European Network of
Transmission System Operators
for Electricity

Oscillation Event 03.12.2017

System Protection and Dynamics WG

March 2018

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1. EXECUTIVE SUMMARY

On Sunday 3 December 2017 in the early morning hours, an inter-area oscillation in the Continental European system was detected by both some power plants and control room staff members. The main symptom was the voltage oscillation amplitude in mid-Europe, observed at around 10 kV. Also, but less significant, the measured frequency deviated by up to 40 mHz.

In Italy, control room staff was alerted by the detection of a frequency undamped oscillation exceeding 300 mHz. This oscillation began at 1.09 a.m. and reached its maximum deviation value at around 1.15 a.m. when a prompt real-time redispatching was implemented, which quickly reduced the power delivered by certain power plants resulting in a reduction of the oscillation. Additional action was taken at about 1.19 a.m. when a shunt reactor was disconnected with the aim of creating discontinuity in the system by stimulating a break in the oscillatory loop. Overall, the incident lasted approximately 10 minutes.

Owing to our continuous exchange of PMU monitoring information, the SPD WG WAMS Task Force was immediately activated and began to collect data that same day. In accordance with task force procedures, a joint TSO effort was launched to analyse the event.

The oscillatory mode frequency under investigation was identified as 0.29 Hz with significant contributions from Southern-Italian power plants. The oscillation observed in Southern Italy was in phase with the oscillation observed in South-Eastern CE countries and part of southern France and Switzerland but was in opposite phase to the oscillation recorded in Northern Europe (Germany, Denmark and France).

The oscillatory frequency is a well-known mode, originally identified in several papers in the 70's and, later on, in studies by the SPD group. It was named the North-South inter-area mode. In explanation, it is the coherent oscillation of the southern part of the European system against the northern part. What makes the current incident special is the limited contribution from Central/Northern Italy and the rest of Southern Europe compared with Southern Italy.

This fact promotes the classification of the phenomenon as a local area frequency oscillation confined to Southern Italy and not affecting the rest of the Italian or other CE systems.

A preliminary analysis of the system state before the event does not show any pre-existent security violations as Italian import and internal power flows were largely inside operative limits as were other electrical parameters recorded.

The root cause of the incident, which is analysed in more detail in this document, can be identified as a combination of these factors:

- Very low consumption (decrease of load contribution to damping)
- High voltage angle difference between inside Italy
- Unavailability of some generators leading to a non-standard power flow in the system during a time of very low demand

- Huge import in the southern part of the ENTSOE system[1]

which led to a gradual decrease of general damping of the system, promptly recovered by the actions of the control room staff. It is worth noting that, under these exceptional circumstances, the efficiency of power system stabilisers (PSS) is drastically reduced.

Must be underlined that in the Italian system, PSS double input (active power and frequency) are mandatory on the transmission grid, and PSS settings are periodically checked during power plant inspections and tests. In addition, after the incident, all Southern Italy power plants were inspected more thoroughly and verified. No malfunctions or incorrect parameters were detected; nevertheless an additional finetuning around the oscillating frequency was conducted.

In line with the conclusions of the document 'Analysis of CE inter-area oscillations of 1 December 2016[2], some additional measures were implemented. The importance of early warning alarms generated by WAMS in the control room was confirmed as well as the value of having prepared standard procedures to counteract any incidents related to this oscillation phenomenon.

In addition, an intensive real-time PMU data exchange between TSOs can help to establish a better overview of dynamic system behaviour.

Additional research must be done before introducing innovative damping countermeasures and additional inertia, designed to compensate for system weaknesses under critical conditions (SVCs, synchronous condensers and a new generation of PSS).

2. EVENT DESCRIPTION

3.1 PRE-INCIDENT SITUATION

At 1.00 a.m., the Italian system was in a normal state with an import from the CE system of approx. 1400 MW and a total demand of around 24 GW. The outage of some generators in the South-Eastern part of the Italian system resulted in an increase in an unusual power flow from the South-Western grid zone. Under normal conditions, this flow is not critical and it is present in several scenarios, but the combination of very low demand and the above-mentioned situation caused an oscillation.
The physical international exchanges of 3 December 2017 at H01 are illustrated in Figure 1

