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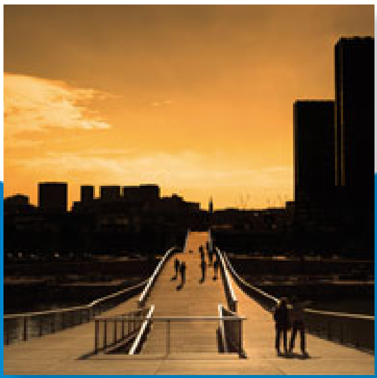

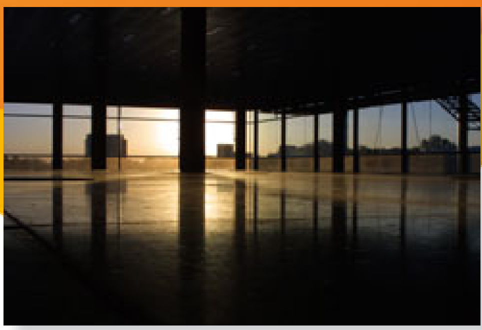

Final Report
System Disturbance on 4 November 2006

union for the co-ordination of transmission of electricity

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Disclaimer

The following Final Report, based on information available concerning the power system disturbances of 4 November 2006, is prepared by the Investigation Committee and is issued by UCTE.

The individuals having prepared this report, as any other UCTE member, including its agents or representatives, shall not be liable in whatever manner for the content of this report, nor for any conclusion whatsoever that any person or third party, could draw from the said report.

This Final Report presents facts and analyses of the events and the root causes as well as final conclusions and recommendations. It is not in the intention of UCTE to express judgments which may prejudice the assessment of liability of any TSO or person.

Even if not explicitly stated, the factual analysis made in this report and the simulations are based on information provided by the TSOs. No direct auditing has been made by the Committee. Everything is expressed in this report refers to the specific events and does not intend to be applied in general to the involved TSOs.

EXECUTIVE SUMMARY

Executive Summary

In the immediate aftermath of the grid disturbances that impacted the continental European transmission grid on 4 November 2006, UCTE decided - upon consultation with Transmission System Operators (TSOs) directly involved - to set up a UCTE Investigation Committee with the mission to deliver to UCTE members, national and European authorities as well as to any interested audience a transparent and complete explanation of the events. Due to the fact that the disturbances affected most of the European countries, the UCTE member companies were invited to participate in this Committee. The investigation work was organized in three different subgroups (according to the borderlines of the physical separation of the synchronously interconnected grid), each of them chaired by a convenor under the supervision of the Committee Chairman.

This report provides a technical analysis of the main phases of the disturbances: the sequence of events leading to the system splitting, the system status and defence actions taken in the individual areas, the re-synchronization process, the analysis of main causes, and finally the analysis of critical factors and recommendations.

General system conditions

Originally, the European interconnected transmission infrastructure had the function to form the essential backbone for the security of supply in continental Europe. For this purpose the system has been developed over the last 50 years with a view to assuring mutual assistance between national subsystems. However, there has been a fundamental change of paradigms over the past one or two decades. European transmission infrastructure is no longer just a tool for mutual assistance but has become the platform for shifting ever growing power volumes all across the continent. Market developments result in higher cross-border exchanges (with short-term commercial objectives). Other cross-continental power flows result from the fast and successful development of regional intermittent energy generation with low predictability (wind power). These developments were not taken into account in the original system design.

Due to environmental reasons, the development of the transmission system is more and more affected by stricter constraints and limitations in terms of licensing procedures and construction times. The reality today is that many UCTE TSOs face significant difficulties to build new overhead lines due to long authorization procedures and regulatory regimes.

All this, also on November 4, led TSOs to operate the system closer and closer to its limits according to current security criteria based on system physics that will therefore remain of decisive relevance for a secure operation of the electricity transmission infrastructure.

<u>Sequence of events</u>

On the evening of November 4 there were significant East-West power flows as a result of international power trade and the obligatory exchange of wind feed-in inside Germany. These flows were interrupted during the event. The tripping of several high-voltage lines, which started in Northern Germany, split the UCTE grid into three separate areas (West, North-East and South-East) with significant power imbalances in each area. The power imbalance in the Western area induced a

severe frequency drop that caused an interruption of supply for more than 15 million European households.

Events in areas with under and over-frequency

In both under-frequency areas (West and South-East), sufficient generation reserves and load shedding allowed to restore the normal frequency within about 20 minutes. The imbalance between supply and demand as a result of the splitting was further increased in the first moment due to a significant amount of tripped generation connected to the distribution grid.
In the over-frequency area (North-East), the lack of sufficient control over generation units contributed to the deterioration of system conditions in this area (long lasting over-frequency with severe overloading on high-voltage transmission lines). Generally, the uncontrolled operation of dispersed generation (mainly wind and combined-heat-and-power) during the disturbance complicated the process of re-establishing normal system conditions.

Resynchronization

Full resynchronization of the UCTE system was completed 38 minutes after the splitting. The TSOs were able to re-establish a normal situation in all European countries in less than 2 hours.
Due to the adequate performance of automatic countermeasures in each individual TSO control area and additional manual actions by TSOs a few minutes after the splitting, a further deterioration of the system conditions and a Europe-wide black-out could be avoided. The decentralized responsibilities of TSOs have demonstrated their efficiency.

The investigations identified two main causes of the disturbance as well as some critical factors which had significant influence on its course.

Two main causes

Non fulfilment of the N-1 criterion

After manual disconnection of the double-circuit 380 kV Conneforde-Diele line (E.ON Netz), the N-1 criterion was not fulfilled in the E.ON Netz grid and on some of its tie-lines to the neighbouring TSOs. Moreover, the resulting physical flow on the 380 kV Landesbergen (E.ON Netz)-Wehrendorf (RWE TSO) line - being in operation - was so close to the protection settings at the Wehrendorf substation (RWE TSO) that even a relatively small power flow deviation triggered the cascade of line tripping. This occurred when E.ON Netz did not undertake proper countermeasures to reduce the flow on this line.

Insufficient inter-TSO co-ordination

The initial planning for switching-off the double-circuit 380 kV Conneforde-Diele line scheduled for 5 November from 01:00 to 5:00 was duly prepared by the directly involved TSOs (E.ON Netz, RWE TSO and TenneT). However, the change of the time for this switching maneuver was communicated by E.ON Netz to the other directly involved TSOs at a very late moment; it was also not sufficiently prepared and checked in order to ensure the secure operation of the system in this area after the switching-off. No specific attention was given by E.ON Netz to the fact that the protection devices have different settings on both sides of the Landesbergen-Wehrendorf line although this information was critical due to the very high flow on this line.

Critical factors

Generator-related issues

During the disturbance, a significant amount of generation units tripped due to the frequency drop in the Western area of the UCTE system. This contributed to the deterioration of system conditions and to the delay for restoring secure normal conditions. In addition, most of the TSOs do not have access to the real-time data of the power units connected to the distribution grids. This did not allow them to perform a better evaluation of the system conditions. Furthermore, in the North-Eastern area, the uncontrolled reconnection of generation units induced very severe conditions and the need for additional time to recover secure system operation.

Limited range of action available to dispatchers for handling grid congestions

In Germany, TSOs have to take different kinds of measures during congestions and emergency situations as stated in the Energy Industry Law and transposed into internal procedures: grid-related measures, market-related measures and other adjustments for the management of emergency situations. The adequacy and effectiveness of such measures are not always supporting an adequate management of such specific conditions like the one on 4 November 2006.

