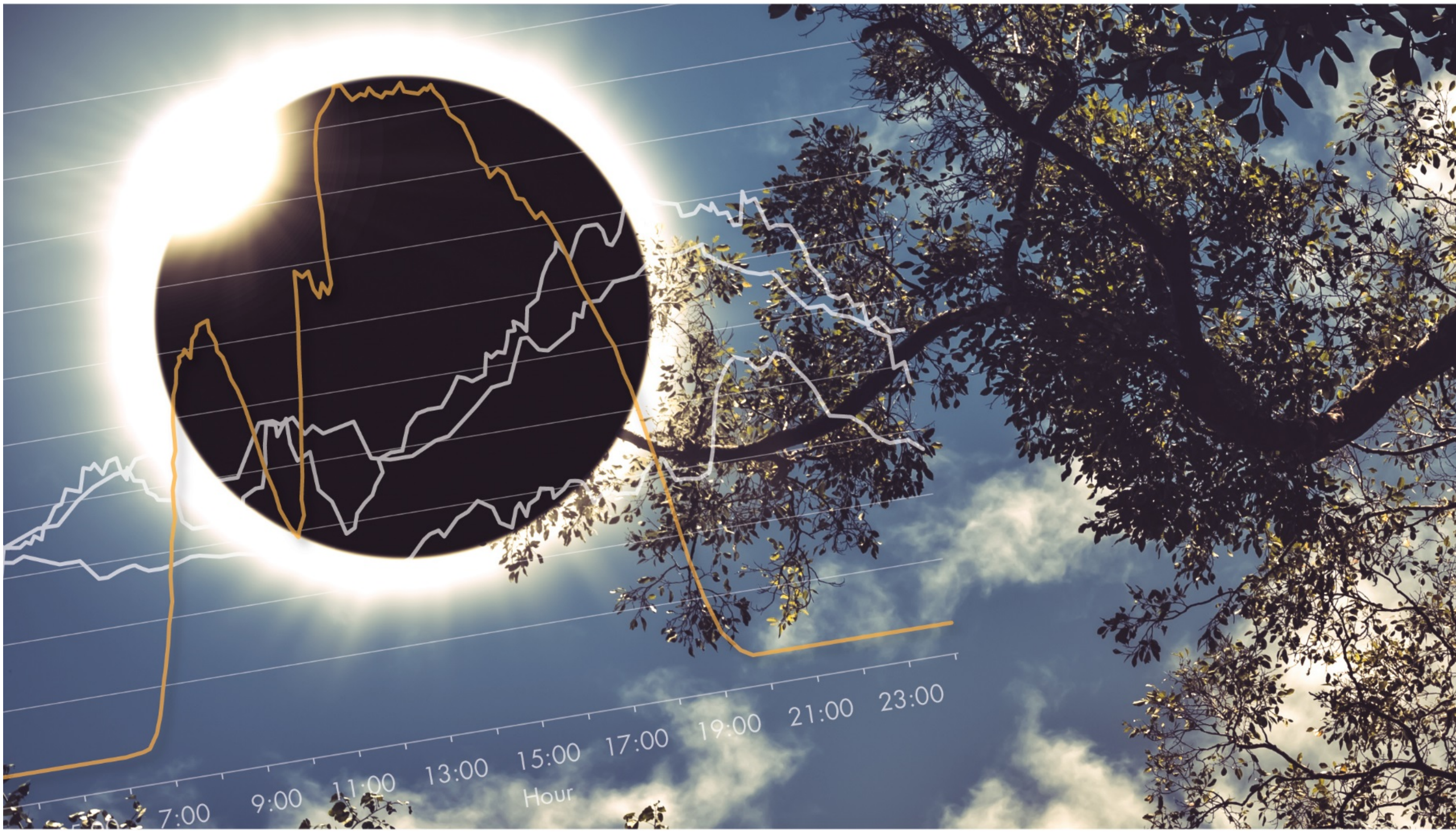
PERFORMANCE OF ISO'S SYSTEM DURING AUGUST 21, 2017 ECLIPSE



California ISO

October 4, 2017

Executive Summary

On August 21, 2017 the ISO system experienced a solar eclipse with obscuration ranging from 58 percent in Southern California to 76 percent in Northern California. The eclipse's effect on the system started at 9:11 a.m., reaching a maximum obscuration level at 10:24 a.m. and rapidly faded out by 11:17 a.m. The effect of the eclipse was reflected on i) a loss of utility-based solar production of approximately 6,000 MW, or about two-thirds of typical production levels., ii) a loss of behind-the-meter production of about 1,460 MW, which in turn led to a corresponding increase of conforming load, and iii) reduction of load from cooler temperatures with the sun obscuration, the effect of which was sustained even well after the eclipse was over.

California has an ambitious renewable energy goal, with a mandate for getting half of its electricity from renewable sources by 2030. The ISO has experienced substantial growth in solar generation in the past few years. With approximately 10,000 MW of utility-scale solar production, solar covers as much as 30 to 40 percent of the grid's energy needs on some days. Additionally, an estimated capacity of about 6,000 MW in rooftop is installed in the ISO's footprint.

Much of the reduction in solar generation during the eclipse was replaced with an increase in electricity imports - including transactions through the ISO's western Energy Imbalance Market (EIM) - natural gas power plants, and hydropower. Imports alone replaced about a half of the reduction in solar output. At the start of the eclipse at 9:11 a.m., solar production was at 6,392 MW, then fell to a low of 2,845 MW at the maximum obscuration at 10:24 a.m., or a dip of 3,547 MW. One megawatt typically powers 750 to 1,000 homes. During the eclipse, the system absorbed a downward ramp of 48 MW a minute; after the sun emerged from the eclipse, solar production ramped upward rapidly as much as 150 MW a minute.

The ISO started planning more than a year ago for the expected drop in solar production during the eclipse. The implementation of a readiness plan allowed the ISO to identify and plan for all the variables that would impact the system. The ISO procured up to 1,000 MW of regulation in the day-ahead market to help control frequency swings and meet required control performance metrics during the rapid change in solar output immediately after the eclipse. This was complemented with tighter control bands and resources closely following their instructed dispatches. Energy prices in both the day-ahead and real-time markets remained stable during the day, with real-time prices going no higher than $30/MWh.

Lessons Learned

With the high level of solar penetration in the ISO system, the eclipse of August 21, 2017 represented a unique test for the ISO's operational and market systems to realize how solar production and demand fluctuations in a short period of time could be effectively managed. It was a test to the underlying resiliency of the interconnected grid as well as the ISO operational and market systems, which is undergoing a significant transformation with the integration of high level of renewables. Some lessons learned through this event include:

- The planning and preparation done well in advance was the key reason the ISO was able to successfully maintain reliable service through the eclipse.
- Accurate forecast of conditions during the eclipse provided the platform to ensure adequate resources were available to position the system during the eclipse.
- The development and application of a readiness plan centered around operational and communication strategies allowed the ISO to define all the potential strategic areas impacted by the eclipse and the steps needed for mitigation.
- Additional targeted training of ISO operators and personnel supporting operations played a critical role to ensure efficient management of the eclipse conditions.
- Communications of the ISO plan and expected conditions to external entities, including gas companies, EIM entities, hydropower and solar resources, allowed for the coordination with the ISO and created clear expectations of involvement and actions expected for stakeholders.
- Stricter operational control during the eclipse, including higher procurement of regulation, tighter bands for AGC controls and ACE, and resources closely following their instructions, provided more manageable conditions to absorb the effects of the eclipse and allowed the market to do its job.
- The ISO markets played an instrumental role by allowing the eclipse conditions to be optimally absorbed and positioning the system with a proper amount and mix of resources. The EIM market also provided an additional level of flexibility to manage the rapid changes induced by the eclipse.

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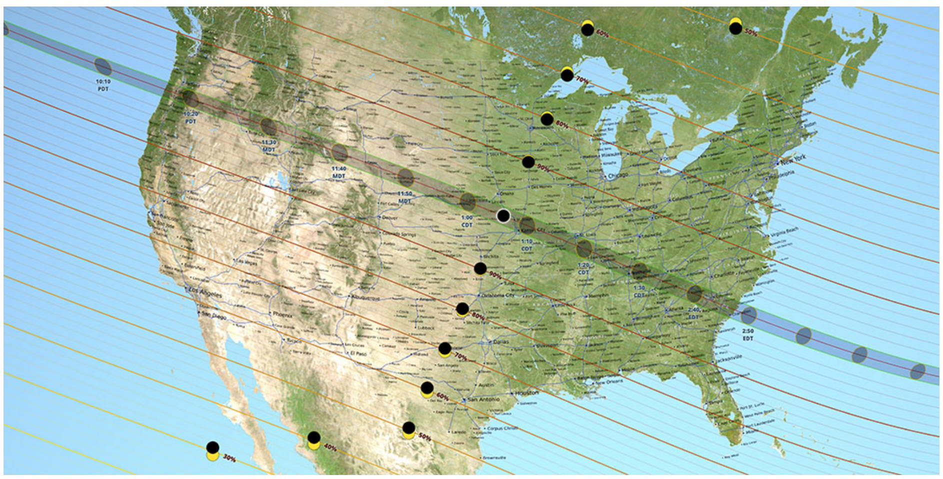
Acronyms

ACE	Area Control Error
AGC	Automatic Generation Control
BAA	Balancing Authority Area
ISO	California Independent System Operator
CPS	Control Performance Standard
CPUC	California Public Utilities Commission
DOT	Dispatch Operating Target
EIM	Energy Imbalance Market
FMM	Fifteen-Minute Market
MAPE	Mean Absolute Percentage Error
PV	Photovoltaic
RTD	Real-time Dispatch (Five-Minute Market)
RUC	Residual Unit Commitment
VER	Variable Energy Resources

Introduction

On Monday, August 21, 2017, a total solar eclipse passed over the contiguous United States between 9:04 a.m. Pacific Time and 11:44 a.m. Pacific Time stretching from Lincoln Beach, Oregon to Charleston, South Carolina. It was the first such eclipse to track from the west coast to the east coast of the US in 99 years. The California ISO control area is south of the path of totality of the eclipse and experienced a range from 58 percent to 76 percent obscuration during the eclipse. The ISO started planning for this event more than one year in advance and was prepared to handle the loss of solar production due to reduction in solar irradiation.

Figure 1: Solar Eclipse trajectory in the US



California has some of the most ambitious renewable energy goals in the nation, including reaching 33 percent renewable energy by 2020, and 50 percent by 2030.

Currently, the ISO has over 10,000 megawatts (MW) of grid-connected solar capacity, which can serve up to 40 percent or more of the ISO's load some days. Additionally, within the ISO's footprint there is roughly 6,000 MW of rooftop solar photovoltaic (PV) installations, of which the ISO anticipated losing over 1,000 MW at maximum obscuration during the eclipse.

The solar eclipse began crossing the ISO's footprint in the morning hours just as the solar production was on the upward ramp and production dropped from 6,392 MW beginning at 9:11 a.m. (PDT) to 2,845 MW at 10:24 a.m. (PDT) for a loss of approximately 3,547 MW.

About the ISO

The California Independent System Operator (ISO) runs one of the largest power grids in the world. It manages the flow of bulk electricity across 26,000 circuit miles of high-voltage power lines to utilities across California and a small part of Nevada, ultimately reaching more than 30 million customers.

The ISO operates California's wholesale electricity market using state-of-the-art technology to match demand with the lowest-cost energy available at any given time. The market runs an automated auction in both day-ahead and real-time, across 5,670 price nodes, generating 29,000 transactions a day.

Figure 2: California ISO balancing authority are

The ISO's commitment to open non-discriminatory access extends to neighbors across the West. The ISO created a market platform — the western Energy Imbalance Market (EIM) that gives western states utilities access to a real-time trading market and sophisticated optimization technology, allowing them to provide benefits to their customers. The EIM has proven to reduce costs, promote greater use of renewable energy and lower greenhouse gas emissions for utilities in eight western states.

