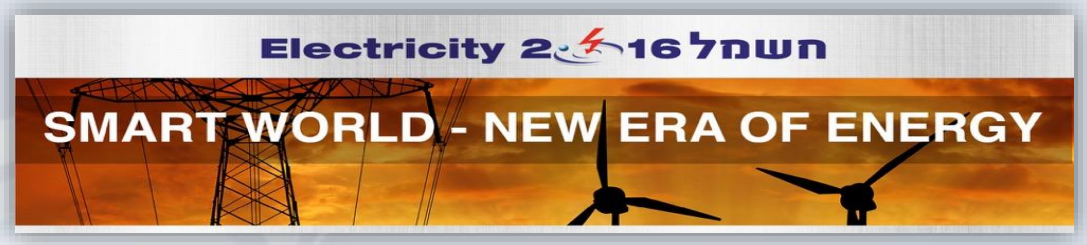
חברת החשמל
Israel Electric



Copying with European Solar Eclipse 2015 and Israeli PV disturbances

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Power Grid Division, IEC

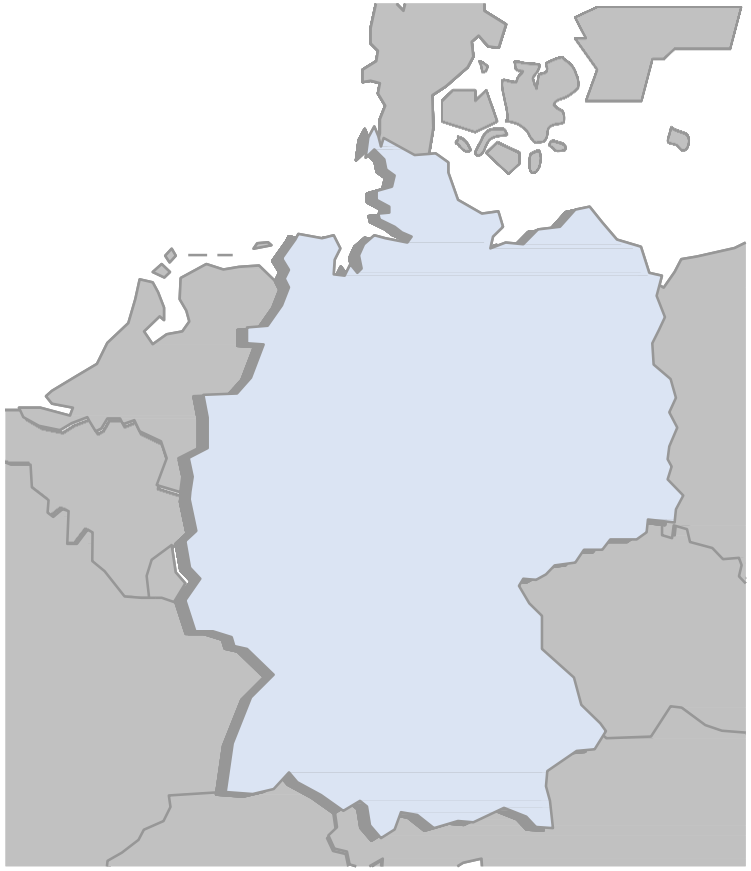
Main subjects

Contents

- German system in a Nutshell
- European Solar Eclipse 2015 challenges and uncertainty
- Preparations and forecast
- Impact analysis , market effect and system operation in real time
- Lessons learned & recommendations
- Israeli renewable energy market – today and tomorrow

German Power System

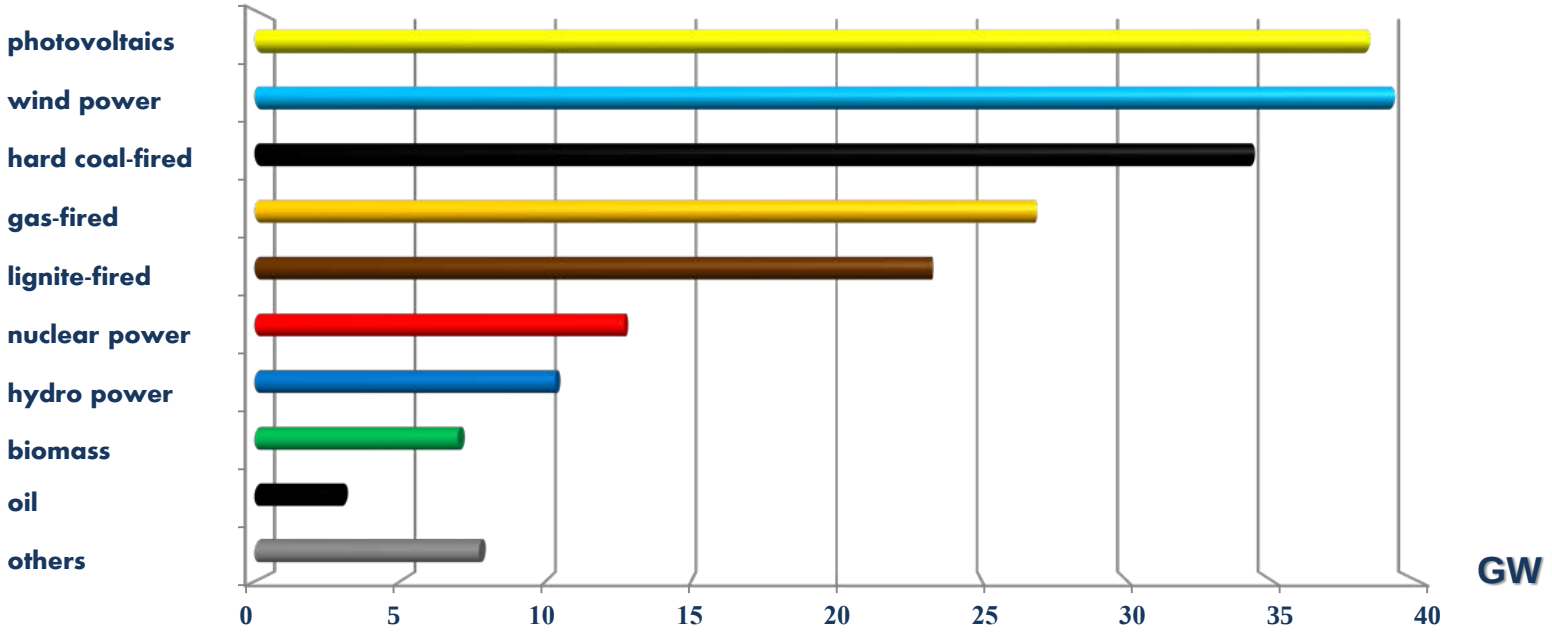
- **Area** 357 168 km²
- **Population** (2015) 81,272 million
- **4 TSOs**
- **883 DSOs**
- **45 million** consumers
- **Peak load** approx. 86 GW
- **Average interruption of electricity (2014):** <12 min



