gas power stations can also be kept on bar before start of eclipse.

d) Sensitise all the constituents in OCC /RPC (Operational coordination committee/Regional power committee) meetings.

e) All regions should be ready for emergency support to each other.

f) HVDC set points may be kept such that adequate margin is available to tackle any contingency during solar reduction or major over drawl by southern states from inter-regional corridor.

ANNEXURE-I

THE ANNULAR ECLIPSE OF THE SUN, DECEMBER 26, 2019

THE ANNULAR ECLIPSE OF THE SUN, DECEMBER 26, 2019							
LOCAL CIRCUMSTANCES OF THE PARTIAL PHASE RELATING TO CERTAIN PLACES OF INDIA							
State	Location	Partial Eclipse Begins (IST)	Greatest Eclipse (IST)	Magnitude	Partial Eclipse Ends (IST)	Duration	Obscuration
		h m	h m		h m	h m	
Andhra Pradesh	Hyderabad	8 08.2	9 30.6	0.803	11 10.3	3 02	74.10%
	Kurnool	8 07.3	9 30.1	0.85	11 10.5	3 03	79.90%
	Nellore	8 08.9	9 33.9	0.858	11 17.3	3 08	80.90%
	Rajamundry	8 12.4	9 38.2	0.763	11 21.8	3 09	69.30%
	Vijayawada	8 10.1	9 34.8	0.798	11 17.3	3 07	73.50%
Arunachal Pradesh	Itanagar	8 46.4	10 0 8.4	0.41	11 39.6	2 53	29.40%
Assam	Dibrugarh	8 51.0	10 12.9	0.391	11 42.9	2 51	27.50%
	Guwahati	8 39.5	10 02.1	0.448	11 35.6	2 56	33.40%
	Sivsagar	8 49.0	10 11.7	0.404	11 42.8	2 53	28.80%
	Silchar	8 40.3	10 05.7	0.466	11 41.9	3 01	35.20%
Bihar	Bhagalpur	8 27.9	9 49.4	0.514	11 24.1	2 56	40.40%
	Gaya	8 23.5	9 44.5	0.548	11 19.4	2 55	44.10%
	Muzaffarpur	8 26.2	9 45.9	0.512	11 18.6	2 52	40.20%
	Patna	8 24.9	9 45.1	0.527	11 18.6	2 53	41.80%
	Sambalpur	8 18.1	9 41.8	0.635	11 21.3	3 03	54.00%
Chhattisgarh	Raipur	8 14.4	9 36.8	0.669	11 15.2	3 00	58.00%
Goa	Panaji	8 04.3	9 24.0	0.902	11 0.40	2 56	86.20%
Gujarat	Ahmadabad	8 06.4	9 22.1	0.743	10 52.0	2 45	66.70%
	Dwarka	8 03.6	9 17.5	0.808	10 45.3	2 41	74.60%
	Gandhinagar	8 06.6	9 22.2	0.738	10 52.1	2 45	66.10%
	Vadodara	8 06.4	9 22.7	0.753	10 53.8	2 47	67.90%
Himachal Pradesh	Shimla	8 20.9	9 32.2	0.5	10 54.5	2 33	38.80%
Jammu & Kashmir	Jammu	8 20.5	9 29.7	0.494	10 49.1	2 28	38.10%
	Srinagar	8 23.0	9 30.7	0.464	10 48.0	2 25	34.80%
Jharkhand	Hazaribagh	8 23.2	9 45.3	0.56	11 21.7	2 58	45.50%
	Ranchi	8 22.3	9 45.1	0.576	11 22.5	3 00	47.20%
	Bangalore	8 06.5	9 29.8	0.93	11 11.2	3 04	89.60%