[1] The southern part of the ENTSOE system is made up of the block composed by France, Portugal, Spain and Italy.
[2] https://www.entsoe.eu/Documents/SOC%20documents/Regional_Groups_Continental_Europe/2017/CE_inter-area_oscillations_Dec_1st_2016_PUBLIC_V7.pdf

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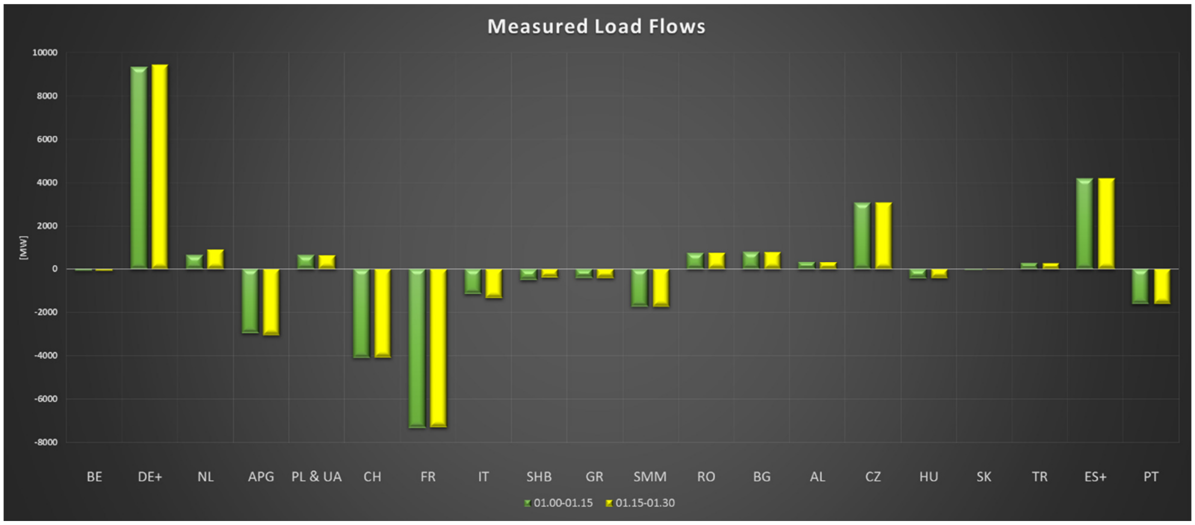

Figure 1: Exchanges between TSOs (Vulcanus platform)

3.2 EVENT CRONOLOGY

At 1.05 a.m., the frequency oscillatory behaviour began to decrease damping, with a significant amplification at 1.10 a.m. In just a few minutes, the frequency amplitude in Southern Italy exceeded 300 mHz, reaching the maximum deviation at 1.15 a.m.

Figure 2 illustrates the main oscillation pattern clearly and is based on overlapping frequency measurements from several CE substations.

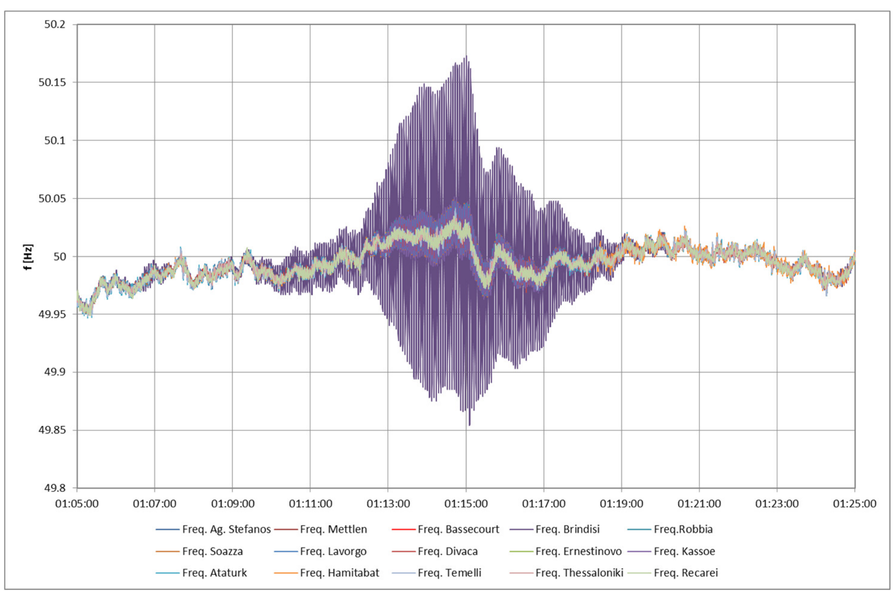

Figure 2: CE frequencies for 3 December 2017 (source: WAMS, 100 ms sampling rate)