As the only independent grid operator in the western U.S., the ISO grants open access to all participants, creating an economic-based mechanism for diverse resources to compete in the ISO's market. The ISO has no financial interest in any market segment, and any power producer can sell energy to any buyer.

Preparation for the Eclipse

For more than a year, the ISO, the California Public Utilities Commission and California utilities were planning for the loss of solar generation during the eclipse. The expectation was that the California solar production areas would be affected by a partial eclipse between 9:02 a.m. and 11:54 am. It was expected that the sun would be obscured from 58 percent in the lower latitudes of Southern California to approximately 76 percent at the higher latitudes of Northern California.

The eclipse anticipated to cause a loss of 4,194 megawatts (MW) of utility-scale solar electricity production. There was also a projected loss of about 1,365 MW of rooftop solar generation, which was expected to cause the net load[1] to increase by about 6,000 MW during the eclipse, a gap that would need to be filled using resources other than solar generation.

In addition to preparing for the loss of significant solar production, the ISO also prepared for the near-immediate reversal and rapid increase in solar production coming out of the eclipse, which could also create operational challenges. It was also anticipated that the rapid increases in large amounts of generation following maximum obscuration could cause oversupply conditions and system frequency management issues.

Estimation of Solar Reduction

During the preparation for the eclipse, it was estimated that solar production would start decreasing from the time the eclipse started at 09:02 a.m. through the maximum obscuration at approximately 10:22 a.m. As the eclipse waned, the return of solar production would be at a much greater ramp rate than normal production because the sun angle will have continued to increase during the time the sun was obscured. The eclipse timeframe from approximately 9:02 a.m. to 11:56 a.m. was estimated to be the period of operational interest the ISO would continue to study to ensure adequate supply of generation and unloaded capacity were available to manage the sharp decline and return of solar production.

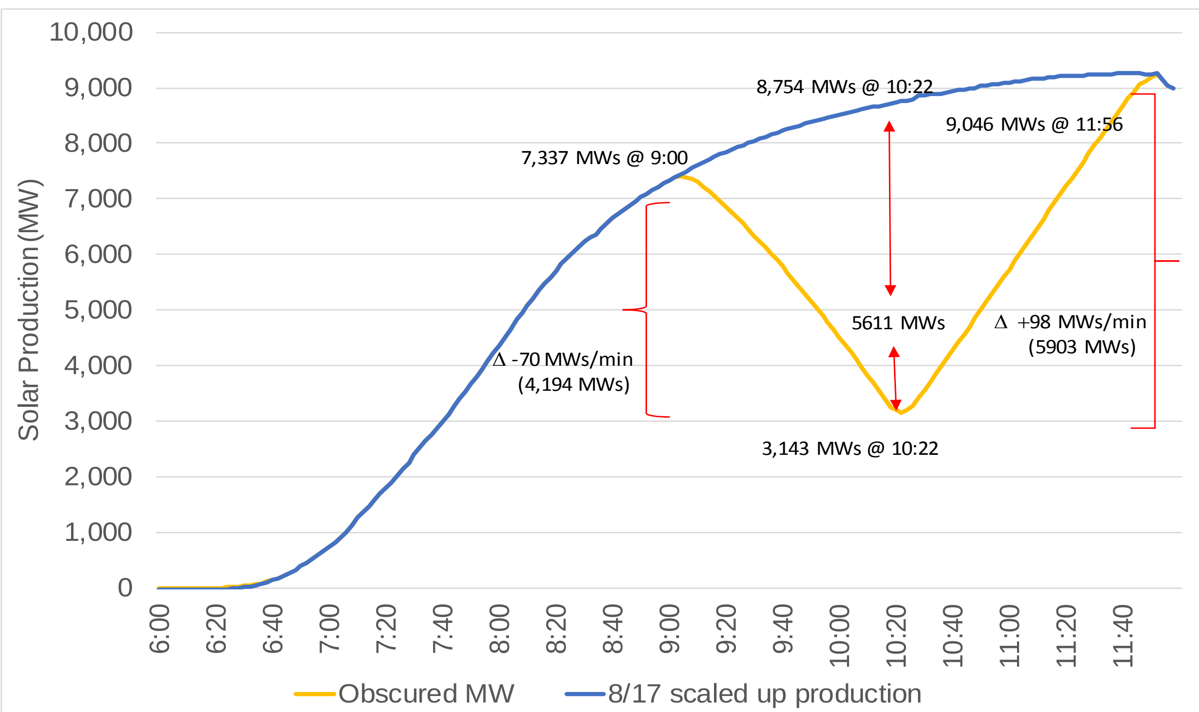
[1] Net load is the CAISO total load less MW produced by utility-scale solar and wind generation.

Table 1: Breakdown of estimated solar production

Forecast Area	Eclipse Start Time	Eclipse Max Time	Eclipse End Time	Eclipse % Max Obscuration	Est. Aug 2017 Area Generation Capacity	Area Production @ Eclipse Start		Area Production @ Eclipse Max		Area Production @ Eclipse End	
						Cap %	MW	CAP %	MWs	Cap %	MW
N. San Joaquin	9:02	10:17	11:39	76%	220	64	140	18	39	79	174
S. San Joaquin	9:03	10:18	11:41	69%	2359	69	1630	27	624	92	2170
Mojave	9:05	10:21	11:45	65%	3122	72	2265	31	970	93	2913
LA Basin	9:06	10:22	11:45	62%	134	26	35	15	20	47	64
Coachella and Imperial Valley	9:09	10:26	11:51	58%	1267	75	944	26	451	87	1104
S. Nevada	9:09	10:27	11:53	72%	1417	77	1093	25	351	83	1172
Colorado River	9:10	10:28	11:54	62%	1480	83	1231	37	540	98	1449

Using the data from the Table 1, an algorithm was developed to calculate the amount of solar energy expected to be produced on August 21, 2017 compared to a clear August 2016 day. It was anticipated that solar PV production from the start of the eclipse just after 9 a.m. would be 7,337 MW.

Figure 3: Forecast grid connected solar production during August 21, 2017 eclipse



Because this was a partial solar eclipse, with varying sun obscured values across California and Nevada, the solar production would never completely cease but would be reduced to a minimum of approximately 3,143 MW at 10:22 a.m. As shown in Figure 3 this was an estimated reduction of 4,194 MW over this 82 minute period or a downward ramp down of -70 MW/min.

As the eclipse waned, the return to normal solar production was anticipated to cause an upward ramp of 98 MW/min reaching 9,046 MW at 11:56 a.m. As a reference, the estimated solar production ramp on a normal clear day without the eclipse from 9a.m. to noon is about 12.6 MW/min on a clear day.

Operations Readiness

In preparation for the eclipse, the ISO's Operations division developed a readiness plan. In this plan, the ISO identified the strategic areas anticipated to be affected by the eclipse and the actions needed for mitigation. Two main areas of preparation were developed in this readiness plan: an operational strategy and a communication strategy.

Operational Strategy

Market simulation and off-line studies. Multiple scenarios were simulated in the day-ahead market to better estimate the market outcomes, such as hourly generation including solar production, ramp requirements, and gas burn. Different scenarios of system conditions were simulated to more accurately anticipate market performance under extreme conditions, including dramatic solar ramps, high regulation requirements, and limited imports. Three different load pattern scenarios were used: a similar day (August 22, 2016), a high load day (June 19, 2017) and a "partial" holiday (July 3, 2017), with the last picture expected by ISO operations staff to be the most likely. All comparison days were also Mondays.

Regulation requirements. Additional regulation requirements were procured for the hours of the eclipse, between 400 MW and 1,000 MW. The final requirements were determined from market simulations.

Thermal generation. Thermal generation is committed through the day-ahead process. Based on the residual unit commitment (RUC) results, there was a plan to issue exceptional dispatches, if necessary to ensure the amount of thermal generation was available.

Hydroelectric generation. Given the abundant rain and snowfall over the winter and resultant flexibility of hydropower generation, the ISO requested participants with these resources to make capacity as flexible as possible by leveraging the use of bids.

VER generation. Since the eclipse would greatly impact solar resources, the ISO communicated to variable energy resources to reflect the solar output taking into account the irradiance and obscuration rates as the ISO intended to rely on the market to dispatch resources to manage the eclipse as much as possible. Scheduling Coordinators were requested to provide flexibility in the real-time market by submitting decremental bids, adhering to their master file ramp rates and following their dispatch operating targets (DOTs).

EIM plan. The ISO communicated the Operations plan to EIM entities and obtained their commitment to leave EIM transfers fully operational for the duration of the eclipse.

Gas Coordination. The ISO reached out to the gas companies, communicated the Operations plan and provided gas burn profiles from the market simulations, to inform them of forecasted thermal generation during the eclipse hours and the potential impact of the thermal generation ramp induced by the eclipse.

Automatic Generation Control (AGC). During the eclipse, the AGC bands were tightened to allow the EMS to control ACE closely to 0 MW.

Training. Operations personnel were trained specifically on the solar eclipse impacts and strategies to handle it.

Staffing. In addition to the regular shift crew, a secondary shift was made available to provide further support as needed. Technical support from different business units were also made available to the shift. An operations center was stood up to quickly address issues and communicate to other business units as needed.

Communications Strategy

Months prior to the eclipse, the ISO developed a communications and stakeholder engagement plan to communicate the impacts of the solar eclipse and the ISO readiness plan. There were at least 12 meetings and calls with an array of stakeholders, the EIM Governing Body, the CAISO Board of Governors and market participants.

Conference calls. Two public web conference calls were scheduled to provide updates on the eclipse preparation in the two weeks prior to the eclipse.

Messages. The CAISO developed a series of messages designed to be issued in real time before, during, and after the eclipse. These messages gave up-to-date information on the most recent developments leading up to and during the eclipse. This included a Restricted Maintenance Operations for August 21 on August 4, or 17 days in advance as a part of the Operations Plan for the solar eclipse. The aim of the messaging was to reduce risk in case the system experienced issues during the solar eclipse.

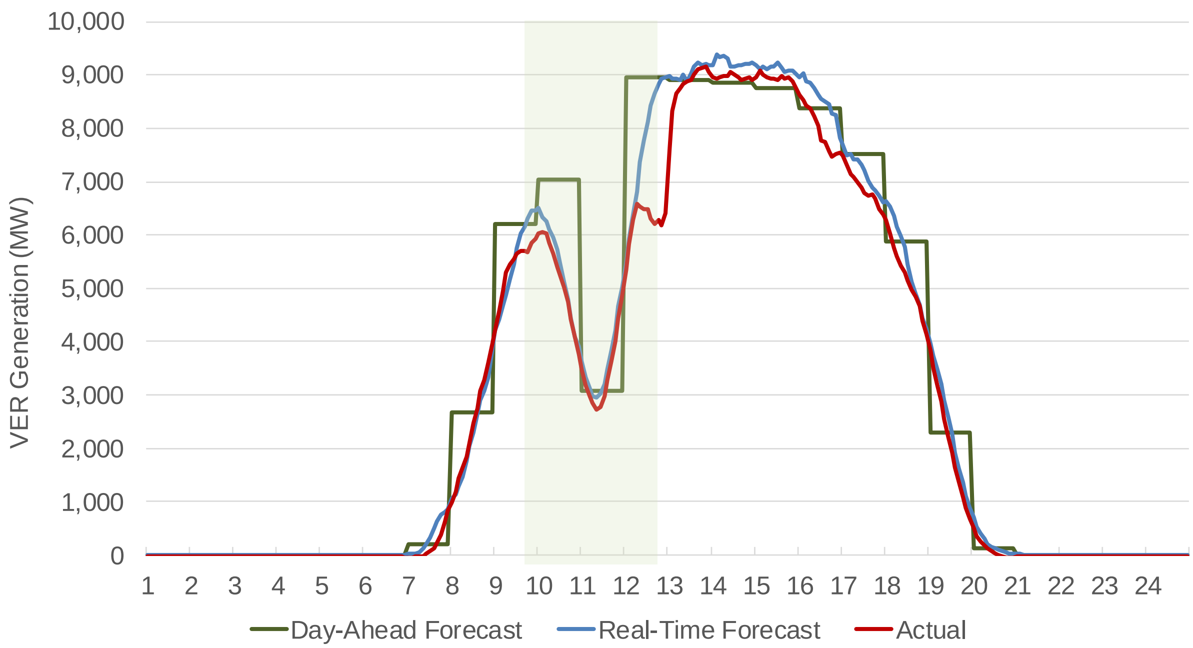
Forecasting

Predominantly clear skies were observed during the eclipse, with the exception of some coastal cloud coverage over Northern to Central California. With a large portion of grid-connected solar facilities located further inland, the full effect of the eclipse was seen in the solar PV production pattern. The ISO markets and system use two types of forecasting; one for system demand and a second one for VERs, primarily wind and solar. As described in subsequent sections, the eclipse had a meaningful effect on both load and solar production, but the effect on wind was negligible.

