European Network of
Transmission System Operators
for Electricity

ANALYSIS OF CE INTER-AREA OSCILLATIONS OF 1ST DECEMBER 2016

13.07.2017

ENTSO-E SG SPD REPORT

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EXECUTIVE SUMMARY

On 1st December 2016, at 11:18 CET, an unexpected opening of a line in the French system (on the western 400 kV interconnection corridor with the Spanish system) triggered an oscillatory incident in Continental Europe electricity system (CE).

The opening of the line increased the impedance between the Iberian Peninsula and France during high power flows between some relevant areas in the system as shown in Figure 4:

- export flows from the south western part to the centre of the system (3.100 MW from Portugal to Spain and 2.250 from Spain to France),
- net importing position of France,
- export flows from central Europe to neighbouring areas, and
- import flows in the eastern part of CE.

All these elements caused a large voltage phase angle difference in the system and decreased the general damping that triggered a permanent oscillation. Undamped oscillations at 0.15 Hz appeared: Iberian Peninsula was swinging in anti-phase with the rest of the CE system (East-Centre West mode) and with a certain participation of Turkey (around 70° voltage phase angle difference to the Iberian Peninsula). The biggest amplitude of the oscillation was registered on the Iberian Peninsula.

The mode excited in this oscillation has already been identified in studies (E. Grebe et al. [1]); see the mechanical analogy and the mode shape in Figure 1.

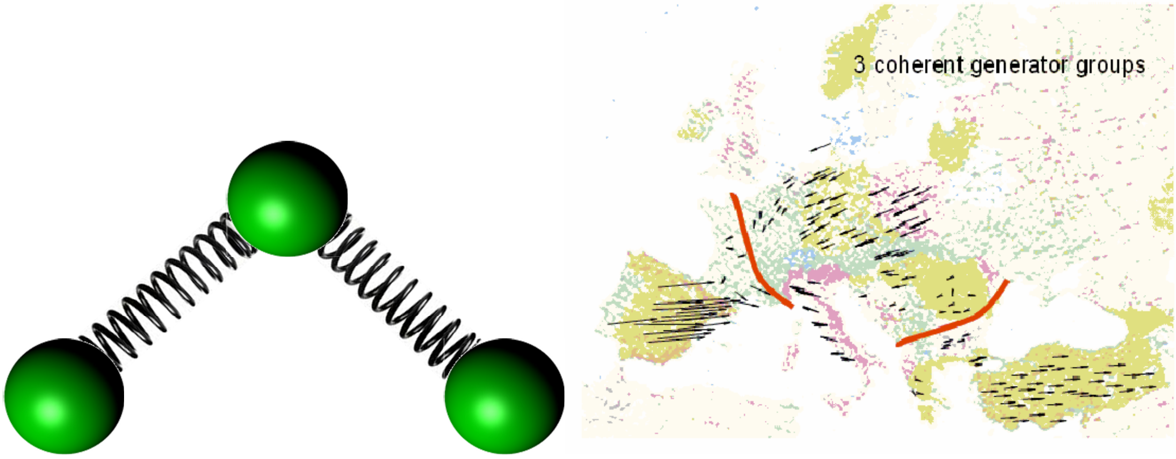

Figure 1. East-Centre-West mode. Mechanical analogy and mode shape (E. Grebe et al.)

[1] Low frequency oscillations in the interconnected system of Continental Europe. E. Grebe, J. Kabouris, S. López Barba, W. Sattinger, W. Winter. Power and Energy Society General Meeting, 2010 IEEE

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Thereby, in principle, the synchronous connected generators of complete areas are oscillating against each other. Permanent measurements within the Continental European system currently show two main oscillation modes called ambient oscillations, namely a North-South mode with a frequency of about 0.25 Hz and an East-West mode with a frequency of 0.15 Hz. Before connection of Turkey the East-West mode was in the range of 0.2-0.3 Hz due to the smaller system size. In addition the above described East-Centre West mode can also occur as a specific sub-mode of the East-West mode.

The Iberian Peninsula subsystem remained connected to CE by the rest of the interconnections with France, i.e. 220 kV line Biescas-Pragnères, 400 kV line Vic-Baixas and HVDC Links 1 and 2 Sta. Llogaia-Baixas, which transmitted approx. 2.000 MW out of scheduled 2.250 MW.