At the same time, around 1.05 a.m., the Terna Control room staff noted the oscillation and initiated a fast redispatching of some units in order to mitigate the phenomenon. The following measures were implemented:

- Reduce flow from South to Central Italy
- Open one shunt reactor in South Italy

The first countermeasure was implemented to reduce the voltage angle from South to North Italy. It is worth noting that the flow was largely within the operative limits of exchange between these areas as well as in line with power flows seen in similar and typical scenarios. The latter action was performed to create a voltage discontinuity to smooth out the oscillation; in fact oscillatory loop is broken by a “step” change of operating point on synchronous machines and loads due to the reactive power variation.

In this period, the oscillation was noticed by other CE TSOs and power plants. More specifically, an oscillation of a maximum voltage amplitude around 10 kV was detected in several substations.

3.2 OSCILLATION ANALYSES

The spectral analysis done by the SPD calculated the amplitude of the frequency spectrum using the recorded signals. The oscillation frequency detected was 0.29 Hz.

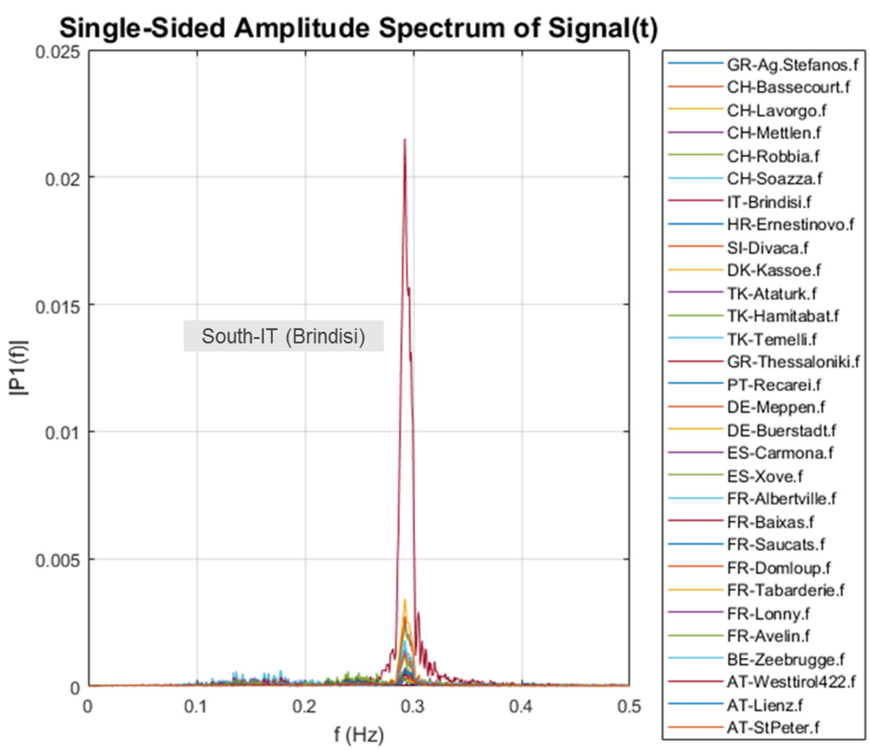

Figure 3: Spectral frequency analysis (source WAMS, 100 ms sampling rate)

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In addition, Figure 4 shows the modal analysis performed during the phenomenon. It is interesting to note that at the beginning of the oscillation, damping was very low only in South Italy (Brindisi). During the first part of the incident, all Southern European locations also showed a low damping.

The modal dominant frequency[3] is also very impressive. At 1.05 a.m. (when the oscillations had been triggered but not yet reached maximum value), we see that the European North-South mode separated from the East-West mode but, at around 1.16 a.m. (when the oscillations reached maximum value), all modes converged at around 0.3 Hz.