Solar Forecasting

Figure 4 shows the day-ahead and real-time forecasts compared to actual generation, with five-minute granularity. Usually, the day-ahead forecast is based on an hourly average value, however, for the day of the eclipse, the maximum value within the hour was taken for the hourly value in hour ending 10 and 12, while the minimum value within the hour was taken for hour ending 11. This allowed the day-ahead market to prepare the system for the most extreme condition observed within each hour. Due to the limited cloud cover, the forecasts tracked well for the ISO's 365 solar plants, based on the path and timing of the eclipse.

Figure 4: Solar generation profile



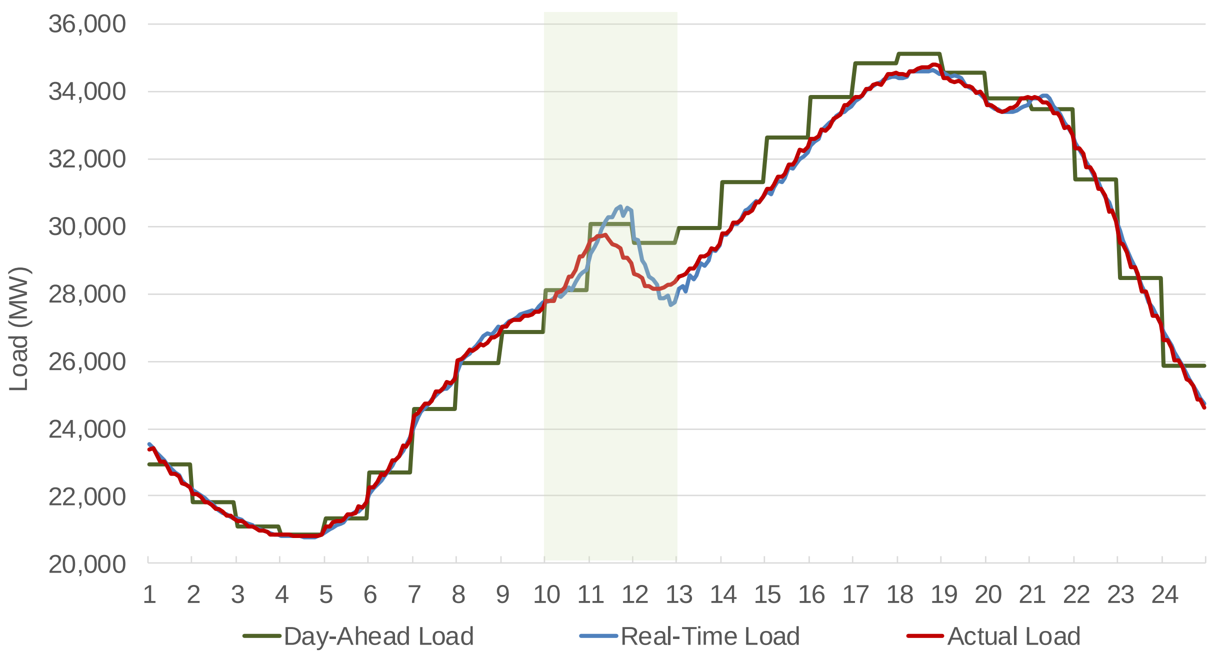
The day-ahead forecast was within a reasonable range of accuracy, as reflected in the real-time market. The solar production at the maximum point of obscuration, where the inflection point from ramping down to ramping upward, was forecasted in the day-ahead with an error of about six percent. The forecast did not represent the decrease in generation of units that were economically dispatched towards the end of the eclipse in hour ending 12, as these were curtailments induced by the market economics.

Load Forecasting

August 21 saw maximum temperatures slightly below climatological averages, and overnight minimums slightly above climatological averages, resulting in a system-wide peak demand of 36,046 MW. During the hours of 9 a.m. to noon, the effect of the eclipse on distributed rooftop solar was readily visible in the demand load levels on the grid.

Figure 5 shows the day-ahead and real-time load forecast compared with the actual load of the ISO system. These profiles do not include non-discretionary pump loads. The values reflect five-minute granularity.

Figure 5: Load forecast profile; no pumps



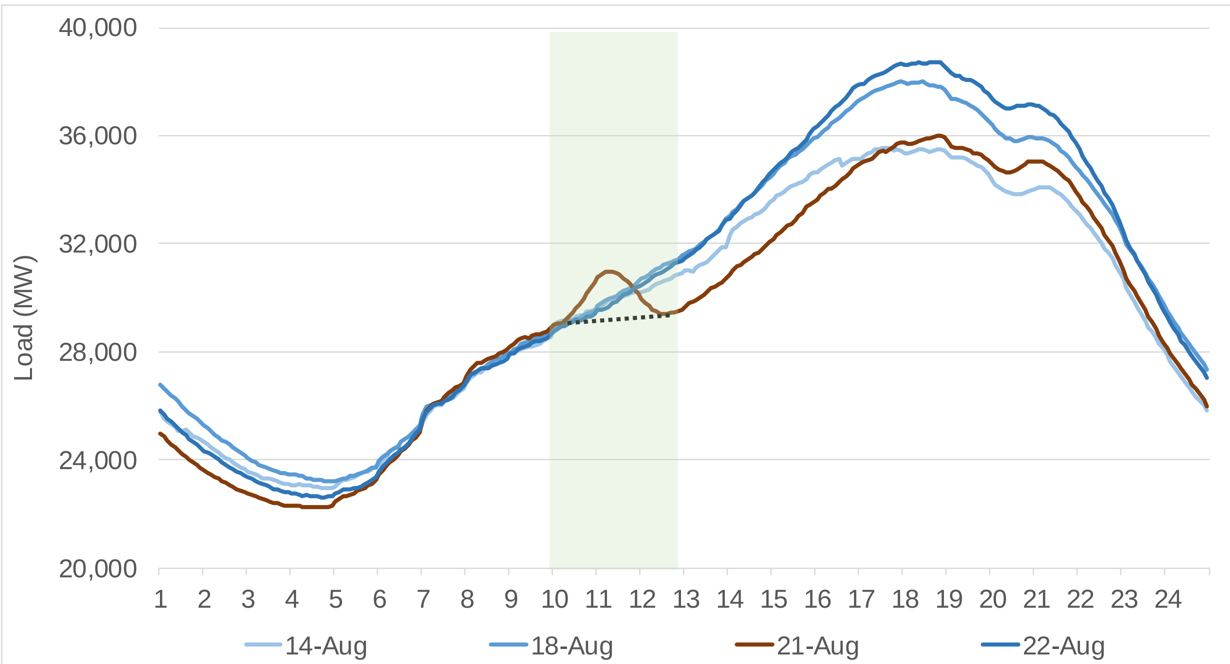
The forecast accuracy for this day is shown in Table 2 below. The mean absolute percentage error, the method the ISO uses to measure load forecast accuracy, was well within the expected error band in each of the ISO markets, and comparable to errors during normal days. The day-head forecast error accrued mostly in the hours after the eclipse. These metrics are based on load forecast without pump loads.

Table 2: Load forecast error

Market	MAPE
DA	1.33 percent
HASP	1.22 percent
RTPD	0.69 percent
RTD	0.43 percent

At the time of maximum obscuration of the eclipse, the load was about 1,200 MW higher than load values in adjacent days, as shown in Figure 6. This figure represents actual loads which includes pumps; this figure is used because it depicts the total load that the system needs to balance for. If we were to measure this increase of load with respect to normal demand with no eclipse effect (trajectory represented with the black dotted line), the difference in load would have been at about 1,800 MW. Also, the dip in load after the maximum obscuration is also a by-product of the eclipse; thus, the increase of load at maximum obscuration may lie between 1,200 and 1,800 MW.