TSO/DSO co-ordination in the context of defense and restoration plans

In some control areas, re-energization of customers was started by DSOs without proper knowledge of the situation in the overall UCTE system; some of them started reconnecting customers without coordination with their TSOs. This worsened the conditions for TSOs action to restore normal system conditions in a controllable way.

Resynchronization process

Actions taken by TSOs during the resynchronization process were not fully coordinated. There have been several unsuccessful attempts to put tie-lines back into operation and to resynchronize the three different areas with only a partial view of the status of the whole grid.

Training of dispatchers

Although training of dispatchers has been well developed for a couple of years for situations related to TSOs internal control area conditions, incidents originating from external networks and affecting a TSO’s own grid are not always trained. Joint simulation training with neighboring TSOs is not yet a common practice.

Conclusions

Until the switching-off of the 380 kV double circuit line Conneforde-Diele, the system was in a state compliant with the security standards currently in force. The severe disturbance on 4 November 2006 and the splitting of the interconnected system were not caused by some extraordinary climatic conditions or technical failures. The disturbance was triggered by causes in the E.ON Netz control area. The very rapid splitting of the interconnected system could not be stopped once the cascade tripping of the lines had started. Due to the good performance of countermeasures activated at UCTE level in the individual control areas, a Europe-wide black-out has been avoided.

In terms of security standards, the proposed recommendations of the Investigation Committee are as follows:

Recommendation #1
The application of the N-1 criterion in Policy 3 of the UCTE Operation Handbook has to be reviewed in terms of the following aspects:

- **Definition of the relevant part and specific conditions in the adjacent systems which have to be taken into account in TSOs security analyses.**
- **Simulation of contingencies (tripping of power system elements) located outside the TSO's own control area.**
- **Mandatory and regular online contingency analysis (N-1 simulations) connected to the alarm processing system.**
- **Preparation and regular check of the efficiency of remedial actions through numerical simulations.**

Recommendation #2
Policy 5 ("Emergency Operations") has to be extended with a "Master Plan" defining principles of operation and TSOs' responsibilities to manage UCTE-wide or regional disturbances. Additionally the following aspects have to be considered:

- **TSOs have to reconsider their defense plans and load shedding philosophy and rating taking into account significant amounts of generation tripped during disturbances with large frequency deviation**
- **The restoration and re-energization process has to be explicitly coordinated by TSOs regarding DSOs actions and the related responsibilities and duties of involved parties must be clarified within a national framework**

Recommendation #3
UCTE has to develop standard criteria for regional and inter-regional TSOs co-ordination approach aiming at regional security management, from operational planning to real time, in terms of joint training, enhancement of exchanges of data, results of security analyses and foreseen remedial actions.

Recommendation #4
UCTE has to set up an information platform allowing TSOs to observe in real time the actual state of the whole UCTE system in order to quickly react during large disturbances.

Recommendation #5
The regulatory or legal framework has to be adapted in terms of the following aspects:

- **TSOs should have the control over generation output (changes of schedules, ability to start/stop the units)**
- **Requirements to be fulfilled by generation units connected to the distribution grid should be the same in terms of behavior during frequency and voltage variations as for the units connected to the transmission network. These requirements should be applied also to units already connected to transmission and distribution grids.**
- **Operators of generation units connected to the transmission grid must be obliged to inform the TSO about their generation schedules and intra-day changes of programs prior to their implementation.**
- **TSOs should receive on-line data of generation connected to DSOs grids (at least 1-minute data)**

INTRODUCTION 1

1. Introduction

1.1. Background

In the night of 4 November 2006, at around 22:10, the UCTE interconnected grid was affected by a serious incident originating from the North German transmission grid that led to power supply disruptions for more than 15 millions European households and a splitting of the UCTE synchronously interconnected network into three areas.

The immediate action taken by all Transmission System Operators (TSOs) according to the UCTE security standards prevented this disturbance to turn into a Europe-wide blackout. However, this event ranks among the most severe and largest disturbances in Europe.

1.2. Investigation Committee

Immediately after the disturbance, on 5 November 2006 UCTE initiated the setup by its members of an Investigation Committee with the task of finding out the root causes of the disturbance and proposing recommendations to avoid such events to repeat.

The main purpose of the Investigation Committee was to bring a transparent and complete explanation of the events of 4 November 2006 to the UCTE members to both stakeholders and the general public.

The main tasks of the Investigation Committee included:

- investigating, at the level of all involved countries, events and causes related to the 4 November disturbance
- evaluating TSOs' actions with respect to the UCTE Operation Handbook and the Multilateral Agreement in force from July 2005 on
- examining their compliance with standards and application of temporary measures to which they committed
- assessing adequacy of present practices and standards,
- defining and proposing improvements to these practices and standards.

The Investigation Committee [IC] was chaired by the Chairman of the UCTE Steering Committee, Gerard A. Maas (TenneT, The Netherlands). IC members being representatives of nearly all UCTE member companies (see Appendix 1).

The working structure of the Committee consisted of three subgroups according to the borderlines of the physical separation of the synchronously interconnected transmission grid, each of them being chaired by a convenor under the supervision of the Committee Chairman.

The subgroup **Western Europe** was chaired by Mrs. Clotilde Levillain (RTE, France) and members of this group include representatives of TSOs from Germany, The Netherlands, Belgium, France, Spain, Portugal, Italy, Switzerland, Slovenia, Croatia and Austria.

The subgroup **North-East Europe** was chaired by Mr. Jerzy Dudzik (PSE-Operator, Poland) and members of this group include representatives of TSOs from Germany, Poland, Czech Republic, Slovakia, Austria and Hungary.

The subgroup **South-East Europe** was chaired by Mr. Yannis Kabouris (HTSO/Desmie, Greece) and members of this group include representatives of TSOs from Serbia, Montenegro, Romania, Bulgaria, Bosnia-Herzegovina, Croatia, FYROM, Hungary and Greece.

This **Final Report** presents facts and analyses on the root causes of the disturbance as well as final conclusions and recommendations.

1.3. UCTE as standard setting organization and TSO co-ordination platform

The "Union for the Co-ordination of Transmission of Electricity" (UCTE) is the Association of Transmission System Operators (TSOs) in continental Europe. It aims at providing a reliable market place through the co-ordination of the operation of electric "power highways" over the entire European mainland.

The transmission networks of the UCTE members supply electricity to about 450 million people with an annual consumption of approximately 2 500 TWh. The UCTE system covers 23 European countries with some 220 000 km of 400/380 kV and 220 kV lines, being thus by far the largest interconnected system in Europe.

Over the 2nd half of the 20th century the UCTE interconnected system was designed in order to implement principles of solidarity and economy. The UCTE system developed progressively into the highly meshed network that provides routes for electricity transport from the generation in-feed to the consumption and allows to get missing power from a neighboring control area through the available reserves of partners. Building on the essential principle of solidarity, the reliability, adequacy and security of supply were continuously improved by strengthening interconnections and formulating binding operation standards.

Today, TSOs are in charge of managing the security of operation of their own networks in a subsidiary way based on the UCTE Operation Handbook. Individual TSOs are responsible for procedures of a reliable operation in their control area from the planning period as in view of the real-time conditions, with contingency and emergency conditions. The co-ordination between TSOs contributes to enhance the shared solidarity to cope with operational risks inherent to interconnected systems, to prevent disturbances, to provide assistance in the event of failures with a view to reducing their impact and to provide restoration strategies and coordinated actions after a collapse.

However, the UCTE interconnected system is operated more and more at its limits. Markets trigger an increase of cross-border power flows between countries since markets by definition aim at optimizing the produced power depending on short term prices differences. This leads to important variations of generation patterns within the UCTE systems displacing substantial amounts of electricity from one area to another one, from one hour to another one, or even shorter.