Three minutes after the reduction of the Spain to France schedule exchange from 2.250 MW to 1.000 MW, agreed by REE and RTE operators, the oscillations were totally damped.

These oscillations lasted for about five minutes (11:18 to 11:23 CET).

The oscillatory phenomenon is very well known in CE region. In the past, some important events happened and it is a major concern when enlargements of the CE system are studied or carried out (Centrel, IPS-UPS, Tunisia-Libya, Turkey, Ukraine-Moldova, etc.).

RTE and REE had performed some simulations[2] and concluded that the reactive power modulation on the HVDC line between France and Spain contributed to damping of the oscillations but with a low influence. REE and RTE are currently working on the possibilities of the HVDC active and reactive power controls to optimise their effect on the damping of inter-area oscillations.

With reference to Power System Stabilisers (PSS):

- In 2008, REE commissioned a study to check and retune the PSS of the combined cycle power plants aiming to damp the 0.2-0.3 Hz East-West mode. REE is has launched a revision of the 2008 PSS study, with the purpose of checking the performance of PSS for damping oscillations in frequencies down to 0.12 Hz.
- The PSS settings in France seem to be well-tuned and no additional adjustments are needed.
- In 2001, REN also commissioned a study to check and retune the already installed PSS and tune the future ones to damp the oscillations found in future grid scenarios. In 2005, the results of this study were provided to power plants for implementation. Apart of some old ones, all new conventional power plants have PSS installed since 2000 at least.
- In parallel to the REE studies, the SPD group will further improve the dynamic model, investigate the PSS settings of the important power stations in CE and support TSOs affected by inter-area oscillations in order to better fine-tune the PSS settings.

[2] Simulations were carried out based on ENTSO-E initial model and TSOs' network simulators.

Since the 2nd of December, PMU data is available in REE control rooms. The event has confirmed the need for improving our knowledge of the oscillatory properties of the CE system (i.e. impact of flow patterns, contingencies, topology and generation mix effect, etc.). For this purpose, sharing PMU data between CE regions is a key activity.

Dispatchers of REE can now see the raw frequency signal from eight substations. In addition, REE and RTE are working on defining damping and amplitude thresholds to generate alarms to the control room and mitigation actions related to these alarms.

The Initial Dynamic Model created by SPD proved to be a pragmatic tool for dynamic studies (transient and eigenvalue analyses), although some modelling improvements are needed to facilitate the analysis and its accuracy.

Finally, as dynamic stability limits get closer to static limits, N-1 power flow analyses might become insufficient to ensure secure system operation. For this reason, Dynamic Security Assessment (DSA) close to real time could become necessary.

1 INTRODUCTION

The objective of this report is to describe and analyse the inter-area oscillation incident occurred on 1st December 2016 at 11:18 CET within the Continental Europe (CE) electricity system.

The incident was triggered by an unexpected tripping of a line in the French system, on the western 400 kV interconnection corridor with the Spanish system. This event excited the East-Centre-West oscillation sub mode of CE system; therefore, the Iberian Peninsula system oscillated almost in phase with Turkish system and in anti-phase with the central part of the CE system.

These oscillations lasted for about five minutes (11:18 to 11:23 CET), and were damped in three minutes, after mitigation measures had been taken by REE.

2 DATA COLLECTION AND COMMON WORK

Since the event happened, RTE, REN and REE started studying the incident and, at the same time, technical channels were established with ENTSO-E experts across the system in order to exchange PMU data (Swissgrid) and also to take advantage of the experience of similar studies and system modelling (TERNA).

3 DESCRIPTION OF THE EVENT

3.1 PRE-INCIDENT SITUATION

The system area close to the interconnection between Spain and Mouguerre 225 kV substation in France was operated with busbar split in Mouguerre in order to avoid overloads on Mouguerre-Cantegrit 225 kV line in case of tripping of Argia-Cantegrit 400 kV line (Figure 2).