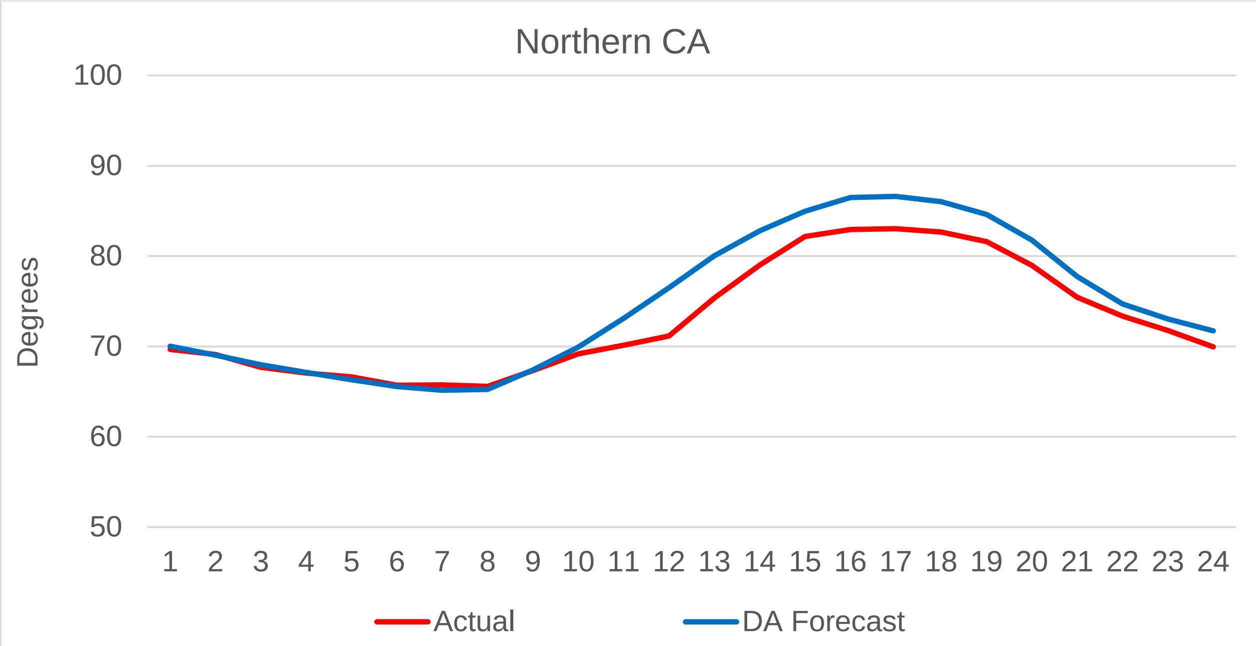
Figure 6: Comparison of load profiles

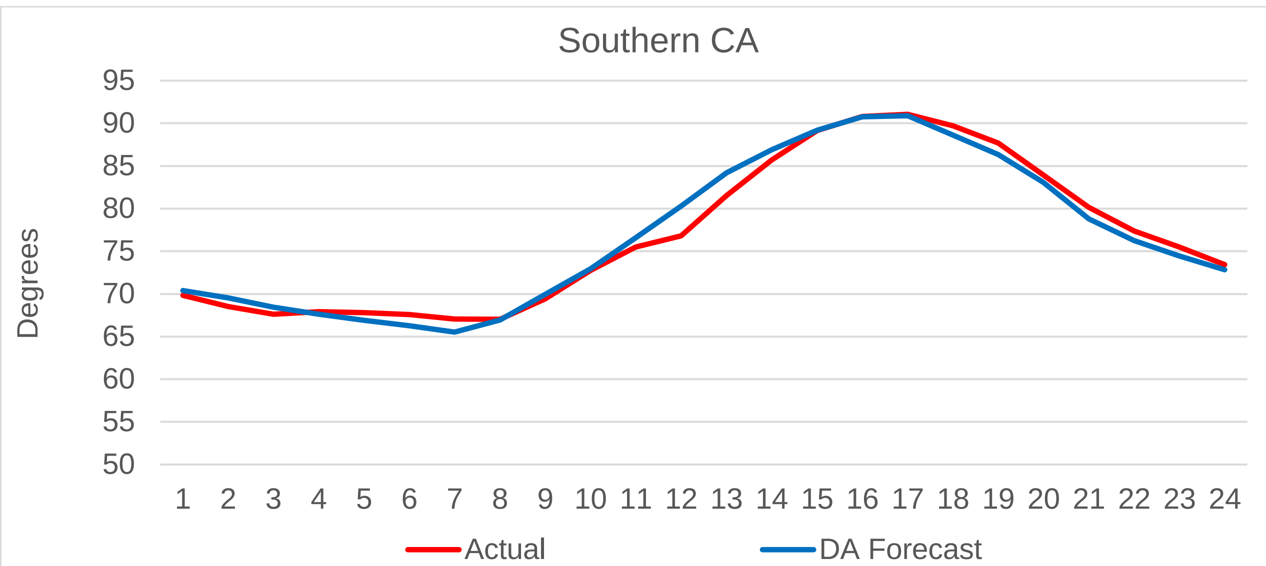


The load ramp from 9:11 to 10:24 a.m. was 1,914 MW, and the downward ramp from 10:24 to 11:37 a.m. was -1,659 MW.

Figure 7 shows the northern and southern California forecasted temperatures used for the day-ahead load forecast, compared to the actual temperatures on August 21. The combination of decreasing temperatures and the return of rooftop solar energy resulted in a lower demand on the grid than originally anticipated. The load ramp down was significant, possibly due to temperatures lowering 2-3 degrees during the max obscuration. With lower temperatures, the demand for air conditioning is less, impacting load.

Figure 7: Comparison of temperatures in California regions

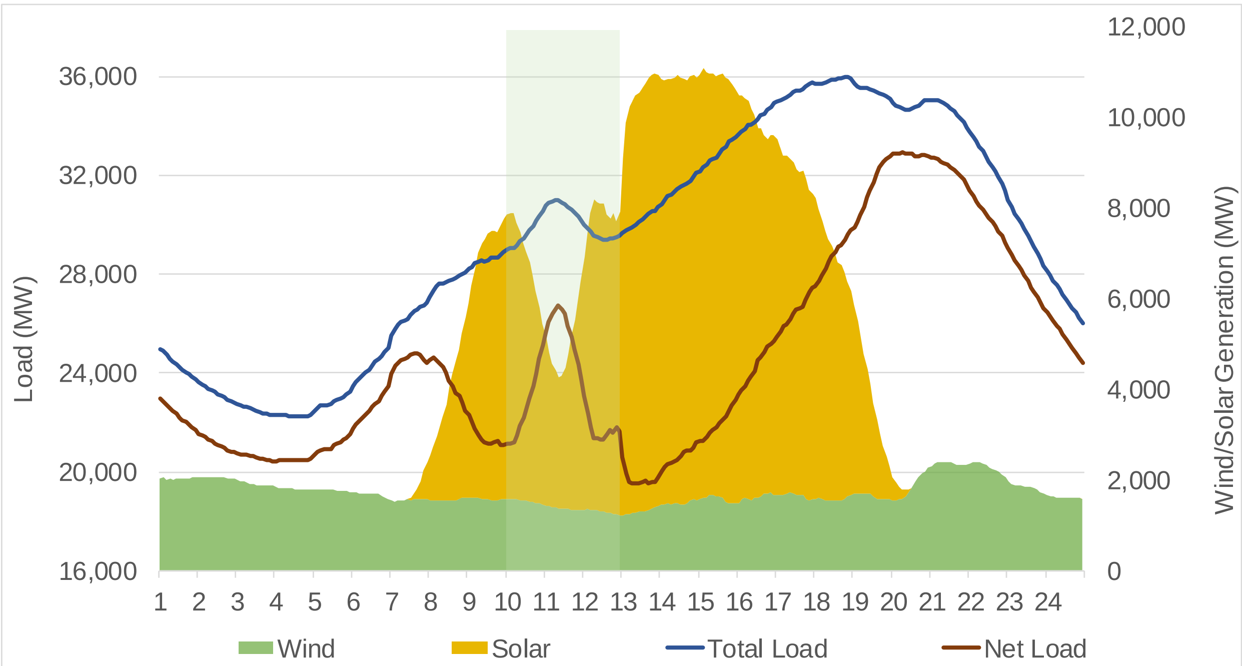




Net Load

Figure 8 shows solar and wind generation trends and compares them with the load and net load trends. The net load is the result of subtracting the wind and solar production from the load. This is the net load that will be supplied from other types of resources. The shape of the ISO's net load curve during the non-summer months is commonly referred as the *Duck Curve*. This curve shape is mostly driven by solar generation. During the eclipse, the net load reflected the inverse effect to the loss of solar production, with net load increasing towards the maximum point of obscuration and then turning down rapidly as the solar production ramped up through the end of the eclipse. This net load illustrates succinctly the challenge for the system to keep up with the ramps induced by the eclipse and covering solar loss through other types of generation during the eclipse. Wind generation was generally stable within a band production of about 1,250 MW to 1,550 MW during the eclipse, and played a minor overall role on the net load.

Figure 8: Load and net load compared to wind and solar generation



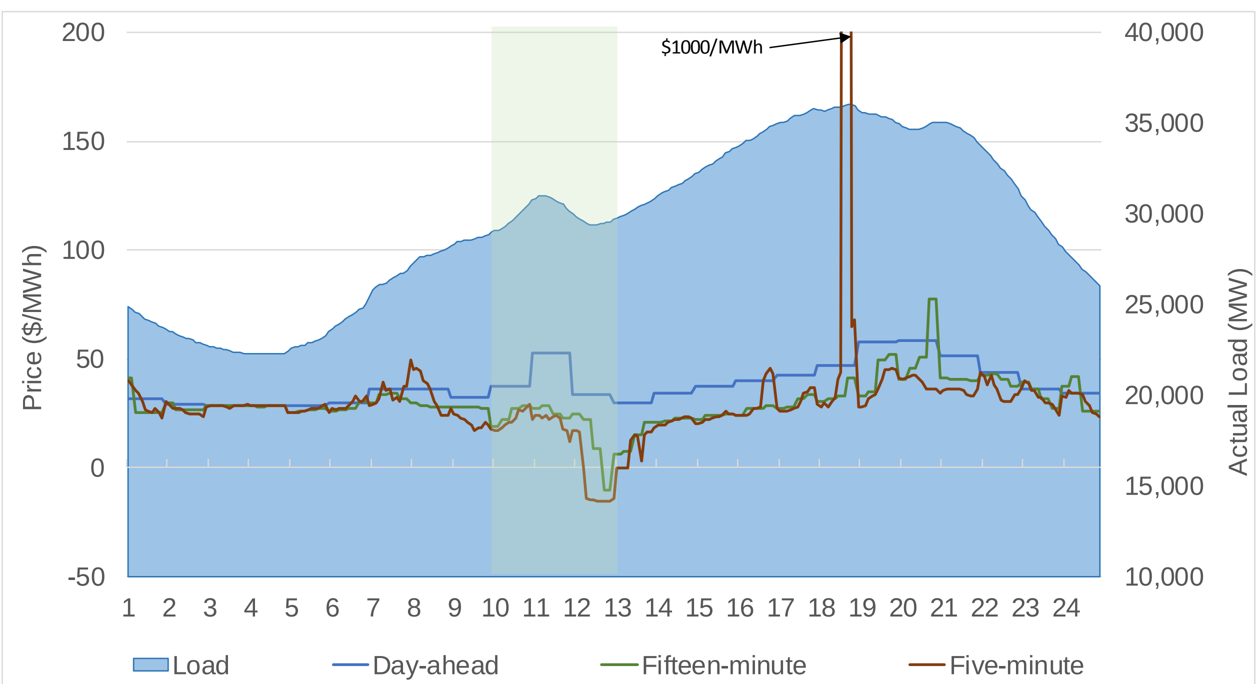
Market Performance

The first opportunity for the market to position the supply fleet for the eclipse is the day-ahead market, where the gross volume of energy is transacted. The day-ahead market is also the opportunity to commit long-start resources that otherwise cannot be committed in the real-time market. The real-time market is the last opportunity for the market to position resources in a shorter horizon. The fifteen-minute market can determine optimal unit commitments in a horizon of up to four and a half hours. It can also procure additional imports and ancillary services if needed. The real-time dispatch determines optimal five-minute dispatches. Both markets rely on a forecast for solar and wind resources. During the eclipse, when solar generation decreases, other types of supply need to be ramped up to offset the loss of generation. Conversely, when the solar generation comes back and ramps to full production, other types of supply need to be ramped down to balance the change. Which resources and how much to ramp down and up is determined by the least-cost market solution achieved through optimization, based on the economic bids of available resources and by the physical and market limitations of the resources and the system.

Market prices

Energy prices observed in the markets on August 21 were within the usual range. Figure 9 shows a comparison of energy prices across markets and correlates these trends with the load profile. The profile is with a five minute granularity. During the eclipse, real-time energy prices only rose moderately. The average wholesale electricity cost was $16.79/MWh at the beginning of the eclipse, which then rose to $28.75/MWh while solar production continued to decline, and stabilized at about $22/MWh at maximum obscuration.

Figure 9: System marginal energy component price in the ISO market



When solar production started to ramp up, the quick increase of supply, which occurred at the same time when the load reached its lowest point during the eclipse, resulted in negative energy prices and solar generation was reduced through economic curtailments. By noon, solar output had fully ramped to near maximum production for the day and prices normalized at about $20/MWh. Overall, day-ahead prices were modestly higher than prices in real time for most of the day, averaging about $38/MWh.

During the eclipse, regulation requirements were adjusted to better position the system to absorb the rapid changes in the supply mix. Both regulation up and down were increased up to 1,000 MW for this purpose. One natural consequence of higher requirements may be higher prices reflecting the value of additional capacity procured. Even with higher regulation requirements, the day-ahead market saw a modest price increase for regulation up, going from $3.25/MWh in hour ending 9 to $22.5/MWh in hour ending 11, while prices for regulation down reach a maximum price of $6.1/MWh.

