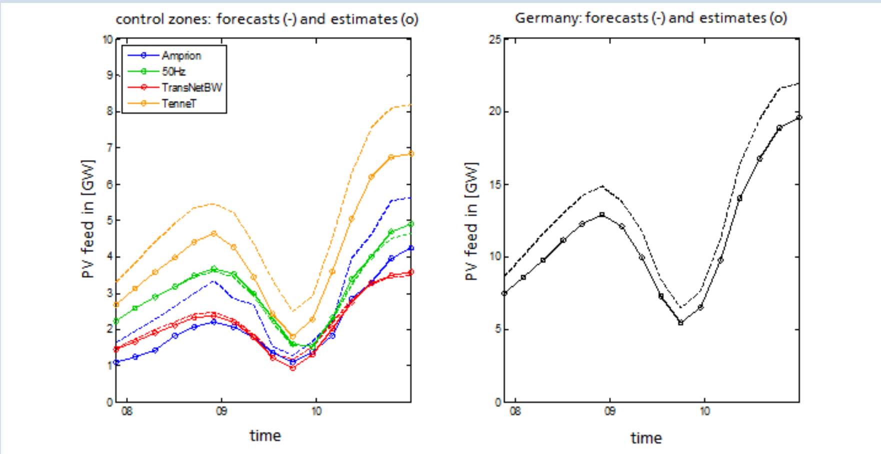
IEA INTERNATIONAL ENERGY AGENCY

How an energy supply system with a high PV share handled a solar eclipse

A retrospective view on early evaluations of the effects of the solar eclipse on March 20th, 2015 on the German energy supply system



PVPS

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

Report IEA-PVPS T14-06:2016
ISBN 978-3-906042-43-5

INTERNATIONAL ENERGY AGENCY
PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

How an energy supply system with a high PV share handled a solar eclipse

A retrospective view on early evaluations of the effects of the solar eclipse on March 20th, 2015 on the German energy supply system

IEA PVPS Task 14, Subtask 3
Report IEA-PVPS T14-06: 2016
April 2016

Corresponding Author: Dr. Rafael Fritz, Rafael.Fritz@iwes.fraunhofer.de

This short report is based on early evaluations done for a press release of Fraunhofer IWES, Kassel, Germany, originally published on 20th of March, 2015.

Main authors were Yves-Marie Saint-Drenan, Rafael Fritz and Dominik Jost.

The authors gratefully acknowledge support by Dr. Garrett Good with translating the document to the English language.

Contact:

Fraunhofer IWES

branch Energy System Technology

Dr. Rafael Fritz

Königstor 59

34119 Kassel

Germany

Tel.: +49 (0)561 7294 - 454

eMail: Rafael.Fritz@iwes.fraunhofer.de

Kassel, 20th March 2015, 29th February 2016.

Table of Contents

Foreword

Recent higher penetration of variable renewable generation such as photovoltaic and wind generation has been causing various technical and financial impacts on many power systems. Many countries and area system operators are making many various efforts of generation, transmission, distribution, demands, system operation and a power market. In PVPS Task 14 "High Penetration of PV Systems in Electricity Grids", through international collaboration, we are surveying and disseminating the methodologies for photovoltaic generation penetration including the aspects of integration of the transmission level.

However, some extreme weather conditions have a possibility to place a critical impacts on power system operation. The solar eclipse in March 2015 in Europe might the first occasion of the critical impact by Photovoltaic generation.

In order to realize the sustainable integration of variable renewable generation, as discussed broadly, we need to integrate more flexible resources and to continuously enhance the skill of the power system operation including the optimized utilization of the flexible resources through the practices of power system operation

This report gives overview of the German power system operation from a preparation stage to a real-time operation as a successful practice of the solar eclipse. The results show the manageability of a power system operation in a solar eclipse under the current situation, and the accumulated efforts made by the related organizations and people will form the foundation of an enhanced power system operation for the further integration of the variable renewable energy.

Kazuhiko Ogimoto

Professor, the University of Tokyo

As a leader of Subtask 3, Task 14, IEA PVPS

Introduction

Although the solar eclipse influenced the solar irradiance in most European countries, German electricity generation was by far the most affected due to the high PV capacity.