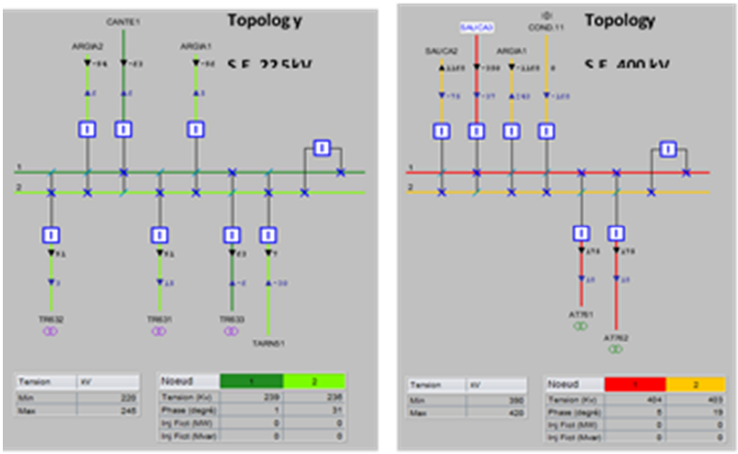

Figure 2: Topologies of Mouguerre and Cantegrit substations

The export from Portugal to Spain (3.100 MW approx.) was almost as much high as the export from Spain to France (2.250 MW approx.). The west part of the interconnection was transmitting more than a half of this power to France (1.450 MW approx., see Figure 3):

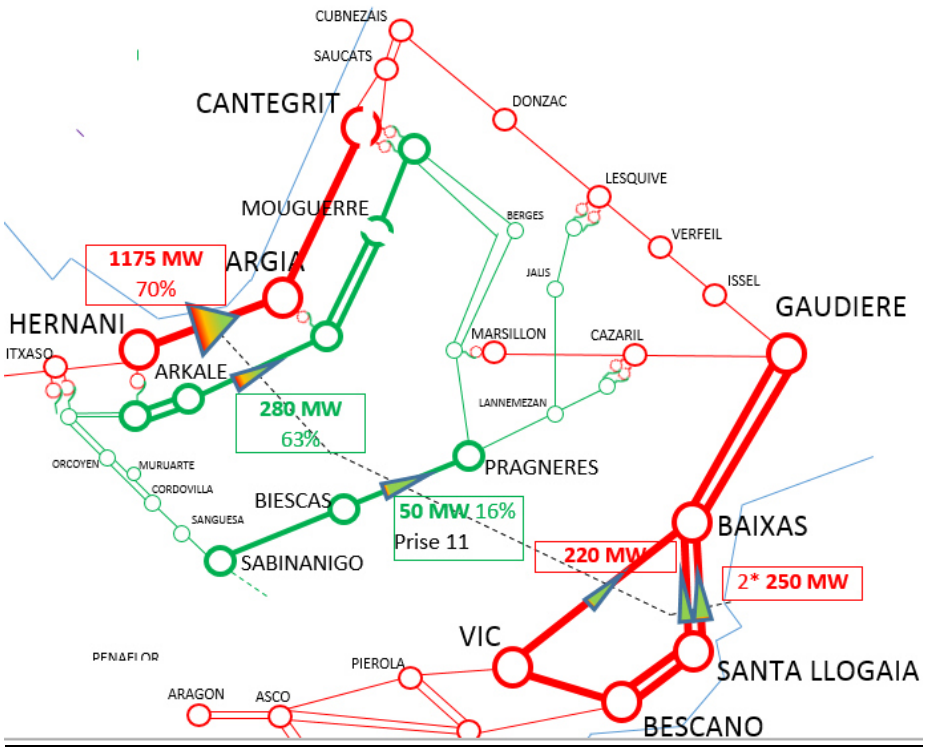

Figure 3: Pre-Incident power flows in Spain-France interconnection

The physical international exchanges of 1st Dec. 2016 for the hour H12 taken from the ENTSO-E transparency platform are depicted in Figure 4 (some values missing due to data unavailability):