Figure 10: Day-ahead regulation requirements and prices

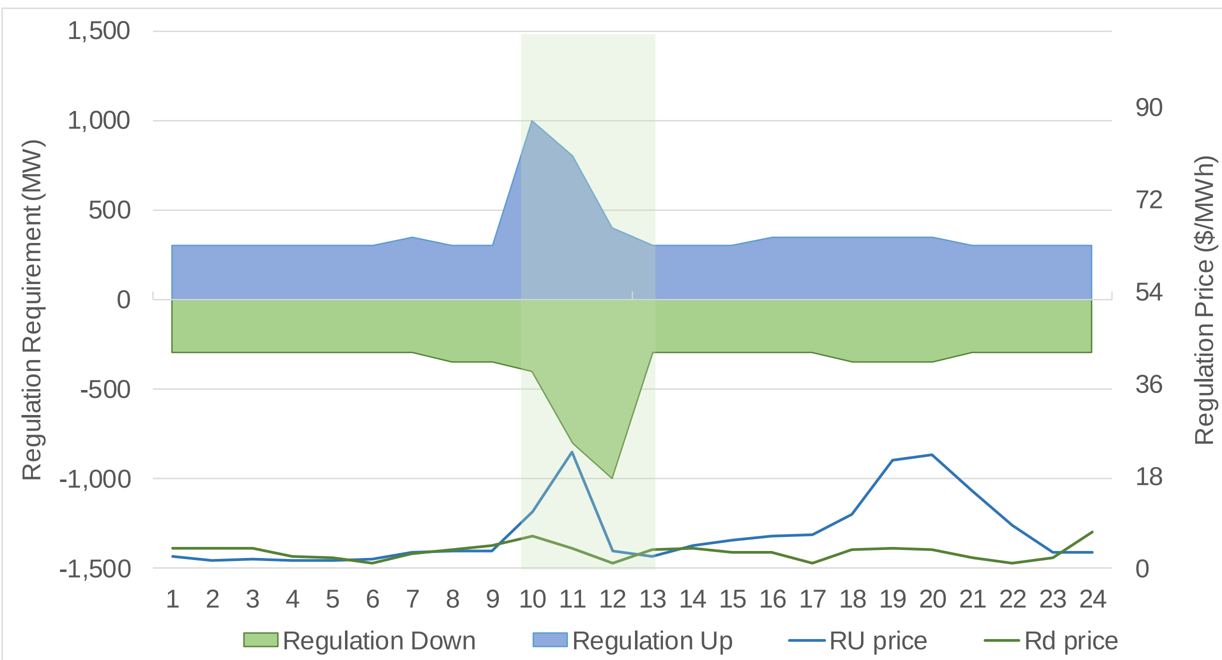
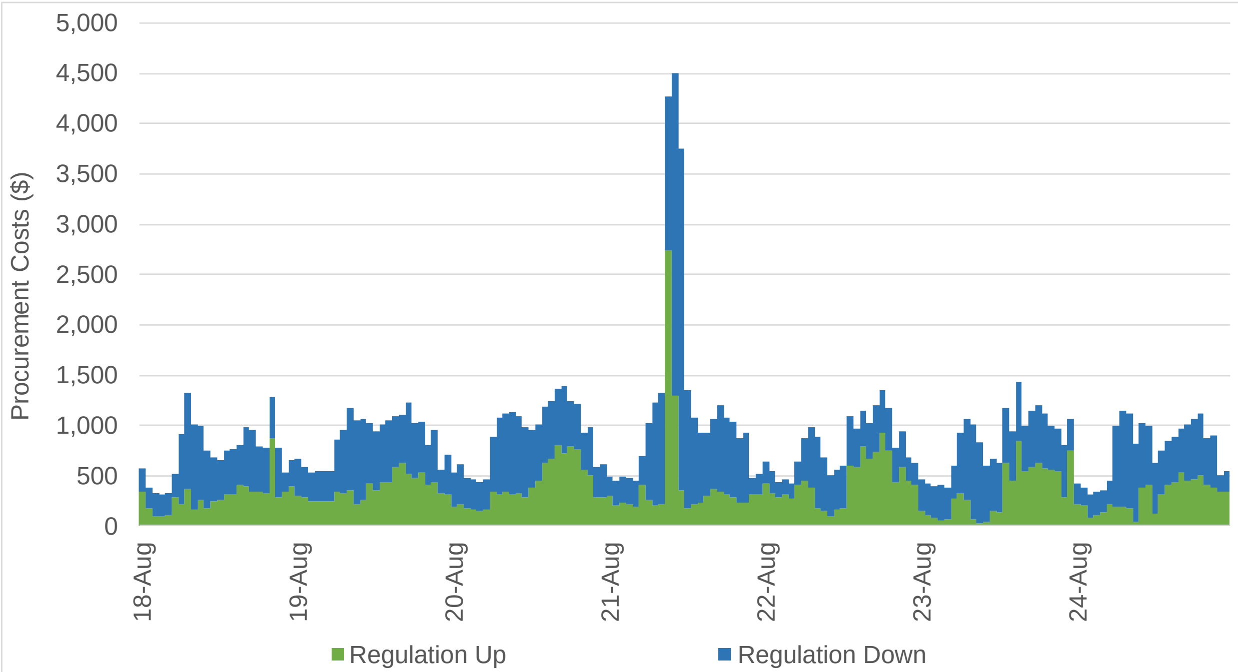


Figure 11 shows the overall cost of procuring regulation up and down in both the day-ahead and real-time markets. The pattern shows moderately higher costs for the eclipse hours due to the increased regulation requirements. However, these costs were fairly low. Overall, the cost for procuring additional regulation for the eclipse was about $10,800 more than the average cost of regulation in days before and after the eclipse.

Figure 11: Procurement costs for Regulation

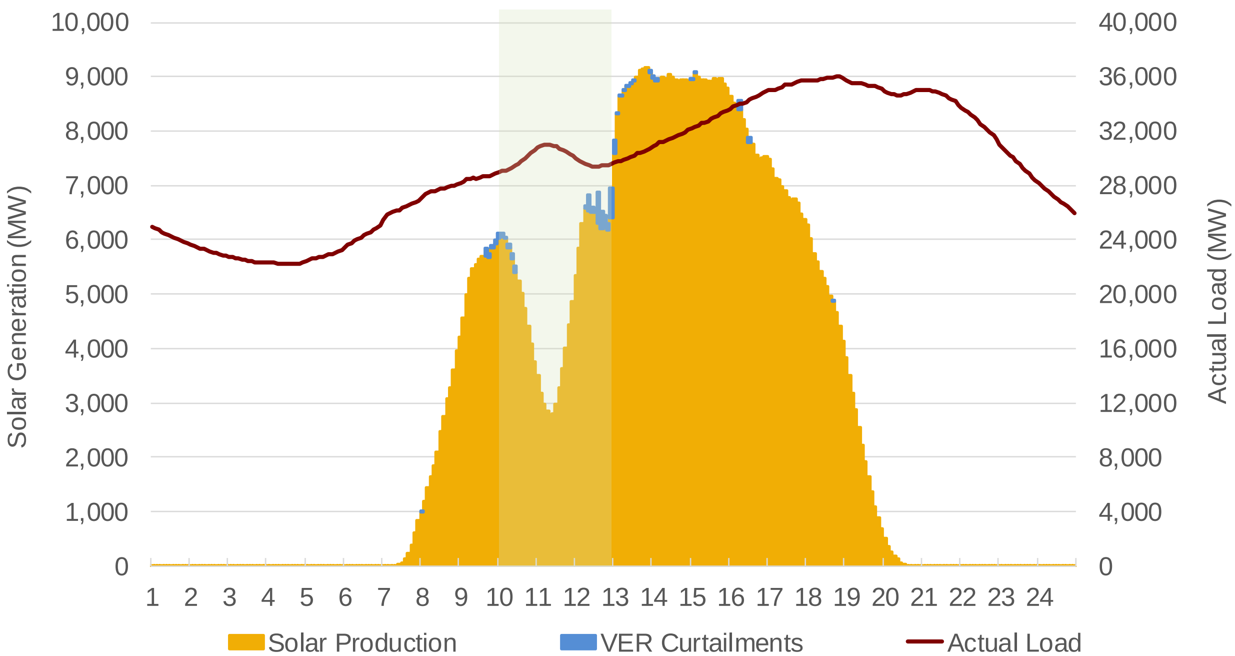


Curtailments

Under certain conditions, such as congestion or oversupply, the market solution may determine the need to curtail renewable dispatches below either the bid-in maximum output or forecasted value. The market will first reduce solar output based on the available economic bids, which reflect the willingness to reduce output. After all the economic bids are exhausted, the market will reduce the output of those resources that have self-scheduled their output to the level of their forecast. The priority and level of curtailments are determined by the associated penalty prices and the overall economics of the system.

Figure 12 shows the profile for solar actual production and actual load compared to the profile of VER curtailments. During the intervals in hour ending 13 when solar generation was ramping back to full production, the load concurrently was reaching a low point and the market was reducing other supply types. This led to a short period of oversupply in the market, which required VER curtailments of up to 600 MW.

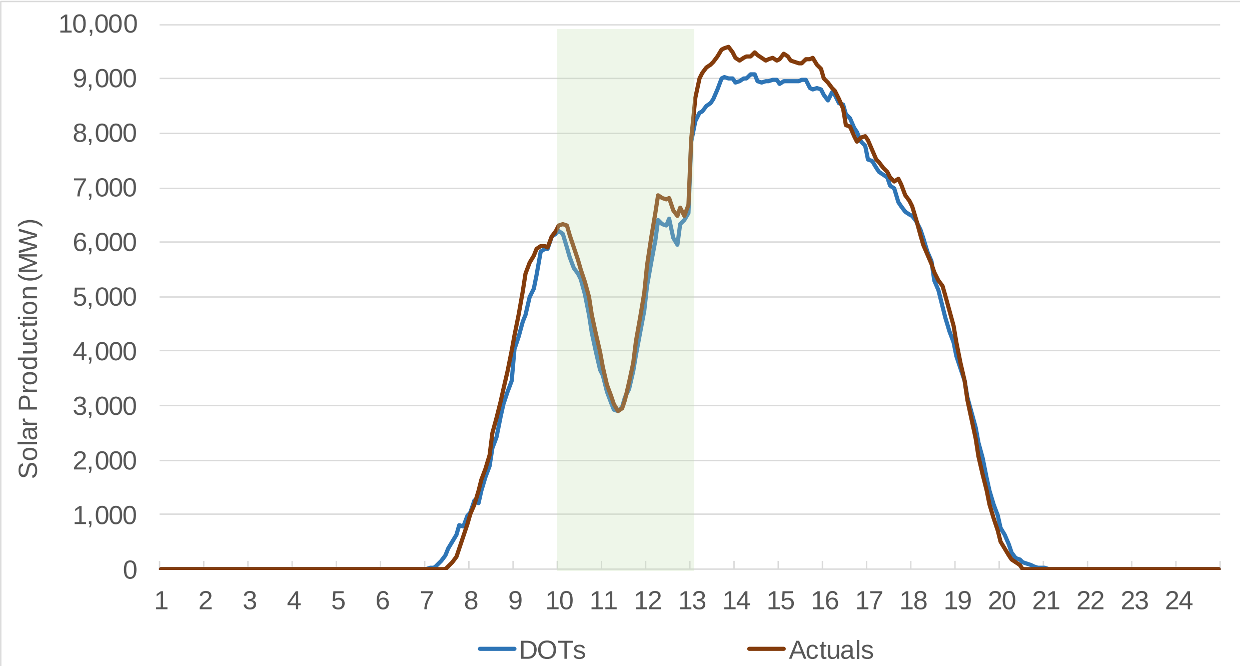
Figure 12: Solar production and VER curtailments



DOT vs Actual Production

The dispatch operating target (DOT) values are the instructions the ISO market generates for resources to be dispatched. Such instructions are optimally determined, taking into account all the market and system information available to the market. As such, DOTs are the most efficient dispatches. In order for the system to realize that optimal outcome, it is of paramount importance that resources follow the instructions because this is how the market believes the resource will behave when determining the optimal solution. All resources, including VERs such as wind and solar, following the DOTs allows the market to optimize the overall solution and reduce burden on regulation that may have occurred if VER resources deviate from DOT. Figure 13 below shows the comparison between the DOTs and the actual solar production. Generally, actual production will be higher than DOTs based on the fact that when VER resources are not curtailed, they can generate up to the irradiance level at any given time, which usually will be higher than the DOT. During the eclipse, the ISO observed, in general, a close tracking to DOTs, indicating that solar resources tightly followed their dispatch instructions, as requested by the ISO.