Source: CIGRE 2016 GERMANY

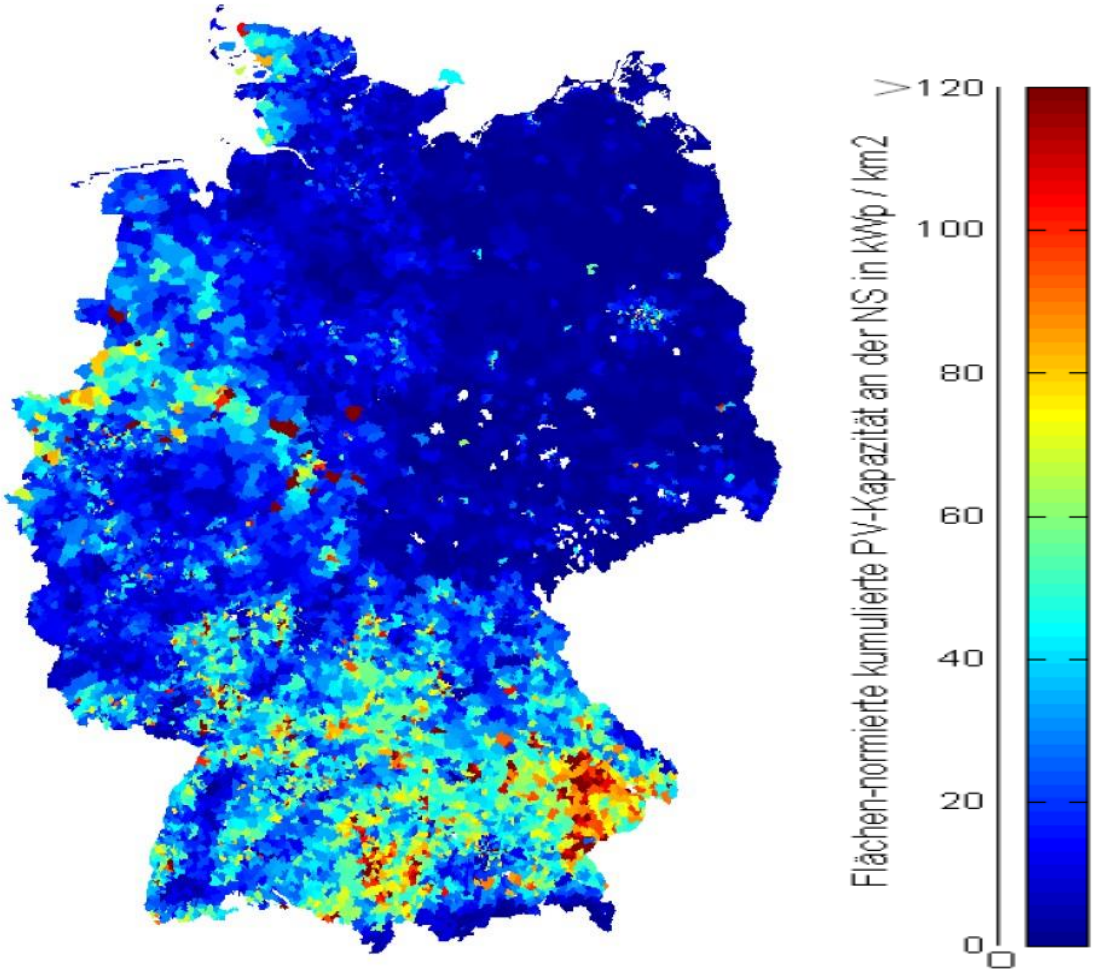
Germany – installed capacity

2014



Source: CIGRE 2016 GERMANY

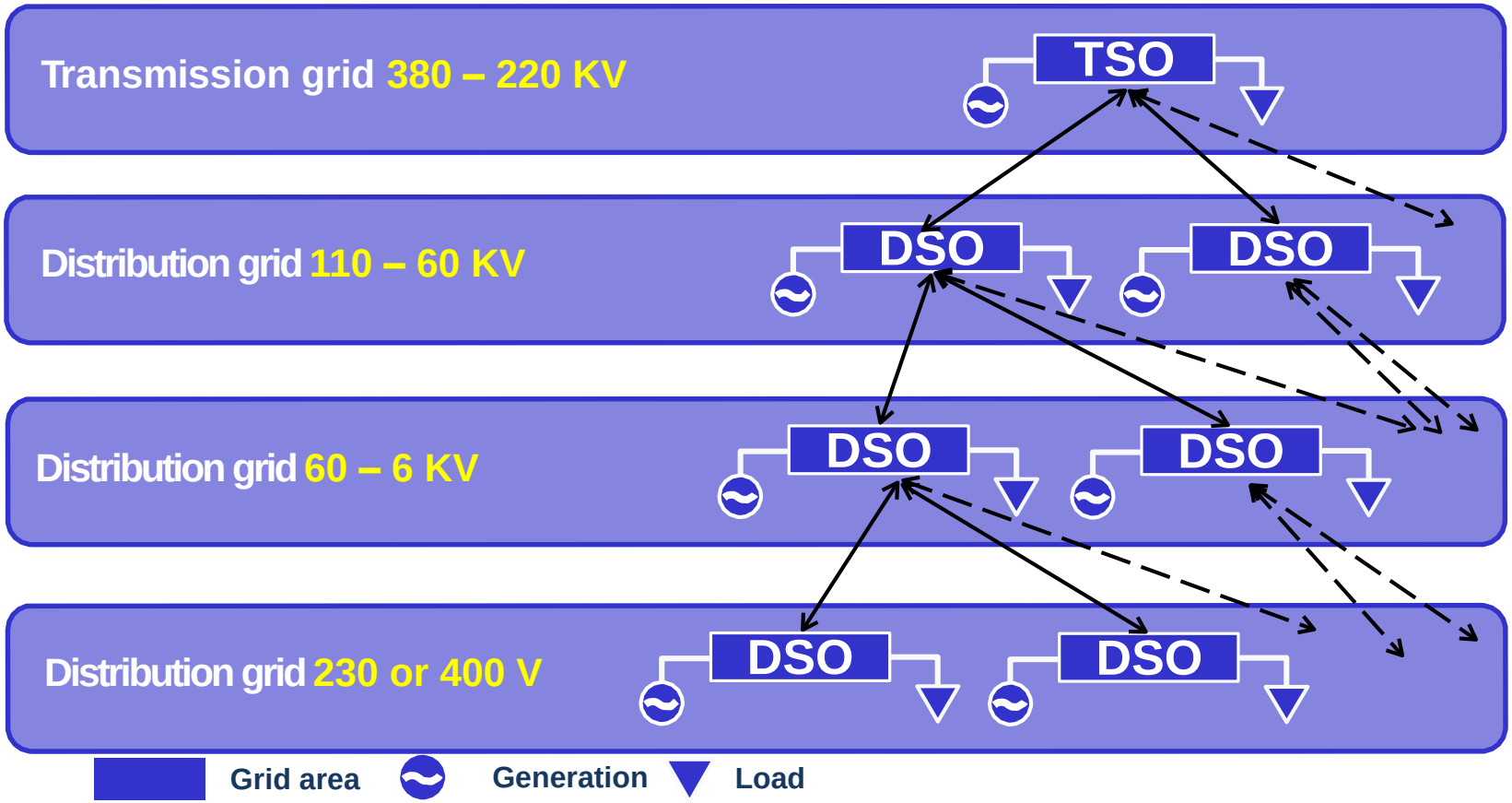
Location and size of PV panels



Source: CIGRE 2016 GERMANY

DSO & TSO cooperation

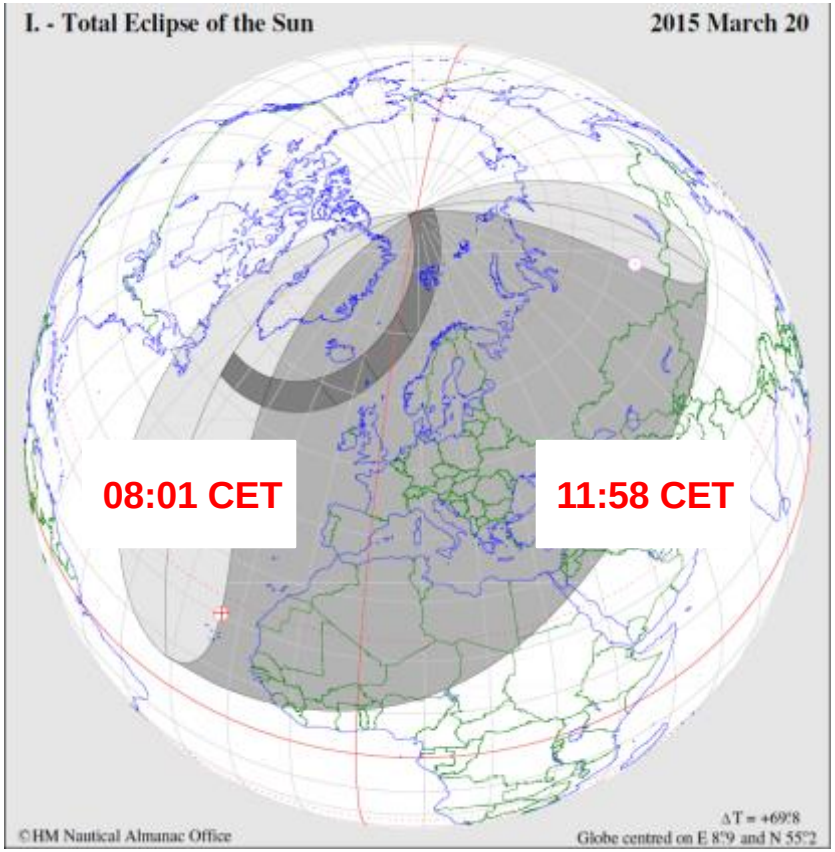
In case of (n- dna OST noitareneg desrepsid hgih ot eud dirg-VHE eht ni snoitaloiv ytiruces -(1 sOSD dna setaitini OST .dirg sOSD ni noitareneg elbawener fo deefni eht rewol ot etaroballoc OSD :edacsac gniwollof gnidrocca serusaem eseht etarepo



Source: CIGRE 2016 GERMANY

European Solar Eclipse 2015 challenges and uncertainty

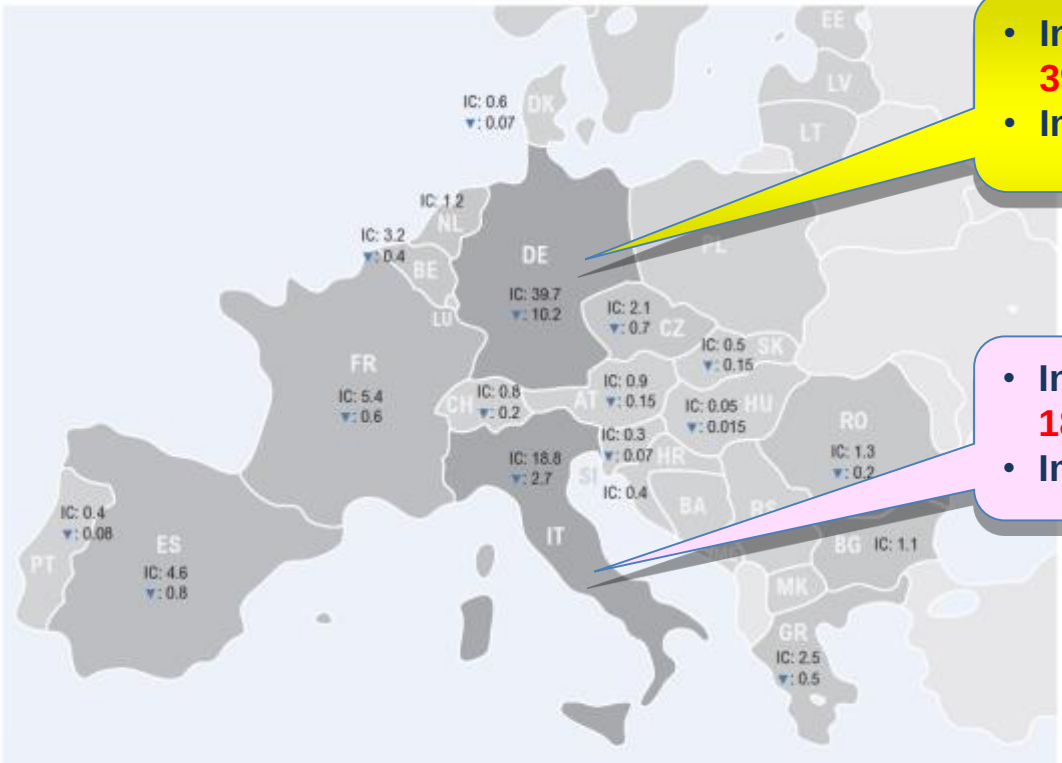
Solar Eclipse trajectory - 20 March 2015



Source: CIGRE 2016 Large disturbance workshop

Impact analysis & preparation

Continental Europe installed PV capacity in GW and estimated eclipse impact



- Installed capacity 39.7 GW
- Impact 10.2 GW

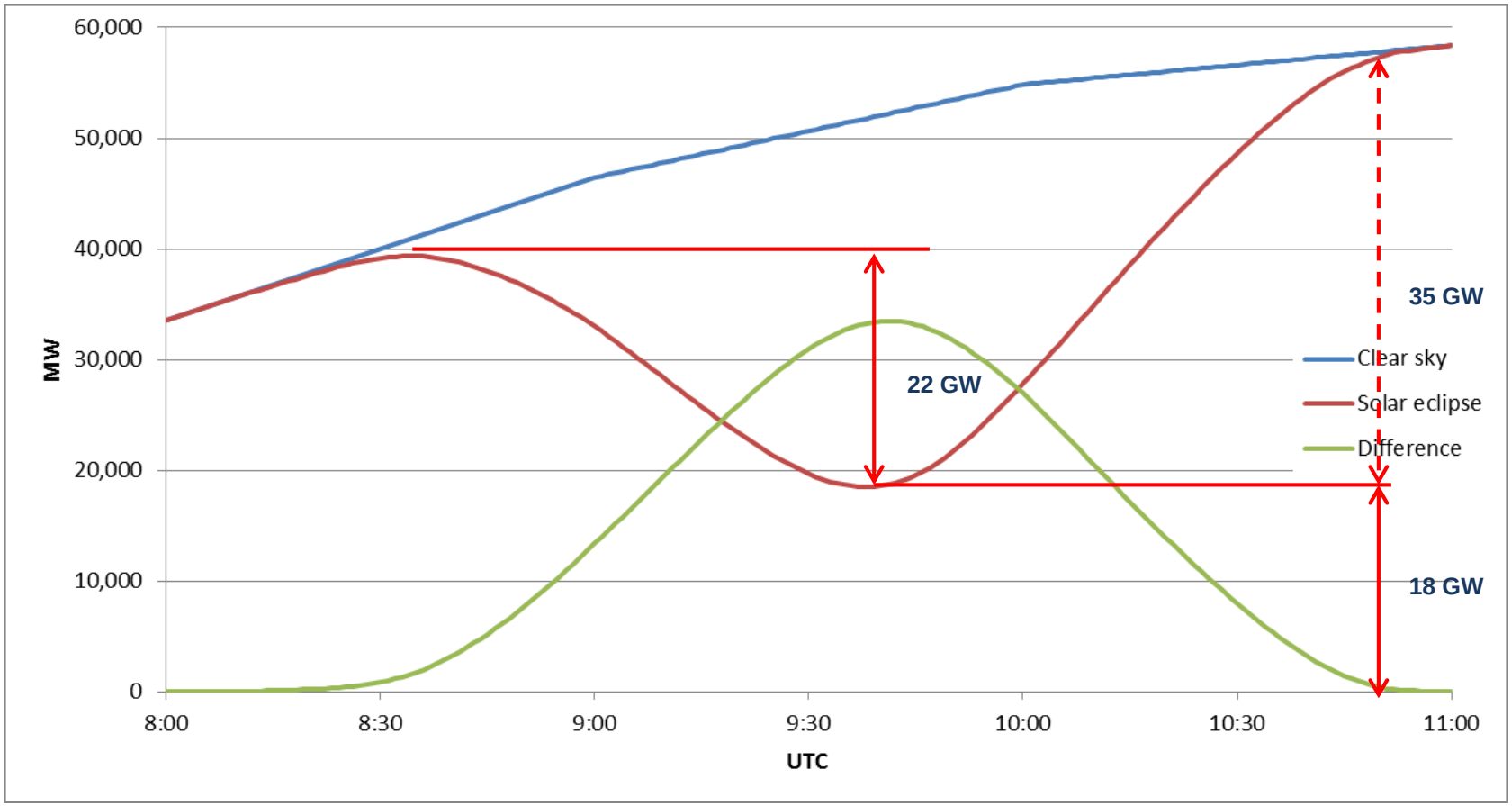
- Installed capacity 18.8 GW
- Impact 2.7 GW