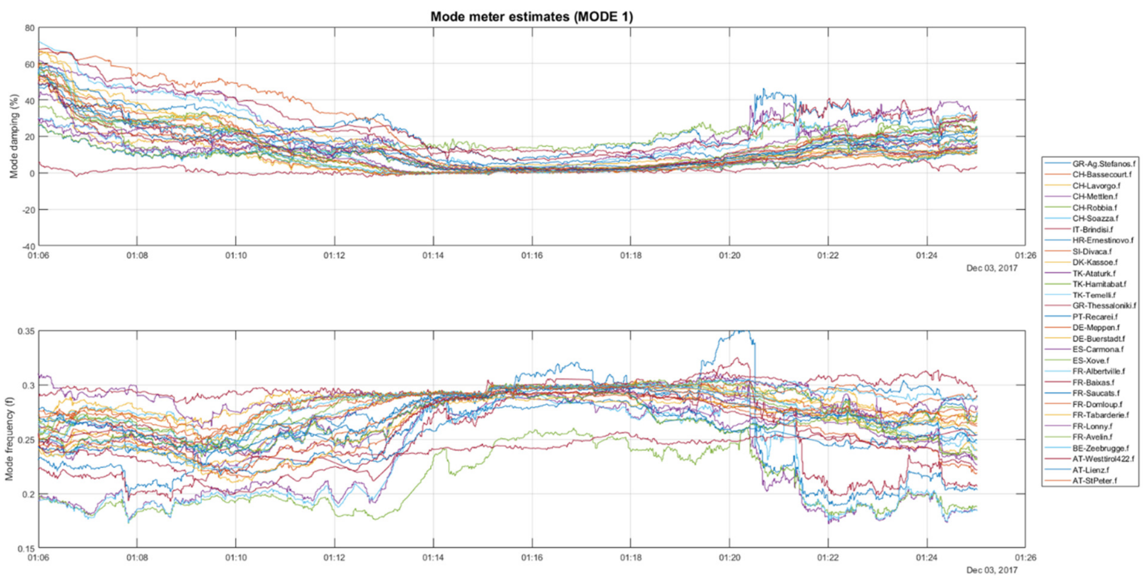

Figure 4: Time-dependent modal analysis

In Figure 5, the SPD reports a mode shape analysis[4] that clearly shows an oscillation in South Italy in a quasi-phase-match with Switzerland, Austria and Eastern Europe when compared to Denmark, Germany, France and the Iberian Peninsula.

[3] Currently considered one of the successful methods used in damping analyses.

[4] The plot shows each ENTSOE selected location as a vector (with amplitude and angle).

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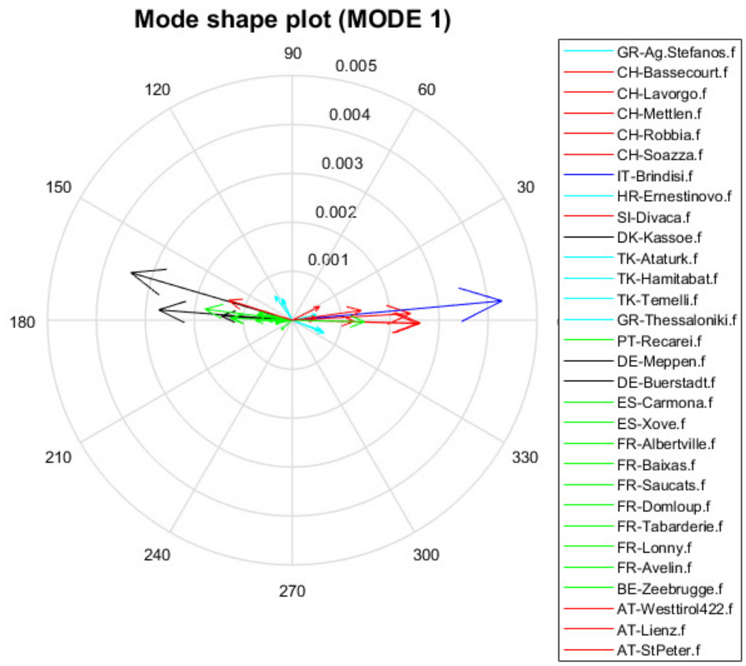


Figure 5: Mode shape of frequency (sags except Brindisi are amplified to a better comparision)

WAMS time domain recordings confirm information derived from previous analyses. By zooming in, the two extremities of this North-South CE inter-area oscillation can be clearly identified in Figure 6. The southern part of Italy (Brindisi) oscillated against the European continent by an amplitude of about ± 150 mHz which was 6 times higher than the ± 25 mHz oscillation observed in Denmark (Kassoe) . The oscillation time period was 3.5 s, corresponding to an oscillation frequency of 0.29 Hz.