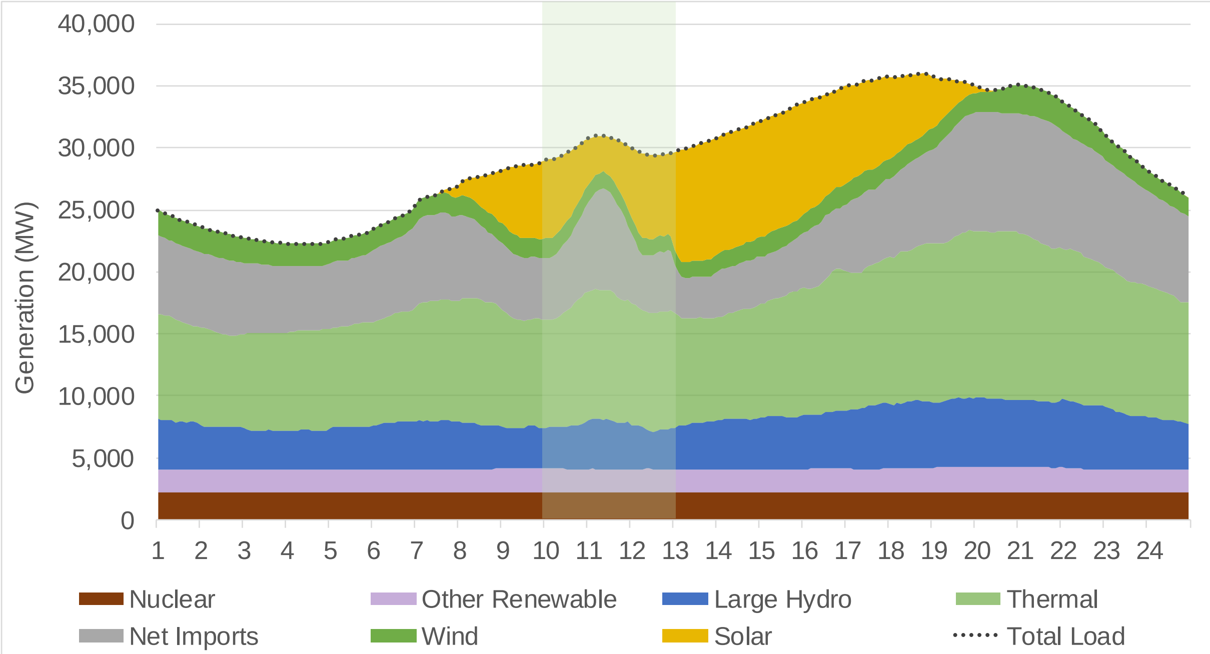
Figure 13: Comparison of DOTs and actual generation from solar resources



Generation Mix

Figure 14 shows the generation mix to support the ISO system load on August 21. It highlights the rapid change of generation mix to fill in for the loss of solar production compounded with the steeper increase of load during the obscuration period. During the event, the solar generation loss was mainly made up from imports, thermal generation and hydropower production. Imports made up about 3,150 MW during the eclipse, or about half of the solar loss. That was mostly scheduled in the day-ahead market, a key part of the ISO's preparations to shore up supply in advance of the eclipse. Additionally, thermal generation increased by 1,594 MW, while hydroelectric resources edged up 791 MW.

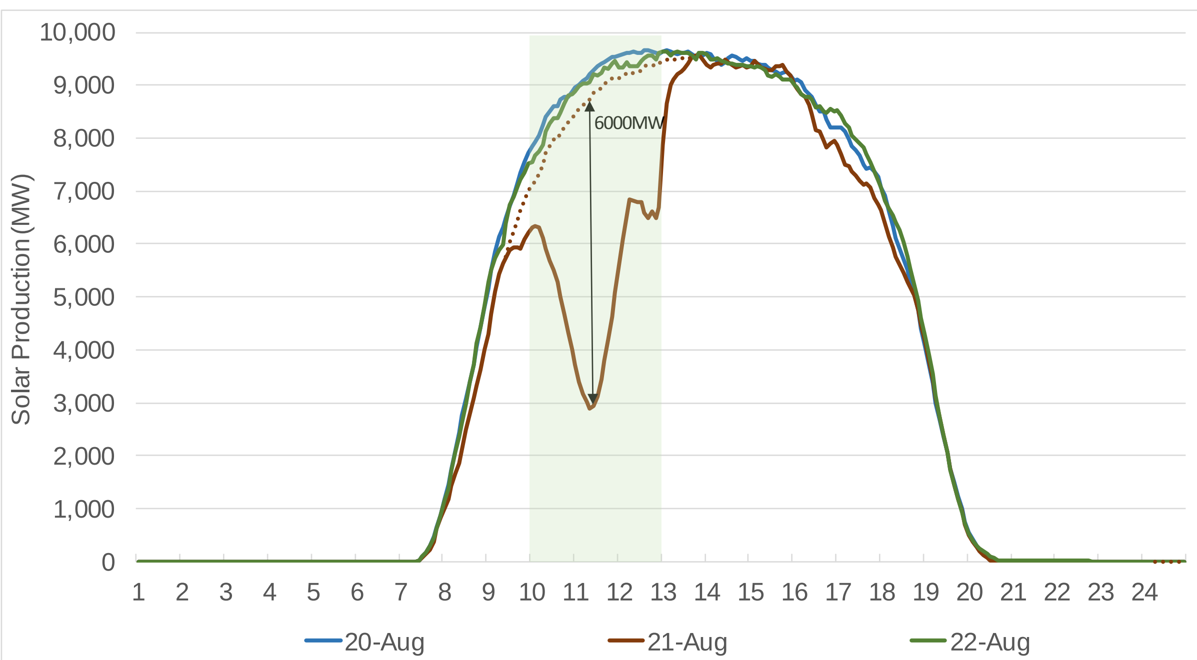
Figure 14: Generation mix to meet load on August 21



Solar generation

Figure 15 shows the solar generation profile during the day of the eclipse in comparison to the adjacent days. August 20 and 22 provide a reasonable reference of the total solar production level that usually is available at that time of the day.

Figure 15: Solar production during the eclipse compared to adjacent days

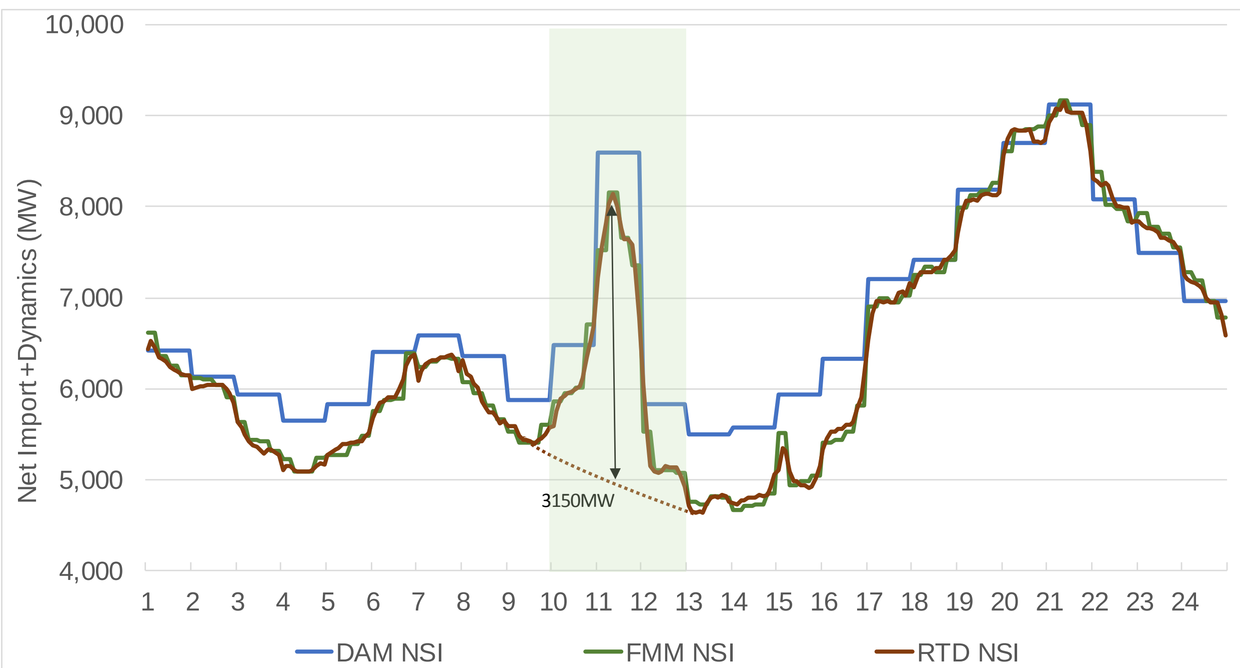


The dotted line is an approximation of what a full solar production day may have been considering that on August 21, solar production seemed to be modestly lower than adjacent days. Based on that approximation, the solar production loss was about 6,000 MW at the maximum obscuration point, this loss represents about two-thirds of typical solar production.

Net Schedule Interchange

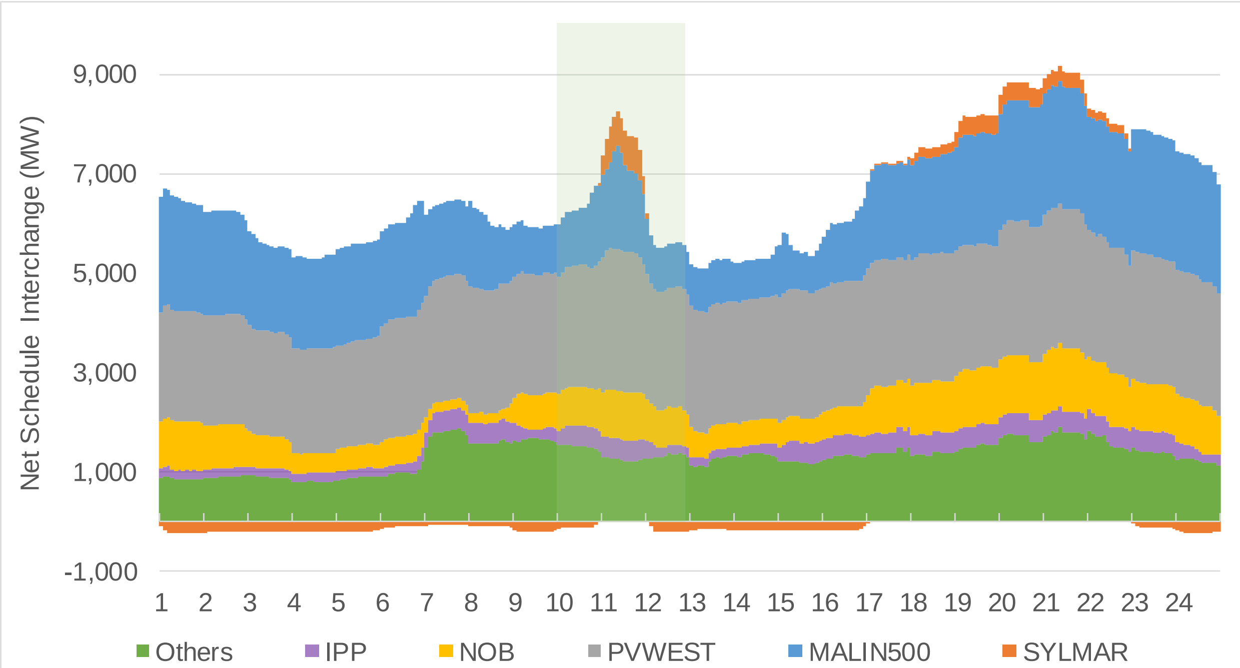
Just prior to the eclipse, the ISO was importing about 5,450 MW of energy from neighboring balancing authorities. At the maximum point of obscuration, the net schedule interchange increased up to 8,150 MW. With respect to a projected trajectory without the effect of the eclipse — represented with red dotted line — that represented an increase on imports of about 3,150 MW. Note that these net schedule interchange figures do not include the EIM transfers. It only includes intertie schedules for imports less exports plus dynamic resources. As shown in Figure 16, the ISO day-ahead market properly positioned the interties for the eclipse; the separation between the day-ahead net schedules and the real-time market interchange reflects the amount of interties that were re-optimized. Just after the eclipse ended the imports reverted to about 4,600 MW.

