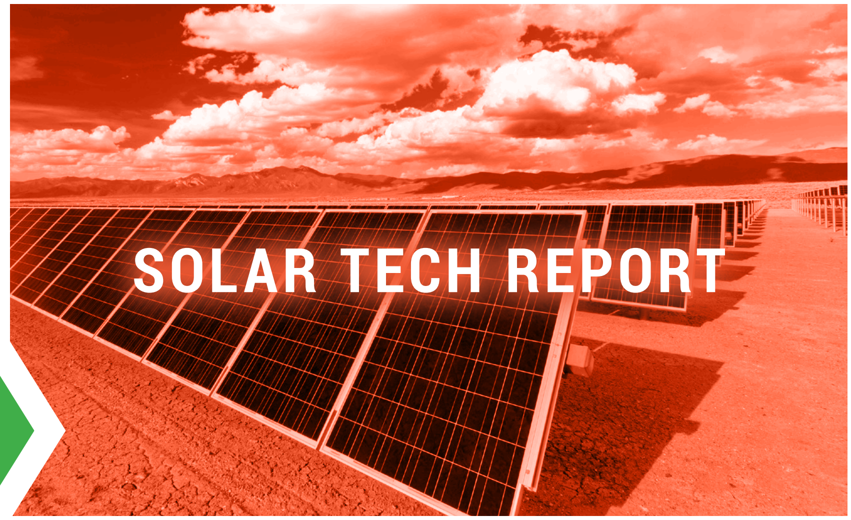


European Solar Eclipse -
MARCH 20, 2015

Solar and wind are continuing to transform the way that energy is produced and managed, driving an ongoing energy transition. There is no doubt that renewable energy has become a preferred choice for many people throughout the world. This ever-increasing level of wind and solar energies is creating new challenges for grid operations. Among these challenges is maintaining operating stability during meteorological and solar events.

A solar eclipse is a special challenge since during an eclipse, large amounts of generation governing a large area can be suddenly removed from and quickly reinserted into a system in a manner of minutes. No large solar system had been tested under these conditions until the solar event which took place in Europe on March 20, 2015. This was the first major eclipse over Europe since the installation of high levels of PV.

European Solar Eclipse Lessons Learned

On Friday, March 20, 2015, under a clear morning sky, in the space of two hours, the German interconnected power system lost 8 GW during a solar eclipse, and regained 17 GW, with a maximum ramp rate of up to 700 MW/minute, or 4.4 GW in a 15 minute market interval.

UVIG held a webinar for its members after the event, featuring three European experts who were involved in the preparations, management and analysis of this event. Dr. Bernard Ernst, Manager of Grid Integration at SMA, provided the background for the rapid growth of PV capacity in Europe; Dr. Ulrich Focken, Managing Director of the meteorology consulting firm Energy and Meteo in Germany, provided the meteorology background for the event; and Roman Sikora, in the System Operations Department of 50Hertz Transmission, a large German TSO, provided the details of the preparation for the event and operating through it.

The PV market in Europe is driven by government policy support, and reached 88 GW at the end of 2014, see *Fig 1*.

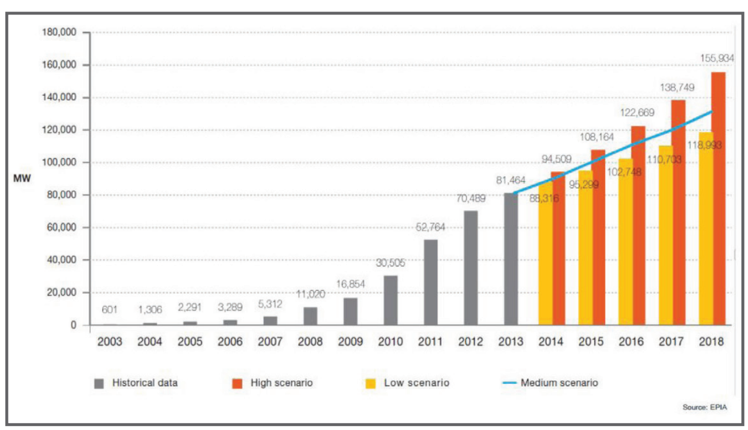


Figure 1

Germany, with the largest installed PV capacity in the world at 38 GW, had been preparing for this unprecedented event for several months, taking appropriate measures to manage the risk and maintain system security.

The Thursday day-ahead PV plant output forecast and the Friday morning intra-day forecast were in close agreement, and predicted the actual PV plant output very accurately, as shown in ***Fig 2*** and ***Fig 3***.