THE ANNULAR ECLIPSE OF THE SUN, DECEMBER 26, 2019							
LOCAL CIRCUMSTANCES OF THE PARTIAL PHASE RELATING TO CERTAIN PLACES OF INDIA							
State	Location	Partial Eclipse Begins (IST)	Greatest Eclipse (IST)	Magnitude	Partial Eclipse Ends (IST)	Duration	Obscuration
		h m	h m		h m	h m	
Karnataka	Mysore	8 05.9	9 28.4	0.959	11 09.0	3 03	93.50%
Kerala	Cochin	8 06.1	9 28.5	0.941	11 09.0	3 02	91.00%
	Thiruvanantapuram	8 07.2	9 30.3	0.912	11 11.8	3 04	87.60%
Madhya Pradesh	Bhopal	8 11.0	9 29.2	0.676	11 02.2	2 51	58.80%
	Ujjain	8 09.3	9 26.6	0.699	10 58.7	2 49	61.50%
Maharashtra	Kolhapur	8 04.4	9 23.7	0.881	10 59.6	2 55	83.60%
	Mumbai	8 04.1	9 21.7	0.845	10 54.9	2 50	79.10%
	Nagpur	8 11.2	9 31.9	0.704	11 08.6	2 57	62.10%
	Nasik	8 05.3	9 23.1	0.804	10 56.5	2 51	74.10%
	Pune	8 04.7	9 23.1	0.84	10 57.6	2 52	78.50%
Manipur	Imphal	8 43.0	10 09.1	0.458	11 45.4	3 02	34.40%
Meghalaya	Shillong	8 39.3	10 03.0	0.457	11 37.5	2 58	34.30%
Mizoram	Aijawl	8 38.5	10 0 5.4	0.488	11 43.6	3 05	37.60%
Nagaland	Kohima	8 45.3	10 10.0	0.435	11 44.3	2 58	32.00%
Odisha	Bhubaneswar	8 20.0	9 46.1	0.64	11 28.4	3 08	54.70%
	Cuttack	8 20.3	9 46.4	0.634	11 28.4	3 08	54.00%
	Koraput	8 14.0	9 39.0	0.713	11 21.0	3 06	63.30%
	Puri	8 19.5	9 46.1	0.651	11 29.0	3 09	56.00%
Punjab	Amritsar	8 18.8	9 29.0	0.516	10 50.0	2 31	40.40%
	Jalandhar	8 20.8	9 30.9	0.494	10 51.6	2 30	38.10%
Rajasthan	Ajmer	8 11.4	9 25.9	0.636	10 53.7	2 42	54.10%
	Jaipur	8 13.1	9 27.8	0.613	10 55.7	2 42	51.40%
	Mount Abu	8 07.8	9 22.6	0.705	10 51.2	2 43	62.10%
	Rajkot	8 4.6	9 19.5	0.787	10 48.7	2 44	72.00%
	Udaipur	8 08.6	9 23.9	0.692	10 53.2	2 44	60.70%
Sikkim	Gangtok	8 34.6	9 54.2	0.452	11 25.1	2 50	33.70%
Tamil Nadu	Chennai	8 08.9	9 34.6	0.892	11 19.1	3 10	85.10%
	Kanyakumari	8 07.8	9 31.5	0.91	11 13.7	3 05	87.30%
	Kavalur	8 08.1	9 33.1	0.904	11 16.7	3 08	86.60%
	Nalgonda	8 08.8	9 32.1	0.804	11 12.9	3 04	74.20%
Tripura	Agartala	8 35.2	10 00.9	0.499	11 38.8	3 03	38.70%

THE ANNULAR ECLIPSE OF THE SUN, DECEMBER 26, 2019							
LOCAL CIRCUMSTANCES OF THE PARTIAL PHASE RELATING TO CERTAIN PLACES OF INDIA							
State	Location	Partial Eclipse Begins (IST)	Greatest Eclipse (IST)	Magnitude	Partial Eclipse Ends (IST)	Duration	Obscuration
		h m	h m		h m	h m	
Uttar Pradesh	Allahabad	8 19.1	9 37.8	0.57	11 10.3	2 51	46.60%
	Lucknow	8 19.8	9 36.7	0.548	11 06.7	2 46	44.10%
	Varanasi	8 20.9	9 40.4	0.558	11 13.7	2 52	45.20%
Uttarakhand	Dehradun	8 20.8	9 33.1	0.507	10 56.8	2 36	39.50%
	Haridwar	8 21.4	9 33.5	0.5	10 57.0	2 35	38.70%
West Bengal	Cooch Behar	8 34.9	9 56.2	0.464	11 29.2	2 54	35.00%
	Darjeeling	8 33.4	9 53.2	0.461	11 24.6	2 51	34.70%
	Hubli	8 05.0	9 25.4	0.882	11 02.9	2 57	83.70%
	Kolkata	8 27.0	9 52.6	0.559	11 32.4	3 05	45.40%
	Midnapore	8 24.9	9 49.9	0.573	11 29.6	3 04	47.00%
	Murshidabad	8 29.7	9 53.2	0.517	11 29.9	3 00	40.70%
	Siliguri	8 33.0	9 53.3	0.468	11 25.6	2 52	35.40%
Andaman & Nicobar	Port Blair	8 27.8	10 07.8	0.771	12 3.50	3 35	70.40%
Chandigarh	Chandigarh	8 21.5	9 32.8	0.494	10 55.0	2 33	38.10%
Dadar & Nagar Haveli	Silvassa	8 05.0	9 22.1	0.803	10 54.4	2 49	74.00%
Delhi	Delhi	8 17.0	9 30.8	0.555	10 56.9	2 39	44.80%
Lakshwadeep	Kavaratti	8 04.1	9 23.1	0.919	10 59.2	2 55	88.30%
Pondicherry	Pondicherry	8 08.6	9 34.3	0.925	11 18.9	3 10	89.10%