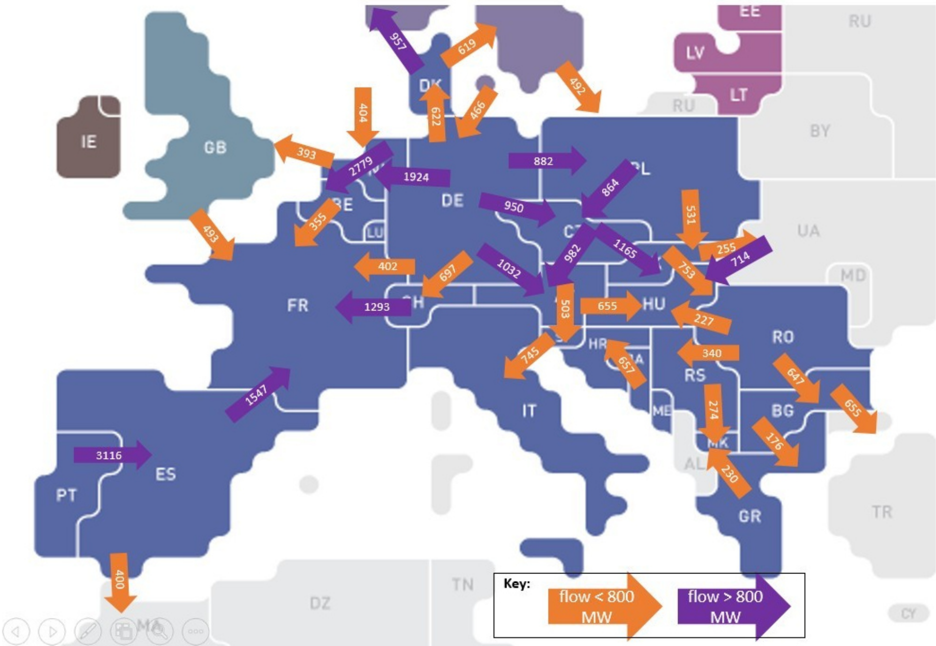

Figure 4: Main power flows in CE. 1st Dec. 2016 at 12h00 CET

The power flow depicted for Spain-France in Figure 4 (1.547 MW) is less than the real flow before the incident (2.250 MW) due to the power reduction applied by the REE operators after the event.

The following can be deduced from Figure 4:

- France is a net power importer of 4.000 MW approx. (high nuclear unavailability)
- Germany is highly exporting energy to the neighbouring countries (6.000 MW approx.)
- Turkey is importing 655 MW approx. from Bulgaria

3.2 CHRONOLOGY OF THE EVENT

The chronology of the oscillatory event is shown below:

- **11:18** am CET: The circuit breaker in substation Cantegrit 400 kV Argia bay opens unexpectedly causing the opening of the 400 kV line Argia-Cantegrit. The tripping and the topological situation in that area cause the separation of the Spanish and French system at the Western side. The Spanish system continues supplying approximately 260 MW to the load of three French substations, Argia 400, Agria 220 kV and Mouguerre 220 kV, through the 400 kV line Hernani-Argia and 220 kV line Arkale-Argia.
  The Iberian Peninsula system remains connected to CE by the rest of the interconnections with France, i.e. 220 kV line Biescas-Pragnères, 400 kV line Vic-Baixas and HVDC Links 1 and 2 Sta. Llogaia-Baixas, which transmit approx. 1.770 MW.
  In total, after the incident, Spain continued delivering some 2.000 MW out of the scheduled 2.250 MW (Figure 5).

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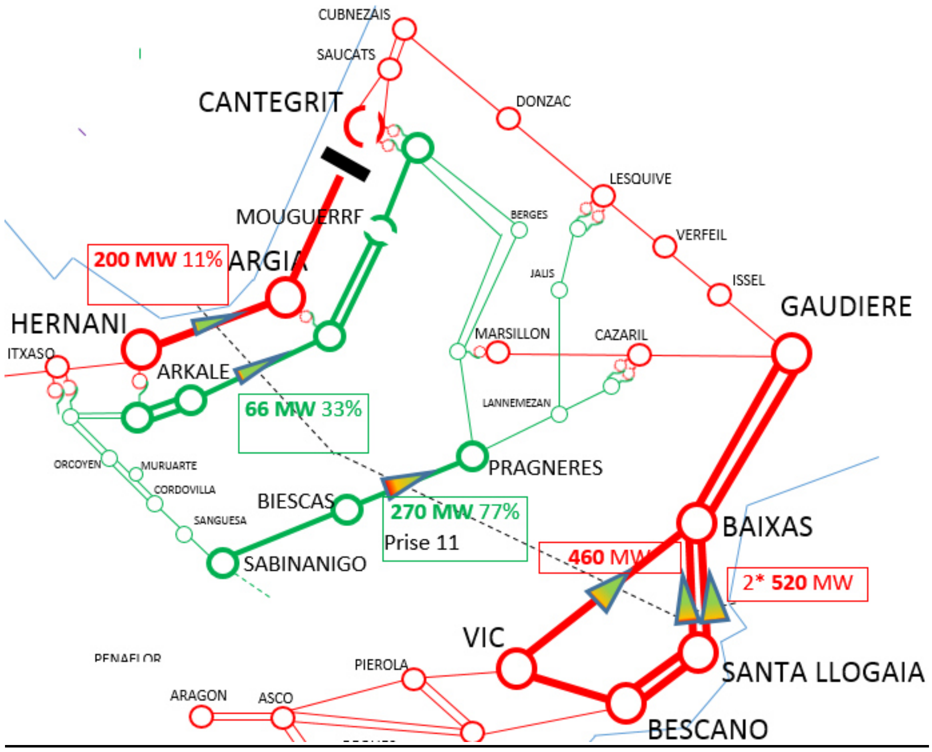

