SOLAR ECLIPSE MARCH 2015:

THE SUCCESSFUL STRESS TEST OF EUROPE'S POWER GRID – MORE AHEAD

Policy Brief • 15 July 2015

On 20 March the European electricity grid passed with flying colours an unprecedented stress test. No one had experienced the effects on the grid of a near to total solar eclipse taking place on a mostly sunny weekday morning with about 90 gigawatts of solar power installed and highly concentrated in some regions.

This was not just a Europe's first. It was a world's first.

SolarPower Europe

European Network of Transmission System Operators for Electricity

entsoe

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EXECUTIVE SUMMARY

Solar eclipses occur all the time, all over the globe. In the traditional generation mix with fossil fuels, they were not a big deal for power system operators. **This changed with the increasing share of solar generation.** An eclipse is thus a button 'off' for solar, taking huge amounts out of the system, within seconds. For power systems where every second needs to be in perfect balance as power moves at the speed of light, very high variations in solar generation that take place during an eclipse are indeed a challenge. The 20 March 2015 solar eclipse was thus first of its kind event; **a true stress test, passed successfully.**

For the first time, a near-total solar eclipse was going to take place on a sunny week day morning over a territory with 90 gigawatts of installed solar panels which were highly concentrated in some regions. No power grid had previously experienced this combination of a large-scale solar eclipse and large quantities of PV.

Despite the unprecedented risk, Europe kept switched on throughout the three hours the eclipse lasted.

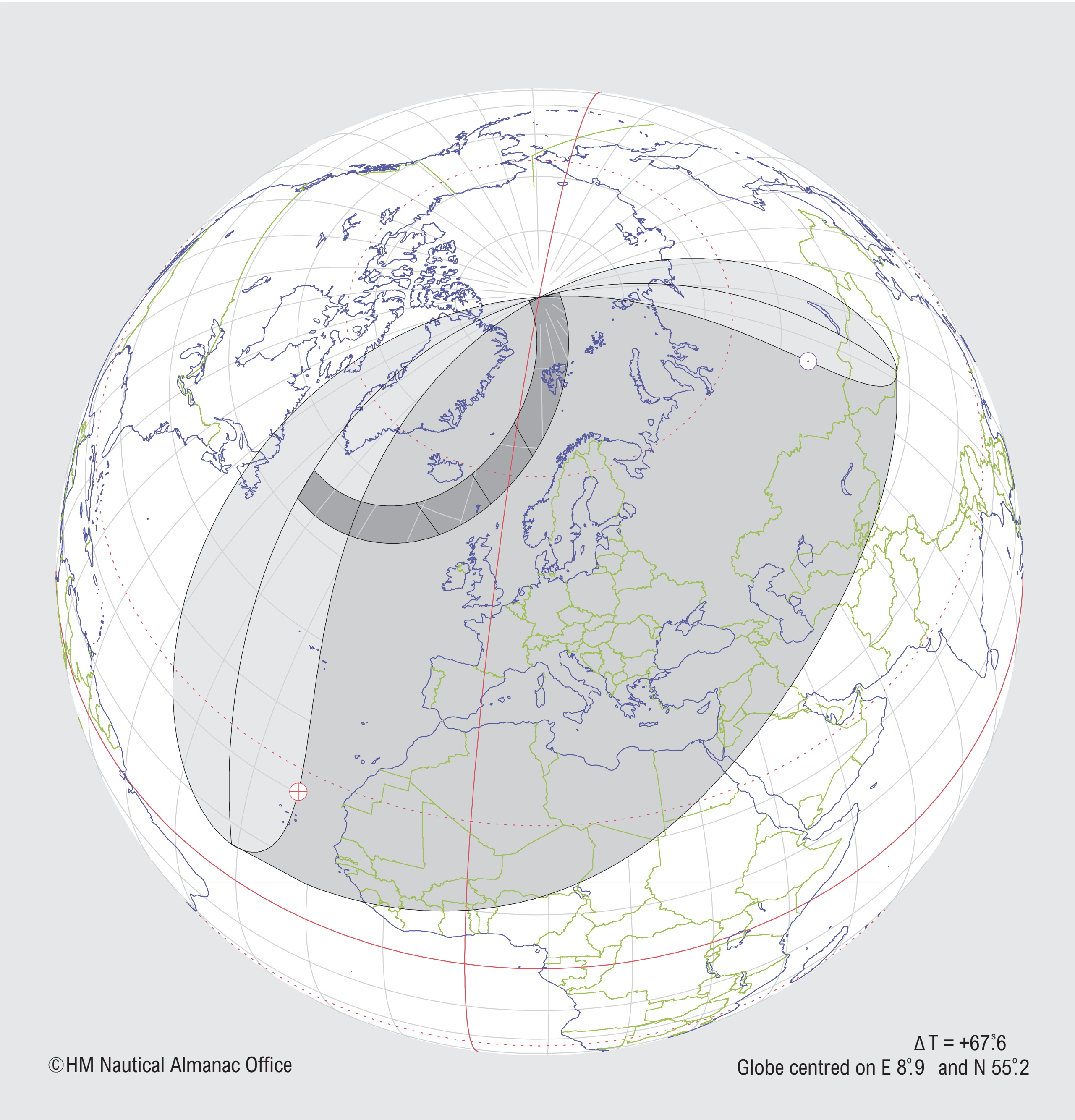
In the first part of the this report, which has been elaborated by ENTSO-E, you will learn in detail what happened on this very special morning for the power sector, as if you had been in the control room yourself. You will read how a first-of-its kind pan-European teleconference, with updates on the state of the grid every 15 minutes, kept the double-sized control rooms in constant communication. You will learn how, with regional security coordination centres where one could monitor on screen the effects of the eclipse on the system, grid operators were able to complement their data with essential information from their neighbours. The integration of renewable and often decentralised generation requires the teaming up of regional and pan-European TSOs and their stakeholders. And you will also understand that not all regions in Europe are exposed the same way: Southern Germany and Northern Italy were the most problematic regions, as a result of their huge share of PV in the mix.

This stocktaking exercise, looking at the variety of options and measures taken in the various countries, is thus very useful as it allows us to identify the ingredients of success. It helps us to both learn and to prepare better for the next event, at which the share of solar power is projected to be **three times higher than today!**

Photovoltaics (PV) is today, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity. Germany, Italy and Spain represent 78 % of the total ENTSO-E solar generation (91 TWh).

In the second part, which has been elaborated jointly by ENTSO-E and SolarPower Europe, the report deep dives into the future: 2021 and 2026 are the next large-scale European eclipses. This future must include European and regional cooperation so as to diminish costs to customers and to ensure reliable power supplies all across our continent. We single out that major efforts have to be undertaken in five areas: adoption and implementation of network codes, regional cooperation, empowerment of customers, smartening of grids to accommodate system services provided by PV and the link up of retail and wholesale, of distribution and transmission.

This joint report sheds light on the fact that stronger cooperation between grid operators, distribution and transmission services, and PV generators is essential to secure power supplies. This way we ensure system safety but also **serve active customers**, who should participate in all markets and start to use PV massively all across Europe. For empowering the customer we need smarter grids, proper data handling and an enhanced interface between distribution and transmission.



PART 1:

THE POWER STRESS TEST PASSED

INTRODUCTION

On 20 March, a solar eclipse took place affecting Continental Europe. The eclipse started at 08:01, in the western part of Portugal and ended at 11:58 in the eastern part of Romania.

The ENTSO-E community launched **several actions internally to be prepared for this phenomenon**. A study was performed by the ENTSO-E Subgroup System Protection and Dynamics (SG SPD). Its task was to analyse the effects this eclipse could have on the grid in Continental Europe. Other regional groups were asked to analyse the impact and make a solid plan to handle the eclipse. For Continental Europe the subgroup Coordinated System Operations formed a taskforce (TF) that looked at the countermeasures that could be useful during the eclipse.