LOCAL CIRCUMSTANCES OF THE ANNULAR PHASE RELATING TO CERTAIN PLACES OF INDIA					
	Annular phase Begins(IST)	Greatest Eclipse(IST)	Maximum. Obscuration	Annular phase Ends(IST)	Duration of Annularity
	h m	h m		h m	m s
Cannanore	9 24.8	9 26.3	92.90%	9 27.8	2 59
Kozikode	9 26.5	9 27.2	93.00%	9 27.9	1 28
Madurai	9 31.5	9 31.8	93.10%	9 32.1	0 36
Mangalore	9 24.3	9 25.3	92.90%	9 26.3	2 01
Trichur	9 28.3	9 28.4	93.00%	9 28.5	0 12
Cannanore	9 24.8	9 26.3	92.90%	9 27.8	2 59
Kozikode	9 26.5	9 27.2	93.00%	9 27.9	1 28

REGION WISE THE ANNULAR ECLIPSE OF THE SUN, DECEMBER 26, 2019

LOCAL CIRCUMSTANCES OF THE PARTIAL PHASE RELATING TO CERTAIN PLACES OF INDIA						
Places	**Partial Eclipse Begins (IST)**	**Greatest Eclipse (IST)**	**Magnitude**	**Partial Eclipse Ends (IST)**	**Duration**	**Obscuration**
	h m	**h m**		**h m**	**h m**	
SR						
Mysore	8 05.9	9 28.4	0.959	11 09.0	3 03	93.50%
Cochin	8 06.1	9 28.5	0.941	11 09.0	3 02	91.00%
Bangalore	8 06.5	9 29.8	0.93	11 11.2	3 04	89.60%
Pondicherry	8 08.6	9 34.3	0.925	11 18.9	3 10	89.10%
Kavaratti	8 04.1	9 23.1	0.919	10 59.2	2 55	88.30%
Thiruvanantapuram	8 07.2	9 30.3	0.912	11 11.8	3 04	87.60%
Kanyakumari	8 07.8	9 31.5	0.91	11 13.7	3 05	87.30%
Kavalur	8 08.1	9 33.1	0.904	11 16.7	3 08	86.60%
Chennai	8 08.9	9 34.6	0.892	11 19.1	3 10	85.10%
Hubli	8 05.0	9 25.4	0.882	11 02.9	2 57	83.70%
Nellore	8 08.9	9 33.9	0.858	11 17.3	3 08	80.90%
Kurnool	8 07.3	9 30.1	0.85	11 10.5	3 03	79.90%
Hyderabad	8 08.2	9 30.6	0.803	11 10.3	3 02	74.10%
Vijayawada	8 10.1	9 34.8	0.798	11 17.3	3 07	73.50%
Rajamundry	8 12.4	9 38.2	0.763	11 21.8	3 09	69.30%
Nalgonda	8 08.8	9 32.1	0.804	11 12.9	3 04	74.20%

LOCAL CIRCUMSTANCES OF THE PARTIAL PHASE RELATING TO CERTAIN PLACES OF INDIA						
Places	Partial Eclipse Begins (IST)	Greatest Eclipse (IST)	Magnitude	Partial Eclipse Ends (IST)	Duration	Obscuration
	h m	h m		h m	h m	
WR						
Panaji	8 04.3	9 24.0	0.902	11 0.40	2 56	86.20%
Kolhapur	8 04.4	9 23.7	0.881	10 59.6	2 55	83.60%
Mumbai	8 04.1	9 21.7	0.845	10 54.9	2 50	79.10%
Pune	8 04.7	9 23.1	0.84	10 57.6	2 52	78.50%
Dwarka	8 03.6	9 17.5	0.808	10 45.3	2 41	74.60%
Nasik	8 05.3	9 23.1	0.804	10 56.5	2 51	74.10%
Silvassa	8 05.0	9 22.1	0.803	10 54.4	2 49	74.00%
Rajkot	8 4.6	9 19.5	0.787	10 48.7	2 44	72.00%
Port Blair	8 27.8	10 07.8	0.771	12 3.50	3 35	70.40%
Vadodara	8 06.4	9 22.7	0.753	10 53.8	2 47	67.90%
Ahmadabad	8 06.4	9 22.1	0.743	10 52.0	2 45	66.70%
Gandhinagar	8 06.6	9 22.2	0.738	10 52.1	2 45	66.10%
Nagpur	8 11.2	9 31.9	0.704	11 08.6	2 57	62.10%
Bhopal	8 11.0	9 29.2	0.676	11 02.2	2 51	58.80%
Raipur	8 14.4	9 36.8	0.669	11 15.2	3 00	58.00%
NR						
Mount Abu	8 07.8	9 22.6	0.705	10 51.2	2 43	62.10%
Ajmer	8 11.4	9 25.9	0.636	10 53.7	2 42	54.10%
Udaipur	8 08.6	9 23.9	0.692	10 53.2	2 44	60.70%
Jaipur	8 13.1	9 27.8	0.613	10 55.7	2 42	51.40%
Amritsar	8 18.8	9 29.0	0.516	10 50.0	2 31	40.40%
Varanasi	8 20.9	9 40.4	0.558	11 13.7	2 52	45.20%
Delhi	8 17.0	9 30.8	0.555	10 56.9	2 39	44.80%
Dehradun	8 20.8	9 33.1	0.507	10 56.8	2 36	39.50%
Shimla	8 20.9	9 32.2	0.5	10 54.5	2 33	38.80%
Allahabad	8 19.1	9 37.8	0.57	11 10.3	2 51	46.60%
Chandigarh	8 21.5	9 32.8	0.494	10 55.0	2 33	38.10%
Jalandhar	8 20.8	9 30.9	0.494	10 51.6	2 30	38.10%
Jammu	8 20.5	9 29.7	0.494	10 49.1	2 28	38.10%
Haridwar	8 21.4	9 33.5	0.5	10 57.0	2 35	38.70%
Srinagar	8 23.0	9 30.7	0.464	10 48.0	2 25	34.80%