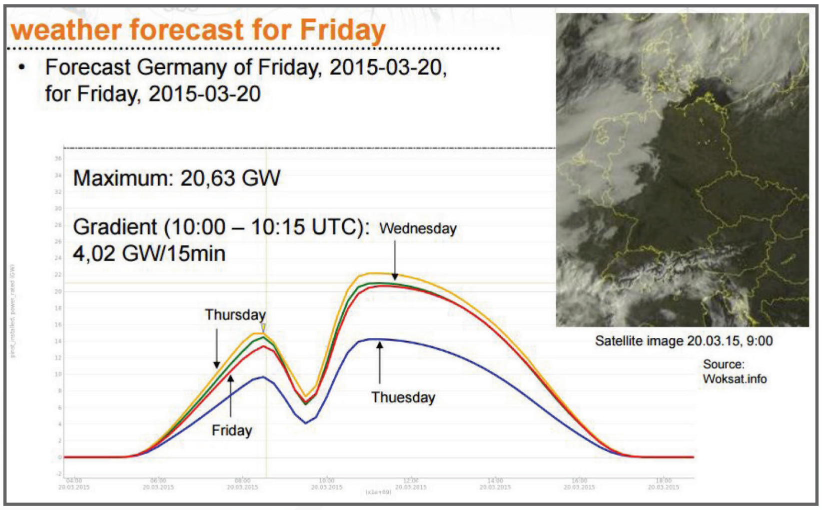


Figure 2

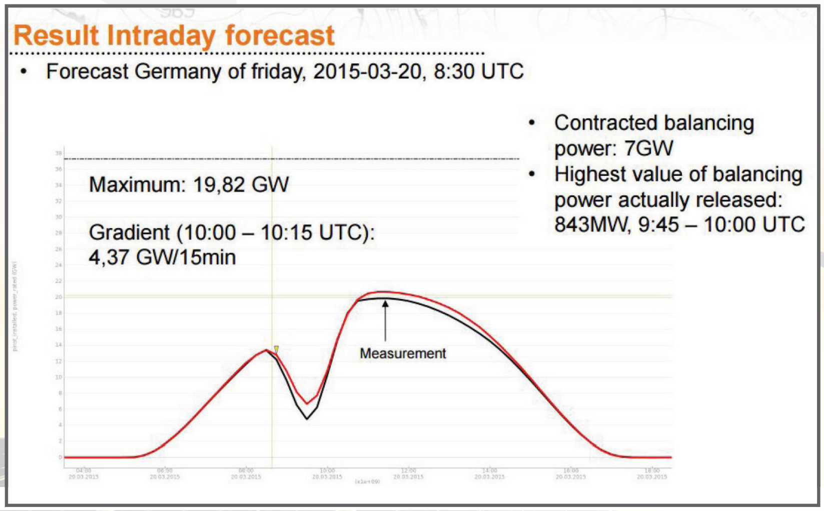
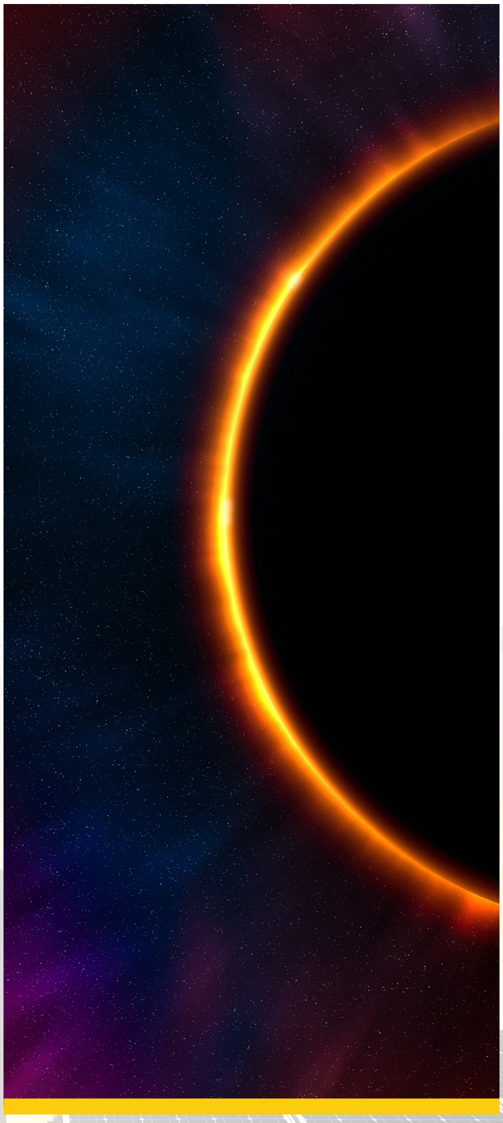


Figure 3



The German TSOs had undertaken extensive operations planning coordination through ENTSO-E, and maintained continuous communication before, during and after the event to coordinate all necessary actions which needed to be taken. This event, and the preparation for it, illustrate the nature of the new challenges which will increasingly face the system operator of the future.

On a normal day, German TSOs contract for approximately +/- 2 GW of automatic frequency restoration reserve (aFRR) and -2/+2.7 GW of manual frequency restoration reserve (mFRR). In preparation for the eclipse, they contracted for +/- 4.3 GW of aFRR, and -3/+3.7 GW of mFRR. As can be seen from ***Fig 4*** and ***Fig 5***, a maximum of about 1800 MW of positive control power was activated during the event, and the aFFR reached almost 2300 MW. The frequency stayed within a band of +/- .05 Hz. The security of supply was never in danger during the event. Extensive preparations prior to the event included the study of a full range of possible scenarios for what might happen, as well as detailed preparation for the specific event.