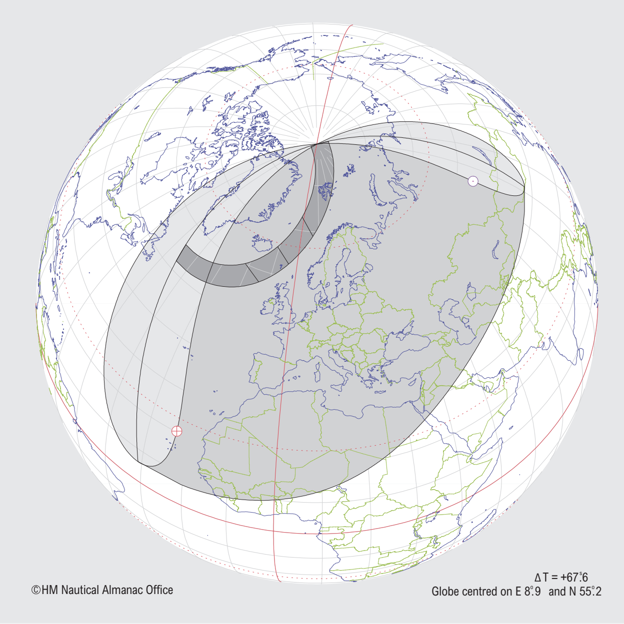


Figure 1: Solar Eclipse trajectory 20 March 2015

This report addresses the following issues related to the solar eclipse:

- Summary of the forecast analysis
- Preparations and Coordination of TSOs in advance and during the solar eclipse
- PV feed-in on 20 March 2015
- Frequency behaviour that was observed during the eclipse timeframe.

1. FORECAST ANALYSIS

1.1 CONTINENTAL EUROPE

In 2015 the installed capacity of PV in the synchronous region of Continental Europe was estimated at approximately 89 GW. The analysis in advance of the solar eclipse showed that the influence of the eclipse might potentially cause a reduction of the PV feed-in by more than 34 GW in case of clear sky conditions in Continental Europe (see figure 2). Together with weather experts, the TF estimated the power gradient to be 2 to 4 times higher than normal daily PV ramping. This situation could have posed **serious challenges** to the regulating capability of the interconnected power system in terms of available regulation capacity, regulation speed and geographical location of 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 2 shows a comparison of expected feed-in from solar on 20 March in case of clear sky conditions, with and without solar eclipse. Note that the x-axis is in UCT time. Figure 3 shows the amount of installed PV generation and the estimated impact on PV feed-in during the eclipse per European country

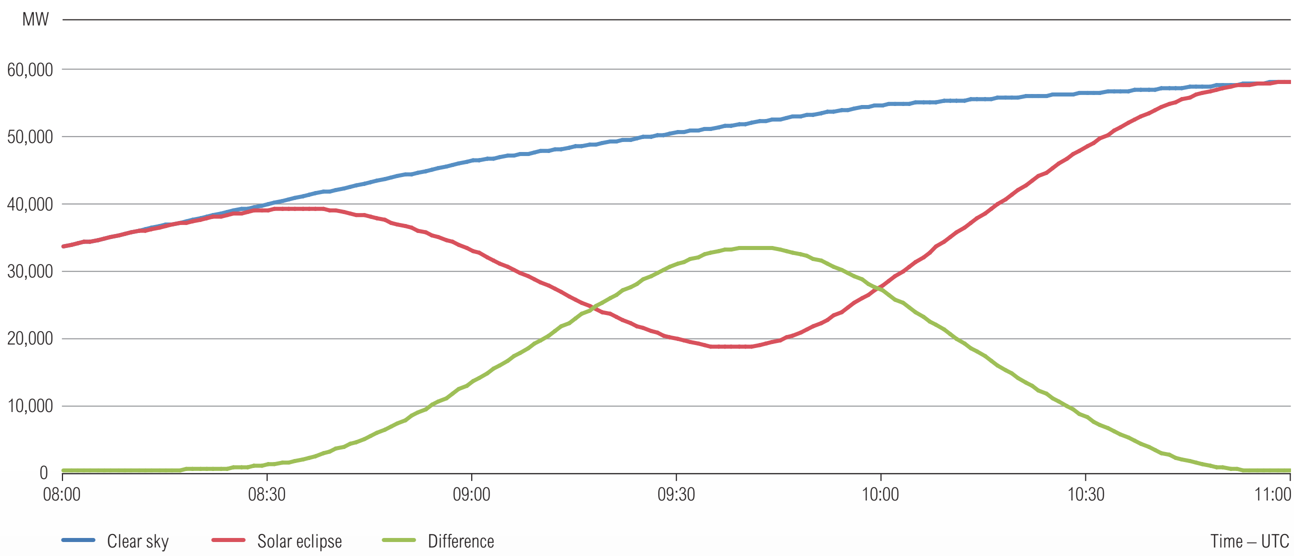


Figure 2: Comparison of expected feed-in from solar on 20 March during clear sky conditions with and without solar eclipse.

Since the study results of the SG SPD was that the solar eclipse would not cause a dynamic effect on the grid, the operational TF Solar Eclipse focussed on quasi-static behaviour and the gradient of changes of PV generation (within minutes).

The input of the operational TF was the basis for all further analysis and defined the **bundle of counter-measures** that could be taken by central European TSOs to cover solar eclipse effects on frequency and flows. It was pointed out that first level of responsibility to handle solar eclipse issues is on the TSOs with PV installations (i. e. Germany, Italy, Spain, etc.). The solar eclipse led to a **strong coordination of measures** aimed at keeping TSOs ACE close to zero in real-time, so additional needs of coordination were required in the operational planning phases and in real-time to avoid frequency deviations outside the 200 MHz band in order to avoid the risk of disconnection of dispersed generation (ref. to chapter 3).

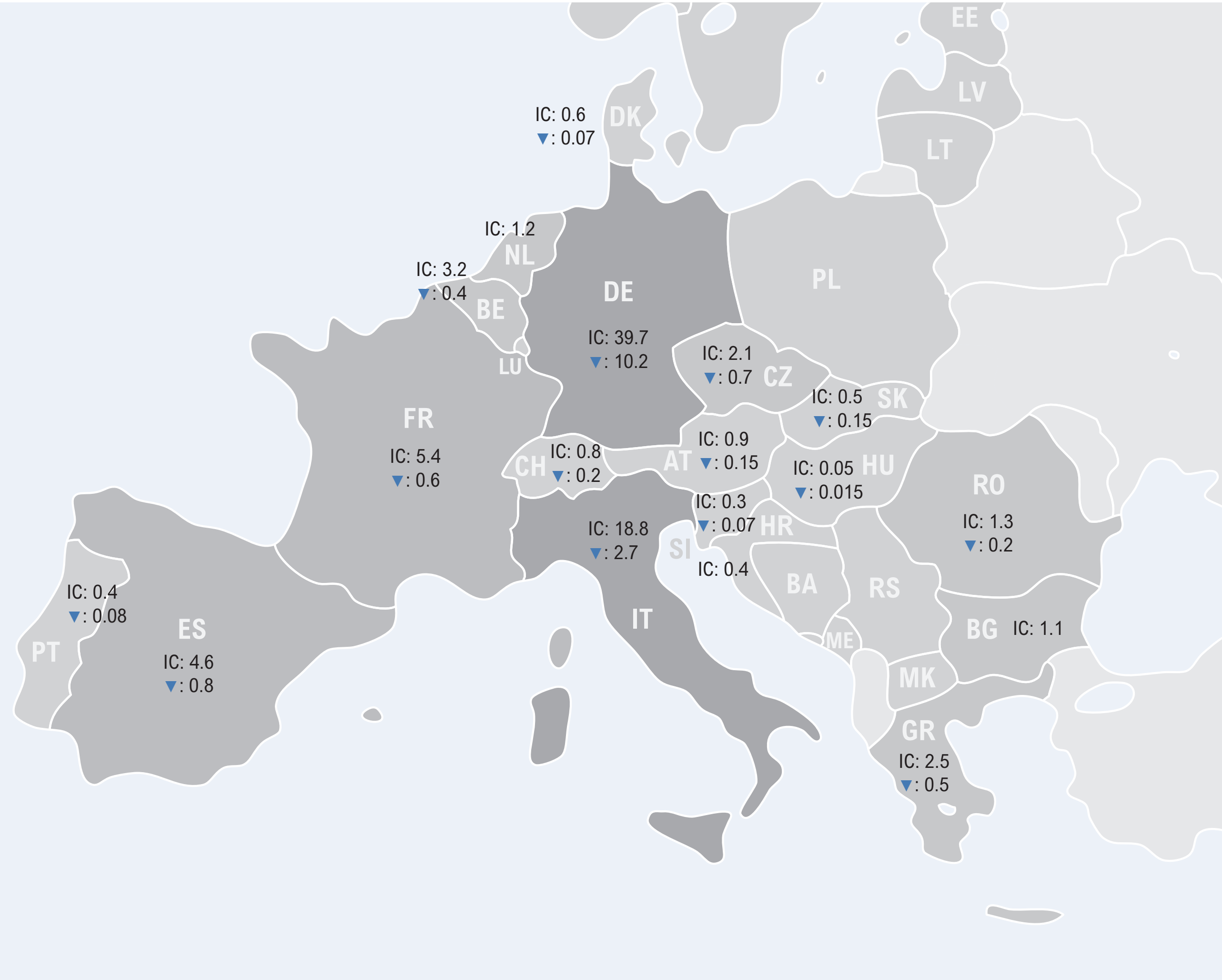


Figure 3: Continental Europe installed PV capacity in GW (IC) and estimated eclipse impact (▼ x GW drop)

1.2 NORDIC

In November 2014, the RG Nordic (RGN), including TSO from DK East, FI, NO and SE, established a working group to ensure Nordic measures and communication concerning the operational handling of the solar eclipse on 20 March. As the Nordic region would not itself be significantly affected by the reduction in photovoltaic (PV) power production, the focus was on investigating the level of **Nordic regulation flexibility** that likely would be available to support Continental Europe (CE), and maintaining communication with neighbouring CE TSOs.