- Installed PV Capacity in Continental Europe: approx. 90 GW
- Influence: potentially more than 34 GW PV reduction

Source: CIGRE 2016 Large disturbance workshop

Impact analysis & preparation

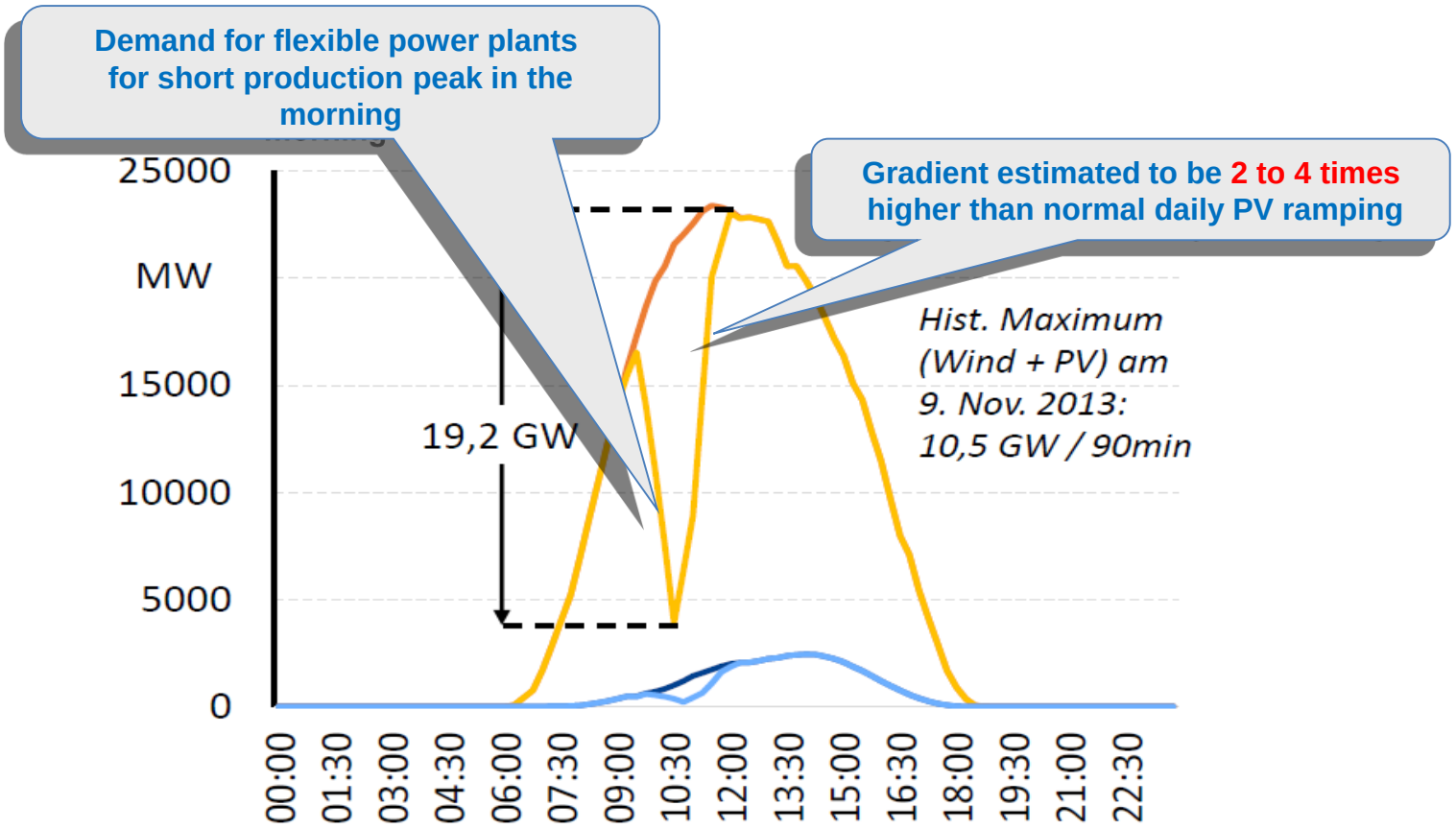
Continental Europe estimated eclipse impact