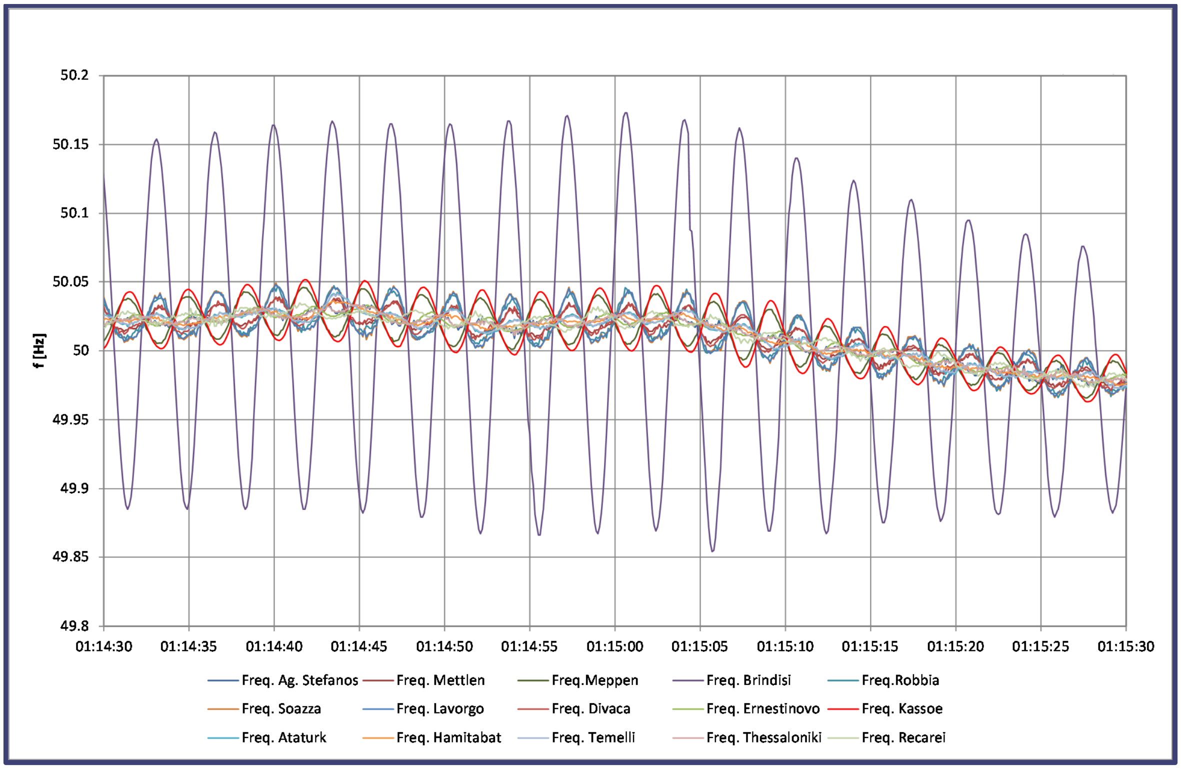


Figure 6: Zooming (source WAMS, 100 ms sampling rate)

At the same time, a significant amount of active power was crossing the Northern Italian border, see Figure 7. Four lines belong to the North-South corridor (Robbia-Gorlago, Robbia-San-Fiorano, Soazza-Bulciago and Lavorgo-Mettlen) and two are part of the East-West corridor (Bassecourt-Mambelin and Bassecourt-Sierentz). The active power oscillation of up to ± 200 MW per line caused the total North-South power oscillation to exceed 1 GW with almost no significant oscillation in the East-West direction.

As a result, there were massive voltage oscillations in the middle of the system of up to ± 2.5 kV and on the Italian peninsula of +7-12 kV, see Figure 8.

Based on these voltage oscillations as well as current oscillations, a few alarms triggered in several CE South-Eastern power systems.