In the days leading up to the eclipse it became clear that the CE TSOs did not have to rely on Nordic regulations for balancing their systems during the event. Instead, RGN was encouraged to limit the exchange between CE and the Nordic synchronous system (NSS) to a level where, in the unlikely event of a blackout in CE, the Nordic system security would not be jeopardized. The Nordic system would then be in a position to help re-energize CE. Based on dynamic power system analyses, the capacities given to the market (ATCs) were 800 MW import to and 3,500 MW export from NSS towards CE. All automatic supporting functions on the interconnections were in operation to be able to supply a possible imbalance in Continental Europe.

The exchange between the Nordic region and Continental Europe was southbound on the HVDC-interconnectors during the event, and was to some extent affected by the limitations on the interconnectors, which lead to some price differences between the areas. The HVDC-interconnectors experienced the most limitations in the northerly direction, but this had no impact on the market.

1.3 GREAT BRITAIN

Forecasts for Great Britain (GB) assumed demand suppression due to people watching the event. During the partial eclipse in August 1999 there was a 3 GW drop in demand over the eclipse. Forecasts for 2015 assumed 40 % of the 1999 effect (see figure 4), based on the level of media interest and weather forecasts for the day. In the event, flattening of the demand curve at peak suggests a small demand suppression of around 10 % of the 1999 effect. In addition, there was around 1,300 MW of demand increase, predominantly due to the increased lighting load due to the duller weather. **It is interesting to note the lag at the end of the event as people seem very slow to turn the lights off again.**

Weather during the eclipse turned out very dull and overcast over much of the country, particularly in London and the South East. This resulted in the eclipse not being visible over most of the population centres, and so limited public interest on the day.

The loss of embedded PV generation caused around 1 GW of demand increase, around 200 MW higher than forecast. The overall forecast error on the day was high, but not exceptional for a normal day.

The demand increase was well dealt with by the control room in real time using pumped storage. Plans for the event had ensured that **maximum possible pumped storage was available** over the eclipse, and this was utilised as planned. At one point all six Dinorwig machines were generating at the same time, which is unusual.

Wind generation during the eclipse dropped by around 10 % (500 MW), as forecast, due to the fall in wind speeds associated with eclipses.

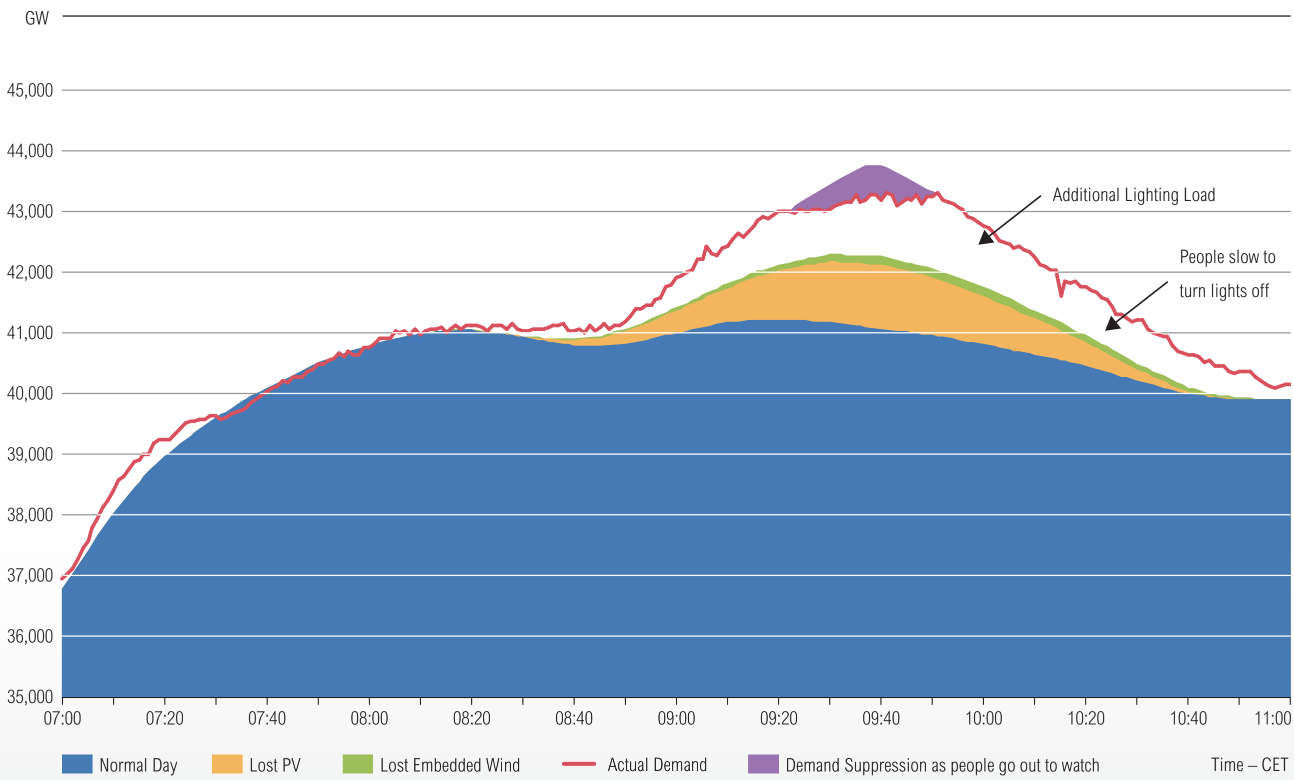


Figure 4: Expected demand of load in GB on 20 March 2015

2. PREPARATIONS AND COORDINATION OF TSOs AHEAD AND DURING THE SOLAR ECLIPSE

Due to different sizes of TSOs, and to different national regulations, TSOs had to evaluate and to confirm both on national (with regulator and ministries, DSOs, power plants) and European level (with other TSOs), their individual needs of measures, and the feasibility to activate different measures.

Because of the large amount of PV installed, Italian and German TSOs were the most affected in relation to their normal levels of available reserves. Other countries had to handle solar eclipse effects in the range of more common changes in the level of PV injections, and of power plants connection/disconnection. Terna and the German TSOs worked on national level with all stakeholders (regulator, DSOs, balancing responsible parties, power plants etc.) to evaluate and confirm measures that were taken by TSOs on short request and/or reserved with predefined lead-time for activation.

The following measures were implemented by TSOs so that they had the ability to handle the effects of the solar eclipse:

MEASURES IMPLEMENTED BY TSOs

- Higher Reserves: Some of the TSOs did increase their amount of primary, secondary and tertiary control reserves to be better able to keep their Area Control Error (ACE) close to zero.
- All TSOs had stated that they would keep their individual ACE close to zero in real-time (i.e. faster than 10 to 15 minutes).
- Strategic use of pump 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 procured approximately double the amount of reserves in comparison to normal operation (see table).
- The German TSOs established a special operational concept for activation of reserves and emergency reserves during the solar eclipse.
- The TSO Terna (Italy) has reduced the total NTC on the northern border of Italy to 1,000 MW.
- In real-time operation, some TSOs have used strategic pump storage power plants.
- According to the German Renewable Energy Act, German TSOs have to market the renewable feed-in via the power exchange. German TSOs successfully marketed the forecasted amount of PV at the quarterly hour market. This ensured that the German TSOs only needed to ensure that they could handle the difference between the quarterly hour market and the real feed-in with high gradient in real-time.
- The TSO Terna (Italy) had a preventive decrease of planned PV production in the day-ahead market of around 4,400 MW; equivalent to installed capacity shutdowns between 7:00 am till 2:00 pm.