As shown in Figure 1, the highest PV generation drop of about 10 GW was prospected in Germany. The second highest generation drop was expected in Italy at around 2.7 GW. In all other countries the expected drop was about 1 GW or smaller, which corresponds to the outage of a large power plant. Consequently, power balancing issues were most likely to appear in Germany, with other countries were rather being influenced via the synchronous grid, necessitating good cooperation between the European TSOs was important. Germany however remains as the focus of this report.

For amateur astronomers and interested observers of the solar eclipse, there could not have been better weather throughout Germany. A clear sky ruled over the entire country. Only Lower Saxony, North Rhine-Westphalia, Rhineland-Palatinate and part of Hesse were overcast by high clouds during the eclipse. The weather situation thus approximated a “worst-case scenario,” with the strongest effects of the solar eclipse on solar power production. Despite these unfavorable conditions, the four German transmission system operators (TSOs) were able to manage the situation.

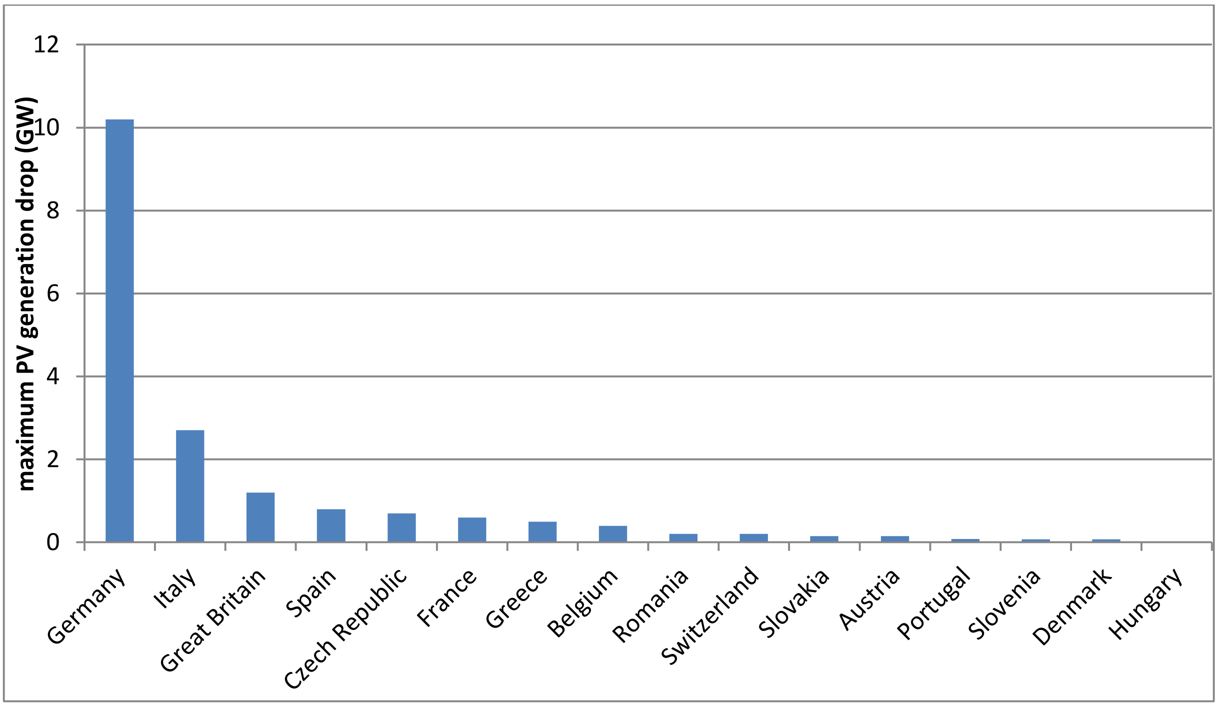


Figure 1: Expected maximum PV generation drop. Data Source: [3].

Stress-Free Network Operation as a Result of Long-Term Preparation

The smooth network operation during the eclipse resulted from many months of preparation. A study by IWES and the German Weather Service (DWD) [4] has emerged with results in very good agreement with other studies. The greatest reduction of 18 Gigawatts due to the eclipse as compared to a clear day without an eclipse occurred at 10:45 am. That the effect would not be overly concerning could be predicted with the assistance of up-to-date weather forecasts.