Source: ENTSO 2015

Impact analysis & preparation

Impact of the Solar Eclipse on PV Generation in Germany, March 20th 2015

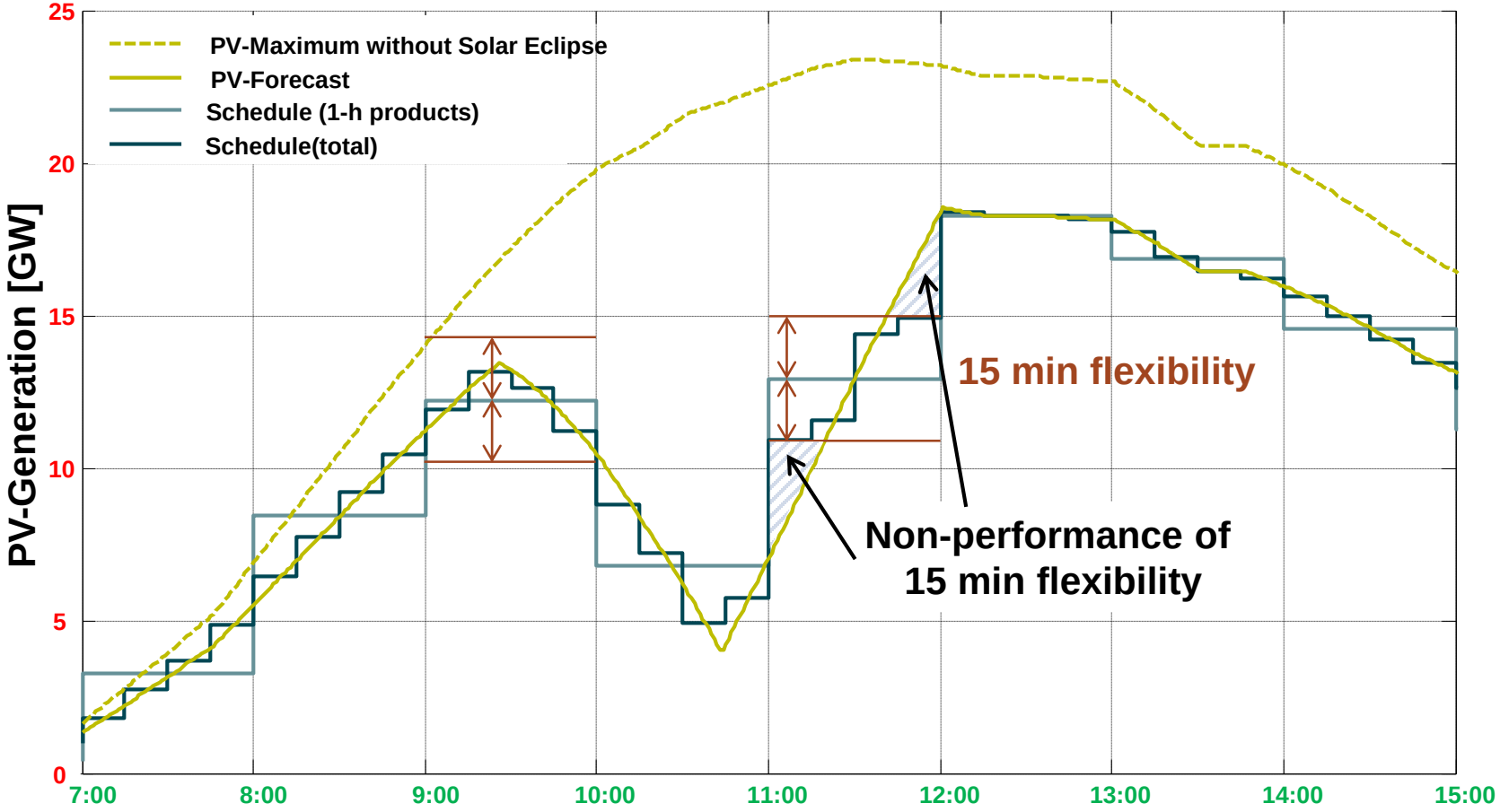


Source: CIGRE 2016 Large disturbance workshop

10

Impact analysis & preparation

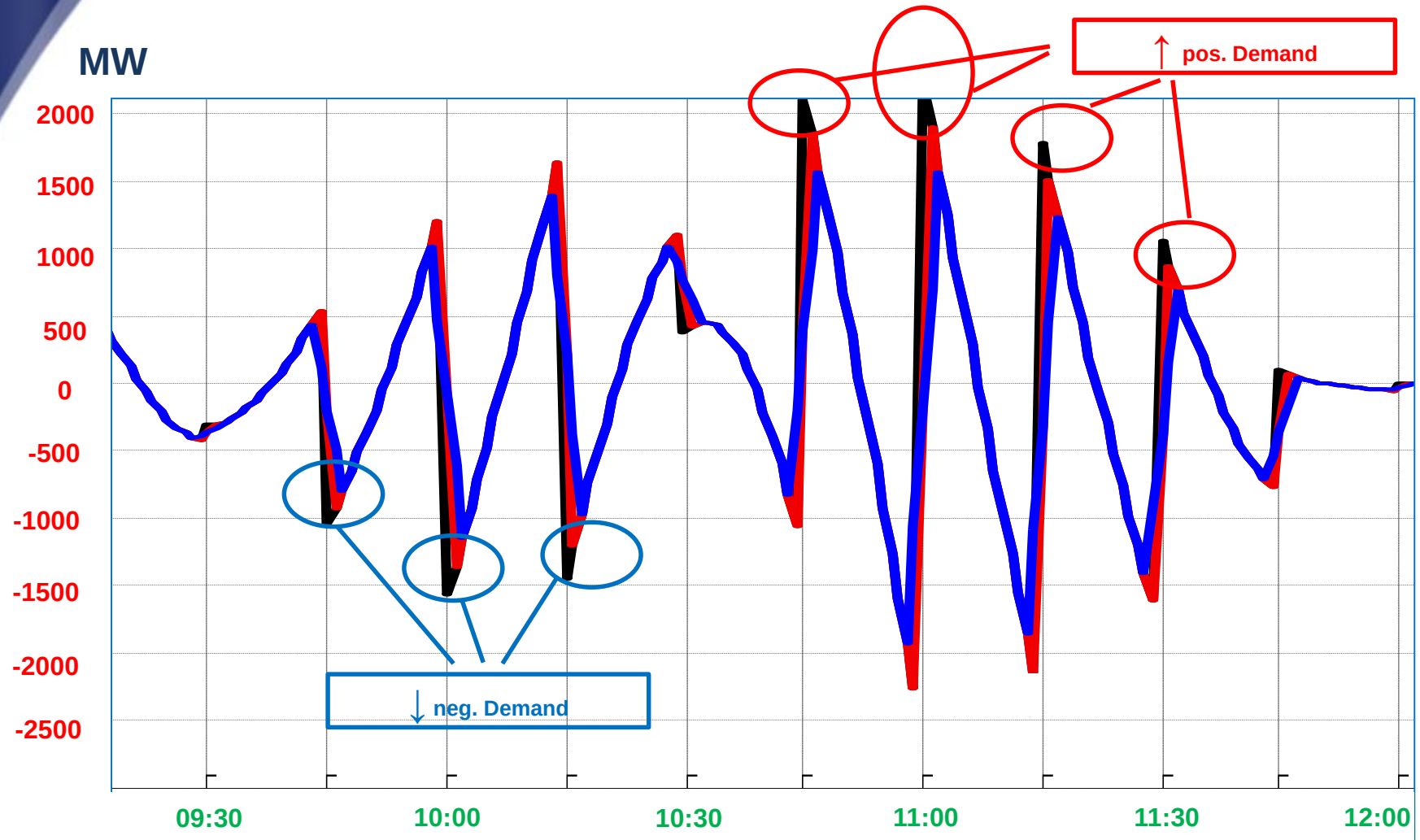
Solar Eclipse ex-ante analysis of German TSOs



Source: CIGRE 2016 Large disturbance workshop

Control energy demand

Solar Eclipse ex-ante analysis of German TSOs



Source: CIGRE 2016 Large disturbance workshop

Impact analysis & preparation

Preparations and Strong Coordination of TSOs in advance and during the solar eclipse

- **Higher Reserves: The German TSOs had procured approximately double amount of reserves in comparison to normal operation.**
- **The German TSOs established a special operational concept for activation of reserves and emergency reserves during the solar eclipse.**
- **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.**
- **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.**

Source: CIGRE 2016 Large disturbance workshop

Impact analysis & preparation

Preparations and Strong Coordination of TSOs in advance and during the solar eclipse (continue)

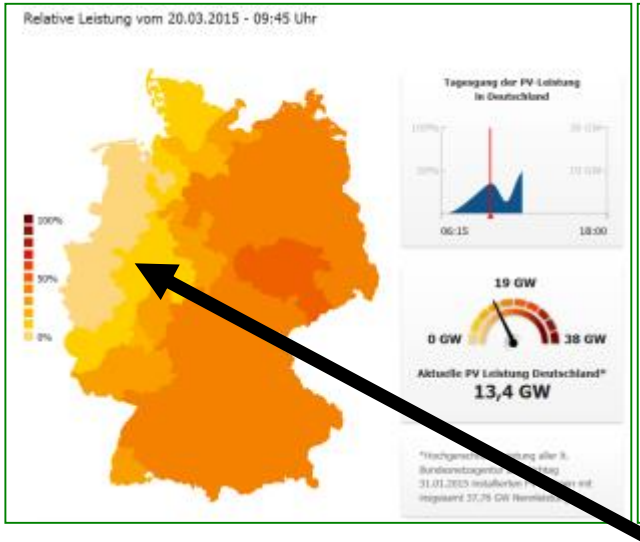
- TSOs had stated that they would keep their individual Area Control Error (ACE) close to zero in real-time (i.e. faster than 10 to 15 minutes).
- TSOs had agreed on to have as little as possible planned outages in their grid during the time of the solar eclipse.
- An operational teleconference called "real-time frequency monitoring Telco" was held among the five TSOs of the frequency monitoring group (Amprion, REE, RTE, Swissgrid, Terna).
- Extra training of control room operators and exercises on coordination procedures was set up especially for this event.
- A lot of TSOs organized the control room with extra operators during the event.