This is why UCTE – supported by the European Commission and all relevant stakeholders - developed from 2002 onwards an own “Security Package” - as a set of complementary tools:

1. The *UCTE Operation Handbook* [OH] as the compendium of technical standards to be applied in the UCTE interconnected system; OH constitutes the technical/operational reference for a seamless and secure operation of the power system;
2. The *Multilateral Agreement* [MLA] as cornerstone of the legal framework for the security of the UCTE interconnected systems, since MLA introduces a binding contractual relation between all UCTE TSOs referring to OH.
3. The *Compliance Monitoring and Enforcement Process* [CMEP] as a recurrent ex-ante process verifying the implementation of the OH standards by all TSOs as well as any measures individual TSOs have committed to towards the entire TSO community in cases of temporary non-compliance.

The UCTE Operation Handbook comprises eight Policies. Policies 1 to 7 are already in force. Before the event on 4 November 2006, it was already decided by UCTE that Load-Frequency Control and Performance, Scheduling and Accounting, Operational Security, Coordinated Operational Planning, Emergency Operations, Communication Infrastructures, Data Exchanges policies need to be enhanced through a regular review process. Lessons learnt from the investigation of the disturbance will also be immediately taken into account. Policy 8 on Operational Training is to be released in early 2007.
In 2006 UCTE started its first pilot project about compliance monitoring of the Operation Handbook standards. The results of this first exercise will be made public mid February 2007. A follow-up 2007 program for the compliance monitoring is in preparation for final decision early March.

Even if due to national legislation and regulatory frameworks as well as due to internal procedures each TSO has to follow additional rules, the UCTE Security Package remains the basic reference for the security of the interconnected system. It substantially increases transparency on the fundamentals of the TSO rules and therefore the necessary mutual confidence of TSOs among themselves as well as their credibility towards stakeholders.

1.4. Changing function of the transmission grid

Originally, the European interconnected transmission infrastructure had the function to form the essential backbone for the security of supply in continental Europe. For this purpose the system has been developed over the last 50 years with a view to assure a mutual assistance between national subsystems. However, there has been a fundamental change of paradigms over the past one or two decades. European transmission infrastructure is no longer just a tool for mutual assistance but has become the platform for shifting ever growing power volumes all across the continent. Market developments result in higher cross-border and long-distance energy exchanges (with short term commercial objectives). Other cross-continental power flows result from the fast and successful development of regional intermittent energy generation with low predictability (wind power). These developments were not taken into account in the original system design.

Against this background day-to-day grid operation has become much more challenging. In a context where the daily operation becomes more and more demanding due to volatile wind infeed and hourly changing trade volume of thousands of Megawatts, the system has to be operated closer to its limits. This was also the case on November 4, 2006.

All this turned to be in recent years a typical situation in the daily operation practice of the European interconnected grid that can only be mastered via an adequate transmission infrastructure and a more complex management of the interconnected networks embedded in a consistent harmonized regulatory framework. Due to environmental reasons, the development of the transmission system is more and more affected by stricter constraints and limitations in terms of licensing procedures and construction times. The reality today is that many UCTE TSOs face significant difficulties to build new overhead lines due to long authorization procedures and regulatory regimes.
Furthermore, the need for a more complex management of the interconnected grid is obvious, but has so far not always been supported by regulators and main stakeholders when TSOs asked for more generation data and intervention rights, especially in emergency situations.
All this lead TSOs to operate the system closer and closer to its limits as allowed by the current security criteria based on system physics that will therefore remain of decisive relevance for a secure operation of the electricity transmission infrastructure.

The new role of the grid requires close co-operation among TSOs and adequate development of the grid system in terms of building new power lines. UCTE has pro-actively taken the initiative some years to develop binding security standards.

EVOLUTION OF THE SYSTEM CONDITIONS DURING THE EVENT

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2. Evolution of the system conditions during the event

2.1. System conditions before the disturbance

This part is presenting the general state of the UCTE interconnected system just before its split into three large areas.

Grid topology

As usual during weekends, when demand is lower than during the working days, several transmission network elements were not in operation due to scheduled maintenance and construction work:

Near the region where the first line trip occurred:

- 380 kV Hamburg Ost - Krümmel 1 circuit (DE)
- 380 kV Gronau-Polsum (DE)
- 380 kV Phase shifter transformer in Gronau (DE)
- 380 kV Oberzier - Niederstedem (DE)
- 380 kV Maasbracht - Meerhout (NL/BE)

On the borders between the separated areas:

- 380 kV line Sándorfalva – Békéscsaba (HU)
- 220 kV line Szolnok – Szeged (HU)
- 380 kV line Melina – Velebit (HR)

Appendix 2 gives a detailed overview of all planned outages in the UCTE network for 4 November.

Additionally, the specific topology in the 380 kV substation of Borken (E.ON Netz) was as follows: two busbars in the substation were split in two parts (for construction work): an eastern part with the lines Mecklar and Bergshausen/Würgassen, and a western part with the lines Twistetal/Nehden and Gießen-Nord. This configuration made the power flow from East to West in this region impossible.

In addition to this, the 380 kV Landesbergen substation (E.ON Netz) was operated with two separated busbars in order to reduce the short-circuit current which would exceed the limit of the switchgear in case Robert Frank 4 power plant is in operation[1].This is the normal configuration of this substation.

Power balance between the three "virtual" areas

Generation in the whole UCTE system at 22:09 is estimated (some data about generation connected to the distribution grid are not available) at around 274 100 MW including approximately 15 000 MW of wind generation (most of which was located in Northern Europe and Spain). This overall figure can be distributed approximately among three "virtual" areas which appeared after the system split as follows:

- Western area: 182 700 MW including 6 500 MW of wind generation
- North-Eastern area: 62 300 MW including 8 600 MW of wind generation
- South-Eastern area: 29 100 MW

The following figure shows the estimated generation (G), the sum of physical exchanges on the lines which tripped in the course of the incident (blue arrows) and exchanges over DC cables (orange arrows).