Starting March 17th, 2015, the DWD executed added model calculations parallel to the operational weather models COSMO-EU and COSMO-DE that explicitly took into account the effects of solar eclipses on insolation and temperature. This allowed the energy sector a rather exact estimate of the weather situation and consequently of the accompanying effects of the solar eclipse on PV-relevant meteorological measures (see attachment). The results of the DWD were made freely available, such that any network operator or forecast provider could incorporate them into its plans.

On the basis of such studies, the TSOs were able to estimate how critical the situation could become for the entire electrical grid. In order to compensate for the high gradient in PV production as well as for possible forecasting errors, more control reserve was made available than normally would be. To this end, the minute reserve capacity was increased to -3,000 MW, or alternatively, to 3,700 MW. In contrast, the more quickly activating secondary control reserve's capacity was set to -4,300 MW and +4,300 MW, more than double its normal value. Figure 2 shows the described capacities held available for the secondary control and minute reserve.

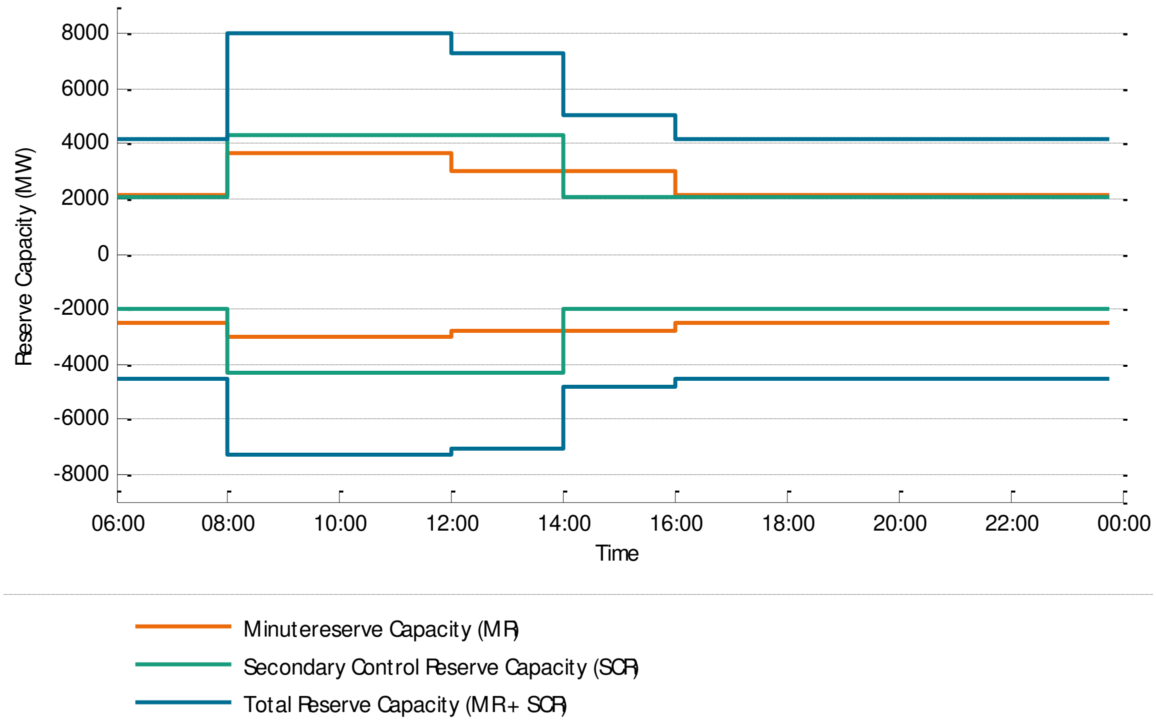


Figure 2: Control reserve capacities on March 20th, 2015. <u>Data source</u>: [5].

Day-Ahead Analysis of the Solar Eclipse

Since the expected power production values from renewable sources are already traded on the previous day at the EPEX Energy Exchange, the day-ahead forecast is an especially important step for the integration of fluctuating power sources. With regards to this, the quality of the projections provided by the DWD and their application by forecasters both play a supporting role.