Source: CIGRE 2016 Large disturbance workshop

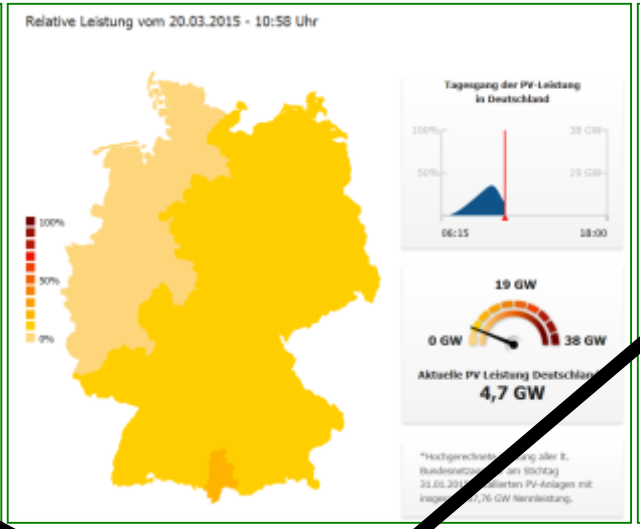
System operations

PV generation - Germany on March 20th, 2015

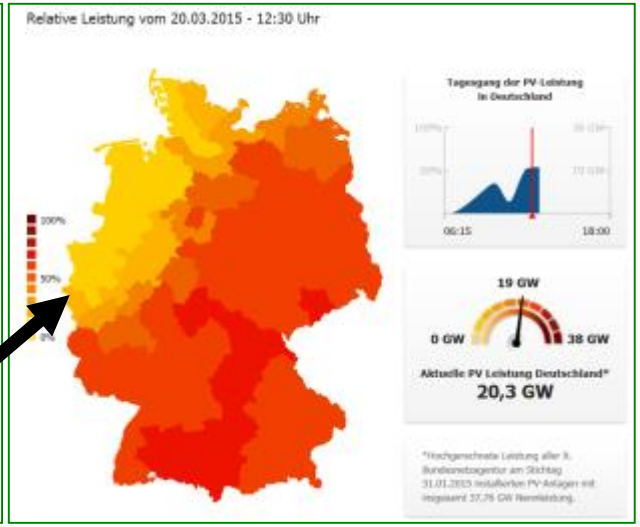
09:45
13,4 GW



10:58
4,7 GW



12:30
20,3 GW

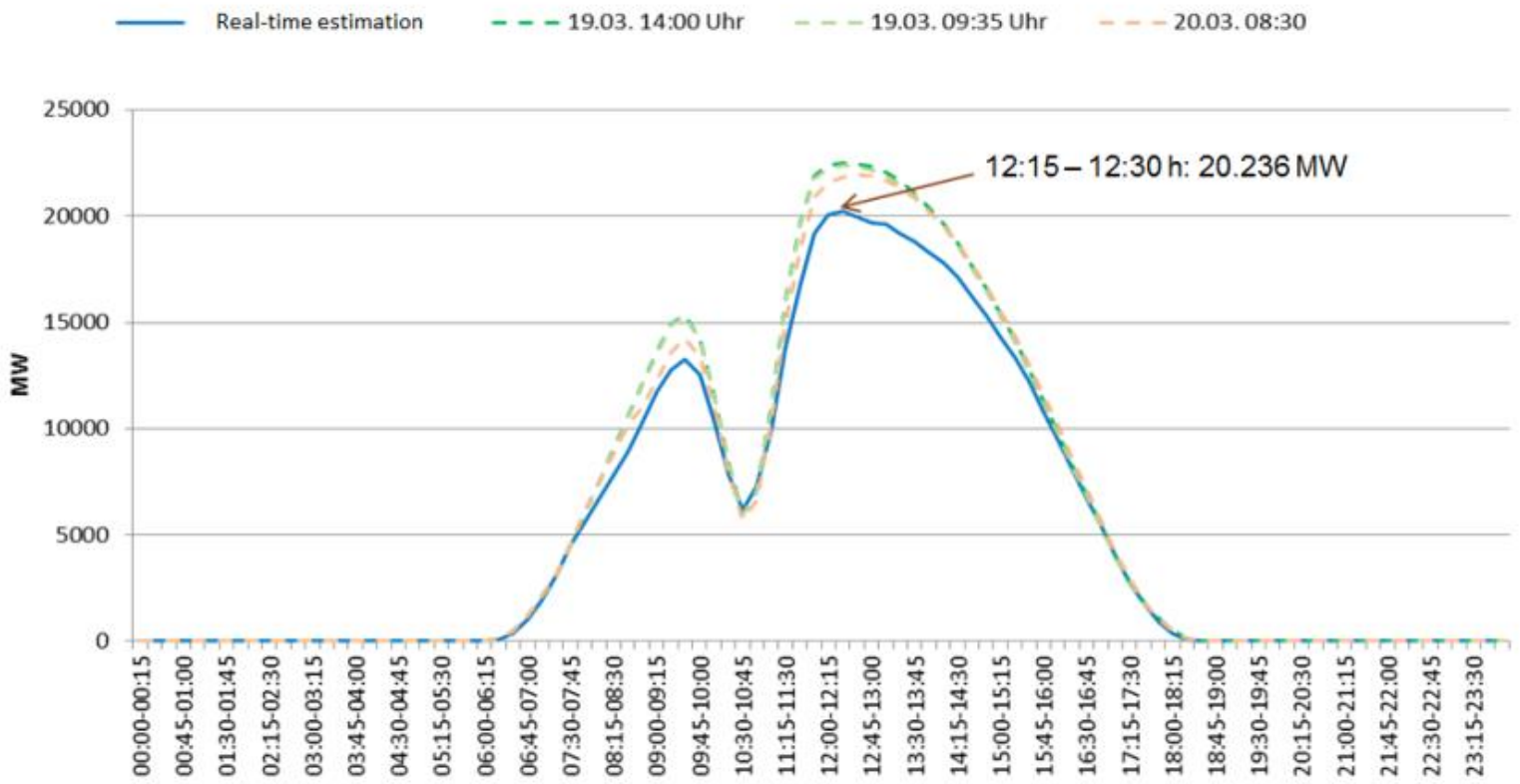


Western Germany: more fog than expected

Source: CIGRE 2016 Large disturbance workshop

System operations

PV forecast and generation on March 20th, 2015

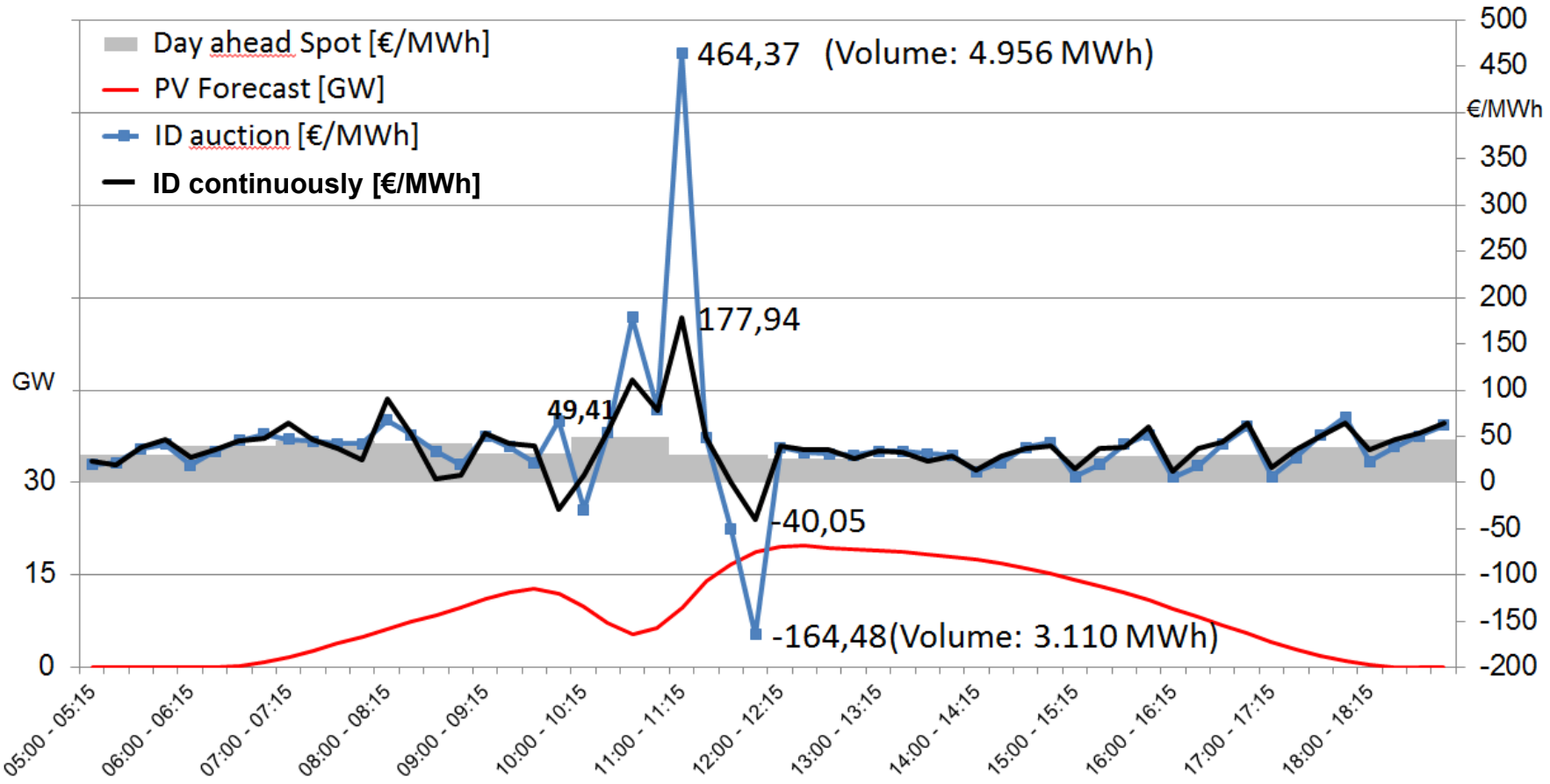


- Significant forecast deviations due to unstable weather conditions require **marketing on intra-day market**

Source: CIGRE 2016 Large disturbance workshop

Market operations

Electricity market behavior on March 20th, 2015

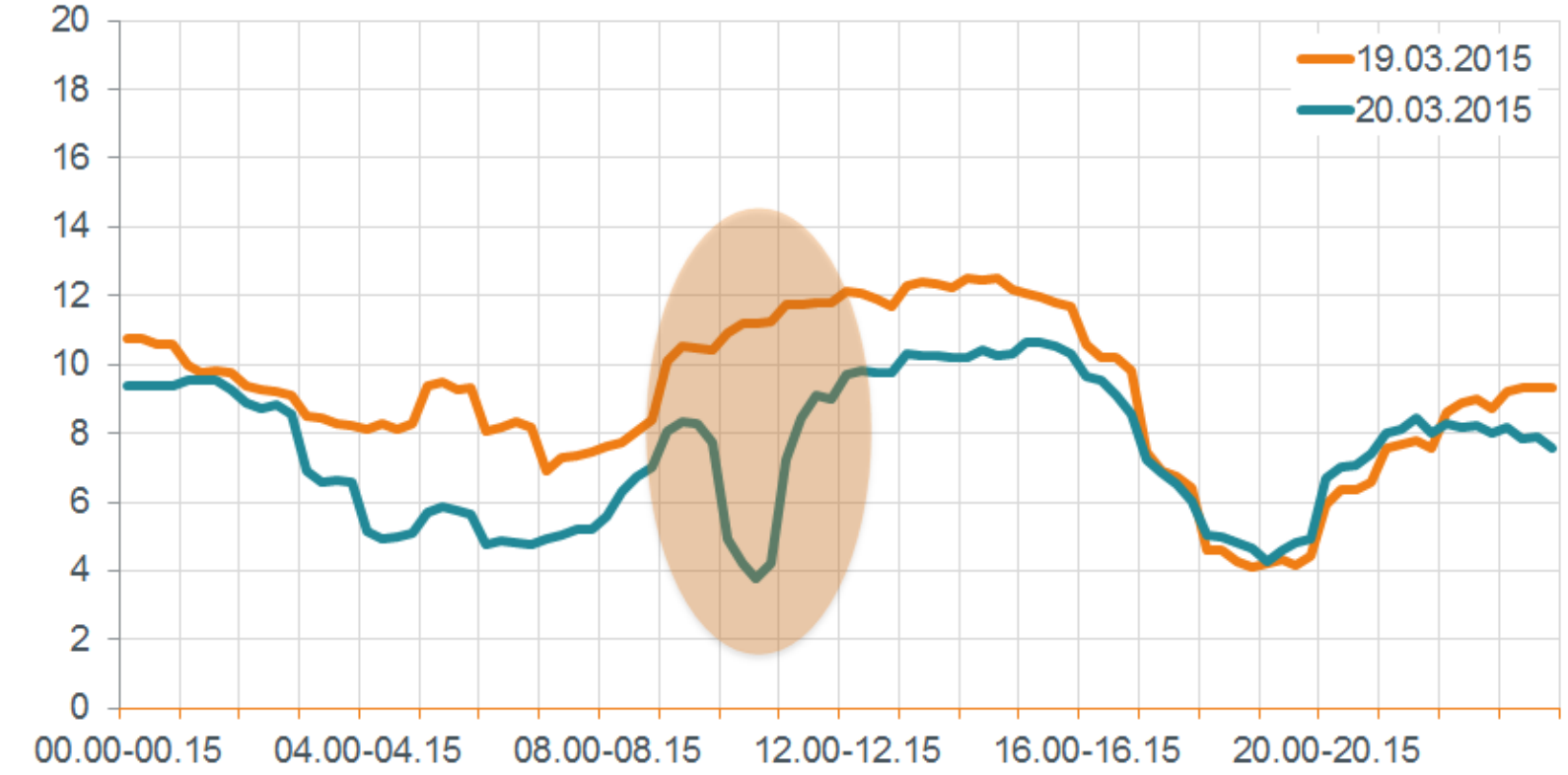


- The market provided the **necessary liquidity available at moderate price** spikes in the quarter hours trading

Source: CIGRE 2016 Large disturbance workshop

System operations

Electricity Exchange of Germany on March 20th, 2015

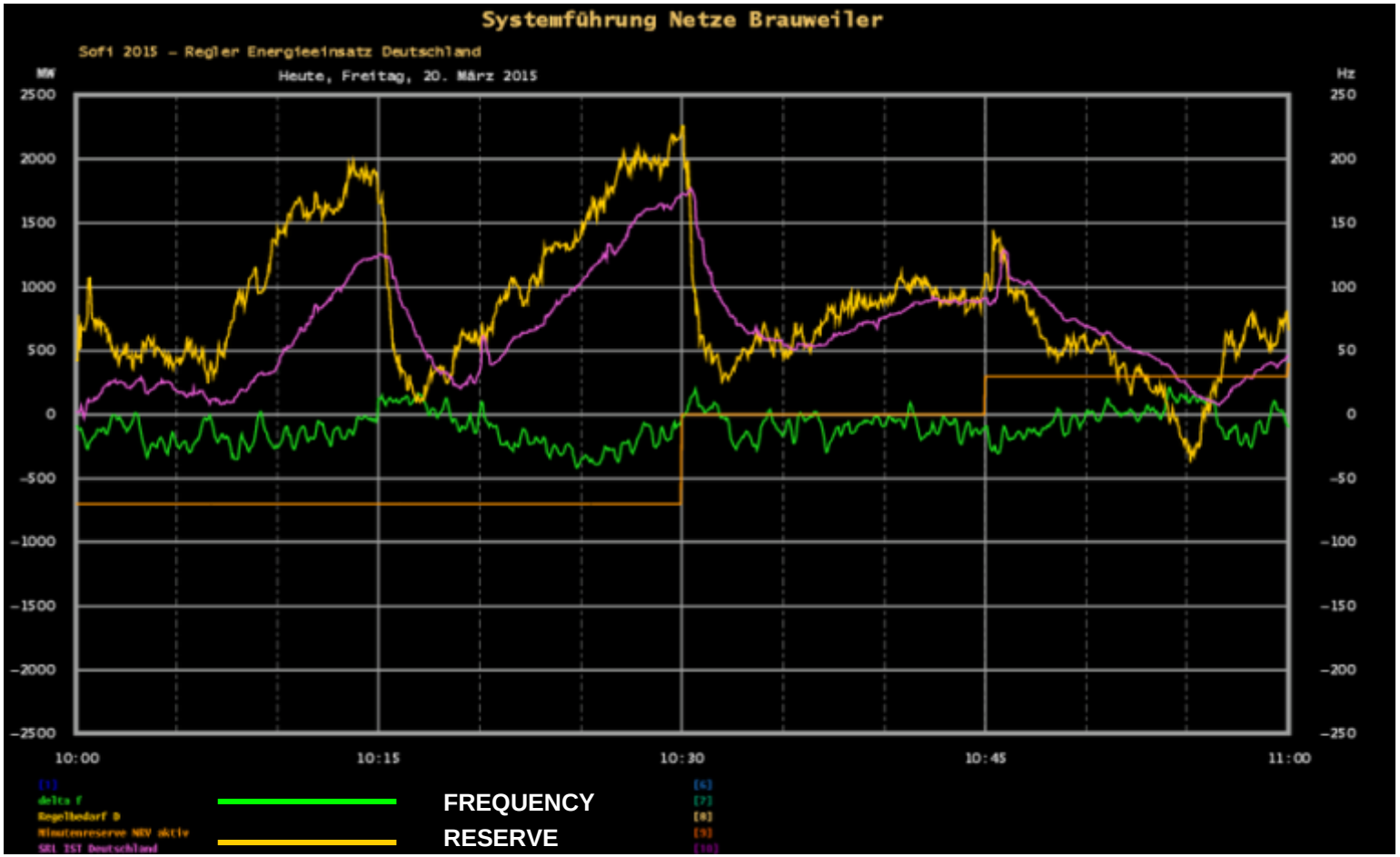


- Much of the gradient could **be balanced via the electricity exchange**
- **Austria and Switzerland** supported with the **management of the quarterly-hour profile**