MEASURES IMPLEMENTED BY TSOs (continued)

- All TSOs had agreed to have as little as possible planned outages in their grid during the time of the solar eclipse. This measure offered the best possibility to have a strong and well-meshed system to cover possible load flow deviations and was already implemented in annual operational planning coordination.
- Capacity on the HVDC cables was reduced by between 18 % and 50 % for the Nordic, UK and CE regions. This ensured synchronous area's 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.
- An operational teleconference called "RG CE real-time frequency monitoring Telco" was held among the five TSOs of the frequency-monitoring group (Amprion, REE, RTE, Swissgrid, Terna). This Telco is normally started if frequency deviation exceeds predefined values. For the solar eclipse this Telco was in place during the entire solar eclipse to avoid any extra time that would otherwise be needed to start it.
- RG CE SG CSO Telco: A back-up Telco among managers of system operation took place during the solar eclipse in order to have a permanent platform to coordinate bilateral or multilateral measures if needed.
- Extra training of control room operators and exercises on coordination procedures were set up especially for this event.
- A lot of TSOs organized the control room with extra operators during the event.
- Some TSOs went into preventive activation of crisis policy, in line with their national crisis organization.
- There was continuous communication between control rooms in CE and the Nordic system during the eclipse, if the need for supportive power in CE should occur.

The table on page 12 gives an overview of available positive and negative individual TSO reserves and additional reserves procured due to the solar eclipse or available via normal balancing. These values are either estimated or correct values.

A part of these reserves have been especially procured by the TSOs to face the exceptional event of the eclipse. Depending on national mechanisms for reserve procurement and pricing, costs of such procurements can be different from one country to the other, and can't be compared. The costs indicated below are those the TSOs had to face for reserve power. It should be noted at once that the disconnection of PV during the eclipse has resulted in higher power prices during that period.

- For Italy the costs of the additional downward/upward reserve (secondary and tertiary reserves) during solar eclipse: approx. 140 kEuro
- For Germany the cost of additional control power procurement: approx. 3.6 MEuro.
- For Czech Republic the cost of additional control power procurement: approx. 215 kEuro.
- For Netherlands the cost of additional control power procurement: approx. 150 kEuro.
- For France, the cost of an additional downward/upward reserve (primary and secondary reserves) during solar eclipse: approx. 40 kEuro.

TSO / COUNTRY	Available total upward / positive TSO reserves (primary, secondary, tertiary, others) including additional reserves for solar eclipse ((MW)	Additional upward / positive TSO reserves for solar eclipse (primary, second-ary, tertiary, others) (MW)	Available total downwards / negative TSO reserves (primary, secondary, tertiary, others) including additional reserves for solar eclipse (MW)	Additional downwards / negative TSO reserves for solar eclipse (primary, secondary, tertiary, others) (MW)
Austria	500	0	395	0
Belgium	1,227	0	223	0
Bosnia	250	0	0	0
Bulgaria	300	0	196	149
Croatia	180	0	360	0
Czech Republic	1,658	411	868	308
Denmark	0	0	200	500
France	5,500	1,500	10,000	1,500
Germany	9,675	4,920	8,975	3,854
Great Britain	1,100	200	750	200
Greece	600	400	300	300
Hungary	800	250	160	150
Italy	6,863	1,966	9,348	4,937
Netherlands	1,135	450	335	0
Poland	2,916	0	4,818	0
Portugal	850	100	1,000	0
Romania	1,500	700	1,500	1,000
Serbia	700	0	1,000	0
Slovakia	941	100	579	73
Slovenia	420	0	250	0
Spain	> 3,500	1,500	> 5,000	0
Switzerland	800	0	800	0
Turkey	5,500	200	5,300	200

3. PV GENERATION ON 20 MARCH 2015

Figure 5 shows the aggregated PV feed-in during the solar eclipse from a subset of European TSOs who could provide data on a quarter hourly basis. The ex-ante analysis showed that in case of clear sky conditions, the PV feed-in could be higher than as shown here.

The estimated PV injection at the start of the eclipse (approx. 09:30 CET) was approx. 22 GW. During the maximum of the solar eclipse at 10:00 CET the feed-in decreased to approx. 14 GW. The estimated PV injection at 12:00 CET was 35 GW. Hence the change in injection between 10:30 and 12:00 was approx. +21 GW.

The table on page 14 gives an overview of influence of the solar eclipse on the PV feed-in of European TSOs. For some TSOs this is an estimate and for others this is not known due to the low amount of installed PV capacity in their grid.

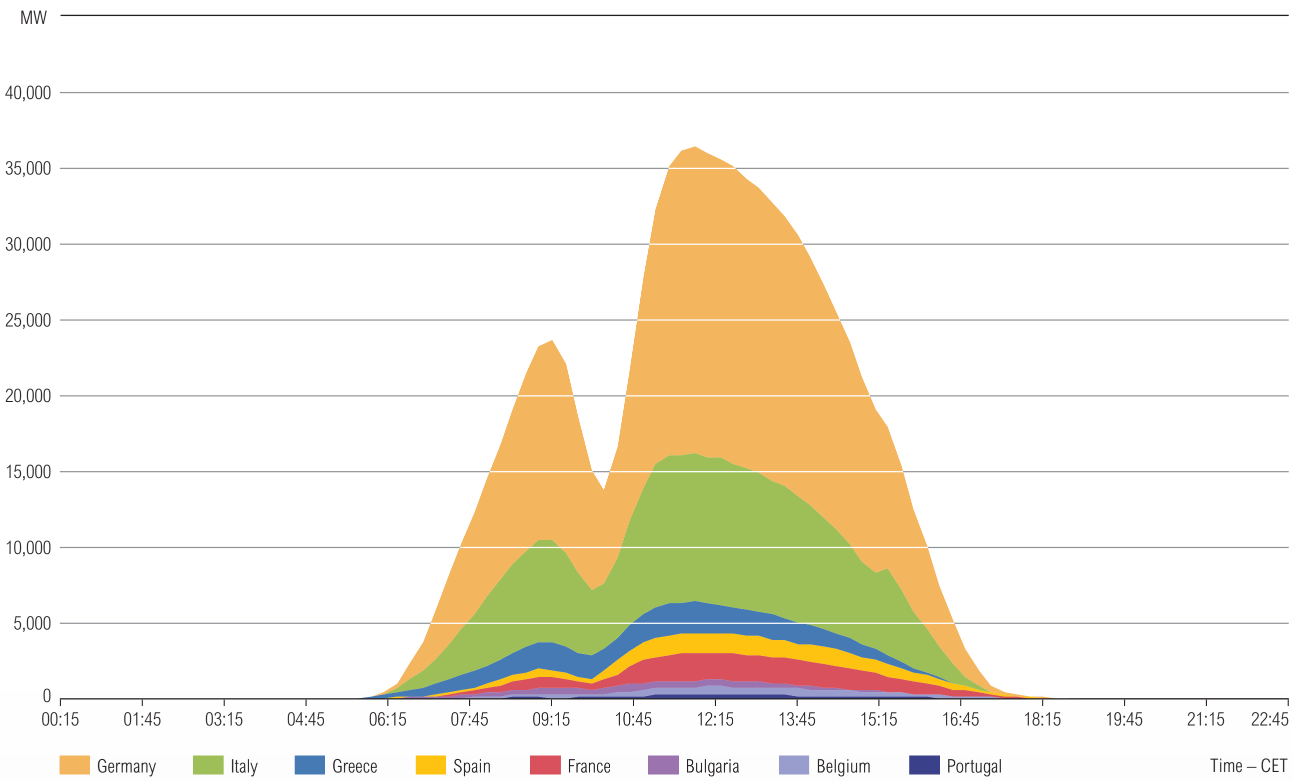


Figure 5: Aggregated PV feed-in from a subset of European TSOs
(Sources: Amprion, TenneT TSO GmbH, 50Hertz, TransnetBW, Terna, IPTO, REE, RTE, ESO, Elia and REN)