LOCAL CIRCUMSTANCES OF THE PARTIAL PHASE RELATING TO CERTAIN PLACES OF INDIA						
Places	Partial Eclipse Begins (IST)	Greatest Eclipse (IST)	Magnitude	Partial Eclipse Ends (IST)	Duration	Obscuration
	h m	h m		h m	h m	
ER						
Koraput	8 14.0	9 39.0	0.713	11 21.0	3 06	63.30%
Ujjain	8 09.3	9 26.6	0.699	10 58.7	2 49	61.50%
Puri	8 19.5	9 46.1	0.651	11 29.0	3 09	56.00%
Bhubaneswar	8 20.0	9 46.1	0.64	11 28.4	3 08	54.70%
Cuttack	8 20.3	9 46.4	0.634	11 28.4	3 08	54.00%
Sambalpur	8 18.1	9 41.8	0.635	11 21.3	3 03	54.00%
Ranchi	8 22.3	9 45.1	0.576	11 22.5	3 00	47.20%
Midnapore	8 24.9	9 49.9	0.573	11 29.6	3 04	47.00%
Hazaribagh	8 23.2	9 45.3	0.56	11 21.7	2 58	45.50%
Kolkata	8 27.0	9 52.6	0.559	11 32.4	3 05	45.40%
Gaya	8 23.5	9 44.5	0.548	11 19.4	2 55	44.10%
Lucknow	8 19.8	9 36.7	0.548	11 06.7	2 46	44.10%
Patna	8 24.9	9 45.1	0.527	11 18.6	2 53	41.80%
Murshidabad	8 29.7	9 53.2	0.517	11 29.9	3 00	40.70%
Bhagalpur	8 27.9	9 49.4	0.514	11 24.1	2 56	40.40%
Muzaffarpur	8 26.2	9 45.9	0.512	11 18.6	2 52	40.20%
NER						
Agartala	8 35.2	10 00.9	0.499	11 38.8	3 03	38.70%
Aijawl	8 38.5	10 0 5.4	0.488	11 43.6	3 05	37.60%
Siliguri	8 33.0	9 53.3	0.468	11 25.6	2 52	35.40%
Silchar	8 40.3	10 05.7	0.466	11 41.9	3 01	35.20%
Cooch Behar	8 34.9	9 56.2	0.464	11 29.2	2 54	35.00%
Darjeeling	8 33.4	9 53.2	0.461	11 24.6	2 51	34.70%
Imphal	8 43.0	10 09.1	0.458	11 45.4	3 02	34.40%
Shillong	8 39.3	10 03.0	0.457	11 37.5	2 58	34.30%
Gangtok	8 34.6	9 54.2	0.452	11 25.1	2 50	33.70%
Guwahati	8 39.5	10 02.1	0.448	11 35.6	2 56	33.40%
Kohima	8 45.3	10 10.0	0.435	11 44.3	2 58	32.00%
Itanagar	8 46.4	10 0 8.4	0.41	11 39.6	2 53	29.40%
Sibsagar	8 49.0	10 11.7	0.404	11 42.8	2 53	28.80%
Dibrugarh	8 51.0	10 12.9	0.391	11 42.9	2 51	27.50%

ANNEXURE-II

Formula of obscuration factor

At time t

% obscuration

$$= \frac{2}{\pi}\left[\cos^{-1}\sqrt{d^2 + {a(t)^2}/{4}} - \sqrt{d^2 + {a(t)^2}/{4}}\sqrt{1-\left(d^2 + {a(t)^2}/{4}\right)}\right]$$