Source: CIGRE 2016 Large disturbance workshop

System operations

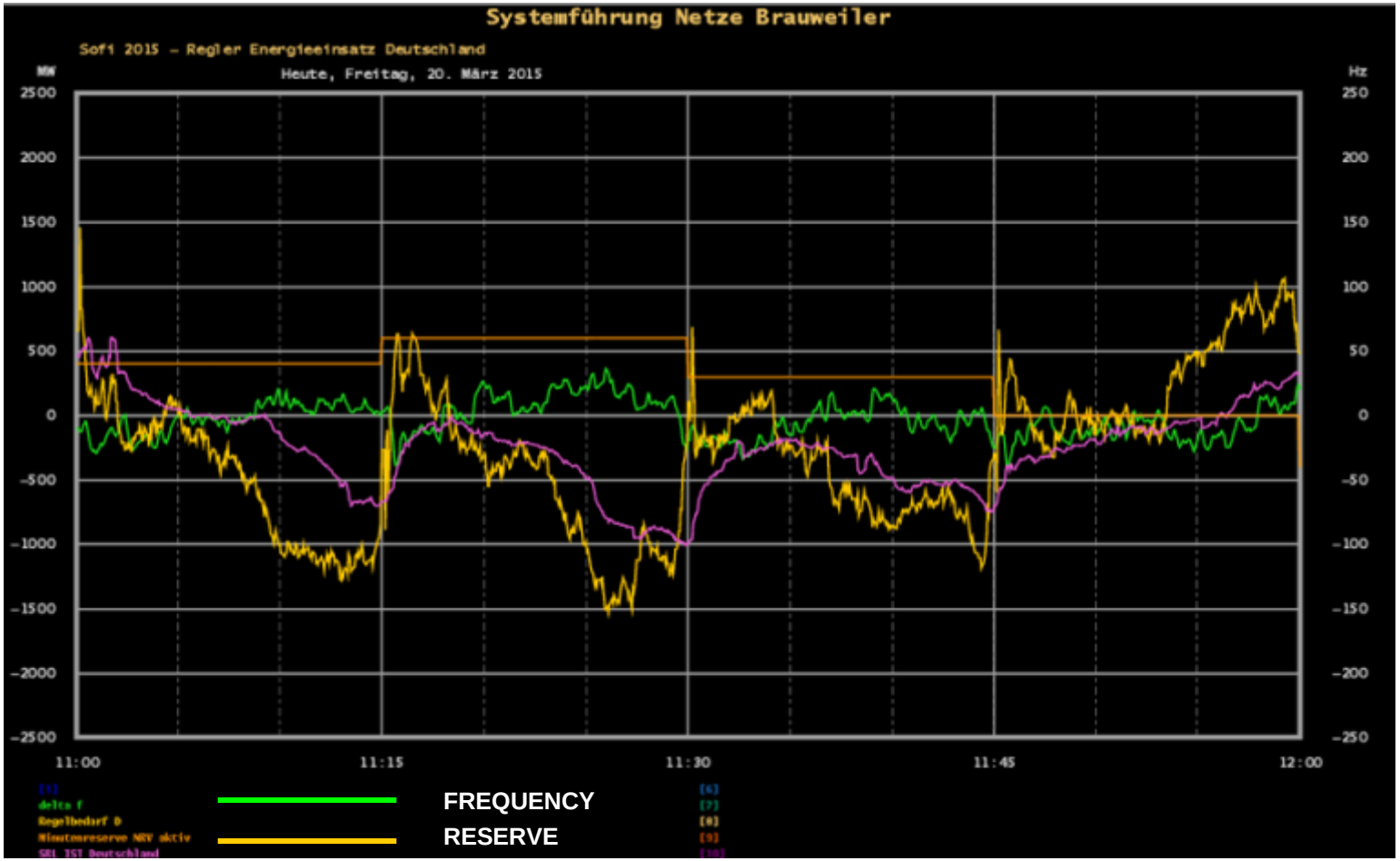
System reserves & frequency on March 20th, 2015



Source: CIGRE 2016 Large disturbance workshop

System operations

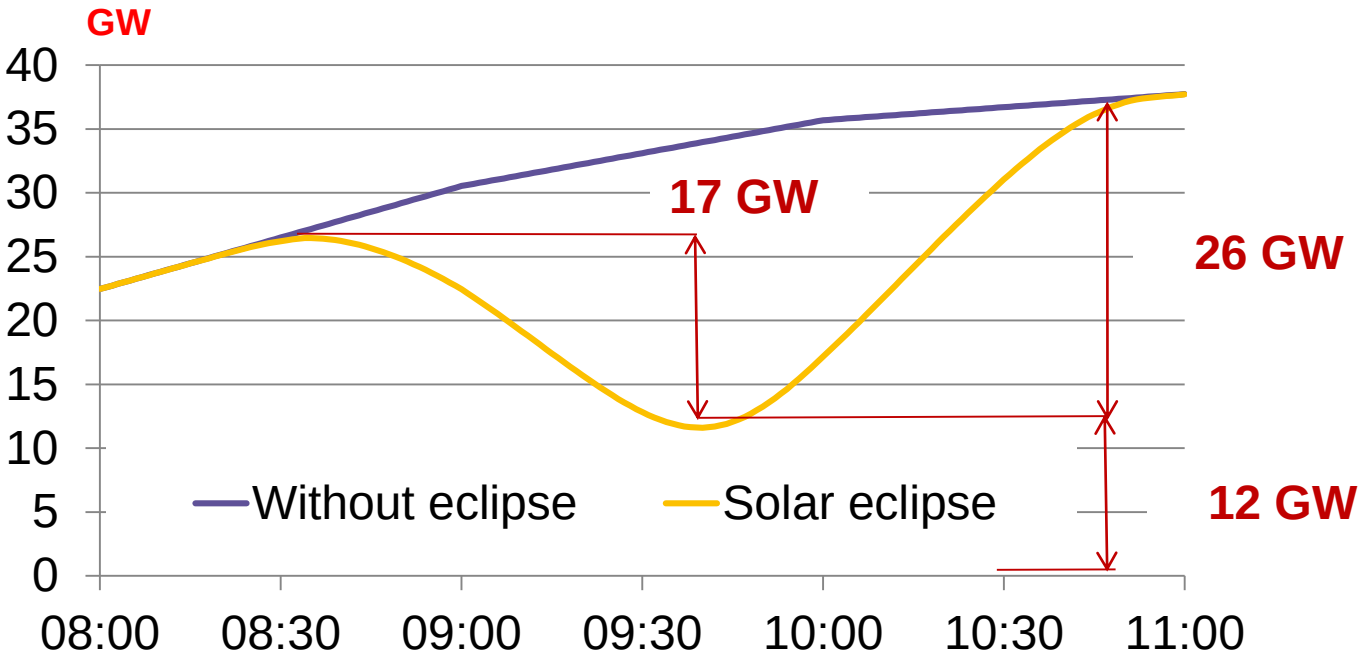
System reserves & frequency on March 20th, 2015

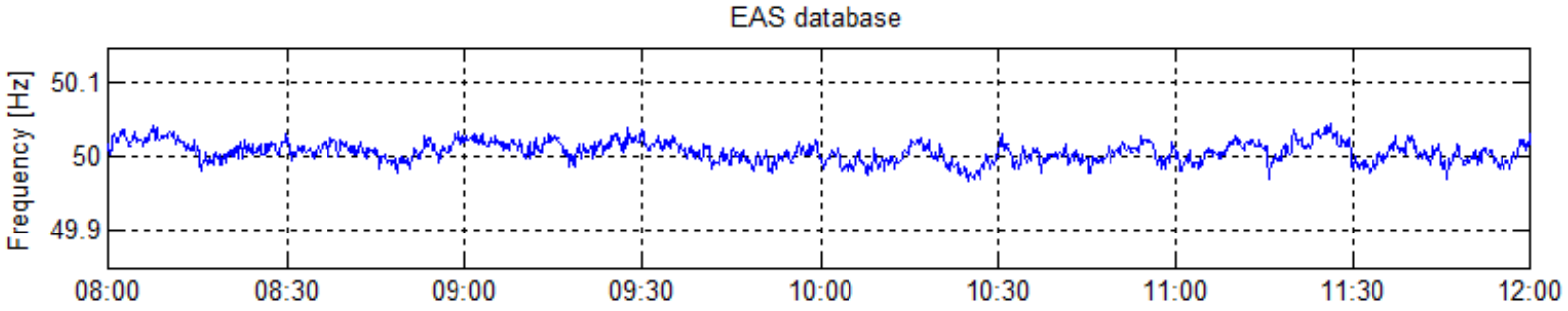


Source: CIGRE 2016 Large disturbance workshop

System operations

PV generation in Continental Europe on March 20th, 2015





Max. Δf = 48mHz

Lessons learned & recommendations

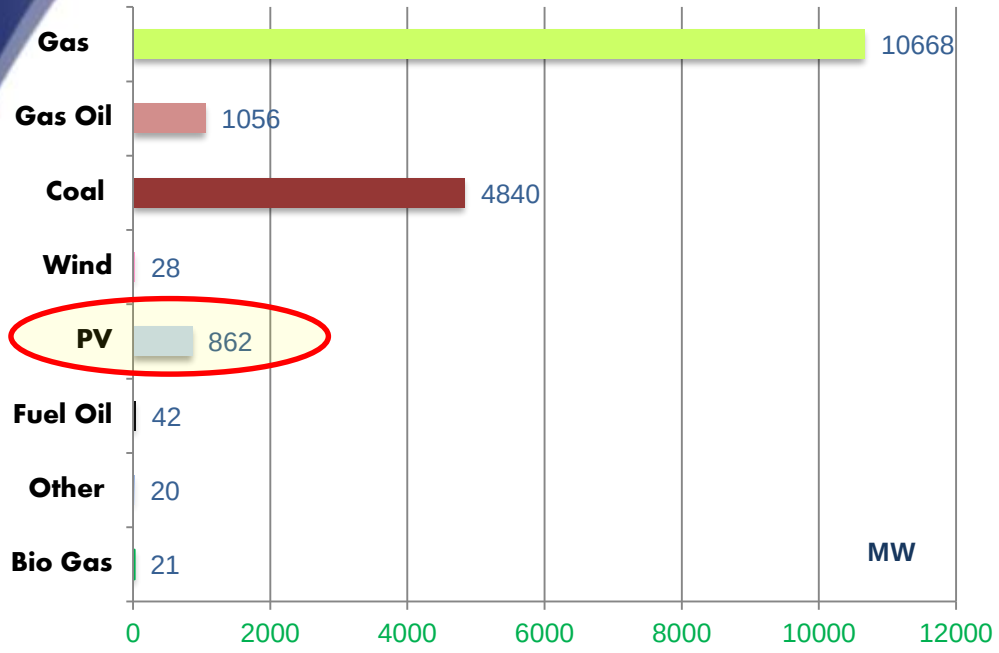
- Analysis of the TSOs met very well the real situation
- TSOs balanced their systems with the available reserves
- Emergency Procedures were not used
- The market provided the necessary flexibility
- Due to the good forecast quality and quarter hour marketing, the activation of control power could be limited to compensate the gradients within the quarter hour
- The quarter-hour market showed big spreads. A European coupling of quarter-hour markets should contribute to increase the liquidity of the market, and reduce these spreads
- Needs of Controllability and Monitoring of PV generation