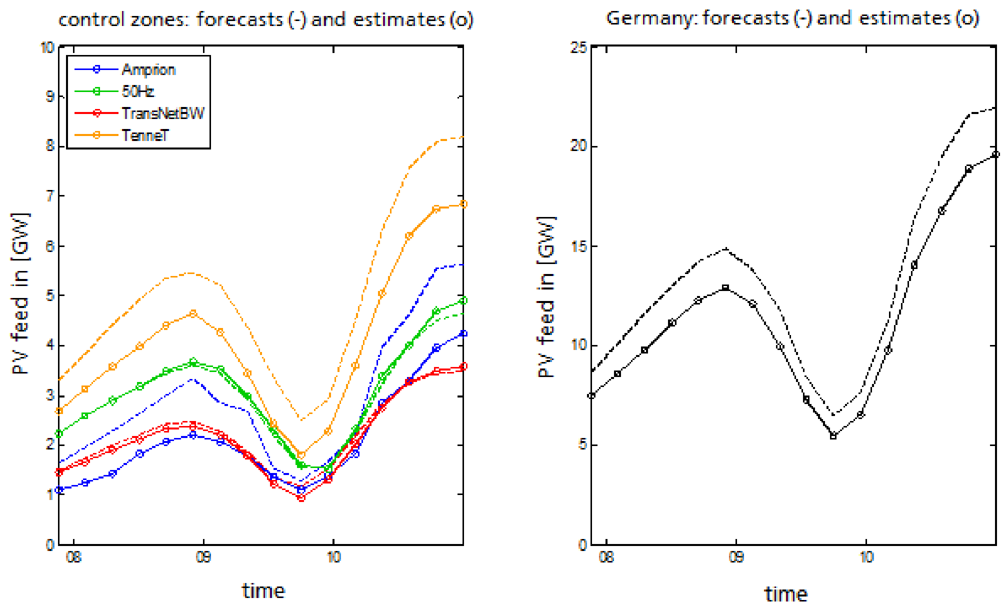


Figure 3: Comparison of the PV feed in and day-ahead forecast for the individual control zones of the four German TSOs (left) and for all of Germany (right). <u>Data Source</u>: [6]–[9]

The Figure 3 plots of the day-ahead forecasts for the individual control regions of the TSOs (left) and for all of Germany (right) show that the exact trajectory of the PV production during the eclipse was already very recognizable in the morning one day before. Only in the Amprion and TenneT regions there was some bias in the forecast due to the increased low stratus clouds (see also in attachment) on the morning of the eclipse, which caused the real value to deviate from the forecast. For better comprehension one should consider the total system load during the eclipse of around 72 GW [1].

The data from the PV estimates, the forecasts in the 50 Hertz and the TransNetBW regions, where there were no low stratus clouds, show that the PV feed-in captured the effect of the solar eclipse with high precision. One therefore sees that the eclipse could be successfully anticipated on the previous day.

Applied Reserve Power and Net Frequency Changes During the Solar Eclipse

The positive following-day projection for PV production, as well as the elimination of lasting effects through trading on the Intraday Spot Market based on short-term forecasts, lead to little need for the correction of forecast errors through the use of balancing power. Figure 4 shows the system imbalance for the German Grid Control Corporation (GCC), which corresponds to the imbalance between power production and consumption, in comparison to the available reserve power. The imbalance occurring during the solar eclipse varies over a range of less than ±1,200 MW. This is a typical value even during normal grid operation. One must however note that the data considered here concerns fifteen-minute averages and that peaks could nevertheless have occurred that are not visible in the data. The shutdowns of loads initiated by their corresponding TSOs are also included in the departures from the forecast described above.