[1] Robert Frank 4 was not in operation on 4 November

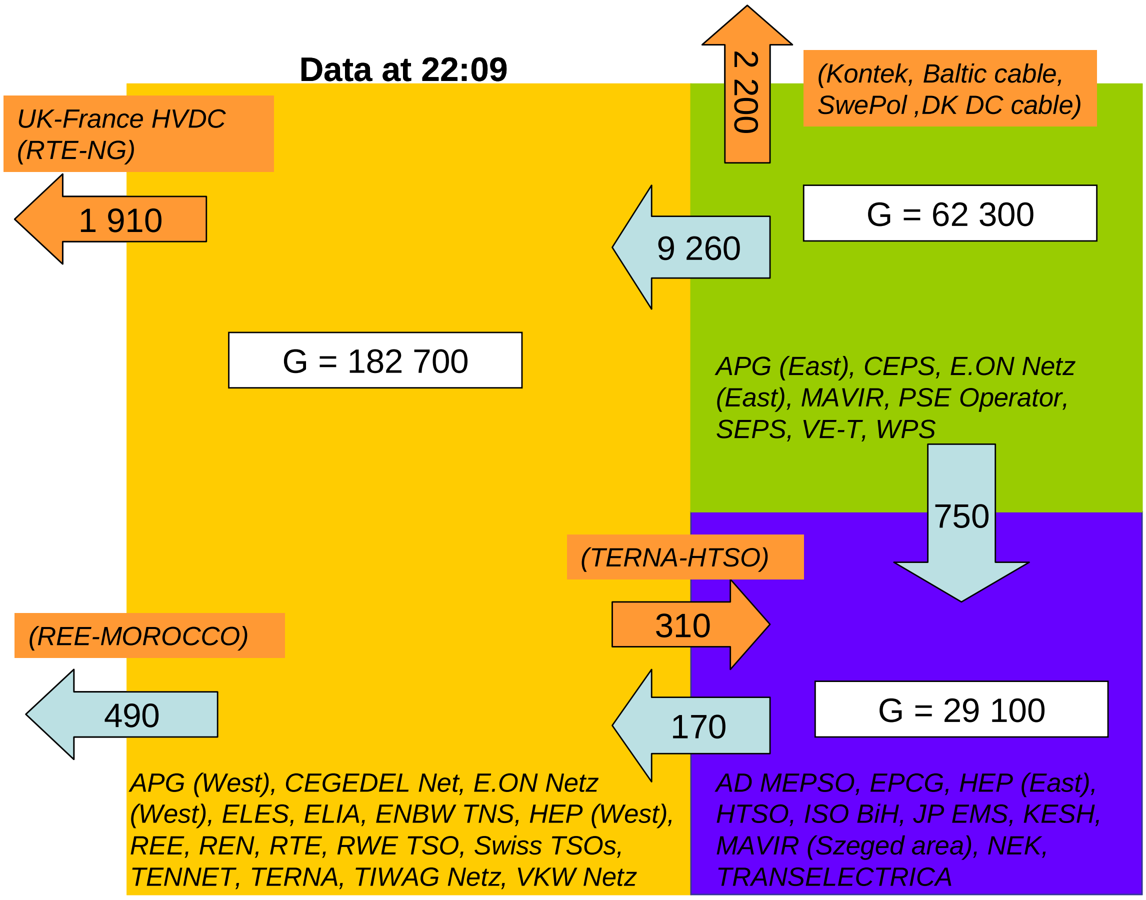

Figure 1: Generation and power flows between the three areas just before splitting 4 November 22:09

Frequency

The frequency from 21:30 to 22:09 is very close to the nominal set point at 50 Hz.

Exchange programs[2] and physical power flows at 22:09 on 4 November

The power flows in a meshed grid are the result of actual state of generation (output and localization), consumption (profiles and localization) and transmission network (topology and technical parameters).

One of the main tasks of the TSOs is to anticipate and manage in real time power flow changes in order to ensure a secure operation of their own control area, and in co-ordination with other TSOs all over the UCTE grid.

Figure 2 shows both exchange programs resulted from trading activities (red) and physical flows (blue) as recorded on 4 November at 22:09. It is not unusual that in a highly meshed network, physical flows significantly differ from the exchange programs.

The main point to be underlined around North Europe (starting point of the disturbance) is the high flow from Germany to The Netherlands and to Poland due to the high wind generation in Germany.

[2] An exchange program represents the total scheduled energy interchange between two control areas or between control blocks.

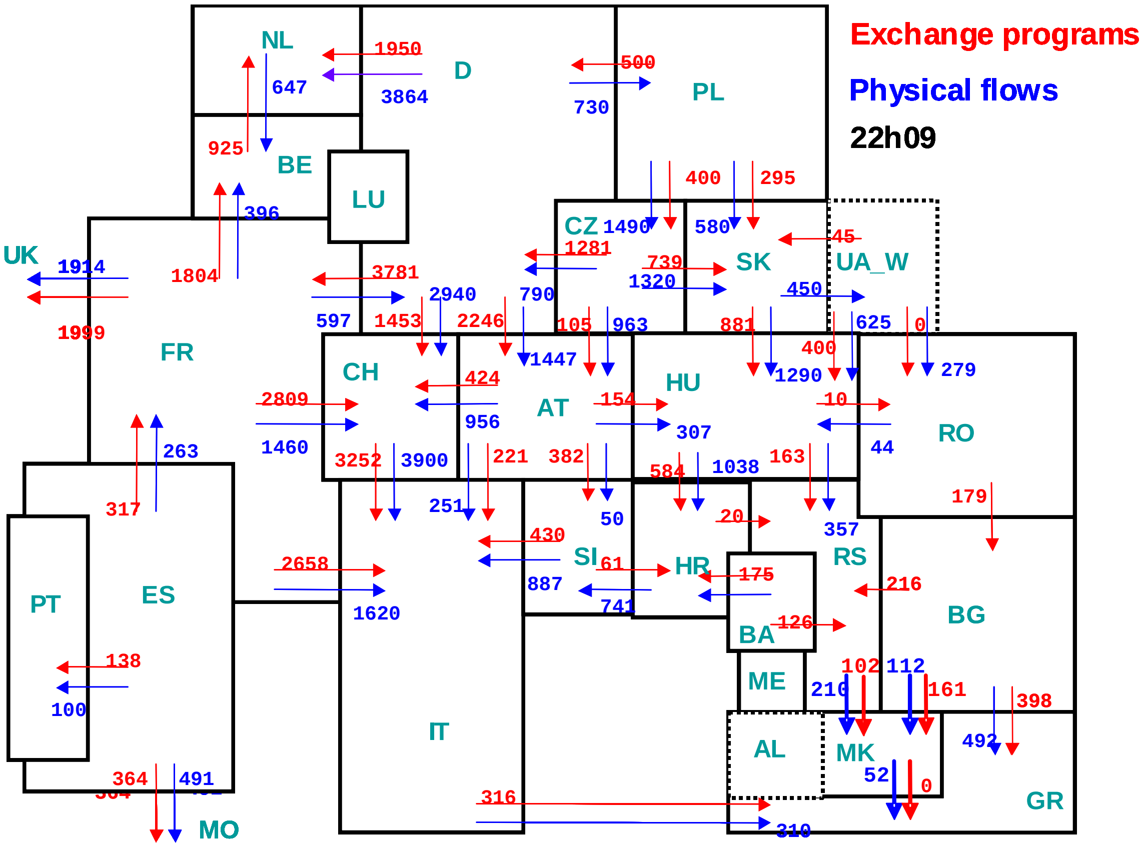

Figure 2: Exchange programs (red) and physical flows (blue) on 4 November at 22:09

Planning for the Conneforde-Diele outage (internal E.ON line, 380 kV, double circuit)

On 18 September 2006, the shipyard (Meyerwerft) sent a request to E.ON Netz for a disconnection of the double circuit 380 kV line Conneforde-Diele for the transport of the ship “Norwegian Pearl” via the Ems River to the North Sea on 5 November at 01:00. Such a switching was done several times during the last years.

E.ON Netz carried out an analysis of the impact of switching off the line on the network situation using standard planning data. Since the analysis did not show the violation of the N-1 criterion in its network[3], E.ON Netz provisionally approved the request of the shipyard on 27 October. At the same time E.ON Netz informed TenneT and RWE TSO about the provisional agreement, so they could carry out an N-1 analysis on their network. The results of those analyses confirmed that the grid would be highly loaded, but secure.

The base case of TenneT used on October 27 was taking into account the planned outage of the Maasbracht (TenneT) – Meerhout (Elia) line. The total import capacity to The Netherlands for 5 November from 00:00 to 06:00 was set to 3 600 MW and shared as follows:

- E.ON Netz => TenneT: 850 MW
- RWE TSO => TenneT: 1 493 MW
- ELIA => TenneT: 1 257 MW

[3] The “N-1” criterion is a basic principal in power system operation. It is defined in the UCTE Operation Handbook – Policy #3: Operational Security as follows: “any probable single event leading to a loss of power systems elements (generating set, compensating installation or any transmission circuit, transformer) should not endanger the security of interconnected operation, that is, trigger a cascade of trippings or the loss of a significant amount of consumption. The remaining network elements, which are still in operation should be able to accommodate the additional load or change of generation, voltage deviation or transient stability regime caused by the initial failure. It is acceptable that in some cases TSOs allow a loss of consumption in their own area on condition that its amount is compatible with a secure operation, predictable and locally limited”.