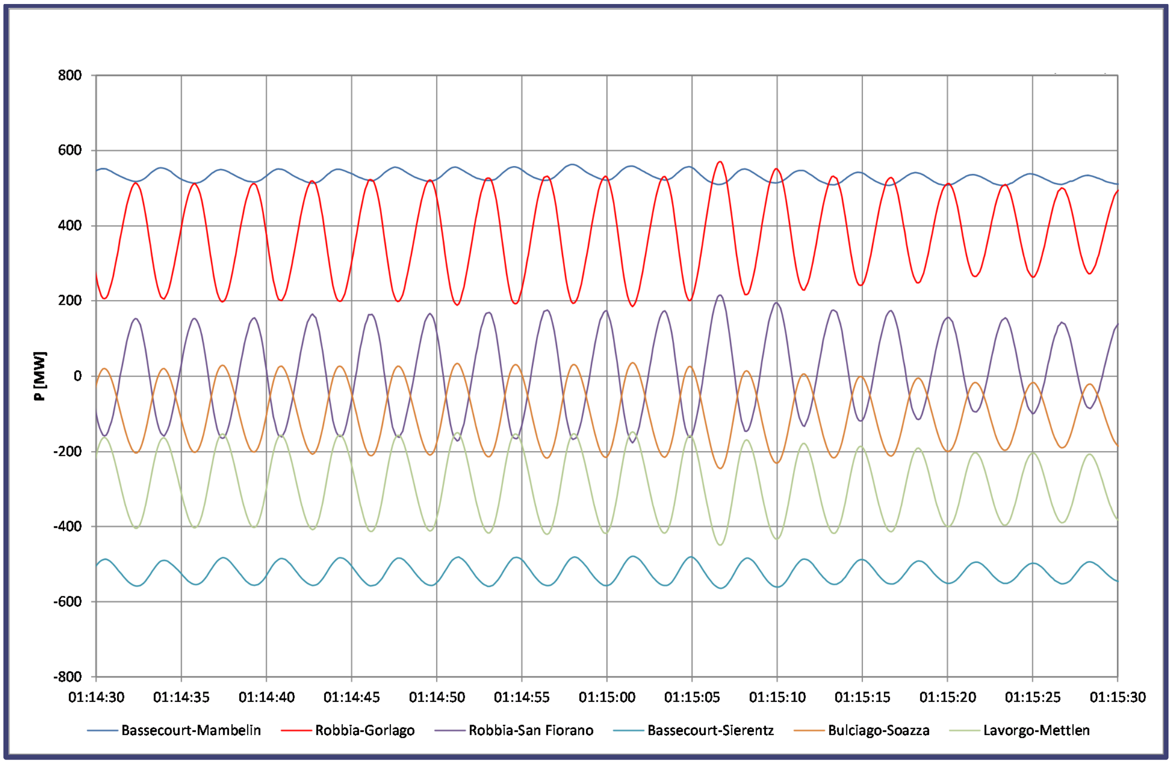


Figure 7: Active power flow over a few Swiss transmission lines, 3.12.2017

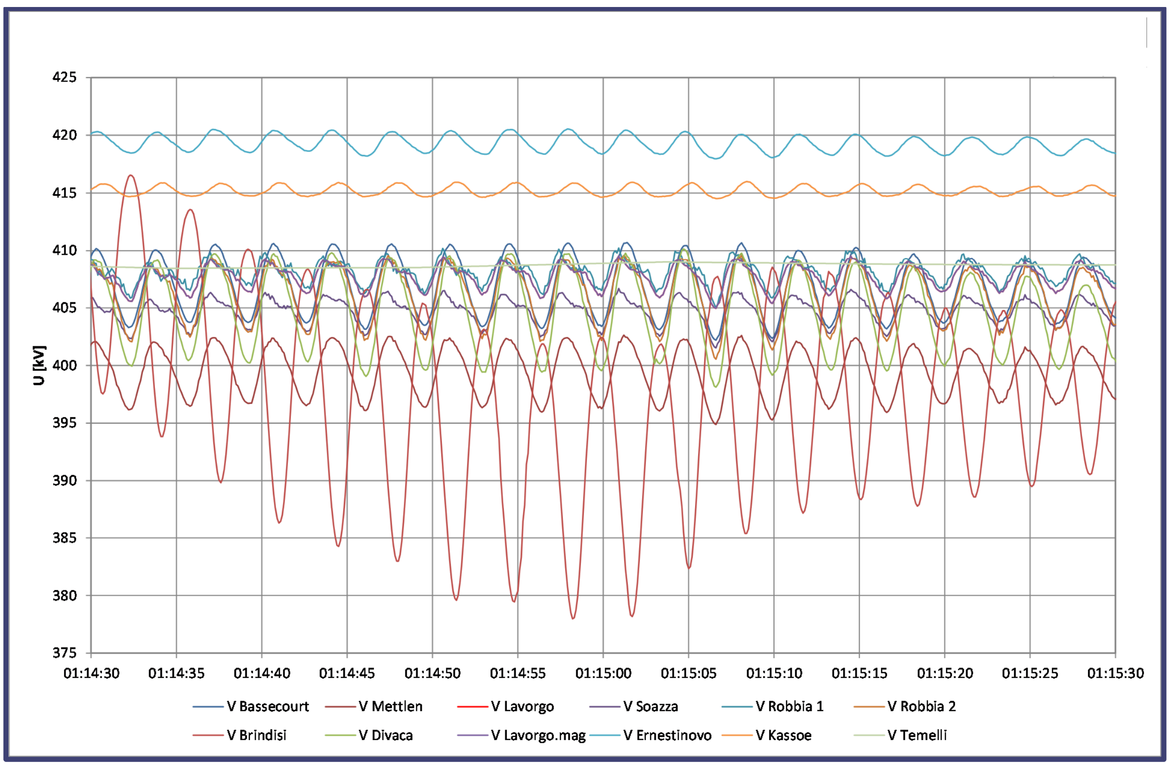
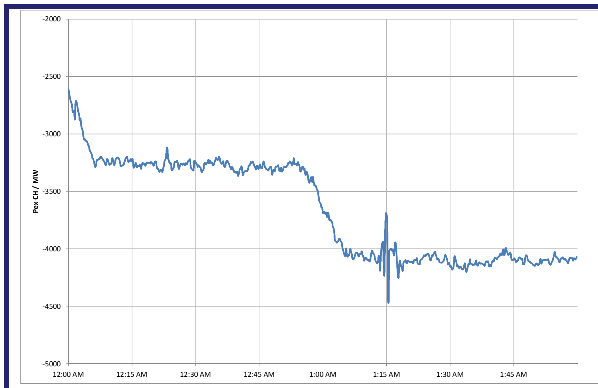
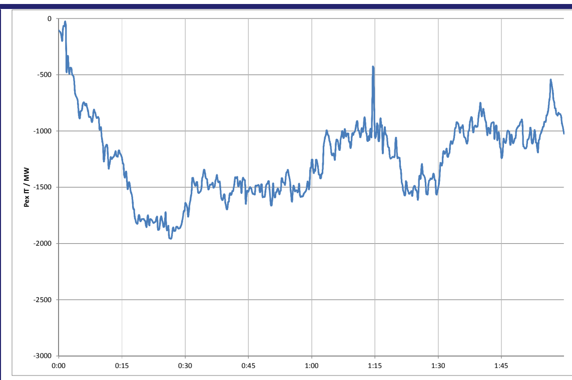


Figure 8: Voltage oscillations on 3.12.2017

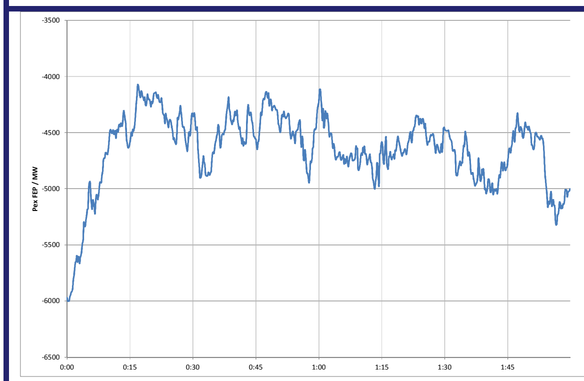
Another important element was the power exchanges between different ENTSO-E control blocks. The following figures clearly show that the Southern CE area was in a significant import situation.