A) Estimated installed solar capacity in March 2015 (MW)
B) Estimated PV injection (MW)/PV generation before the eclipse (approx. 09:30 CET)
C) Estimated injection with full solar eclipse (MW)/PV generation at the maximum of eclipse (approx. 10:30 CET)
D) Day-ahead forecast value for PV generation at 12:00 CET (MW)
E) Estimated real PV injection at 12:00 CET (MW)
F) Estimated max. change in injection from 10:30 to 12:00 CET (MW)
G) Impact on consumption (if known) (MW)

TSO/Country	A)	B)	C)	D)	E)	F)	G)	Comment
Austria	750	308	150	400	400	250	0	Weather as predicted
Belgium	2,916	293	81	1,650	519	438	0	Weather was cloudier than forecast
Bosnia	0	0	0	0	0	0	0	Unknown
Bulgaria	1,039	321	381	437	455	74	0	
Croatia	400	17	12	0	20	8	0	
Czech Republic	2,282	1,260	500	1,540	1,540	1,040	0	Clear weather
Denmark	600	65	10	0	110	100	0	Cloudy weather
France	5,300	880	650	2,300	1,900	1,250	1,000	Weather was cloudier than forecast
Germany	37,268	13,200	6,200	22,000	21,000	15,000	- 2,500	Weather cloudier then expected (high fog in North-West Germany)
Great Britain	4,640	542	583	1,820	1,450	870	1,000	Cloudy weather reduced impact of PV reduction
Greece	25,000	1,100	650	0	1,290	640	0	Weather was sunny as forecasted
Hungary	50	20	20	0	40	20	0	Weather was sunny as forecasted
Italy	18,856	6,718	4,340	7,500	9,653	5,313	0	Sunny day with some clouds in the north (Alps region)
Luxembourg	0	0	0	0	0	0	0	Unknown
Netherlands	1,200	600	200	0	600	400	0	Weather very foggy no solar eclipse visible in the NL
Poland	7	0	0	0	0	0	0	Installed capacity 7 MW; no measurement or forecast
Portugal	400	60	50	0	160	110	0	Estimated values
Romania	1,300	456	248	0	346	98	200	
Serbia	0	3	2	0	4	2	0	
Slovakia	500	294	145	0	350	205	100	Weather was sunny as forecasted
Slovenia	266	117	67	140	122	111	0	Estimated values, real data available in D+1
Spain	4,600	580	285	0	1,350	1,065	0	Weather has been cloudier than forecast
Switzerland	800	180	80	0	335	255	600	Cloudier than forecast
Turkey	0	0	0	0	0	0	0	Cloudy weather in most of Turkey. Limited amount of installed PV

4. FREQUENCY QUALITY DURING THE ECLIPSE

During normal operation, frequency has to be managed within an acceptable range of ± 50 mHz, called **standard frequency range**[1)].

The following limits are also monitored on real-time operation in order to avoid wide area incidents caused by frequency disturbances:

- Some generators start disconnecting at 50.5 Hz. However, 50.2 Hz is the frequency leading to automatic Disconnection of PV generation in some zones[2)].
- 49 Hz is the frequency leading to automatic load shedding. Pump load shedding shall start over that limit.

The evolution of system frequency[3)] between 08:00 and 12:00 is presented in the following diagram:

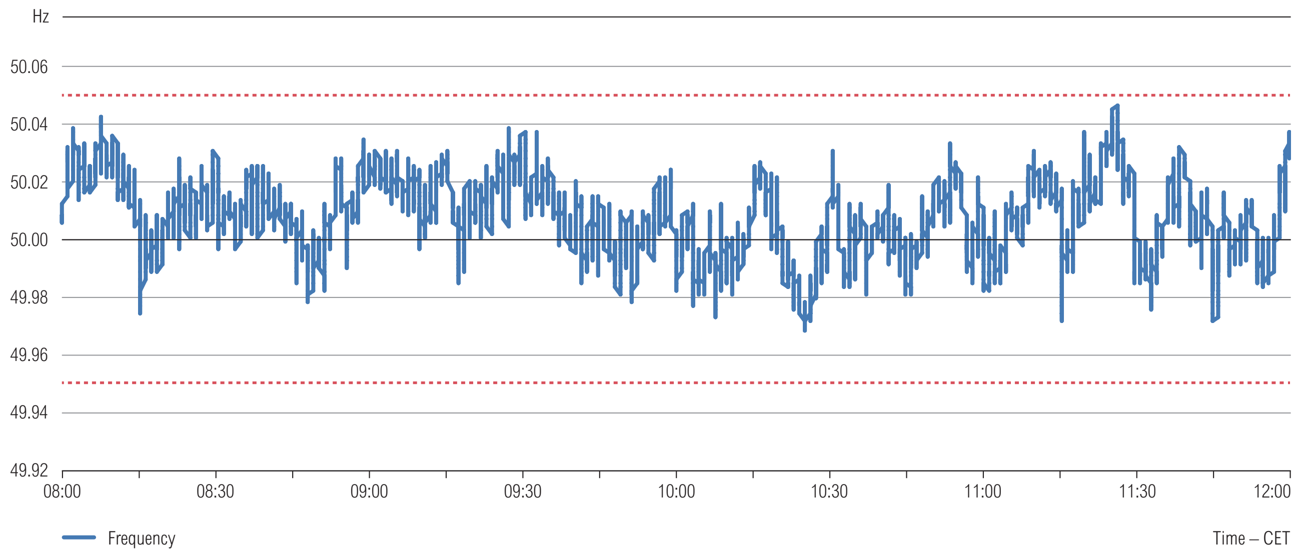


Figure 6: Frequency evaluation between 08:00 CET and 12:00 CET of Continental Europe

The frequency quality during the eclipse timeframe **was very good**. The maximum absolute frequency deviation from the set point observed was 48 mHz (between -49.968 Hz and 50.048 Hz), therefore **at no point the acceptable range of ±50 mHz was exceeded.**

1) Frequency measurement from Swissgrid SCADA with 1 second granularity.

2) A large amount of PV installed capacity was initially tuned for automatic shedding at 50.2 Hz. A wide retrofitting campaign was performed since 2011 in order to avoid this technical specification, mainly on German and Italian areas. On German area 4 GW of PV installed capacity remains not retrofitted. For Italy the completion of retrofitting will be fulfilled in 2015

3) Cf. Network Code on Load-Frequency Control and Reserves, Chapter 3 Frequency Quality, Article 19 Frequency quality target parameters

The GB system is **much smaller** than the Continental European system, and so routinely experiences larger frequency fluctuations. Statutory frequency limits are ±0.5 Hz, and operational standards allow 1,500 excursions per year outside the operational targets of ±0.2 Hz.

Frequency was well controlled throughout the event, only briefly exceeding operational targets at 0800 CET.

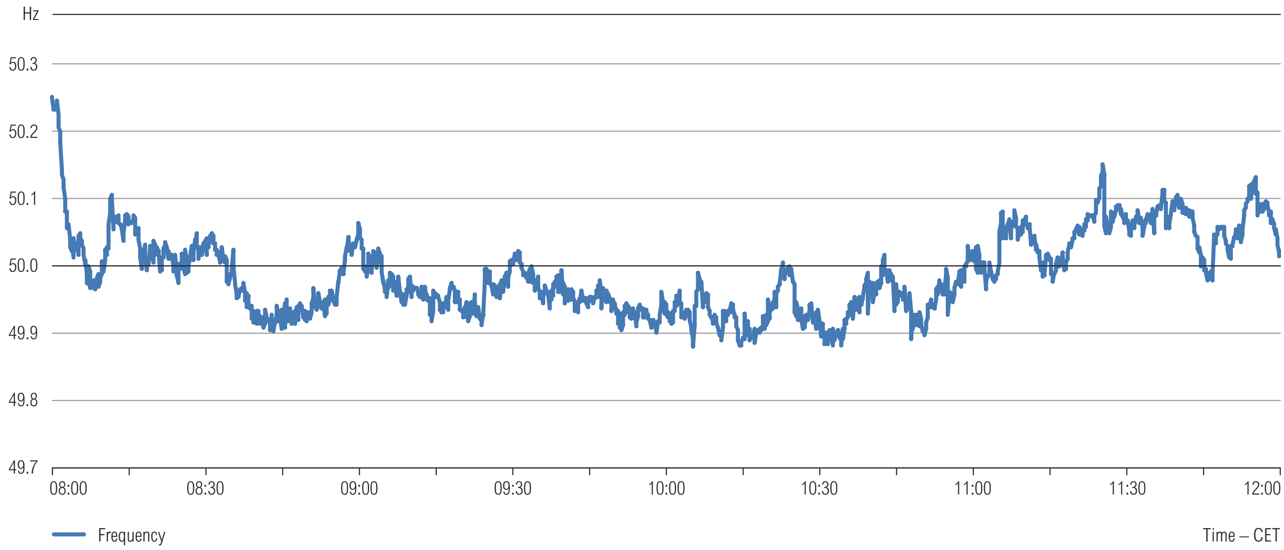


Figure 7: Frequency evaluation between 08:00 CET and 12:00 CET in Great Britain

5. SUMMARY AND CONCLUSION

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.