Figure 5: Incident power flows in Spain-France interconnection

- Undamped oscillations at 0.15 Hz appeared (Figure 6). The highest frequency deviations in Continental Europe were recorded in the Iberian Peninsula (140 mHz peak to peak).

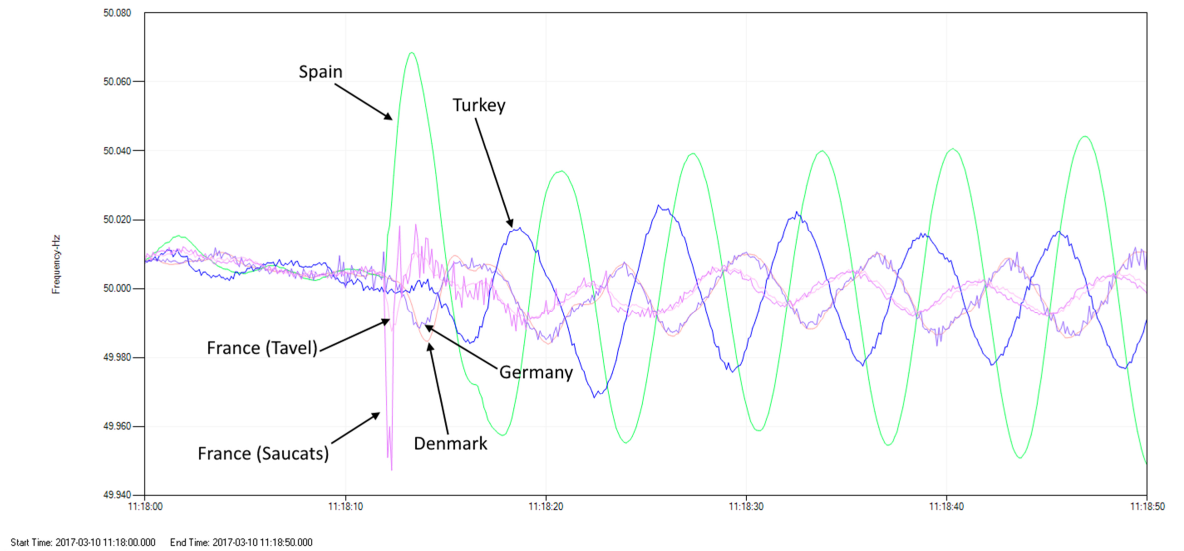

Figure 6: Frequencies in different locations of CE. Starting of the event.

- **11:20** am CET: REE and RTE operators agree on reducing the Spain to France exchange from scheduled 2.250 MW to 1.000 MW to restore N-1 security. FRR (Automatic Frequency Restoration Reserve) providers in Spain start activating the reduction of the actual exchange between Spain and France.
- **11:21** am CET: the damping starts to be positive.
- **11:24** am CET: the oscillations are totally damped.
- **11:45** am CET: RTE operators close the line 400 kV Argia-Cantegrit.