Close communication and cooperation were maintained among the European and German TSOs, as well as the German TSOs with solar forecast providers, DSOs, balancing groups, control power providers, and active PV market traders. Additional technical personnel and special training were provided for the transmission control center, trading department, and back office; regional security initiatives created detailed forecasting reports, and 600 MW of interruptible load was activated.

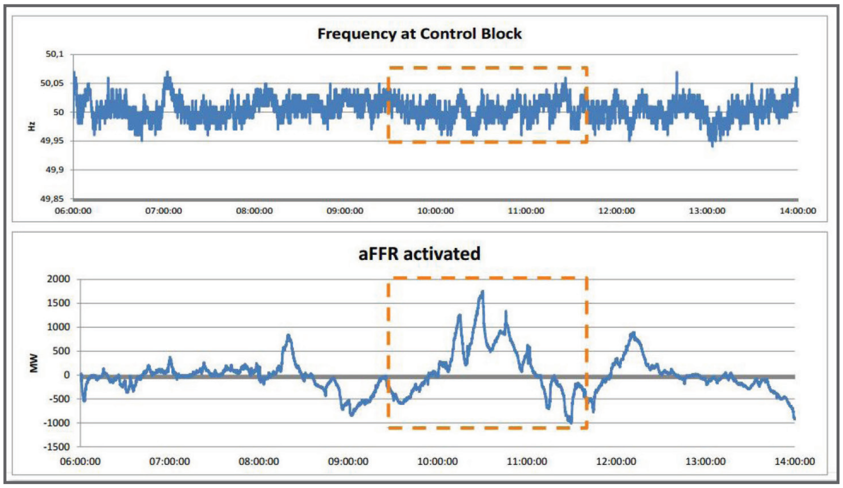


Figure 4

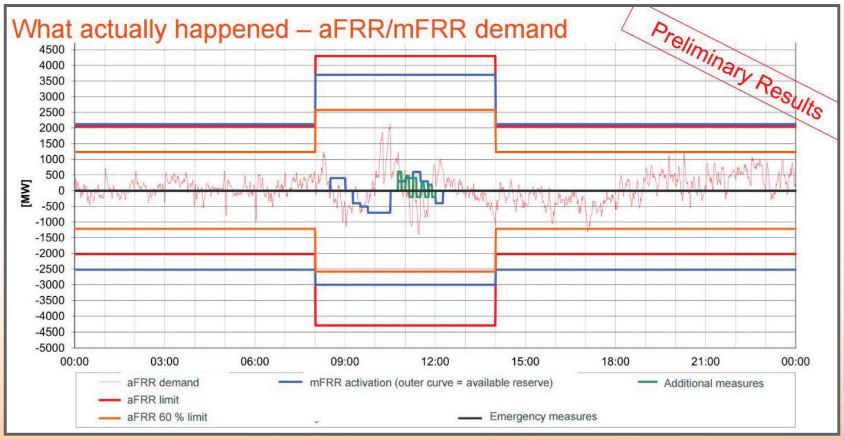


Figure 5

WHAT WAS LEARNED

The eclipse provided a valuable operating experience and preparation for the future for all those involved, and provided a variety of lessons learned:

1. During the eclipse, security of supply was never endangered. With adequate planning and preparation, large deviations can be managed.

2. PV curtailment was not an option in Germany due to inadequate communication and the concern that further uncertainty would be introduced into the energy market. In the future, reliable two-way communication should make visibility and control available for larger distributed generators.

3. Solar PV plant output forecasting systems are good and getting better, but fog is still a challenge. The forecasts illustrated the increased value of forecasting closer to real time and aggregation of plant output over a large region.

4. Energy markets as well as TSOs were well prepared for the event, with additional sources of automatic and manual frequency restoration reserves contracted, and interruptible load on notice.

5. The frequency containment reserve (FCR, or primary control reserve) was increased with an additional tender for March 20 from 8 am – 2 pm. Approximately 1100 MW above the standard 600 MW was contracted, of which approximately 25% was activated.

6. While both frequency response reserves and interruptible load were activated during the event, the activated reserves were approximately half of the contracted reserves, and system frequency never went outside of normal bounds.

7. Low wind infeed during the event was beneficial, providing increased transmission capacity and system export capability.

8. Even though over-frequency protection was available on the PV converters, it was not required during the ramp up. Frequency deviations stayed in a band of +/- .05 Hz during the event, and never approached + .2 Hz.

9. It may be desirable to look at a solar eclipse as a credible contingency event in the future.

10. The European electricity system is capable of high fluctuations in feed-in from renewables, with future gradients equal to the eclipse gradients if installed capacity increases in line with political targets. It must prepare for such excursions on a regular basis in the 2030 time frame.

Learn more at www.uvig.org

It is clear from preparing for and managing through this event that both forecasting and flexibility are critical for future system reliability. Forecasting has already advanced to a very high level compared to just five years ago, and is in widespread use. There is a very large effort underway around the world to understand the myriad sources of flexibility and unlock access to them. This effort is critical to a future power system with a high share of variable generation and will be engaging the time and talents of many people for a long time to come.