As a result of co-ordination among TenneT and E.ON Netz for the outage of the Conneforde-Diele line, the TSOs agreed to reduce the cross border transmission capacity from E.ON Netz to TenneT by 350 MW for 5 November from 00:00 to 06:00.

On 4 November, TenneT in coordination with RWE TSO and E.ON Netz decided to further reduce the capacity between Germany and The Netherlands for 5 November to take into account the wind forecast and to manage flows on tie-lines to TenneT. As no wind feed-in was expected from E.ON Netz due to the planned outage of the Diele Conneforde line, the reduction of 159 MW was made only on the capacity from RWE TSO to TenneT.

Finally the import capacity from Germany to The Netherlands amounted to 1 834 MW for 5 November from 00:00 to 06:00.

Also on 3 November, around 12:00, the shipyard requested E.ON Netz to advance the disconnection of the line by three hours, to 4 November at 22:00. A provisional agreement was given by E.ON Netz after a new analysis did not reveal a violation of the N-1 criterion in its network. At this point RWE TSO and TenneT were not informed about this procedure so no special security analyses were made to take into account the new timing in the neighboring TSOs.

The late announcement of the shipyard made it impossible to reduce the exchange program between Germany and The Netherlands for the outage of the Conneforde-Diele line in the same way as prepared for 5 November. According to TenneT, no exchange program reduction is possible after 08:00 for the day ahead due to the agreed auction rules (capacity is considered as firm, except in the case of “force majeure”).

Additionally, there was no indication of the switching of the Conneforde-Diele line in the planning tools and data (DACF[4]) distributed by E.ON Netz to all UCTE TSOs on 3 November around 18:00 with the forecast for 4 November at 22:00 and beyond.

Only at 19:00 on 4 November E.ON Netz informed TenneT and RWE TSO about the new time for switching off the Diele-Coneforde line.

At the same time TenneT agreed with E.ON Netz and RWE TSO to change the tap position on the phase shifter in Meeden (TenneT) in order to reduce high flows expected for the coming hours on the Meeden – Diele line. Half an hour later, at 19:33, TenneT changed the tap positions of the phase shifter in Meeden to secure the flows between E.ON Netz and TenneT (lower flow on the Diele-Meeden interconnector).

Around 21:30, TenneT and RWE TSO confirmed to E.ON Netz that the flows between Germany and The Netherlands were high, however since TenneT and RWE TSO grid would be secure, TenneT and RWE TSO gave its agreement to the switching operation of the Conneforde-Diele lines.

2.2. Factual sequence of events leading to UCTE system splitting

At 21:29, according to E.ON Netz, a load flow calculation made by E.ON Netz did not indicate any violation of limit values. Based on an empirical evaluation of the grid situation, E.ON Netz staff assumed, without numerical computation, that after switching of the Conneforde-Diele line the N-1 criterion would be met in the system.
At 21:30, just before the opening of the Conneforde-Diele line, RWE TSO made a load flow calculation and an N-1 analysis with the outage of the Conneforde-Diele line. The results confirmed that RWE TSO grid would be highly loaded but secure.

According to the UCTE Operation Handbook, each TSO has to be able to check the compliance of the N-1 criterion from the planning stage to the real time. Each TSO must check that it has sufficient remedial actions which can be implemented within the available time to maintain secure operation.

[4] DACF (Day Ahead Congestion Forecast) data and files are prepared by each TSO every day at around 18:00 for the coming day. UCTE is requiring 4 time stamps per day. E.ON Netz is providing 24 time stamps data for each hour and a half. These DACF files can be used by all UCTE TSOs to make security analyses on a larger basis than their “home” grid.

Also, according to the rules in force in E.ON Netz, the dispatchers had to check the respect of the N-1 criterion before opening the 380 kV double circuit line Conneforde-Diele.

At 21:38, E.ON Netz switched off first circuit of the 380 kV line Conneforde-Diele, so called Conneforde-Diele red.
At 21:39 E.ON Netz switched off second circuit of the 380 kV line Conneforde-Diele, so called Conneforde-Diele white.
At 21:39, after the switching operation, E.ON Netz received several warning messages about the high power flow on the lines Elsen-Twistetal and Elsen-Bechterdissen.
At 21:41, RWE TSO informed E.ON Netz about the safety limit value of 1 795 A on the line Landesbergen-Wehrendorf (an interconnection line between E.ON Netz and RWE TSO). However, at this point of time the current on this line was still under the given limit (1 795 A), and the N-1 criterion was still met in the internal RWE TSO network.

The protection settings on both sides of the Landesbergen-Wehrendorf line are different. They are summarized in the table below.

	E.ON Netz (Landesbergen)	RWE TSO (Wehrendorf)
Steady state value (thermal capacity of the line)	2 000 A	2000 A
Warning value (alarm)	1000 A and 2 000 A	1 795 A (90% of the max. limit value)
Maximal accepted value	2 550 A (85% of tripping current) for a max. time 1 hour.	1995 A (95% of the tripping current
Tripping current	3 000 A	2 100 A

Table 1: Current limit values on the line Landesbergen-Wehrendorf

According to E.ON Netz, dispatchers were not aware of the settings in the protection system in Wehrendorf (RWE TSO substation). Therefore the dispatchers did not take into account the correct values for their evaluation of the situation.

RWE TSO stated that it informed E.ON Netz about the protection settings in Wehrendorf and was reciprocally informed about the protection scheme values of E.ON Netz in Landesbergen. This information was provided as part of data exchange concerning protection values and set-up of protection units implemented among the German TSOs. The last actualization of the values was provided by RWE TSO in September 2003.

In additional telephone calls between E.ON Netz, RWE TSO and Vattenfall Europe Transmission at 21:46, 21:50 and 21:52, the situation was considered to be tight. Additionally, in one of the phone calls, RWE TSO informed E.ON Netz about the settings of the protection units.

Between 22:05 and 22:07, the load on the 380 kV line Landesbergen-Wehrendorf increased by 100 MW exceeding the warning value of 1 795 A for RWE TSO.
This triggered an immediate reaction of RWE TSO that called E.ON Netz at 22:08 with the request for urgent intervention to restore safe grid operation. E.ON Netz made an empirical assessment of corrective switching measures without any load flow calculations for checking the N-1 criterion. E.ON Netz expected that coupling of the busbars in the substation of Landesbergen would end in a reduction of the current by about 80 A. This maneuver was done at 22:10 without any further co-ordination with RWE TSO due to necessary rush.

The ex-post simulations made in the course of investigations showed that this action led to a result which was contrary to what dispatchers expected; the current on the line increased by 67 A (instead of decreasing) and the line was automatically tripped by the distance relays in the Wehrendorf substation (RWE TSO) due to overloading.

The increase of the flow on the Landesbergen-Wehrendorf line up to the moment of tripping is shown in Figure 3 below. The manual switching of the Diele–Conneforde line at 21:38 resulted in a significant increase (over 600 MW) in the power flow on the Landesbergen-Wehrendorf line. The loading of this line exceeded 1 200 MW close to the secure limit for RWE TSO. At around 21:50, a small decrease (about 100 MW) can be observed, however from 22:02 the loading gradually increased. The line tripped immediately after coupling the busbars in Landesbergen. This tripping led to cascading line trippings throughout the UCTE area. All lines tripped due to overloading that triggered distance protection. These line trippings are listed in Appendix 3.