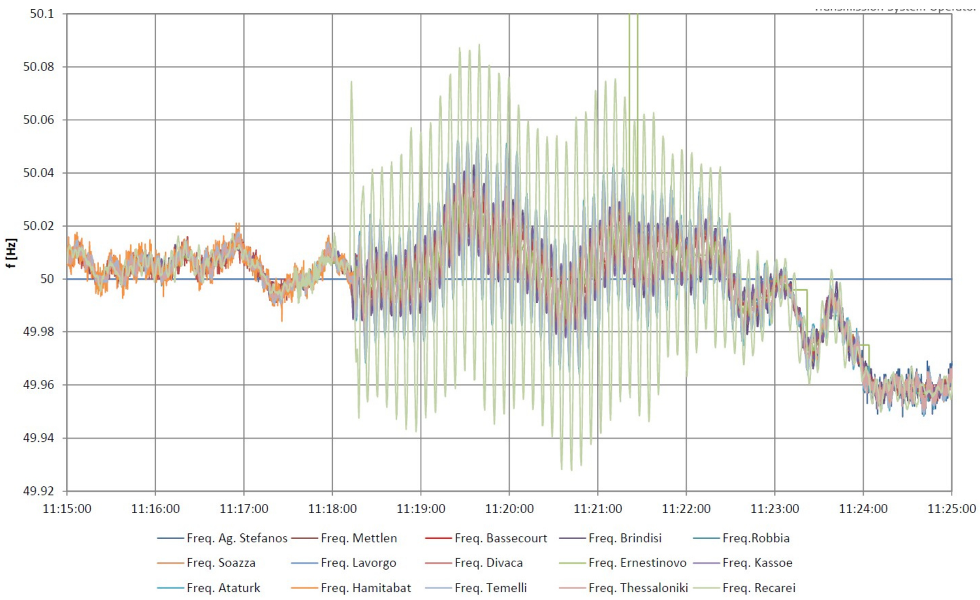

Figure 7: Frequency recordings in different locations of CE (Swissgrid).

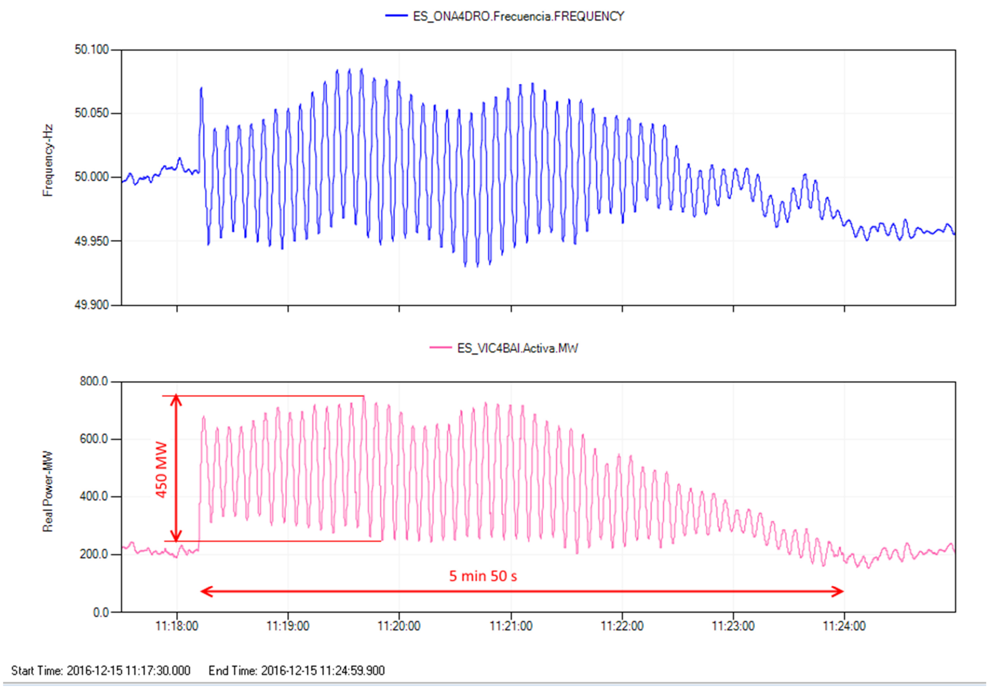

Figure 8. Frequency in Spain and active power through 400 kV Vic-Baixas tie line.