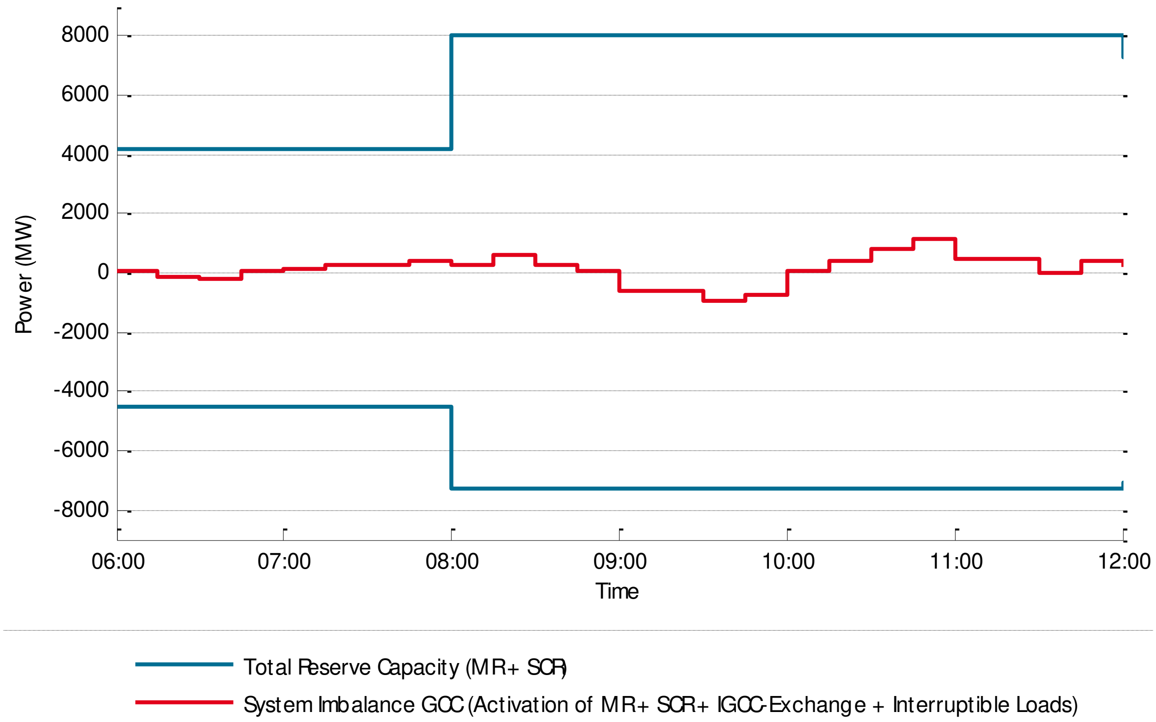


Figure 4: Quarter-hourly average values of the system imbalance for the German Grid Control Corporation(GCC) as compared to available reserve capacities. Data Source: [5].

The examination of the grid frequency (shown in Figure 5), an indicator for imbalances that persist in the grid despite the use of balancing power in the individual control zones, gives no indication that a critical situation could have arisen during the solar eclipse. The deviation from the nominal frequency remained at all times below 0.05 Hz and therefore within the target range defined by the ENTSO-E. The primary reserve power was thus barely used, as a full deployment of the reserved 3,000 MW only occurs upon deviations of at least 0.2 Hz.

Figure 5: Progression of the self-measured net frequency and resulting activation of primary control reserve power. Data Source: Fraunhofer IWES.

Summary

Overview

The solar eclipse on March 20th, 2015 was announced by the press as a stress test for grid operators and for the Energiewende in total, Germany's move to renewable energies. The analysis of the most important parameters of the energy system shows that despite a solar eclipse whose effect was even enhanced by mostly cloud-free conditions, there was no sign of danger to the energy system.

The PV forecasts for the following day agreed with the estimated values of the TSOs to the greatest possible extent. The forecasts in the 50 Hertz and TransNetBW control zones actually performed better than what can be expected on average. For Amprion and Tennet, the forecast errors were larger due to low stratus clouds. These errors can in any case be primarily traced back to weather conditions and not to the solar eclipse.

Preparation

A foreseeable stress test like the discussed solar eclipse is very manageable when the needed preparation is accomplished in time. German as well as European TSOs and other market players started to prepare almost one year in advance. Possible impacts were studied and discussed and different plans of how to handle the eclipse were developed, evaluated and combined. Several different measures ensured the grid security:

- TSOs constantly worked for the awareness of all stakeholders, since it was clear that planning and communication would be required for a successful process;
- Several European TSOs significantly increased their reserves during the period and especially in Germany this was associated with extraordinary high costs[1];
- It was agreed to minimize the area control error in nearly real-time rather than at typical intervals of 15 minutes;
- Maintenance operations were scheduled to other time so that the grid would be available at maximum performance;
- Staff was trained beforehand and doubled during the eclipse;
- Phone conferences were held regularly and kept open during the eclipse.