Due to the **careful and coordinated planning** of the TSOs in advance (from August 2014 until March 2015) and thanks to a good communication before and during the eclipse it was not necessary for TSOs to provide any assistance to each other. Even though during this predictable event no issues occurred, it still indicates careful planning and coordination between TSOs in all operation phases will be necessary during similar events.

The main lessons learned are as follows:

MAIN LESSONS LEARNED

- **Controllability of PV:**

  As Terna successfully showed, it is possible to disconnect in advance part of the installed PV production. This shows promising results for the future, but to use such practice on a large scale the following needs to be taken into consideration:

  - The exact amount of PV feed in that will be switched off
  - Timing of switching PV off from the grid and switching PV back on to the grid
  - Steps that are taken during switching PV back on to the grid
  - Which retroactive effect shutdowns have on the system

- **Observability of PV generation:**

  - A clear description of the installed PV capacity and their capabilities is needed 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

- **The German TSOs had instructed the power plants to keep in continuous operation, which had a positive impact on the available control power within a quarter of an hour.**

MAIN LESSONS LEARNED (continued)

- **Quarter-hour market:**
  - The hourly day-ahead market was mainly unaffected by the eclipse. German TSOs successfully marketed the PV in a first step at the hourly market and in a second step at the quarter-hour market.
  - In case of high demand or supply, there is a de facto quarter hour market (OTC and power exchange) in DE, AT and CH which can provide significant contributions for intra-quarter-hourly compensation. This solution is a fine-tune balancing done by the TSO.
  - The quarter-hour market showed big spreads. A European coupling of quarter-hour markets should contribute to increased liquidity of the market and reduce these spreads. At the same time the quarter-hour trading should be combined with the hourly market.

- **Thanks to higher amounts of reserves, all European TSOs managed to balance themselves and to keep their individual ACE close to zero in real-time (i.e. faster than 5 minutes). Nevertheless, these additional reserves have a significant cost, and this solution must be kept for exceptional situations.**

- **Thanks to strong coordination and transparency in preparation for and during the event, all the TSOs were aware of the risks and the existing remedial actions and methods of implementation, and the availability of help from each other should the need arise.**

In the future, fast gradient changes of PV feed-in are expected due to the increasing amount of installed PV capacity in the grids. Such events will be a **challenging opportunity for the RSCIs to provide strong support to the TSOs** in their task of guaranteeing secure and efficient operation of the interconnected system in every critical grid condition.

PART 2:

CONNECTING MORE SUN – READY FOR 2021 AND 2026

INTRODUCTION

Solar eclipses similar to that of 20 March 2015 will occur in 2021 and 2026. By then, the amount of solar panels in Europe will have tripled. SolarPower Europe foresees that in 2021, the amount of installed PV capacity would add up to 170 GW. In 2026 it would reach 250 GW.

Solar generation, which now covers 3.5 % of the EU demand for electricity, could cover 7 % in 2021 and 10 % in 2026 going up to 15 % by 2030. This further uptake of solar power will be supported by continued cost decreases of photovoltaics. In less than 10 years, PV system prices have already decreased by around 75 %. Today, large-scale PV generation costs already compare with conventional electricity production, and the costs of solar power at the distributed level are already below retail prices in many countries. By 2025, large scale power system are expected to produce at 4 to 6 ct€/kWh, going down to 2 to 4 ct€/kWh by 2050.[1)]

1) Fraunhofer Institute for Solar Energy Systems ISE/ Agora Energiewende: PV Cost Vision for 2050, 01.09.2014

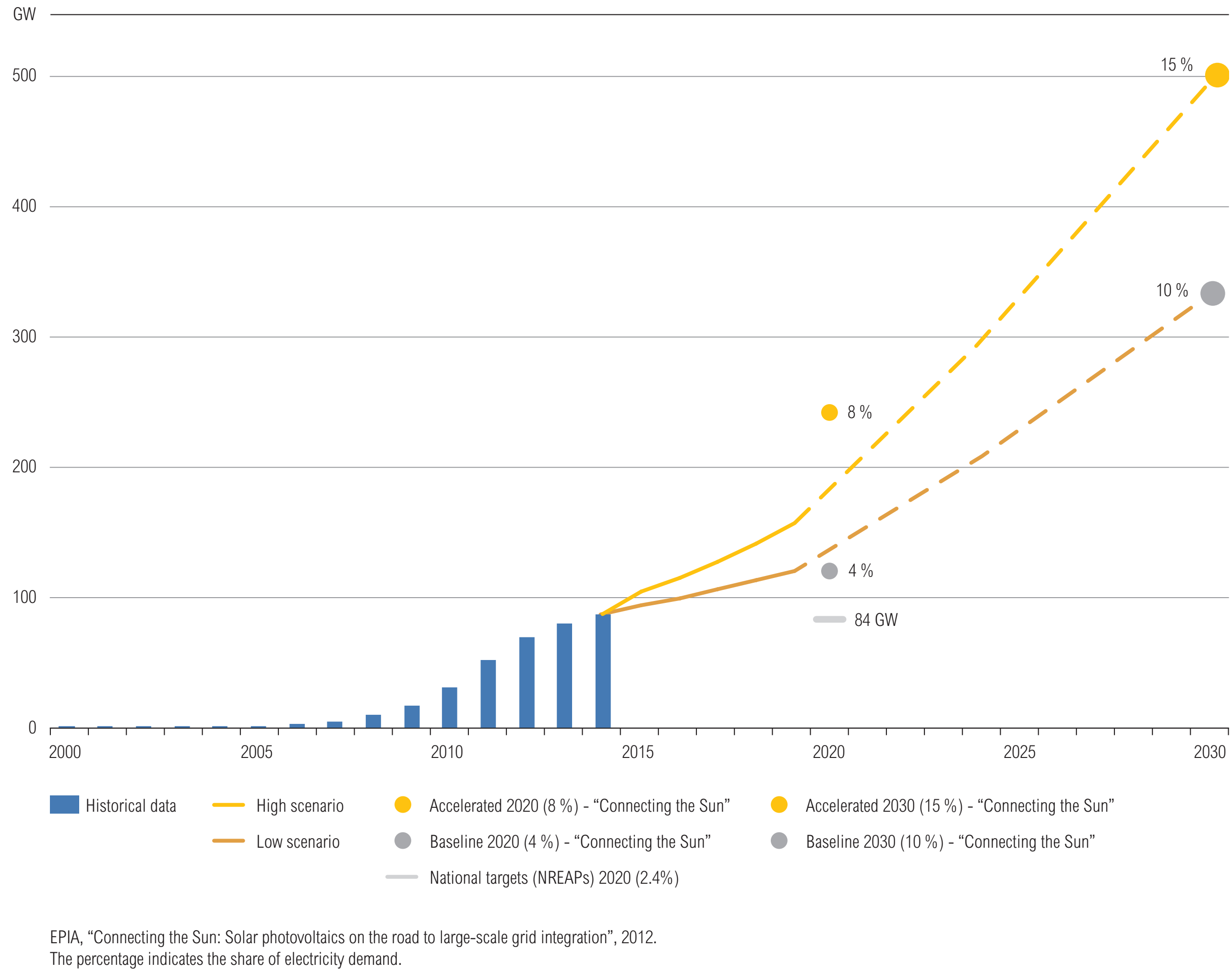


Figure 8: Solar PV cumulative capacity forecast compared to SolarPower Europe's scenarios

As described in part one, managing a solar eclipse of a significant scale with 90 gigawatts took a year's meticulous preparation and coordination. **Managing similar eclipses in 2021 and 2026** with twice and three times as much PV in Europe **calls for change and rapid action in key areas**.