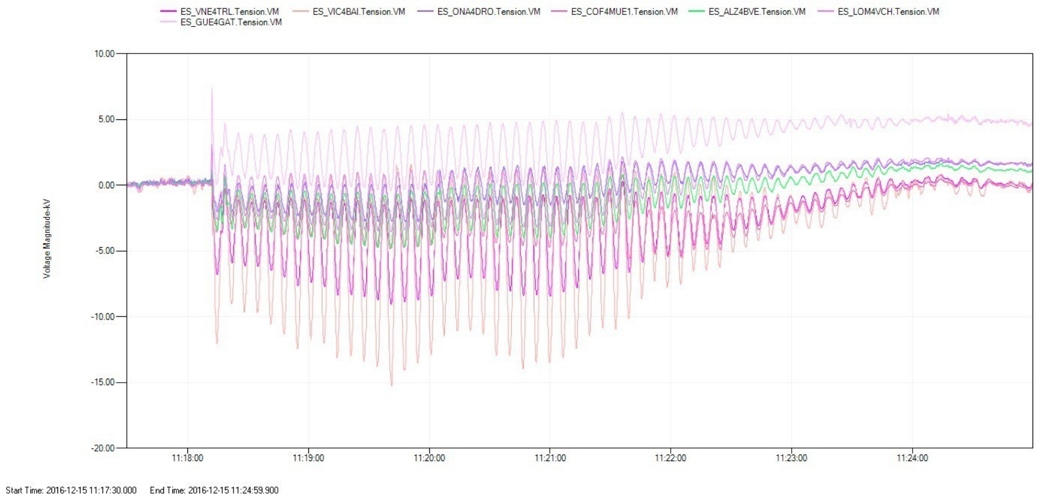

Figure 9: Phase to ground voltages in the Spanish system referred to the pre-incident values.

3.3 ANALYSIS OF THE OSCILLATION

The spectral analysis conducted by SPD was done by applying the Fourier spectral analysis on the recorded frequencies. This information helps reconstructing the voltage angle differences between the different locations.

Figure 10 clearly shows that the Iberian Peninsula oscillated in phase opposition to the rest of Continental Europe and around 70° degrees against Turkey and Greece.

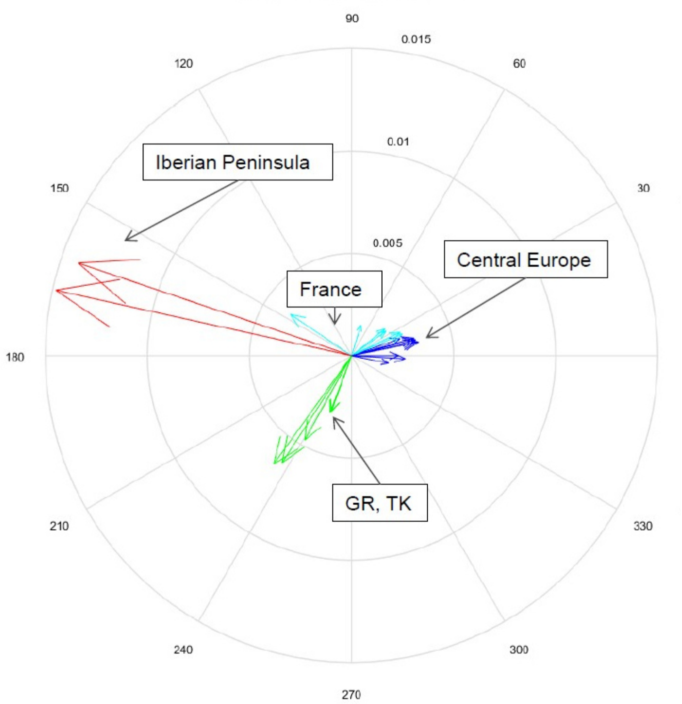

Figure 10: Voltage angle differences to the slack node for different European locations in the beginning of the incident.

Figure 11 shows the damping and oscillation frequency during the incident. This Prony[3] analysis clearly shows that the dominant frequency oscillation is fully correlated with the described events.