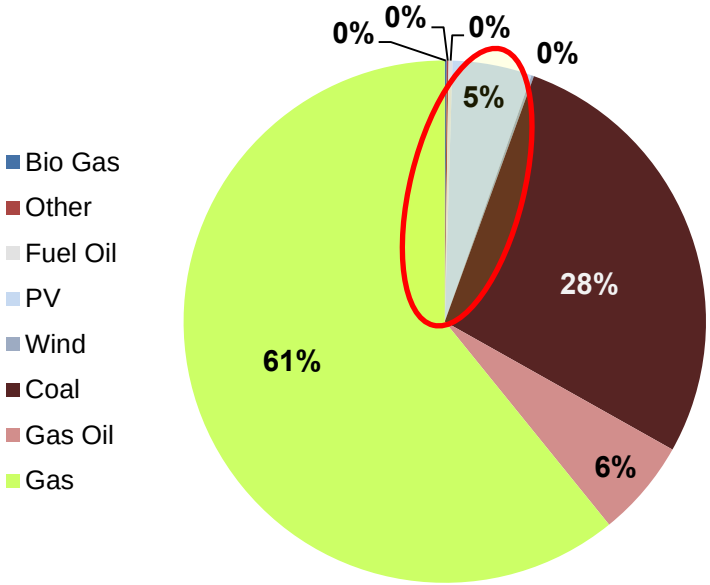
Lessons learned & recommendations

- Thanks to a strong coordination and transparency in the preparation of the event and during the event, all the TSOs were aware of the risks and well prepared, knowing the existing remedial actions and the way of implementing them, and helping each other in case of need
- In the future, fast gradient changes of PV feed-in are expected due to the increasing amount of installed PV capacity in the grids
- The Management of the Solar eclipse event as an excellent example of strong and successful coordination of the European TSOs
- Successful stress test of European power system

Israeli installed capacity

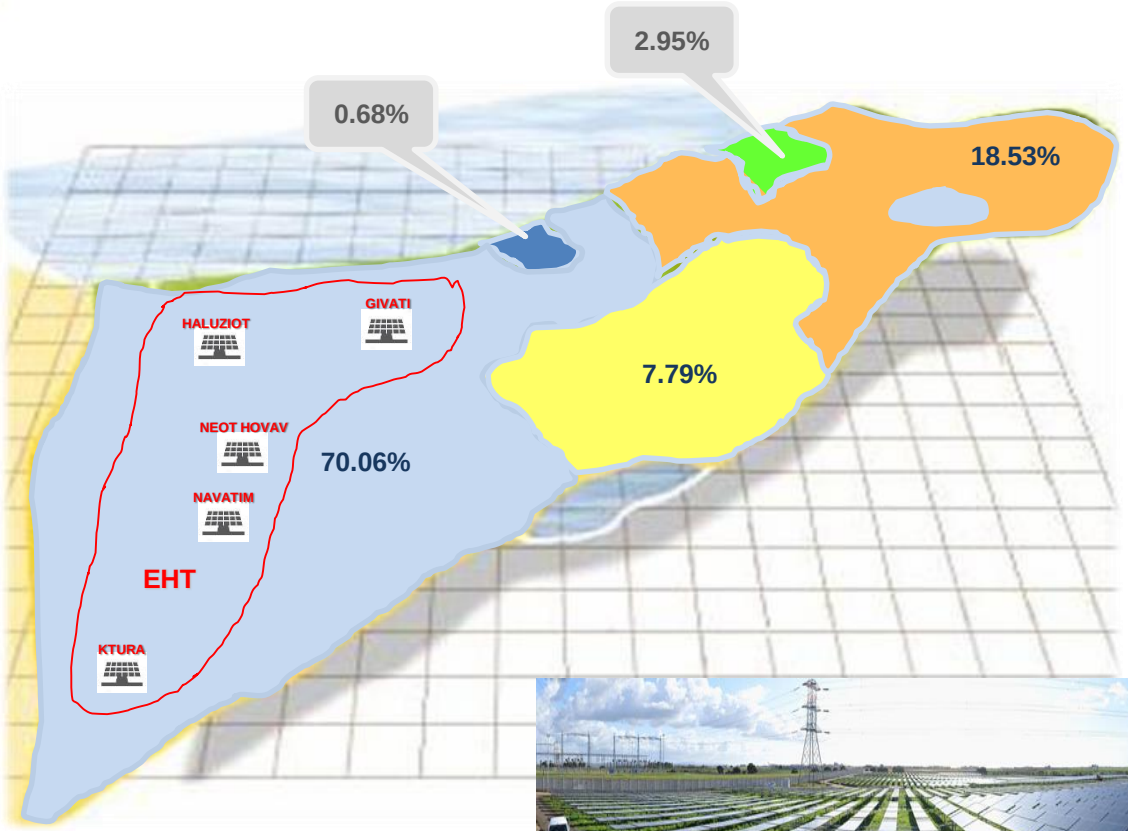
17537 MW, November 2016





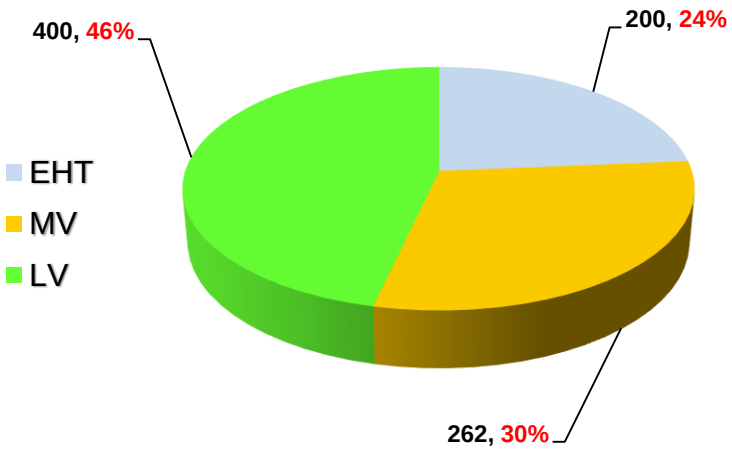
PV Installations' map

Total installed Capacity – 862MW , November 2016



District	MV	LV
South	82.83%	46.60%
Dan	0.00%	1.46%
Jerusalem	9.79%	10.47%
Haifa	1.45%	5.41%
North	5.93%	36.07%

TSO Control & Monitoring



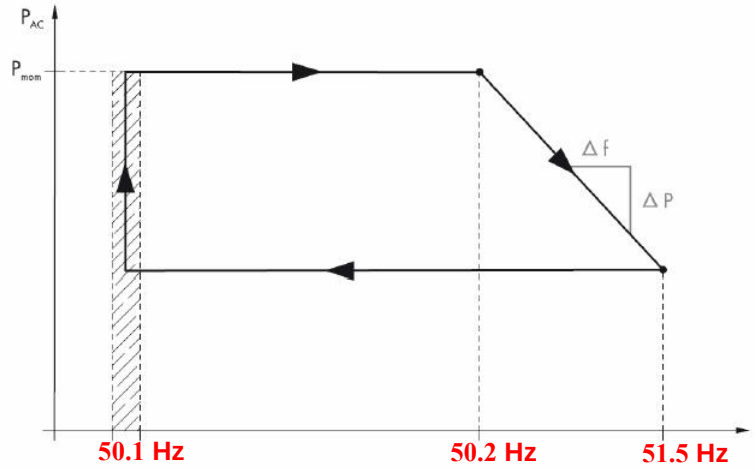
	CONTROL	MONITOR	MEASURE	WEATHER DATA
EHT 200 MW, 5 Facilities	👍	👍	👍	👍
MV 262 MW, 54 Facilities	👍 👎	👍	👍	👎
LV 400 MW, 9727 Facilities	👎	👎	👎	👎

PV's Grid Support

Frequency and Voltage control

Frequency-dependent control of active power

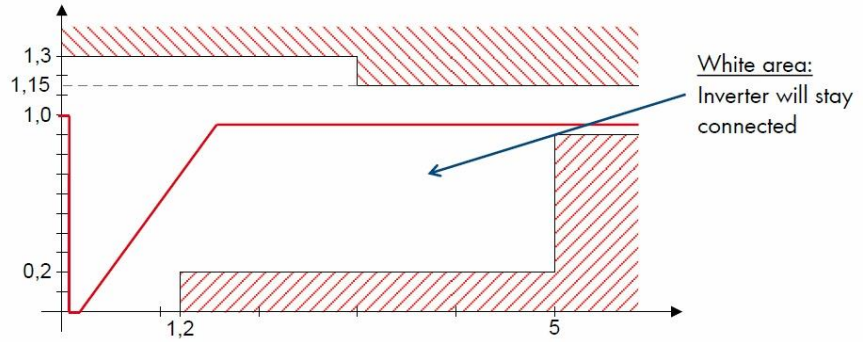
Frequency > 50,2 Hz reduction of active power



Target: Reducing the active power in the grid : Avoiding over-production prevent overload of lines

Dynamic grid support

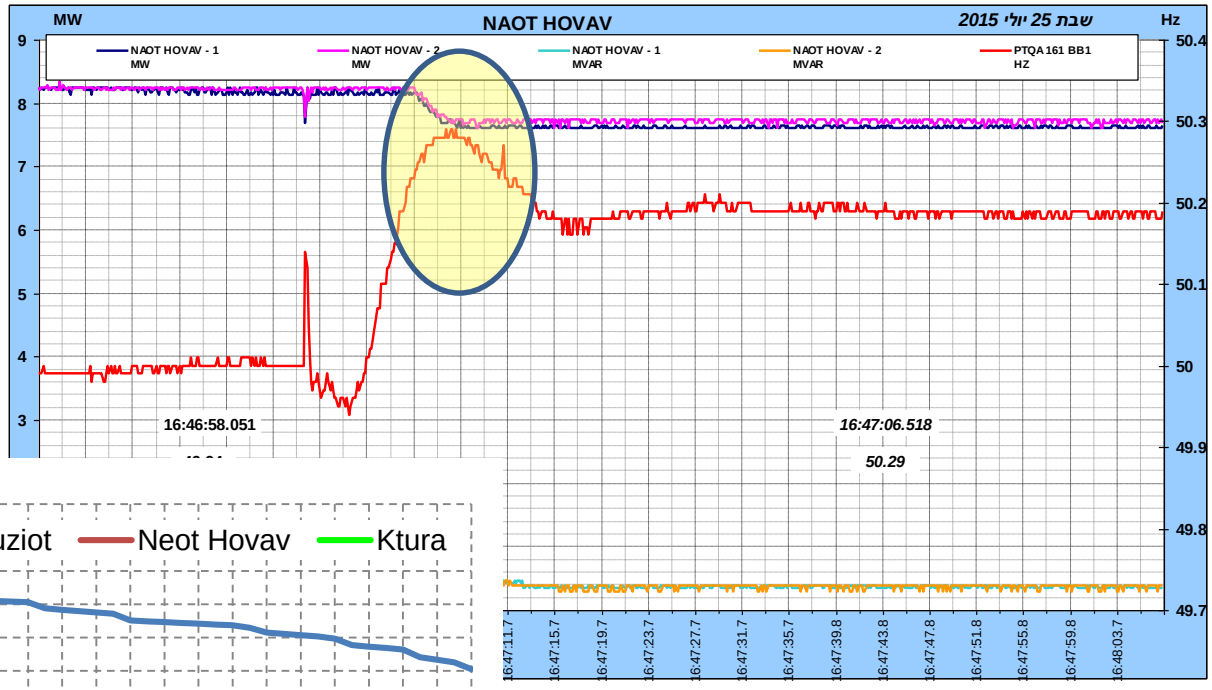
During a grid failure the inverter stays on the grid (specific time and special conditions) and /or detects a Island situation (specific local requirements, active or passive)