where

$$a(t) = A\left[2\left(\frac{t-t_s}{t_e-t_s}\right)-1\right]$$

$$A = 2\sqrt{1-d^2}$$

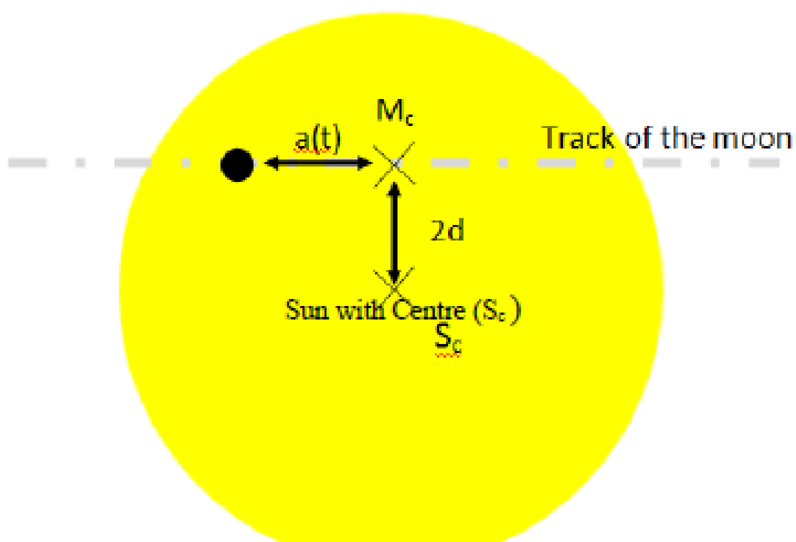
and d is evaluated by solving

$$M_o = \frac{2}{\pi}\left[\cos^{-1}d - d\sqrt{1-d^2}\right]$$

Assumptions

Assume :

- Sun and Moon are the same size.
- Centre of moon travels across Sun's disc in a straight line at constant speed.



d.1

ANNEXURE-III

Average Generation required with Ramp Rate (MW)/ 5 minute from other sources					
Time	All India	Andhra Pradesh	Karnataka	Tamil Nadu	Telangana
	Ramp Rate (MW)	Ramp Rate (MW)	Ramp Rate (MW)	Ramp Rate (MW)	Ramp Rate (MW)
8:05	54	25	47	23	30
8:10	216	55	105	52	67
8:15	420	51	101	42	67
8:20	431	52	99	40	82
8:25	418	46	100	36	69
8:30	431	50	116	18	76
8:35	425	50	96	44	73
8:40	415	48	105	29	67
8:45	407	48	102	34	66
8:50	404	47	91	30	72
8:55	407	47	94	35	68
9:00	392	44	97	39	59
9:05	348	46	84	30	55
9:10	373	45	90	30	62
9:15	390	45	102	29	68
9:20	343	47	69	36	52
9:25	330	38	74	37	47
9:30	323	39	80	22	49
9:35	340	36	64	18	48
9:40	320	40	66	39	46
9:45	288	35	65	17	46

Average Generation required with Ramp Rate (MW)/ 5 minute from other sources					
Time	All India	Andhra Pradesh	Karnataka	Tamil Nadu	Telangana
	Ramp Rate (MW)	Ramp Rate (MW)	Ramp Rate (MW)	Ramp Rate (MW)	Ramp Rate (MW)
9:50	368	44	82	37	78
9:55	444	64	60	46	81
10:00	297	53	70	7	39
10:05	305	34	55	37	44
10:10	311	41	88	12	59
10:15	303	39	63	12	36
10:20	288	35	52	68	33
10:25	231	22	53	5	32
10:30	253	22	59	22	33
10:35	189	29	34	10	26
10:40	206	27	62	3	30
10:45	256	21	42	43	26
10:50	220	28	31	29	28
10:55	161	22	38	5	26
11:00	155	20	38	12	17
11:05	213	17	27	19	22
11:10	172	22	33	37	16
11:15	175	19	40	7	20
11:20	86	17	19	-6	18

Average Generation required with Ramp Rate (MW)/ 5 minute from other sources						
Time	Gujarat	Madhya Pradesh	Maharashtra	Rajasthan	Punjab	Uttar Pradesh
	Ramp Rate (MW)	Ramp Rate (MW)	Ramp Rate (MW)	Ramp Rate(MW)	Ramp Rate (MW)	Ramp Rate(MW)
8:05	17	0	7	11	0	0
8:10	28	10	15	25	0	0
8:15	30	31	14	61	11	12
8:20	32	32	15	61	11	8
8:25	38	32	17	61	11	7
8:30	38	32	14	69	12	8
8:35	34	32	16	61	10	8
8:40	41	30	15	56	11	12
8:45	38	29	15	58	9	8
8:50	35	33	13	64	9	8
8:55	33	29	13	73	9	6
9:00	38	23	13	59	11	10
9:05	32	29	13	40	9	9
9:10	32	30	12	55	10	7
9:15	39	29	18	46	8	6
9:20	39	25	14	48	8	5
9:25	25	19	11	65	8	6
9:30	31	25	13	67	10	6
9:35	33	26	11	69	8	5
9:40	25	19	13	57	8	6
9:45	56	22	12	21	8	5
9:50	38	23	13	38	9	6
9:55	27	29	12	93	7	6