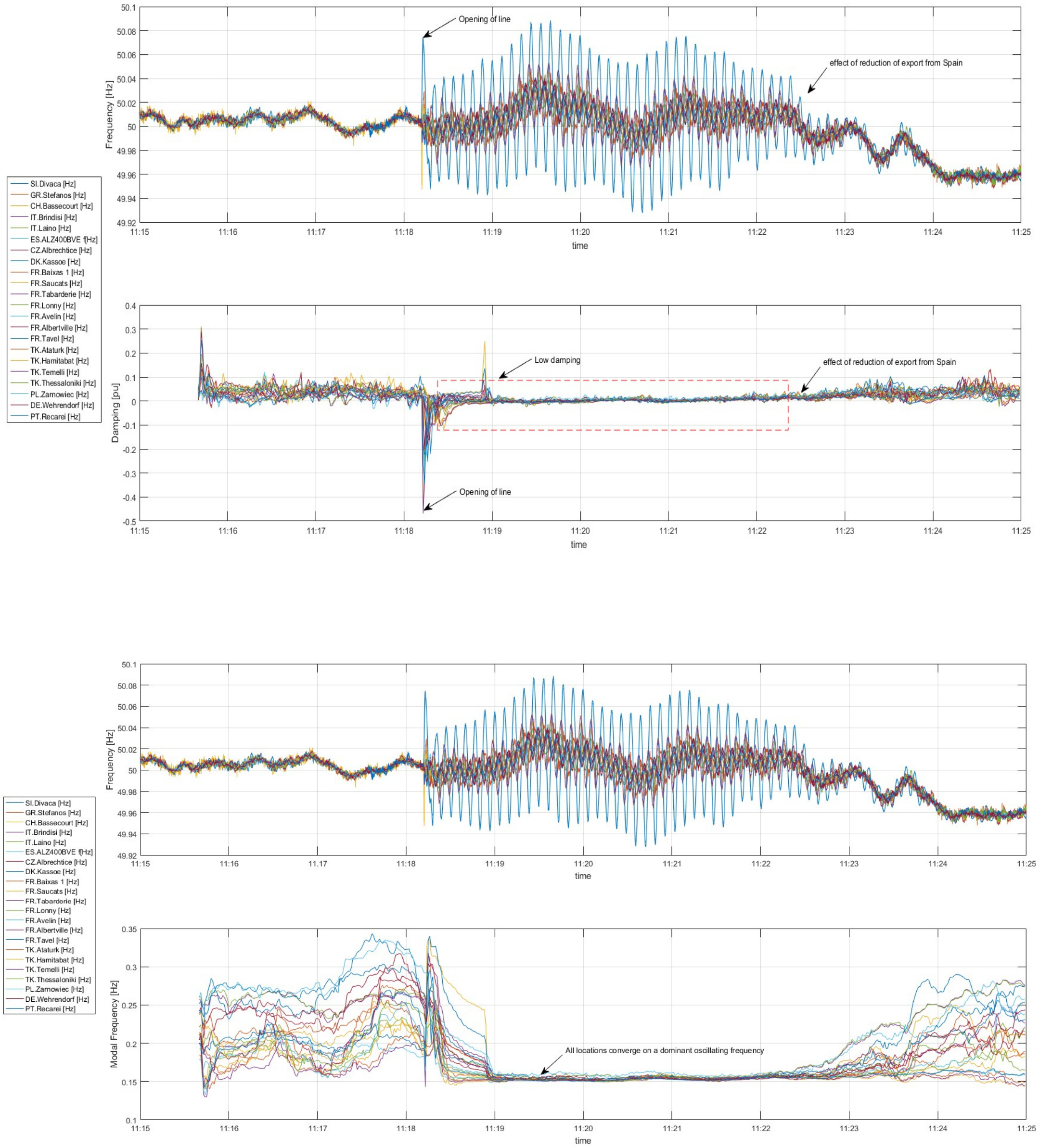

Figure 11: Prony analysis on measured frequencies.

[3] as one of the currently successfully used methods for damping analysis, FFT or Kalman filtering deliveris similar results.

4 CONCLUSIONS

The event demonstrates that coincidence and combination of different factors can influence the system stability. Each factor may not normally be critical in itself, but in this particular case the combined effect decreased the general damping. The physical aspects and root causes of phenomena are clear and as demonstrated in the present report. In fact this event shows that power transport over long distances together with too high impedance can cause a too low system damping with respect to inter-area oscillations and should, therefore, be treated carefully.

Aspects such as HVDC influence and PSS settings across the CE system will be further investigated by SPD and concerned TSOs. As foreseen in network codes on Operational Security, it is evident that dynamic evaluations on the system behavior become more and more necessary.

It is also important to note that prompt coordination between the TSOs played a vital role in the mitigation of the transient.

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