Figure 16: Comparison of net schedule interchange



Regarding the amount of interties' increase during the eclipse, 38 percent came from Malin, 31 percent from Sylmar, 15 percent from Paloverde, 9 percent from NOB and 7 percent from IPP. At the same time, about 400 MW of capacity was reduced from the rest of interties. The import profile by intertie is shown in Figure 18.

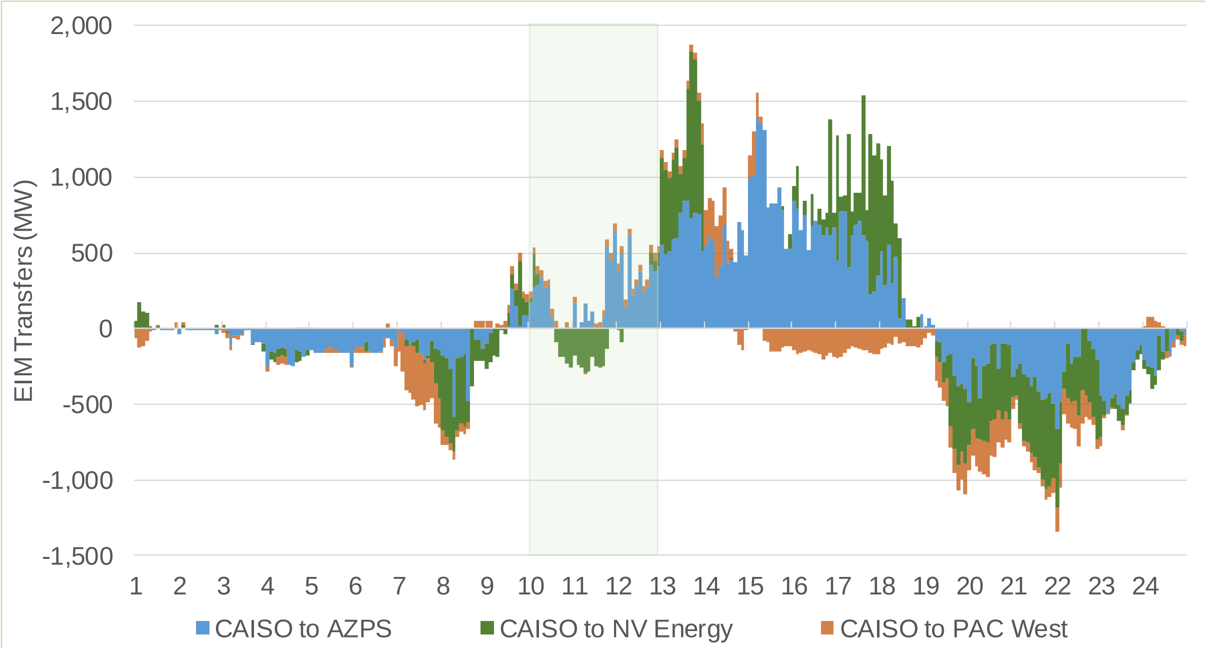
Figure 17: Comparison of net schedule interchange



EIM Transfers

In the real-time market, supply is optimized with the optimal transfer among EIM entities; based on economics, transfers from one Balancing Authority area (BAA) may be used to balance the load in another BAA. On August 21, transfers were taking place between the ISO BAA and adjacent BAA's. Figure 18 shows the five-minute EIM transfers involving the ISO BAA. Just before the eclipse, the ISO was sending transfers to Arizona Public Service (APS), Nevada Energy (NVE) Energy, and Pacific Corporation West (PACW) areas. As the eclipse began and solar generation was gradually lost within the ISO area, the majority of the transfers reversed direction; transfers from NV Energy of up to 300 MW came into the ISO area, for example. After the max obscuration, solar generation was ramping up and other types of supply had to be ramped down; that was partially offset when the transfers reversed direction. On net, the ISO was sending transfers of up to 640 MW, mostly to the APS BAA.. After the eclipse, when the solar generation fully ramped to maximum production, the ISO increased transfers to APS and NVE BAAs, reaching up to 1,880 MW in hour ending 13.

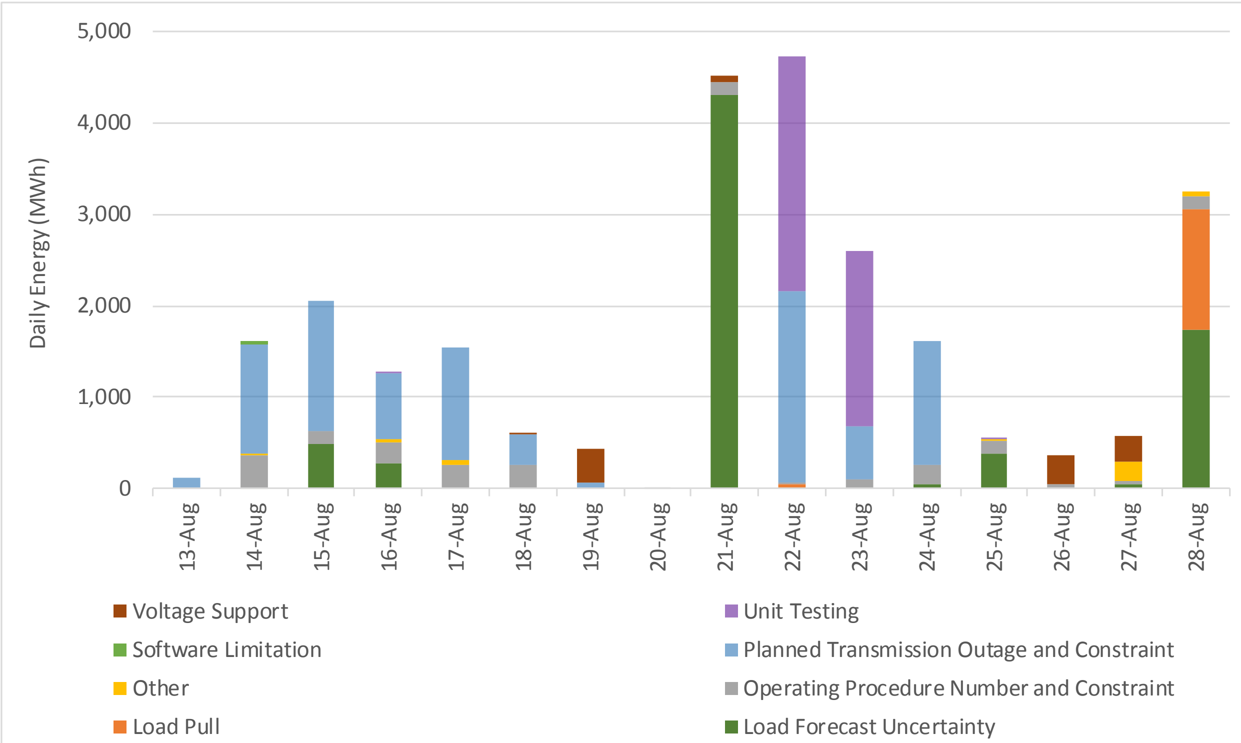
Figure 18 : EIM transfer in the five-minute market



Exceptional Dispatches

For the day of the eclipse, the ISO issued few exceptional dispatches, and those were mainly for load forecast uncertainty. The purpose of the dispatches was not to manage the ramping of solar resources during the eclipse but were, in general, for the overall day, including the evening ramp. Figure 19 shows the volume of exceptional dispatches for the days adjacent to the day of the eclipse.

Figure 19 : Exceptional dispatch volume

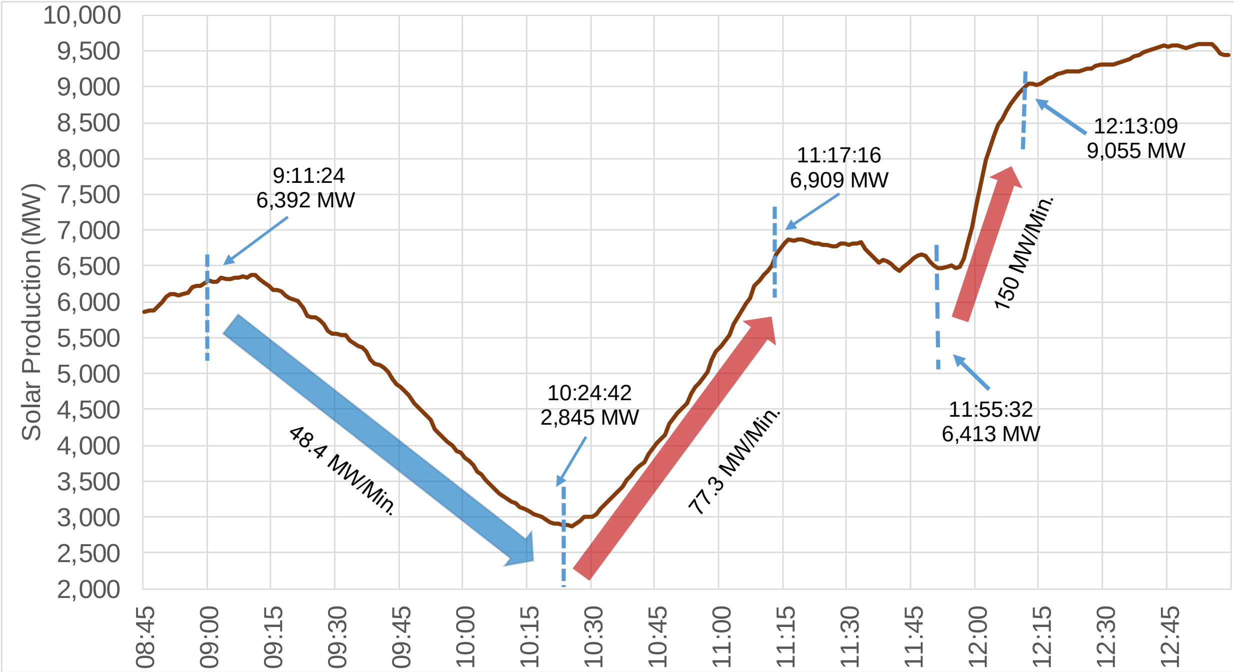


Operational Performance

For the five weekdays before the eclipse, August 14 through August 18, the ISO load increased by an average of about 739 MW between 9:11 a.m. and 10:24 a.m. The solar upward ramps during this same time period averaged 1,108 MW or 15.2 MW/min. Typically, the ISO procures about 400 MW of regulation up and 400 MW of regulation down to manage the variability and uncertainty through Automatic Generation Control (AGC) via real-time four-second dispatch. For the hours of the eclipse, the ISO increased its regulation procurement to ± 1,000 MW.