1. THE KEY INGREDIENTS OF AN ECLIPSE-PROOF POWER GRID

In ENTSO-E and SolarPower Europe's view progress is needed in **five key areas** to keep the EU grid safe during the upcoming eclipses of 2021 and 2026: upgraded market- and system rules, reinforced regional cooperation, active customers, new system services provided notably by PV, and an enhanced TSO/DSO cooperation.

1.1 NETWORK CODES ARE THE FIRST PART OF THE ANSWER

The EU network codes are setting the new rules of the game for an electricity system that is experiencing a vast paradigm shift. They have been drafted by ENTSO-E following guidelines set by ACER and the Commission.

All codes were heavily consulted with stakeholders. **In mid-2015, ACER had recommended for adoption 9 of the 10 network codes.** Two, capacity allocation and congestion management (CACM) and the requirement for generators (RfG), have been adopted by Member States and after scrutiny by Parliament and Council should become binding across the EU member states and will be implemented by all the ENTSO-E members, which covers the EU and 6 additional countries.

The RfG code especially defines important elements to allow the integration of more and more decentralised and variable energy sources safely into the transmission grid. Some countries, like Italy and Germany, have already started partial retrofit programmes of their PV installations to make them compliant with the requirements set in the code, thus concretely working towards greater system safety.

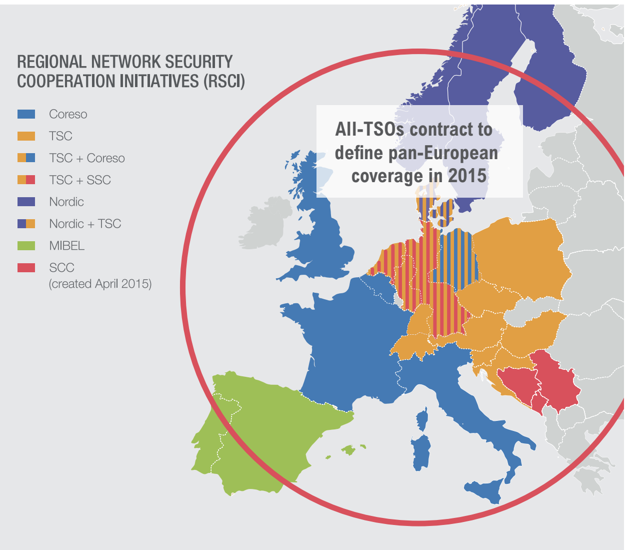
The Demand Connection Code (DCC) soon to enter 'comitology' lays the groundwork for customers to become active and have more control of when they consume electricity.[1)]

All the network codes are vital pieces of a jigsaw which, when put together, will create a stronger, more sustainable and cost-efficient power grid for Europe and its citizens. Having all these streamlined rules in place is the first step to guarantee the safe management of future solar eclipses in Europe at the most reasonable cost for society.

1) The annex of this report provides an extensive overview on how network codes will play an important role to facilitate the integration of renewables.

1.2 REGIONAL SECURITY COORDINATION PROVIDES THE SECOND

This solar eclipse exemplified the importance of regional and pan-European cooperation for Europe's security of supply. The good coordination of TSOs ahead of and during the eclipse was key in getting through the event without any interruption of power supply for consumers. As market integration progresses combined with the rise of variable generation, it seems more and more logical to systematise the regional and pan-European approach to system security. This is already foreseen by the operational network codes.



In 2015, Germany and 12 other member states signed the **Pentalateral Forum Declaration on regional coordination of policies in electricity security of supply.** The Energy Union is also set to give a political push to an already successful voluntary regional cooperation in the energy field, which led to great progress on market coupling, early implementation of pan-EU network rules, and system security as illustrated by the Regional Security Coordination Initiatives (RSCIs) such as Coreso in Brussels, SSC in Rommerskirchen, TSC in Munich or SCC in Belgrade.

Transmission System Operators have been cooperating in regions for years. **RSCIs have been pioneered and developed pro-actively by TSOs.** They offer regional coordination services and provide TSOs with an overview of electricity flows at regional level to complement their own system data. This enables them to identify and manage potential threats to secure system operations arising from large-scale, regional power flows or from extreme natural phenomenon, like solar eclipses for example. RSCIs are to play an increasing role in the future. **Up to now, three quarters of Europe's population is covered by an RSCI.** ENTSO-E has the objective to cover 100 % of the population by having all of its members belong to a RSCI by end 2015.

1.3 CUSTOMERS HOLD THE KEYS

Energy transition means more and more dispersed and variable generation. This calls for greater flexibility. Increasing power reserve is one solution but it comes at a cost (as illustrated in the extreme by the case of the March 2015 solar eclipse) and does not always fit with Europe's ambition of decarbonisation.

Given that domestic demand makes up 30 – 40 % of electricity use, giving consumers the opportunity to reduce their consumption at certain peak periods (and save money in the process) represents a huge potential for system flexibility. Demand-side response (DSR) creates value for consumers and society by allowing consumers to be rewarded for changing their consumption behaviour and to therefore reduce the costs of energy. For system operators, it is a cost-efficient way to balance their system. It optimises the utilisation of infrastructure and investments in the grids. The DCC network code provides a framework to deploy DSR-ready electric appliances (able to adjust automatically their electricity consumption).

In view of this great potential and this win-win situation for the consumers and grid operators, demand-side response should be considered on an equal footing with storage and generation. Consumers should be allowed to enter all markets and be able to aggregate regardless of their connection points (distribution or transmission). Being able to act on demand is another guarantee that the 'power stress tests' of 2021 and 2026 will be successful.

1.4 EMPOWERED PV CAN CONTRIBUTE TO THE SOLUTION

As there is great potential in enabling customers to pro-actively participate in system security, there is equally a lot of benefit in **leveraging the system services that solar power can offer to the grid**. Today, PV can already provide some of them. For example, inverters allow solar systems to provide reactive power for voltage support as well as negative balancing power (if controllable). Such services could potentially be extended when combining solar PV with self-consumption and battery storage. In that way, it would also be possible to provide positive balancing power as well as an increased self-regulation on consumption as illustrated in the Table below.

		SOLAR PV SYSTEM SIZE					
		Small scale		Large scale		Aggregation	
		Technical Aspects	Procedures	Technical Aspects	Procedures	Technical Aspects	Procedures
Frequency	FCR	red ●	red ▲	orange ●	orange ▲	green ●	orange ▲
	FRR	red ●	red ▲	orange ●	red ▲	green ●	orange ▲
	RR	red ●	red ▲	orange ●	red ▲	green ●	orange ▲
	FFR	red ●	orange ▲	green ●	orange ▲	orange ●	red ▲
	RM	red ●	red ▲	green ●	red ▲	green ●	red ▲
Voltage	SSVC	green ●	green ▲	green ●	green ▲	green ●	red ▲
	FRCI	orange ●	red ▲	green ●	orange ▲	green ●	red ▲

Source: ReserviceS Project 2014

TECHNICAL ASPECTS	PROCEDURES: Grid Code Requirements, prequalification procedures and Network Code Requirements, amongst other
green ● Implemented	green ▲ Well defined requirements / specifications in most procedures at european level
orange ● Partially implemented / implementable / low cost or investment to enable the required capacities	orange ▲ Poorly defined requirements / specifications or not addressed in most procedures
red ● Not implemented / implementable / high cost to implement	red ▲ Not defined / not possible due to requirements in all or most procedures
Existing Grid Support Services	New Grid Support Services

Existing frequency support services include:

- Frequency Containment Reserve (FCR)
- Frequency Restoration Reserves (FRR)
- Replacement Reserves (RR)

New frequency support services refer to:

- Fast Frequency Response (FFR)
- Ramping Margin (RM)

Voltage support services include:

- Steady Stage Voltage Control (SSVC)
- Fast Reactive Current Injection (FRCI)

In the future, with all the network codes in place and the right communication and measurement technology & infrastructure, especially between distribution and transmission, **Europe will be able to use the full potential of solar power** in terms of system services.

The table above shows what PV can do already for frequency and voltage support services and what it could be doing if procedural and technical prerequisites were in place.

Europe represents today a best in class demonstration project for placing solar power in the energy sector. **The European solar PV sector is experiencing the transition from feed-in tariffs towards a more market-based development framework** with a general move to progressively integrate solar PV in the electricity market at wholesale and retail levels.