Average Generation required with Ramp Rate (MW)/ 5 minute from other sources						
Time	Gujarat	Madhya Pradesh	Maharashtra	Rajasthan	Punjab	Uttar Pradesh
	Ramp Rate (MW)	Ramp Rate (MW)	Ramp Rate (MW)	Ramp Rate(MW)	Ramp Rate (MW)	Ramp Rate(MW)
10:00	27	23	11	74	9	4
10:05	32	20	10	58	10	5
10:10	46	22	12	48	8	5
10:15	35	20	9	49	6	3
10:20	24	20	11	30	9	6
10:25	34	22	15	35	7	6
10:30	33	12	12	47	8	6
10:35	16	18	9	37	5	4
10:40	28	15	10	20	6	5
10:45	23	10	14	70	5	4
10:50	25	18	7	40	8	5
10:55	19	11	10	25	3	1
11:00	20	13	4	54	4	4
11:05	20	18	7	44	6	3
11:10	17	5	4	30	6	3
11:15	18	23	20	21	4	4
11:20	14	7	6	7	6	0

ANNEXURE-IV

State wise Average Solar Generation Ramp Rate (MW)/ 5 Minute during Solar Eclipse

Time	Andhra Pradesh	Karnataka	Tamil Nadu	Telangana	Gujarat	Madhya Pradesh	Maharashtra	Rajasthan	Punjab	Uttar Pradesh
7:30	36	66	32	50	14	20	9	25	6	6
7:35	35	65	34	56	18	23	10	31	7	8
7:40	43	83	38	68	19	25	13	34	7	8
7:45	42	82	35	58	20	28	9	34	8	9
7:50	43	86	36	71	22	28	13	36	9	7
7:55	41	76	34	64	24	27	12	44	10	6
8:00	50	107	44	77	20	29	14	58	10	8
8:05	29	58	6	50	19	30	7	36	10	10
8:10	21	45	25	38	18	24	7	48	10	9
8:15	16	33	9	26	16	19	5	43	6	8
8:20	12	22	3	32	16	18	4	40	5	3
8:25	3	12	-4	15	17	17	4	36	5	2
8:30	1	14	-20	15	14	15	1	38	5	2
8:35	-4	-11	-5	6	9	12	2	29	2	2
8:40	-9	-15	-19	-4	11	9	-1	21	2	4
8:45	-14	-27	-19	-10	6	6	-2	19	0	1
8:50	-19	-43	-25	-12	1	8	-4	20	0	0
8:55	-23	-51	-26	-21	-3	3	-5	23	-1	-2
9:00	-29	-59	-28	-31	-3	-3	-6	9	0	0
9:05	-33	-73	-35	-37	-8	-1	-7	-6	-2	-1
9:10	-37	-80	-38	-39	-11	-2	-9	0	-2	-2
9:15	-42	-86	-42	-42	-10	-4	-7	-8	-3	-4

State wise Average Solar Generation Ramp Rate (MW)/ 5 Minute during Solar Eclipse										
Time	Andhra Pradesh	Karnataka	Tamil Nadu	Telangana	Gujarat	Madhya Pradesh	Maharashtra	Rajasthan	Punjab	Uttar Pradesh
9:20	-45	-102	-44	-53	-13	-8	-11	-10	-4	-4
9:25	-52	-109	-47	-59	35	-12	-12	-4	-4	-4
9:30	-55	-115	-52	-62	39	-11	18	70	-4	-5
9:35	61	118	44	79	42	-12	19	74	13	-5
9:40	65	124	49	82	41	31	20	71	13	10
9:45	66	130	48	85	59	34	20	52	14	10
9:50	72	140	54	101	52	35	22	64	15	11
9:55	83	140	59	108	49	40	22	102	14	11
10:00	83	149	51	94	50	38	22	94	16	10
10:05	80	149	62	99	55	37	22	87	17	11
10:10	86	168	55	111	67	40	25	82	16	11
10:15	88	163	56	102	62	40	24	86	15	10
10:20	89	163	84	103	57	41	25	73	18	12
10:25	84	168	57	104	66	43	29	79	16	13
10:30	86	176	67	107	67	37	28	91	17	13
10:35	92	165	62	105	56	43	26	85	15	12
10:40	93	188	58	109	67	41	28	72	17	13
10:45	91	178	85	108	64	38	32	119	15	13
10:50	98	173	79	112	68	46	26	94	19	14
10:55	95	181	63	112	64	40	30	81	15	10
11:00	95	184	69	106	20	42	25	111	15	13
11:05	94	177	76	112	20	48	28	44	6	12
11:10	100	186	93	108	17	36	4	30	6	12

State wise Average Solar Generation Ramp Rate (MW)/ 5 Minute during Solar Eclipse

Time	Andhra Pradesh	Karnataka	Tamil Nadu	Telangana	Gujarat	Madhya Pradesh	Maharashtra	Rajasthan	Punjab	Uttar Pradesh
11:15	99	196	69	112	18	54	8	21	4	4
11:20	17	19	56	18	14	7	6	7	6	0
11:25	16	29	87	7	18	7	6	19	5	4
11:30	12	27	14	19	19	12	4	43	3	5
11:35	22	9	30	15	8	10	4	32	1	2
11:40	11	40	16	11	18	9	5	26	5	1
11:45	8	17	18	9	15	10	7	13	4	2
11:50	10	-1	1	9	16	2	6	17	5	2
11:55	11	27	-12	5	15	16	6	16	6	3
12:00	8	12	-9	7	14	10	0	26	3	2