As shown in Figure 20, the solar production began to rapidly increase following the maximum solar obscuration at 10:24 a.m. and the system experienced a dip in demand as rooftop solar began to carry its load and diminished the ISO's load seen from the grid. This resulted in excess generation on the system, causing real-time energy prices to fall below zero, which in turn triggered the real-time market to use economic bids to reduce up to 600 MW of solar for about 40 minutes to mitigate the system-wide oversupply.

Figure 20: Instantaneous values for solar production and ramps during the eclipse

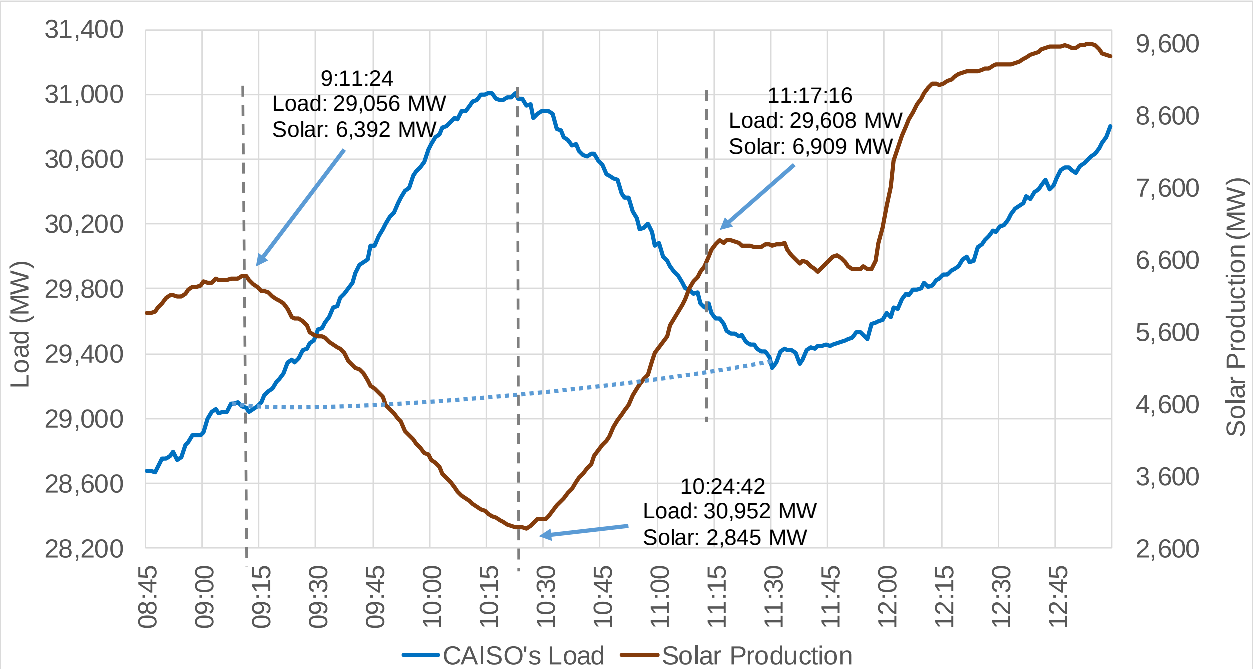


From the start of the eclipse at 9:11 a.m. to maximum obscuration at 10:24 a.m., the ISO experienced a 55 percent loss of transmission connected solar production, going from 6,392 MW to 2,845 MW or 3,547 MW. During this 73-minute period, solar production dropped off at an average of approximately 48.4 MW/min.

Actual Ramps Observed During the Eclipse

Figure 21 shows that the load increased from 29,056 to 30,952 MW or by 1,896 MW as the solar production dropped off between 9:11 a.m. and 10:24 a.m. As the eclipse progressed beyond the maximum obscuration at 10:24 a.m., the solar production rapidly increased by 77.3 MW/min reaching 6909 MW at 11:17. During the same timeframe, load dropped off by about 1,344 MW, which was primarily due to the roof top solar picking back up its load and the cooling effect caused by the partially obscured sun. Just after the eclipse, from 11:55 a.m. to 12:13 p.m., the solar production increased by 2,642 MW or 150 MW/min over a 17.6-minute period.

Figure 21: ISO load and solar production



Using the load for the weekdays August 14 through August 18 prior to the eclipse as a reference, that means load increased by about 739 MW between 9:11 a.m. and 10:24 a.m. However, during the eclipse, the blue dashed line in Figure 21 is an estimate of the load increase from the beginning of the eclipse to the point of maximum obscuration, which was about 150 MW. This slow increase in load was primarily due to cooler temperatures throughout the ISO's service area.

Also, from the beginning of the eclipse, the Area Control Error (ACE), changed by about 278 MW, falling from 298 MW to 20 MW at maximum obscuration. Thus, the estimated loss of rooftop solar from the beginning of the eclipse to maximum obscuration was about 1,468 MW (1896 MW-150 MW-278 MW).

Automatic Generation Control & Regulation Procurement

The ISO changed its AGC control bands in order to more tightly control the system through regulation within the intra five-minute market dispatch intervals.

Table 3 shows the three AGC bands and the times at which these bands were changed to better manage ACE.

Table 3: AGC control bands

	Prior to 8:30 a.m.	8:30 a.m.	10:16 a.m.	12:09
Emergency Band (MW)	350/-350	350/-100	100/-100	350/-350
Permissive Band (MW)	200/-200	250/-75	75/-75	200/-200
Dead Band (MW)	100/-100	50/-50	50/-50	100-100

Where the following definitions apply:

Dead Band: No AGC control action is initiated when ACE is within the dead band limits.

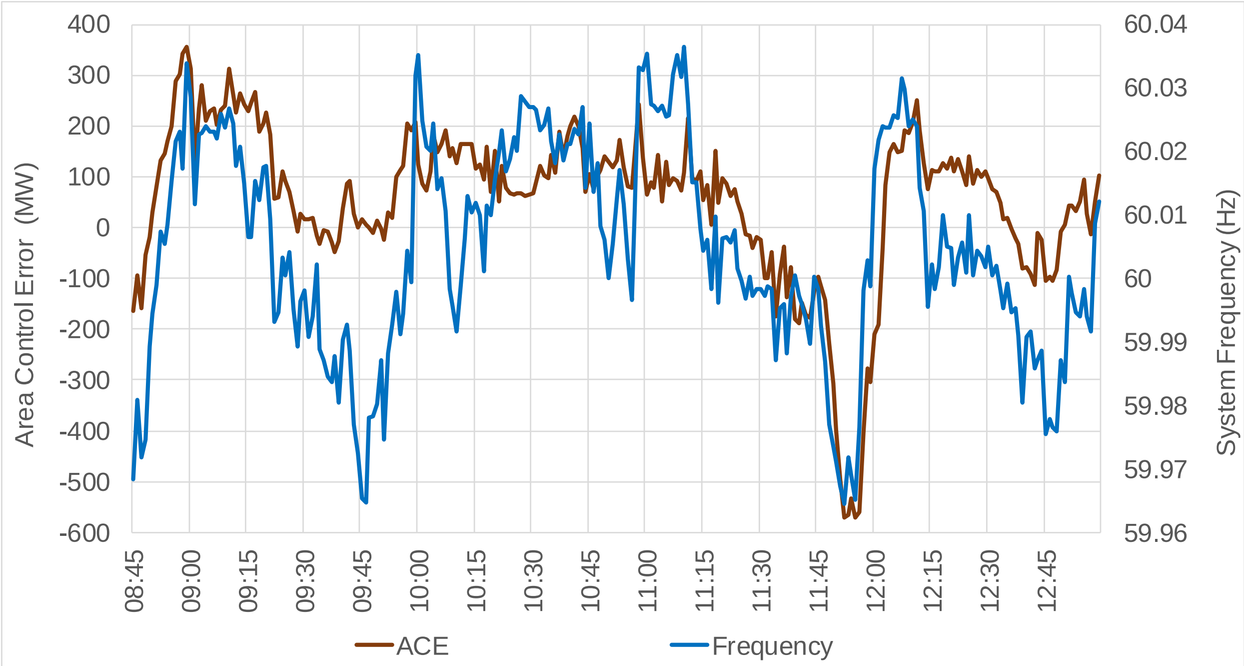
Permissive Band: Within the Permissive Region, AGC first moves units on regulation control to improve ACE. Control signals are not sent to units on regulation control that can harm ACE.

Emergency Band: Within the Emergency Assist Region, all resources on regulation control are moved to reduce ACE regardless of economics.

ACE/Frequency

During the eclipse, as shown in Figure 22 the ISO was able to maintain its ACE within ± 200 MW because of the proactive changes made to the AGC control bands and the decision to increase its regulation procurement.

Figure 22: ISO ACE and system frequency



As the solar production dropped during the eclipse, the ISO ability to control ACE contributed to maintaining a healthy system frequency around 60 Hz..

Figure 23: Solar production compared to ACE

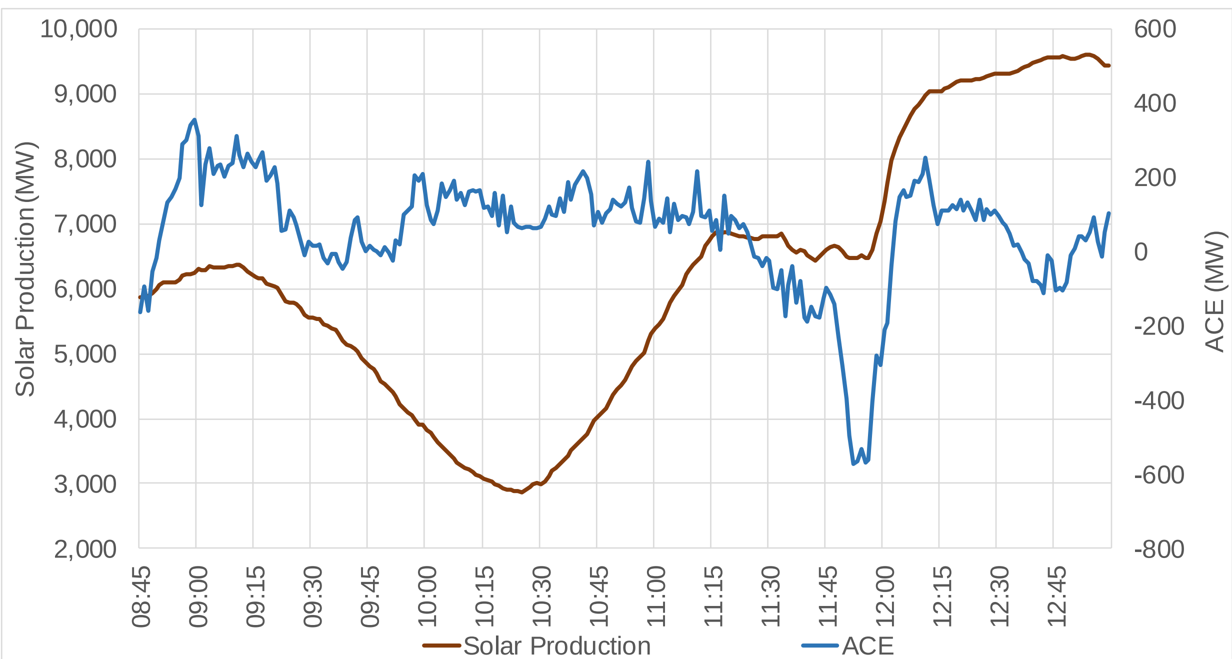


Figure 23 and Figure 24 show a comparison of solar production to ACE and system frequency. From about half an hour before maximum obscuration at 10:24 to about 11:15, the ISO was able to maintain a positive ACE. The interconnection frequency during this timeframe was primarily above 60 Hz, indicating that the supply was more than adequate to serve demand

Figure 24: Solar production compared to system frequency