This transition is essential to steer innovative approaches. At the same time, it needs to happen smoothly and depends on the right market conditions, so as to avoid destabilisation and price increases. Much of it relies on a strong link between distribution and transmission.

1.5 EUROPE'S ELECTRICITY NEW FRONTIER

A reconsidered TSO/DSO interface is a condition sine qua none not only for the integration of PV, but for other decentralised renewables and planning of the system.

Appropriate arrangements for data management are also needed to ensure that TSOs, DSOs, suppliers and other market participants are able to have access to the required data in a timely and transparent manner.

The upcoming convergence of wholesale and retail markets is one of the main challenges for European regulation to deal with in the next decade. **This convergence can be regarded as the New Frontier for Europe's power system.** ENTSO-E and European associations of DSOs have taken action already on a voluntary basis, signing a memorandum of understanding and subscribing to an agenda of common actions.

2. THE WAY FORWARD

Taking stock of what kept the EU system eclipse-proof on 20 March 2015 is important for preparing the future. Lessons can be drawn from this successful power stress test. They will help prepare the European electricity system and market to connect more sun and pass the 2021 and 2026 'stress tests' with equal success.

The key insight of this report is that those developing new generation technologies and those operating the grid at distribution and at transmission level have to work hand in hand. This is the message that ENTSO-E and SolarPower Europe wanted to convey by co-signing this publication.

2015 TO 2026: INGREDIENTS OF PREPARATION

Managing a high voltage power system, where there needs to be at all times enough generation to cover demand, requires clear visibility and control on how much power is injected in the system. Nearly all solar generation is connected to the distribution level. The overview for transmission on these capacities is yet limited, but has to be build up. The eclipse in March, with 90 gigawatts of PV installed, has been managed, thanks to a thorough and competent preparation. But managing with 250 gigawatts PV installed by 2026, the date of one of the next solar eclipses to hit Europe, requires a yet different preparedness and important adaptations to the system are essential. The objective remains the same: security of supply at lowest cost to society.

CODES COUNT!

The energy transition is changing the power system to a customer centric one, with many new opportunities emerging at the 'new downstream' side of the power sector value chain. The rules of the game have to be adapted to reflect this paradigm shift. The EU network codes, and the requirements for generators and demand connection codes in particular, aim to reflect this new reality of more decentralised and more variable power systems. The RfG code sets the technical conditions to safely integrate large amounts of renewables in the system. PV installations, which are linked to the transmission grid via the distribution grid, need to have certain technical characteristics that allow their safe interaction with sophisticated and sensitive high voltage system. Work on adapting existing PV installations to the RfG requirements, for example as is the case in Italy and Germany, is a concrete step towards greater electricity security.

The Demand Connection Code is equally important as it is setting the conditions for the smartening of grids. Smarter grids mean more active customers able to provide the system with the much-needed flexibility in a cost efficient manner. Innovative and enhanced grids will allow PV and other renewable generation to play a greater role in balancing the system.

NETWORK OPERATORS TO TEAM UP

The linking up of retail and wholesale is where a great deal of regulatory and policy-making effort is needed. Balancing the system can no longer remain the sole responsibility of the TSOs; DSOs have a role to play and regulation should allow this. The next legislative push has to be about opening up possibilities.

ENTSO-E AND SOLARPOWER EUROPE …

… are equally committed to turn the challenge of more and more PV in the system, into an opportunity. The European Commission Energy Union proposal and related legislative initiatives should support their momentum and adapt the framework so that the grid remains eclipse-proof for the next decade to come.

ANNEX:

ROLE OF NETWORK CODES FOR RENEWABLE INTEGRATION

EU network codes are divided into three main categories or 'families' of codes: connection, operation and market code. As the table below shows, integrating the European electricity markets is one of the objectives that led to the drafting of the codes. But equally as important is the integration of renewable energy sources.

CONNECTION CODES	
Requirements for Generators (RfG)	RES technologies have different technical characteristics compared to the generators that have traditionally connected to transmission grids and are often smaller in size. As variable production share rises, more and more grid support services will have to be provided by renewable generators. The requirements in RfG define what ancillary services each generator should be capable of delivering. It does not dictate how these services should be procured or remunerated, leaving this to the market to decide.
Demand Connection Code (DCC)	The DCC ensures that all distribution networks and demand facilities (suppliers and customers) contribute effectively to the stability of the system across Europe. The DCC clarifies the role that demand response will play in increasing the proportion of energy from renewable sources. The code specifies the basic functional requirements for electricity users who want to feed power back into the system from small-scale renewable generation technologies. It provides a framework for making different household appliances 'DSR ready' (able to adjust their electricity usage automatically), making it easier for consumers to provide demand side response.
High Voltage Direct Current Connections (HVDC)	HVDC technology is used to construct interconnectors between countries (such as the East-West Interconnector between Ireland and Great Britain) and to connect offshore wind farms. In the future it could form part of a "supergrid" or provide long distance onshore connections, though is unlikely to completely replace AC onshore. The requirements in the NC HVDC will allow this to happen. Without these requirements, it would not be possible to integrate very large amounts of renewable energy into electricity grids (for example countries such as Ireland and Denmark produce 50% of electricity from renewables at certain times). Hence, the NC HVDC (together with NC RfG) is critical for countries to continue to connect large volumes of renewable energy in future.

OPERATIONAL CODES	
Operational Security (OS)	It defines the TSO-DSO coordination framework critical due to the increasing renewable energy sources installed in DSO networks. It harmonizes the requirements for data provision from grid users ensuring secure integration of RES; a necessary condition for increased RES penetration.
Operational Planning & Scheduling (OPS)	OPS establishes requirements for TSOs with respect to generation forecasts and their accuracy to be employed in the operational security analysis taking into account the uncertainties introduced by RES; the harmonization in this respect will enable more efficient coordinated operational planning and secure RES integration. It introduces requirements for coordinated Contingency Analysis and other relevant Operational Security Analysis at cross border level; this guarantees security of supply in highly meshed areas of the European grid and secure integration of RES. The Adequacy assessment framework included in the code requires contributions of generation from RES to be taken into account therefore early detection and resolution of issues is possible; this is critical for increased RES penetration.
Load Frequency Control & Reserves (LFCR)	The code establishes the technical basis for balancing (reserve dimensioning and activation); it provides the necessary conditions for efficient integration of RES with market solutions that serve system needs (by creating the correct market signals for increased flexibility from generation and demand, the RES penetration is facilitated). Harmonised rules for frequency control management that take into account the characteristics of RES. The code provides the basis for further TSO coordination in optimizing their resources with respect to balancing thus increase the potential for further secure RES integration.
Emergency and Restoration (ER)	The code establishes the framework for the management of frequency deviations; it ensures efficient coordination between the different actors and allows for increased RES penetration as the means for frequency management are used in an optimal way. The code sets up the rules for coordinated TSO actions for system restoration after wide area incidents; clear roles and responsibilities are defined through which RES are efficiently managed during these events. TSO-DSO coordination framework for emergency and restoration detailed; critical due to the increasing RES installed in DSO networks

MARKET CODES

Capacity allocation and congestion management (CACM) & Forward Capacity Allocation (FCA)	The objective of CACM and FCA is to create the largest and most competitive electricity market in the world. The codes set out the rules that will enable a transition from the current system, in which there are different rules for electricity market participants in different countries or regions, to a single set of electricity market rules applied across Europe. A competitive internal electricity market will allow a wider range of companies to enter the energy market, particularly small companies and those that invest in renewable energy sources (RES), and will help guarantee that the electricity system in Europe can continue to operate effectively, notwithstanding changing electricity generation and consumption patterns in Europe. A key role of the forward market (FCA) is to provide market participants with the ability to manage the risk associated with cross-border electricity trading. Market players are able to buy long-term transmission rights (which come in either physical or financial forms) which allow them to hedge price fluctuations within day ahead markets. Long-term transmission rights facilitate cross-border trading, competition and provide efficient and reliable long-term price indication. They create a sound, more stable business environment, which will allow smaller businesses, including RES producers, to enter the market.
Electricity Balancing (EB)	As variable RES keep developing, balancing the grid on real time is more and more challenging. The optimisation of this system at European level is essential to keep the cost under control for consumers across Europe. A key part of the NC EB is that it is a first step towards a more level playing field for all potential providers of balancing services, including demand side response and variable sources (like wind and solar power) by introducing standardised rules. This creates additional revenue streams for RES generators.

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