A very important step at the initial stage of the planning process was the execution of reliable numerical weather predictions that do not otherwise usually account for such strong variations of solar irradiance at the top of the atmosphere.

[1] Summing up to around 3.6 million Euros [3].

In large part, the dedication of the German weather service can be thanked for the forecasting errors having remained so small. The DWD made available weather projections taking the eclipse into account already three days before the event. In addition to the standard operation of the COSMO-EU and COSMO-DE weather models, this required the execution and integration of special model calculations for the duration of the eclipse.

In preparation for the unusual situation of the eclipse, the TSOs markedly increased the amount of reserve power in order to be able to quickly respond to possible imbalances between supply and demand. In hindsight, these cautionary measures were not necessary, as the need for reserve power did not exceed that under normal operating conditions.

Conclusions

The problem-free operation of the German energy supply system with about 37 GWp of installed PV capacity during the solar eclipse on March 20th, 2015 shows above all that the integration of renewable energies into the supply system has already made great progress. With regard to this, the four German TSOs, the German weather service and PV production forecasters have played key roles.

Situations certainly occur throughout the year with much graver consequences for the network operation than were caused by the solar eclipse. Days with expansive fields of low stratus clouds or with cold fronts could be just as or still more critical for the grid. Much research and development work into the field of weather and power forecasting thus remains necessary in order to still further improve the integration of solar power into the grid during such extreme events.

Outlook

From the authors' point of view, there are two important facts to remember:

- Solar eclipses are not rare events. They happen once or twice per year across our planet.
- Distributed photovoltaic production units increasingly contribute to the energy supply systems worldwide.

As a consequence, the importance of understanding the influence of solar eclipse events on electricity systems will increase. In general, such events should be preceded by long-term preparation and the consideration of all relevant local circumstances. The European case described in this paper demonstrates that with high awareness and international communication the impact on an energy supply system and the available and needed measures to safely run it during the event can be successfully estimated. The lessons learned we described here might be a guide for upcoming events like the total solar eclipse on the 9th of March, 2016, this time in Asia/Australia.

References

[1] P. Graichen, M. M. Kleiner, and C. Podewils, "Die Energiewende im Stromsektor : Stand der Dinge 2015," 2016.

[2] ENTSO-E, "Hourly load values for a specific country for a specific month (in MW)." [Online]. Available: https://www.entsoe.eu/db-query/consumption/mhlv-a-specific-country-for-a-specific-month/. [Accessed: 19-Jan-2016].

[3] ENTSO-E and SolarPowerEurope, "The successful stress test of Europe's power grid – more ahead," 2015.

[4] C. Köhler, A. Steiner, D. Lee, J. Thieler, D. Ernst, C. Becker, M. Zirkelbach, and B. Ritter, "Assessing the impact of a solar eclipse on weather and photovoltaic production," Meteorol. Zeitschrift, 2015.

[5] Regelleistung.net, "Control reserve capacities." [Online]. Available: www.regelleistung.net. [Accessed: 01-Jun-2015].

[6] Amprion, "photovoltaic forecast and estimate of actual feed in." [Online]. Available: http://www.amprion.de/bilanzkreis-eeg#. [Accessed: 01-Jun-2015].