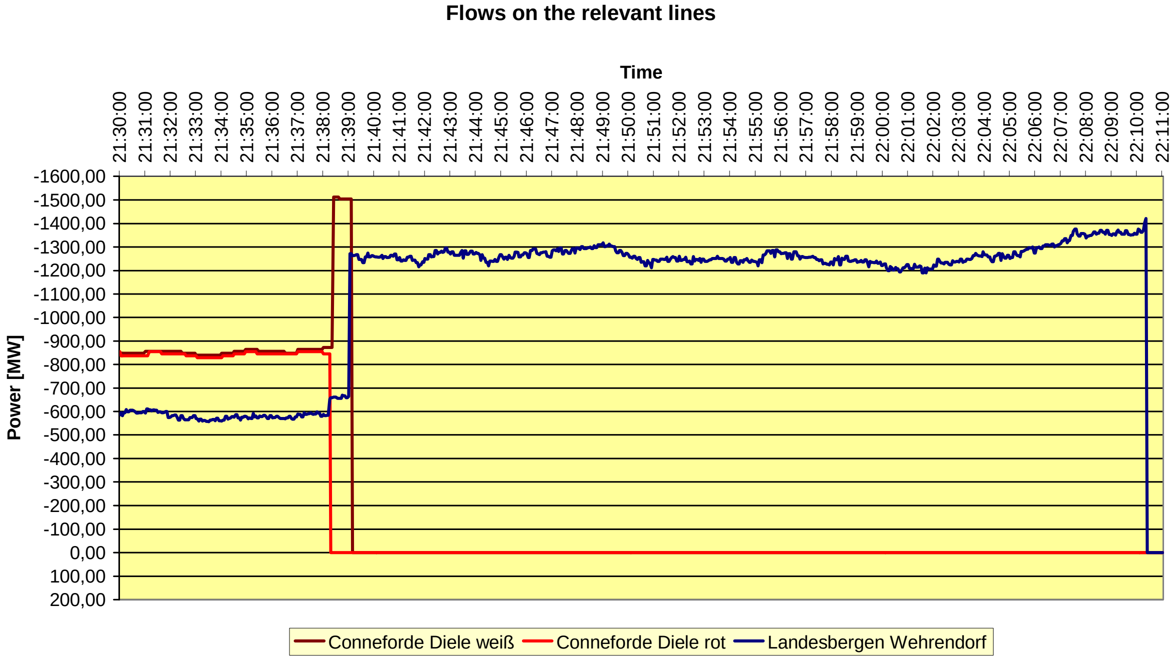

Figure 3: Power flow on the Landesbergen-Wehrendorf line before and after Conneforde-Diele switching off

According to E.ON Netz the dispatchers were aware about possible re-dispatch actions with power plants in Wilhelmshaven, Heyden or the nuclear plants in Unterweser and Brokdorf. These measures were carried out several times in similar situations of heavy load on lines in the area around Landesbergen (once in the past also for switching off the line Conneforde-Diele for the shipyard).
Other measures such as re-dispatch (e.g. with Denmark) were also possible to secure the system but according to the German law[5] and E.ON Netz internal procedures this would only be possible if topology changes were not effective to bring back the security of the network[6]. Nevertheless, between 21:40 and 22:07 E.ON Netz assumed that there was no immediate need for re-dispatching. After 22:07 any re-dispatching would have taken too much time to stabilize the grid situation.

According to RWE TSO, topology changes and further changing of tap positions on phase shifter transformers in Meeden (TenneT) were not possible (TenneT changed the tap positions at 19:33 to

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[5] § 13 (1) German Energy Industry Act of 13 July 2005.
[6] German TSO dispatchers have to examine the following possibilities in case they have to manage a congestion in the following order:

1. Grid-related measures which are non-cost measures :
   - all possible topology changes
   - full utilization of the operational limits (e.g. lowest acceptable voltage level)
2. Market-related measures which are cost measures based on contracts with third parties:
   - re-dispatching
   - counter trading
   - activating of tertiary reserve
   - switching of special loads
   - capacity reduction (only in day-ahead)
   - activating of additional reserves (e.g. from neighboring TSOs)
3. If all measures of 1 and 2 are fully utilized or time is too short:
   - shortening of already confirmed exchanges schedules
   - load shedding
   - voltage reduction beyond acceptable limits
   - direct order to all kinds of power plants including wind generation.

reduce the flow on the Diele-Meeden interconnector). Re-dispatching, which was also considered by RWE TSO, would require the increase of power output of the power plants Ibbenbüren (hard coal) and Emsland (nuclear) which was not possible since they were already operating with the maximum generation output.

According to TenneT, before the outage of the double circuit line Conneforde-Diele, no counter trading measures between The Netherlands and Germany were discussed in real time because all grid analyses performed by all concerned TSOs for their own grids showed that the grid situation after the switching-off was secure even if lines were highly loaded in the whole area of RWE TSO, TenneT and E.ON Netz.

As derived from Appendix 4 (Sequence of events), the UCTE system was split at 22:10:28 following the tripping of the interconnection lines between E.ON Netz – RWE TSO, internal E.ON Netz lines, internal lines in APG (AT), interconnection lines between HEP (HR) and MAVIR (HU) as well as the tripping of internal lines in HEP (HR) and MAVIR (HU). Finally, at 22:10:32, the interconnection lines between Morocco and Spain tripped due to low frequency. Figure 4 depicts the three areas resulting. The area 1 and 3 remained asynchronously connected through the DC link between Italy and Greece during the whole event.

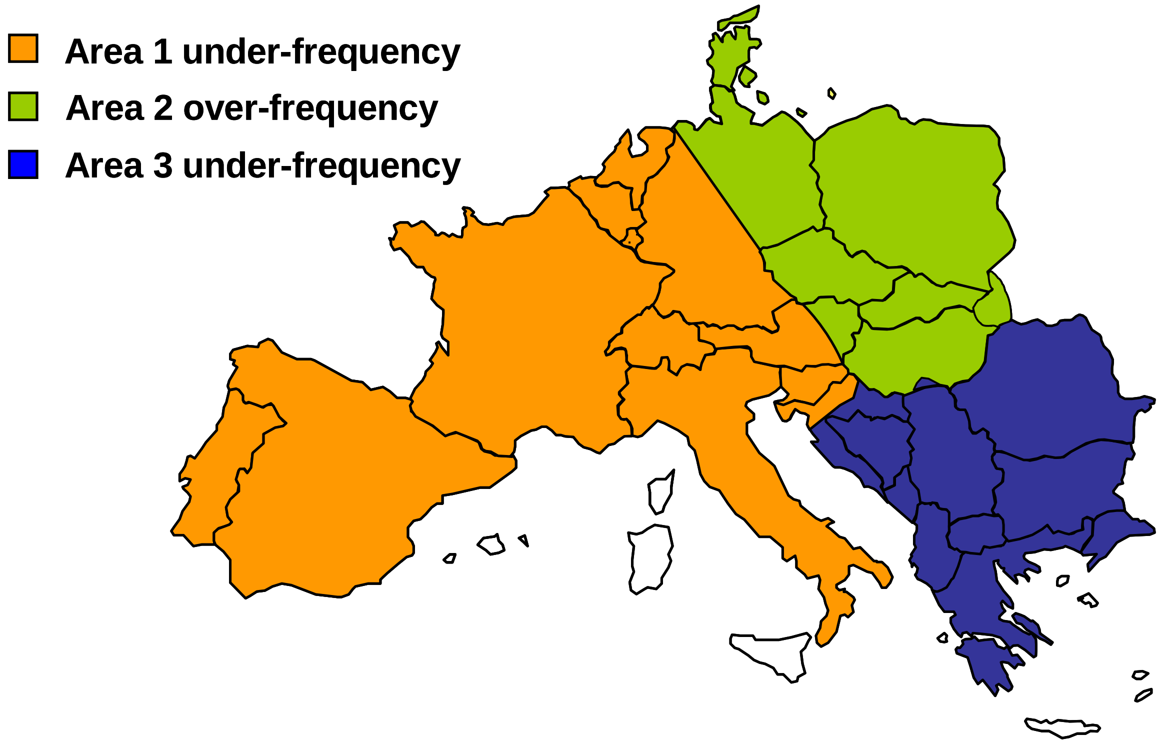

Figure 4: Schematic map of UCTE area split into three areas

The list of TSOs in each area is given in Appendix 4.