ANNEXURE-V

SRLDC Real Time Security Desk Report for July 12, 2019

1. Load Generation Profile considered for Real Time Case

Kolhapur	Sholapur	Chandrapur	Wardha
-475	1577	460	1847

Talcher	Jeypore	Angul
1964	655	1440

TELANGANA	
Demand	9665
Wind	0
Solar	141
Hydro	91
Thermal	4977
Drawal	4280

KARNATAKA	
Demand	11405
Wind	66
Solar	193
Hydro	1980
Thermal	2081
Drawal	5673

-2

782

ANDHRA PRADESH	
Demand	8639
Wind	132
Solar	104
Hydro	80
Thermal	3482
Drawal	3612

-420

512

150

2975

KERALA	
Demand	3567
Wind	0
Solar	0
Hydro	1128
Thermal	8
Drawal	2431

1936

TAMIL NADU	
Demand	14832
Wind	16
Solar	62
Hydro	499
Thermal	4849
Drawal	7654

367

PUDUCHERRY	
Demand	365
Wind	0
Solar	0
Hydro	0
Thermal	0
Drawal	365

SR Demand	48473	SR Loss	1621

ISGS/Regional Gen	
Simhadri	1323
Lanco	0
SEPL+MEP	0
SEIL-1	1494
SEIL-2	1378
NP Kunta	31
RSTPS	2798
Kaiga	1036
Kudgi	2056
Neyveli	1880
MAPS	0
Vallur	910
KKNP	1792
NTPL	686
Coastal	730
ILFS	1035
ISGS Wind	95
Total	17244

Corridor	Flow
S1-S2	3637
S3	2448

2. Branch loadings, Bus voltages and L-index

Top Line Loadings	%Loading
400 kV GTYNLM-FSC--NELAMANGALA--T1	55
400 kV GOOTY--GTYNLM-FSC--T1	55
400 kV NEYVELI1EXP--NEYVELI-II--T1	54
400 kV RSTPS NTPC--MALKARAM--T2	52
400 kV GHANAPUR--GAJWEL--T1	50

High Bus Voltages	Voltage (kV)
400 kV THAPPUGUNDU	423
400 kV ANIKADV4	421
400 kV RASIPALYAM	420
400 kV PALAVADI	415
765 kV CUDDAPAH-PG	790

Top ICT Loadings	%Loading
400/110 kV SRIPRMBDR-TN--2	89
400/110 kV SRIPRMBDR-TN--1	89
400/220 kV VEMAGIRI--3	88
400/220 kV VEMAGIRI--2	88
400/220 kV VEMAGIRI--1	88

Low Bus Voltages	Voltage (kV)
400 kV HOODY	382
400 kV YELAHANKA	383
400 kV NELAMANGALA	386
400 kV SOMANAHALLI	388
400 kV KOLAR	388

Line Name	Angle
400 kV GTYNLM-FSC--NELAMANGALA--T1	14.85
400 kV GTYSMN-FSC--SOMANAHALLI--T1	12.26
400 kV KUDUGI-PG--TUMKUR--H2	10.6
400 kV KUDUGI-PG--TUMKUR--H1	10.6
400 kV RSTPS NTPC--MALKARAM--T2	10.03

Bus Name	Lindex
220 kV MYLATTY	0.4
220 kV TALAPARAMBA	0.35
220 kV KANHIRODE	0.33
220 kV VADAKARA	0.3
220 kV MANTHANI	0.29

3. Contingency Analysis:

Lines with N-1 Violation	Max Loaded branch	% Loading
400/220 kV VEMAGIRI--1	400/220 kV VEMAGIRI--3	112
400/220 kV VEMAGIRI--2	400/220 kV VEMAGIRI--3	112
400/220 kV VEMAGIRI--3	400/220 kV VEMAGIRI--2	112
400/220 kV NELLORE-AP--1	400/220 kV NELLORE-AP--3	102
400/220 kV NELLORE-AP--2	400/220 kV NELLORE-AP--3	102

Branch Outage
400 kV GOOTY--GTYNLM-FSC--1
400 kV GOOTY--GTYSMN-FSC--1
400 kV NUNNA--LANCO--T1
400 kV VEMAGIRI--GAUTHAMI--T1
400 kV SIMHAPURI--NELLORE-PS--Q1
400 kV SIMHAPURI--MEENAKSHI--Q1
400 kV JAMALAMADUGU--TALARICHER--Q2
400 kV URAVAKONDA--VELTOOR--Q2
400 kV RSTPS NTPC--GHANAPUR--T4
400 kV GAJWEL--NARSARPUR--T1
400 kV GAJWEL--CHANDULAPUR--T1
400 kV KAKATIYA TPS--CHANDULAPUR--T1
400 kV MALKARAM--SURYAPET--T1
400 kV SHANKARPALLI--SURYAPET--Q2
400 kV SUNDILLA--NIRMAL--Q2
400 kV HIRIYUR--PAVAGADA--T2
400 kV YERMARUS TPS--BPS--Q1
400 kV YERMARUS TPS--BPS--Q2
400 kV KKNPP--TUTICORINPS--Q2
400 kV METTUR-III--PALAVADI--Q1
400 kV METTUR-III--PALAVADI--Q2
400/220 kV KALIKIRI--2
400/220 kV ASUPAKA--1
400/220 kV KUDGI-NTPC--1
400/230 kV SRIPRMBDR-TN--1
400/230 kV ANIKADV4--5
400/230 kV KAYATHAR--2
400/230 kV TUTICORINJV--1
400/230 kV RASIPALYAM--1