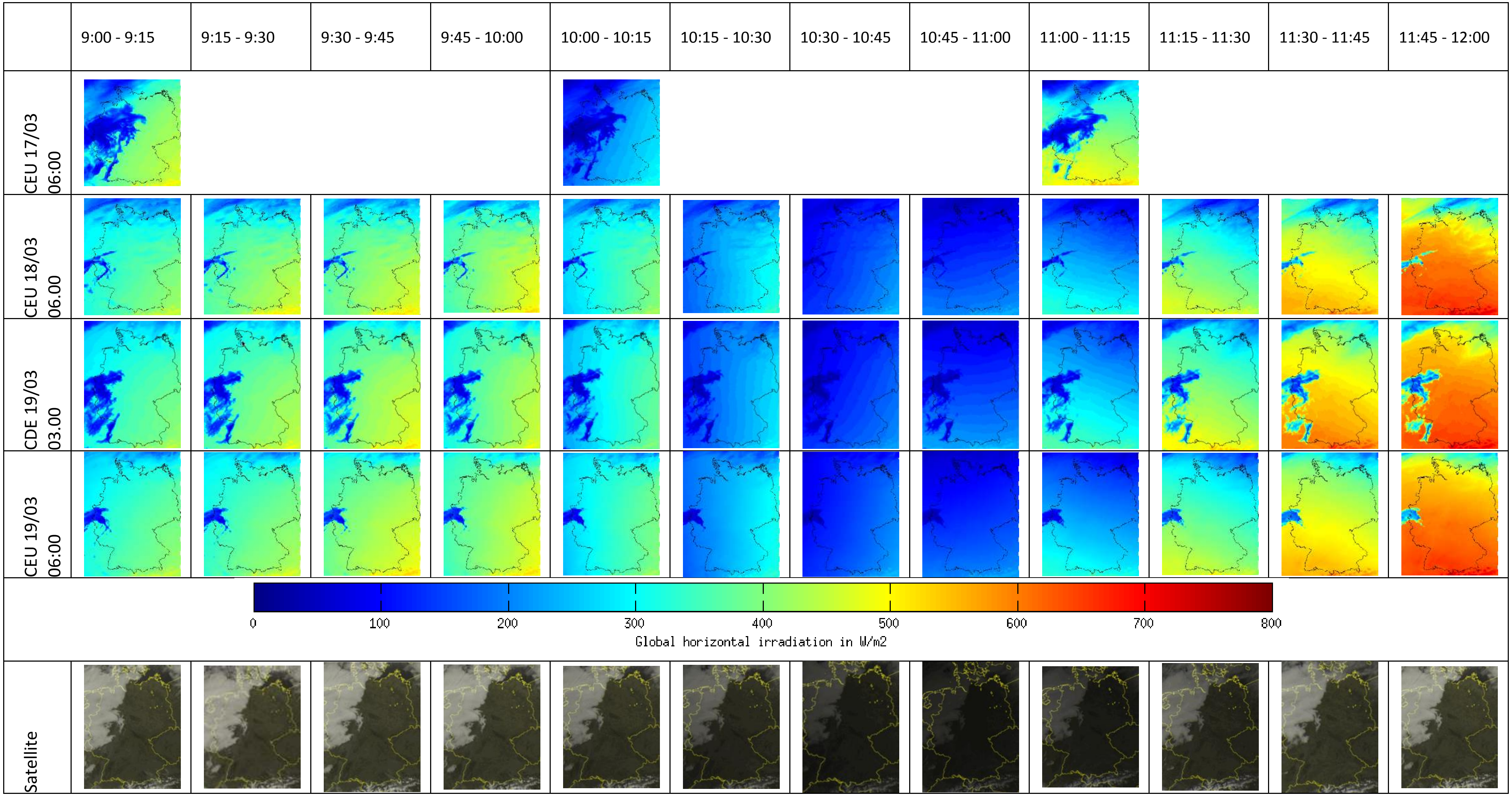
[7] 50Hertz, "photovoltaic forecast and estimate of actual feed in." [Online]. Available: http://www.50hertz.com/de/Kennzahlen/Photovoltaik/Hochrechnung. [Accessed: 01-Jun-2015].

[8] TenneT, "photovoltaic forecast and estimate of actual feed in." [Online]. Available: http://www.tennettso.de/site/en/Transparency/publications/network-figures/actual-and-forecast-photovoltaic-energy-feed-in. [Accessed: 01-Jun-2015].

[9] TransNetBW, "photovoltaic forecast and estimate of actual feed in." [Online]. Available: http://www.transnetbw.de/de/kennzahlen/erneuerbare-energien/fotovoltaik. [Accessed: 01-Jun-2015].

[10] Sat24.com, "Historical satellite images." [Online]. Available: http://www.sat24.com/history.aspx. [Accessed: 19-Jan-2016].

Figure A1: DWD irradiance forecasts from 17th, 18th and 19th of March for the event on 20th, plus satellite images. Data Sources: DWD, [10]



ISBN 978-3-906042-43-5