Figure 5 shows the frequency recordings retrieved by Wide Area Measurement Systems (WAMS) in the three areas from 22:10:06 to 22:10:30. The time stamps of the manual switching in the Landesbergen substation, the tripping of the Landesbergen-Wehrendorf line as well as the time stamp when the splitting of the areas was completed are indicated. The manual switching in the Landesbergen substation triggered frequency oscillations which continuously increased as different lines were tripped. It is worth mentioning that the frequency oscillations in area 3 were initially more intense.

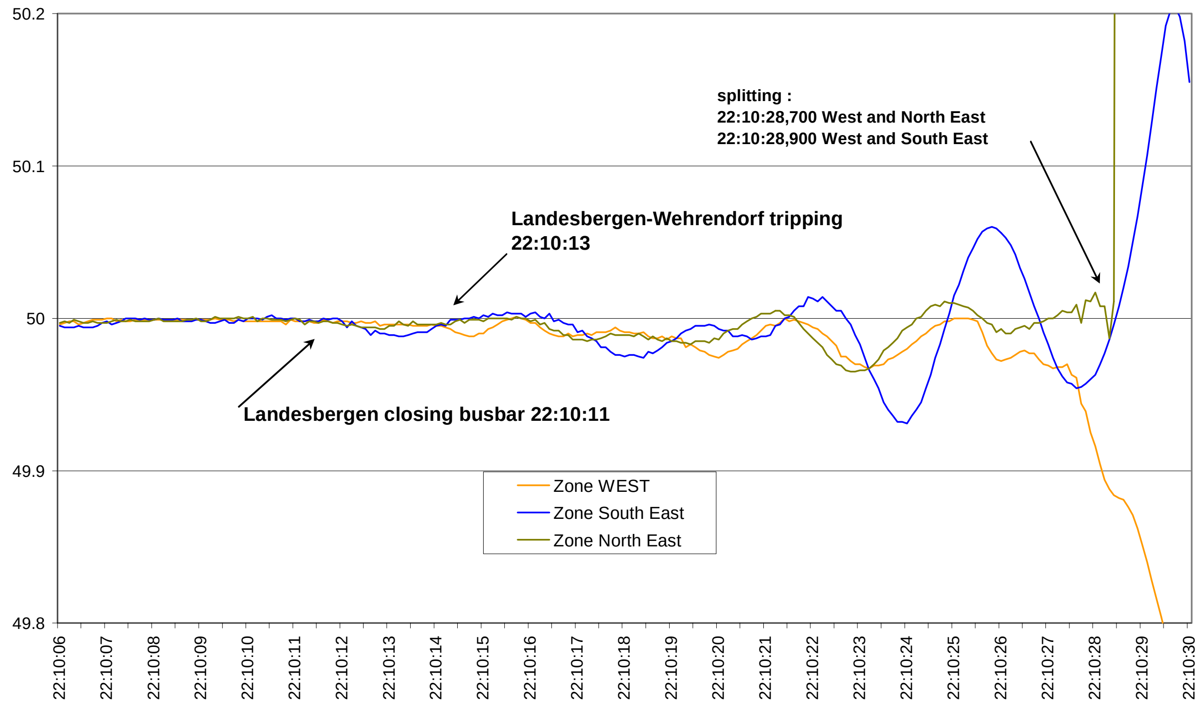

Figure 5: Frequency recordings until area splitting

Figure 6 is presenting frequency recordings as retrieved by Wide Area Measurement Systems (WAMS) in the three areas from 22:09:30 to 22:20:00

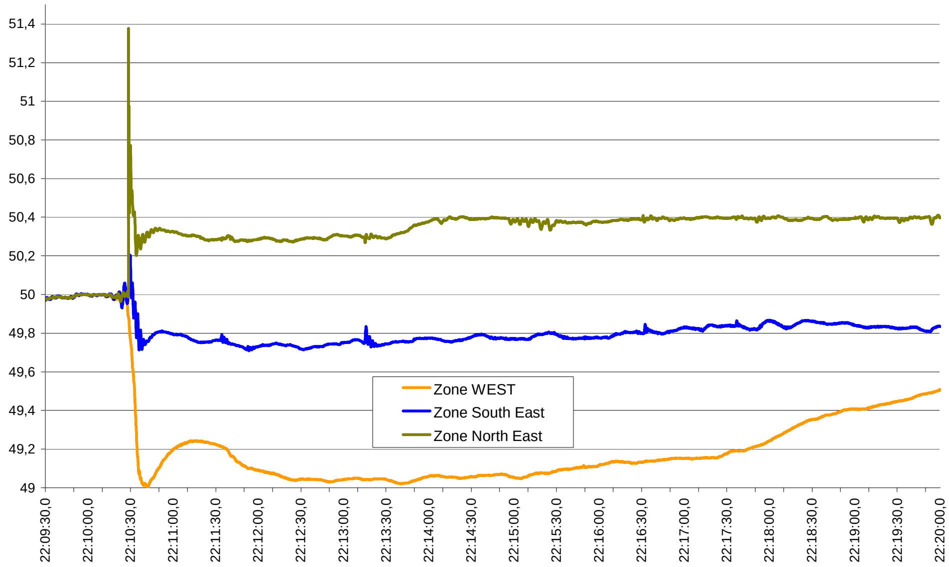

Figure 6: Frequency recordings after the split

As presented in Figure 1, the power balance in each area at the splitting time was no longer ensured. About 9 500 MW which came from the East area to the Western area was cut and those areas could not ensure the balance any more. Therefore the frequency sharply dropped at about 49 Hz in the Western area due to the sudden lack of power. On the contrary, the North East area faced a surplus of generating power of the same magnitude which induced a high over-frequency reaching about 51.4 Hz in the peak.

Just after the splitting, the South East area was missing an amount of power of around 800 MW which induced a slight under-frequency of about 49.7 Hz.

2.3. Stability conditions of the UCTE system

The analysis of the system dynamics before, during and after the UCTE system separation into three areas is mainly based on the following sources:

- Two snapshot data sets of the whole interconnected system for load-flow calculation for 21:30 and 22:00 respectively.
- WAMS recordings from several substations in Germany, Switzerland, Slovenia, Italy, Croatia, Austria and Greece.
- Transient fault recordings of protection equipment of transmission lines which tripped during the event.
- SCADA/EMS recordings of inter-area power flows, system loads and area controller data.

The detailed analysis can be found in Annex 6. However, the system dynamic behaviour between 21:30 and 22:30 can be distinguished into three phases:

The highly loaded East-West corridor in the northern part of Germany was substantially weakened by the opening of the two Conneforde-Diele lines. However, the system damping at that time was still satisfactory.