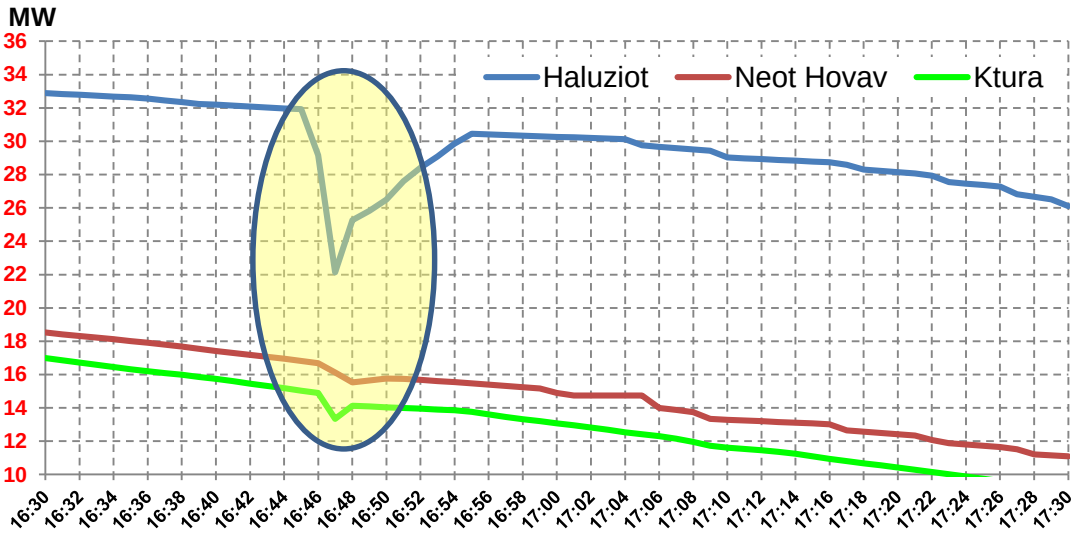


Target: Stabilize the grid during grid failure

PV generation & frequency

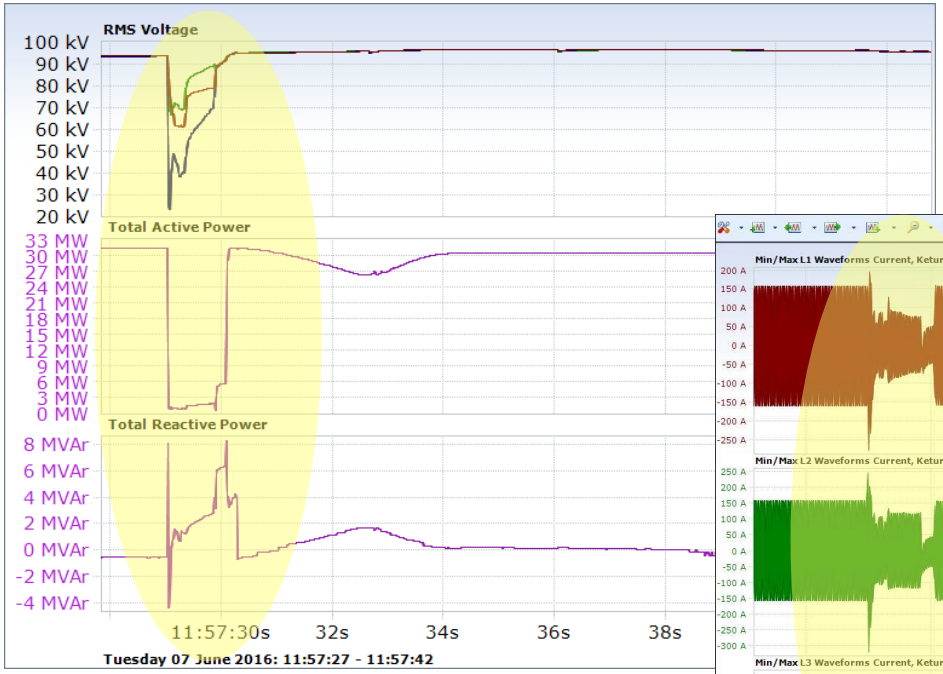
System disturbance on July 25th, 2015

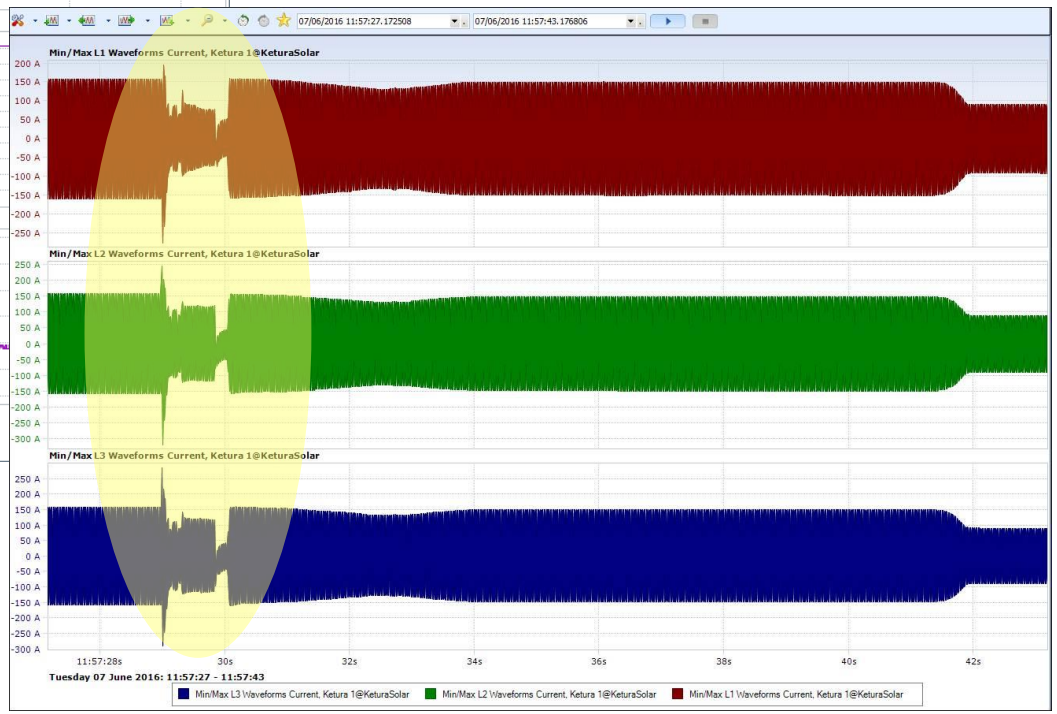




PV generation & voltage

System disturbance on June 7th, 2016





Israeli Grid Future Challenges

Energy - 10% by 2020, 17% by 2030 of renewables

- System response
- System inertia
- Power reduction
- Load shedding

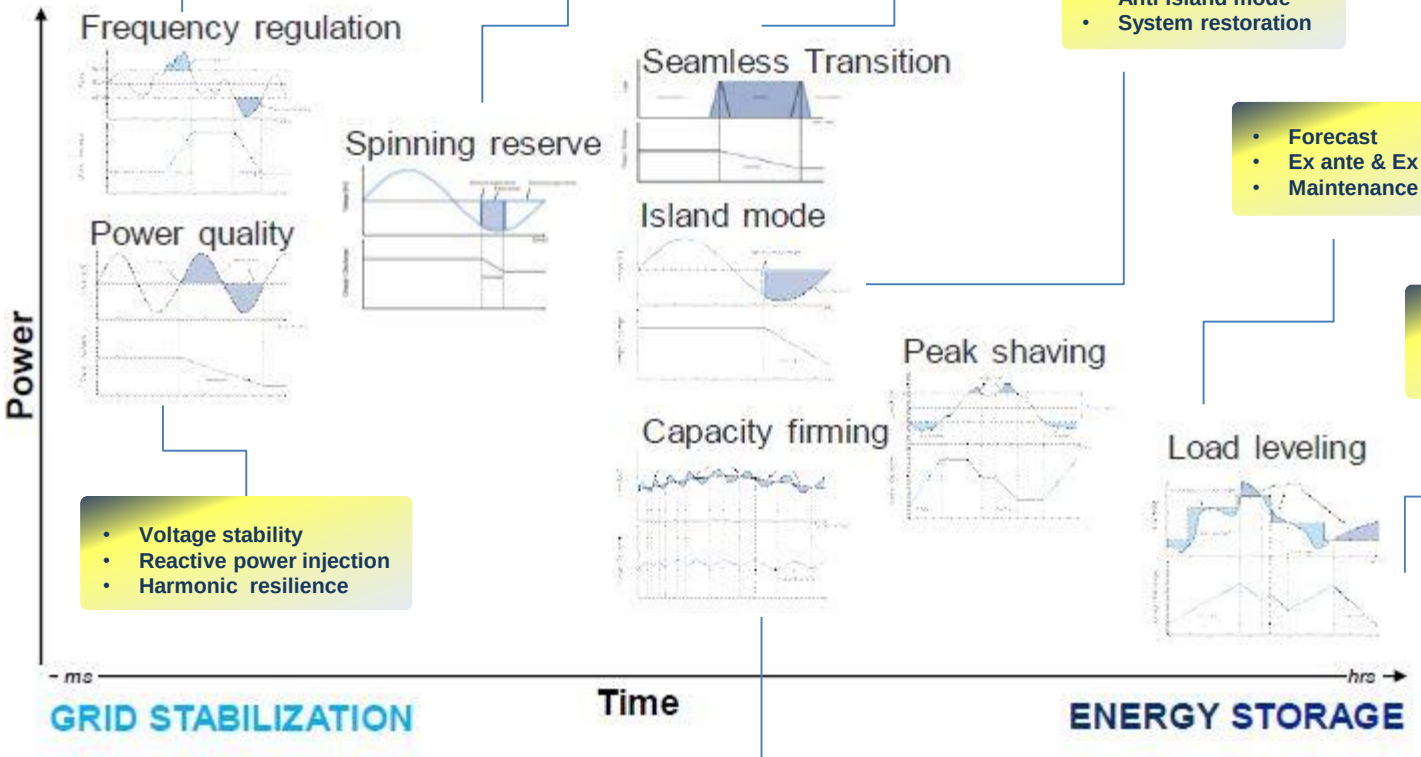
- Forecast uncertainty
- System inertia
- Power reduction
- Ex ante & Ex post

- Undispatchable energy
- System inertia
- Power reduction

- Black Start
- Anti island mode
- System restoration

- Forecast
- Ex ante & Ex post
- Maintenance planning

- Real time market
- System flexibility
- System restoration
- System inertia



- Voltage stability
- Reactive power injection
- Harmonic resilience

- Day Ahead Market
- Distributed energy
- Ex ante & Ex post
- Awareness situation

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Questions

Thanks for your attention