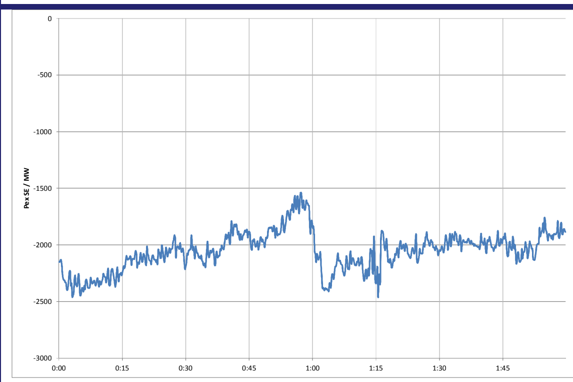
Switzerland exchange power – 3.12.2017, 0:00-2:00



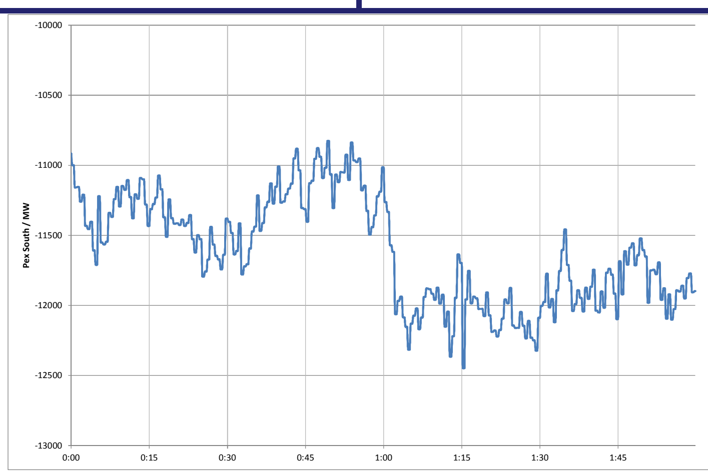
Italy exchange power – 3.12.2017, 0:00-2:00



France, Spain, Portugal exchange power – 3.12.2017, 0:00-2:00



South-Eastern area exchange power – 3.12.2017, 0:00-2:00



South Europe exchange power – 3.12.2017, 0:00-2:00

Figure 9: Exchanges between ENTSOE blocks on 3.12.2017

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3. CONCLUSION AND RECOMENDATIONS

The analysis of the incident on December 3rd, 2017 allows us to conclude that, as per similar events, the combination and coincidence of adverse circumstances can lead to undamped inter-area oscillations over the interconnected system.

The first important element is load; in fact, load can contribute significantly to the stabilisation and damping of the oscillation behaviour. Experience gained from similar events over the last ten years shows that in times of low load (usually during nights or on holidays) an additional reduction of load has the worst effect.

Another important factor is the power angle displacement between different parts of the system. The possibility for monitoring angles is one of the added values provided by WAM systems. High power angle differences across the transmission system weakens the grid and can be increased, as seen in this incident, by unusual/rare generator patterns.

Power system stabilizers may contribute to better damping performance, but their effect is reduced when power angle differences across the system are high. In addition, the combination of low generator operating points and reactive power flows during low load periods may worsen the scenario.

Another factor is the power flow path and direction through the ENTSO-E system. This will be investigated further to detect the correlation with damping performance.

Fast and correct reactions in control room reactions also play a primary role. The present report proved this as control room staff not only triggered the alarms but also quickly implemented countermeasures that blocked the oscillations.

This event confirms the importance of accurate real-time monitoring of voltage magnitudes and phase angles and frequency by WAM systems. Therefore, the SPD group is working to develop and to disseminate coordinated concepts in order to increase the level of information exchanged between TSOs.

Due to system changes and the integration of new technologies in the European electricity grid, additional innovative damping countermeasures and devices must be developed and introduced into the grid in order to minimize serious consequences of inter-area oscillations.

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Reference

[1] Walter Sattinger, Hans Abildgaard, Agustin Diaz Garcia, Giorgio Giannuzzi, Anatoli Semerow, Sebastian Hohn, Matthias Luther "Dynamic Study Model for the Interconnected Power System of Continental Europe in Different Simulation Tools", https://www.swissgrid.ch/dam/swissgrid/current/News/2015/dynamic-study-model.pdf

[2] D E. Grebe, J. Kabouris, S. Lopez Barba, W. Sattinger, W. Winter "Low Frequency Oscillations in the Interconnected System of Continental Europe," IEEE PES General Meeting, Minneapolis, 2010.

[3] P. Korba, M. Larsson and C. Rehtanz "Detection of Oscillations in Power Systems using Kalman Filtering Techniques", IEEE Conference on Control Applications 2003.

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