Branch Outage
400/230 kV RASIPALYAM--2
110/400 kV ANAIKADAVU--1
110/400 kV THENAMPATTY--1
110/400 kV THENAMPATTY--2
400/220 kV TRIVENDRUM--2

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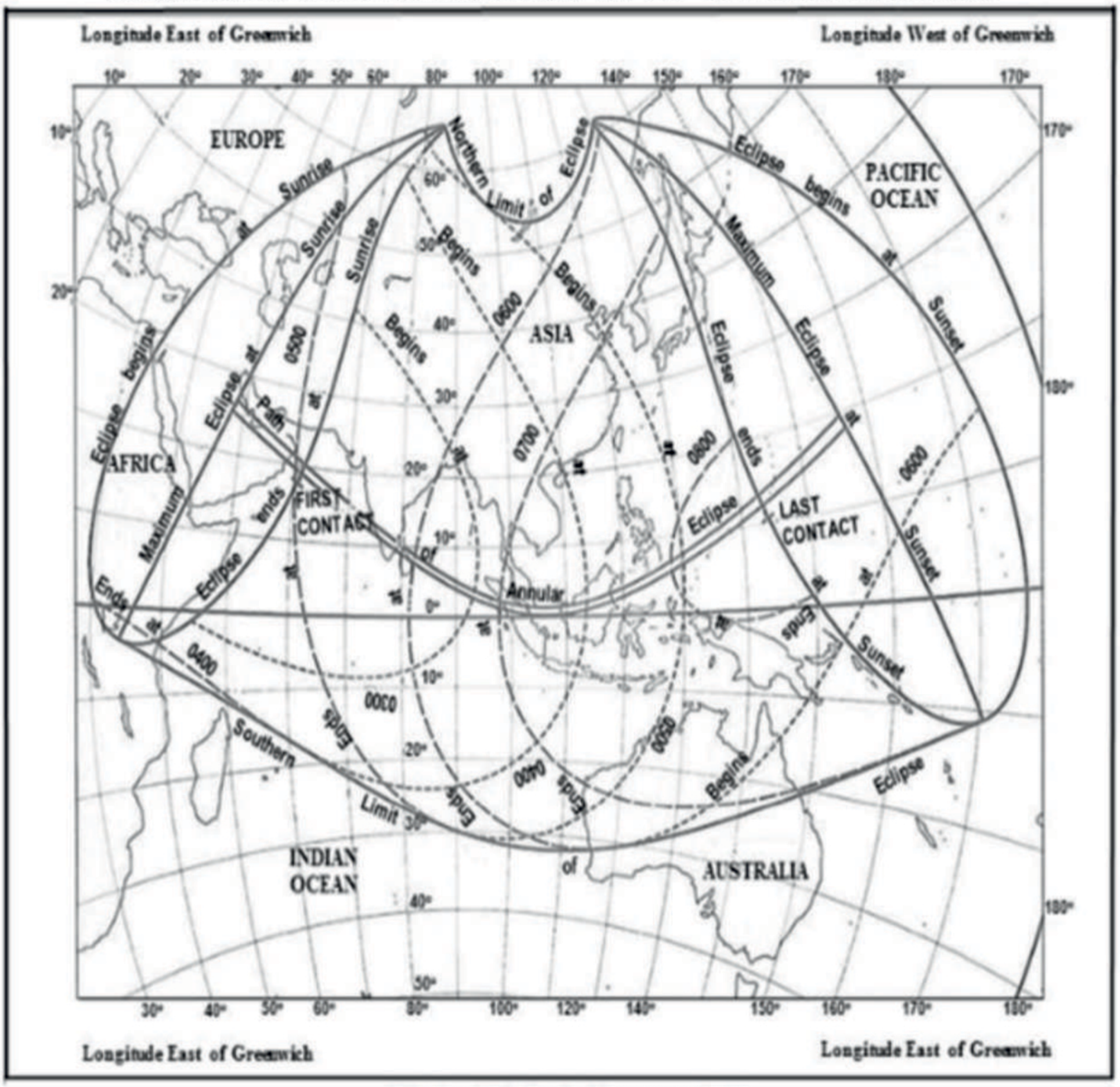
ANNULAR SOLAR ECLIPSE OF 26th DECEMBER 2019



The timings of beginning and ending are expressed in UT

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