The overload trip of the Landesbergen-Wehrendorf line triggered a cascade of further line disconnections. In the first stage, the lines tripped due to overcurrent protection. Starting at 22:10:28, as the system was weakened by tripped lines and stability conditions could not be ensured any more, all lines south of the Main river in the middle of Germany tripped due to underimpedance protection due to a dramatic voltage drop on both ends of those lines. At this time, there was a loss of synchronism between the three areas. However, due to the fast separation, subsequent damages to equipment caused by high mechanical forces were avoided.

SYSTEM STATUS AND DEFENSE ACTIONS IN INDIVIDUAL AREAS

3

3. System status and defense actions in individual areas

This chapter describes the consequences of system split in terms of load shedding, automatic generation tripping and generation starting/stopping by TSOs in each area.
Remark: for generation connected to the low voltage grid the data is given as TSOs' estimation.

3.1. Western area

After cascading overloads and lines' tripping leading to the splitting of the UCTE grid in three large separate systems, the Western area (composed of Spain, Portugal, France, Italy, Belgium, Luxemburg, The Netherlands, a part of Germany, Switzerland, a part of Austria, Slovenia and a part of Croatia) faced significant supply-demand imbalance.

- Total generation of the Western area : 182 700 MW[7]
- Power imbalance due to missing import from the East: 8 940 MW

This huge imbalance invoked a quick drop (in 8s) of frequency down to about 49 Hz compared to the normal set point value in UCTE of 50.00 Hz (see Figures 5 and 6).

Such a frequency drop resulted in a succession of events on the generation units and automatic activation of the defense plans.

Defense plans were activated in each TSO area and led to automatic load shedding (meant as cut of the power to customers) and pump storage units tripping when the frequency drops under a defined threshold. All these actions occured in a very short time (8 seconds during the frequency drop) and will not be detailed in this document. Only the final status will be described.

According to the UCTE Operation Handbook, these automatic actions should prevent the system collapse as a result of significant power imbalance. The amount of load shedding in each TSO area which is defined in the defense plan depends on the frequency threshold and sometimes on the speed of frequency decrease. For every TSO, the general rule is to trip the pumped-storage units when the frequency drops to 49.5 Hz and start the automatic load shedding step by step at a frequency near 49 Hz with thresholds every 0.4 Hz or 0.5 Hz.

Load shedding and pumps shedding
During the incident, the load shedding and pumps shedding was in line with the values declared by TSOs in defense plans (see Appendix 5). Finally, a total of about 17 000 MW of consumption was shed and 1 600 MW of pumps was shed (Figure 7). Whereas the load shedding related to the imbalance caused by the splitting of the grid amounted to about 9 000 MW, additional load shedding was necessary due to tripping of generation.

[7] values are rounded at 100 MW step

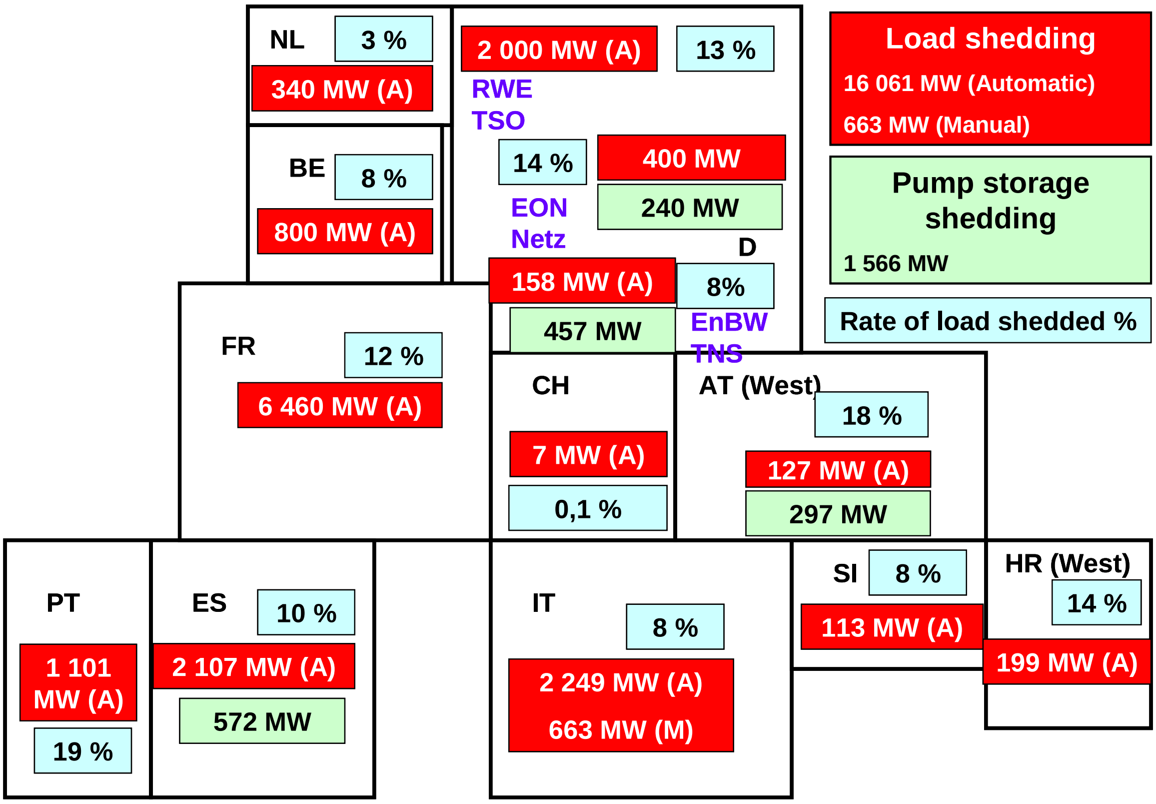

Figure 7: Map of load and pumps shedding by TSOs

In red square, the total of automatic (A) load shedding separated of manual (M) load shedding. The value in the blue square is the rate of load shedding and pump shedding related to the total estimated total load (or load in the TSO grid, where the total load cannot be determined at the moment). The values in green squares show the automatic pumps shedding (which can be activated according to the defense plan). This action has been made only by a few TSOs due to the hour of the incident (just after 22:00) when most of the pumps were not yet in operation.

The defense plan actions triggered by each TSO helped to restore the frequency close to its nominal value in relatively short time. In some control areas (Italy and Austria), the automatic load shedding was completed by manual load shedding or pumps shedding actions due to the low stable frequency near 49.2 Hz a few minutes after the incident.

Generation tripping

Generation contributes to frequency supplying primary reserve and keeping the connection to the grid between 47.5 and 51.5 Hz. Unfortunately immediately after the frequency drop, some generation units tripped thus increasing the imbalance between demand and supply in the area. Generation units which tripped are usually small power units but they are numerous and not directly controlled by TSOs.

Wind generation and combined-heat-and-power is generally connected to the distribution grid, therefore the relevant standards for their performances in case of a frequency drop are less constraining. Usually they have to withstand a frequency drop at 49.5 Hz. Thus for the 49 Hz event that occurred in the Western area, a significant amount of units tripped on 4 November.

About 40% of the total generated power which tripped during the incident was wind power units. Moreover, 60 % of the wind generation connected to the grid at 22:09 tripped just after the frequency drop. Similarly, 30% of combined-heat-and-power in operation just before the event, tripped during the frequency drop.

In addition to this, except for one thermal generation unit of about 700 MW of nominal power (in Spain), no high power generation units connected to the TSO network tripped.

In the Western area, a total of about 10 900 MW tripped (see details in Figure 8).

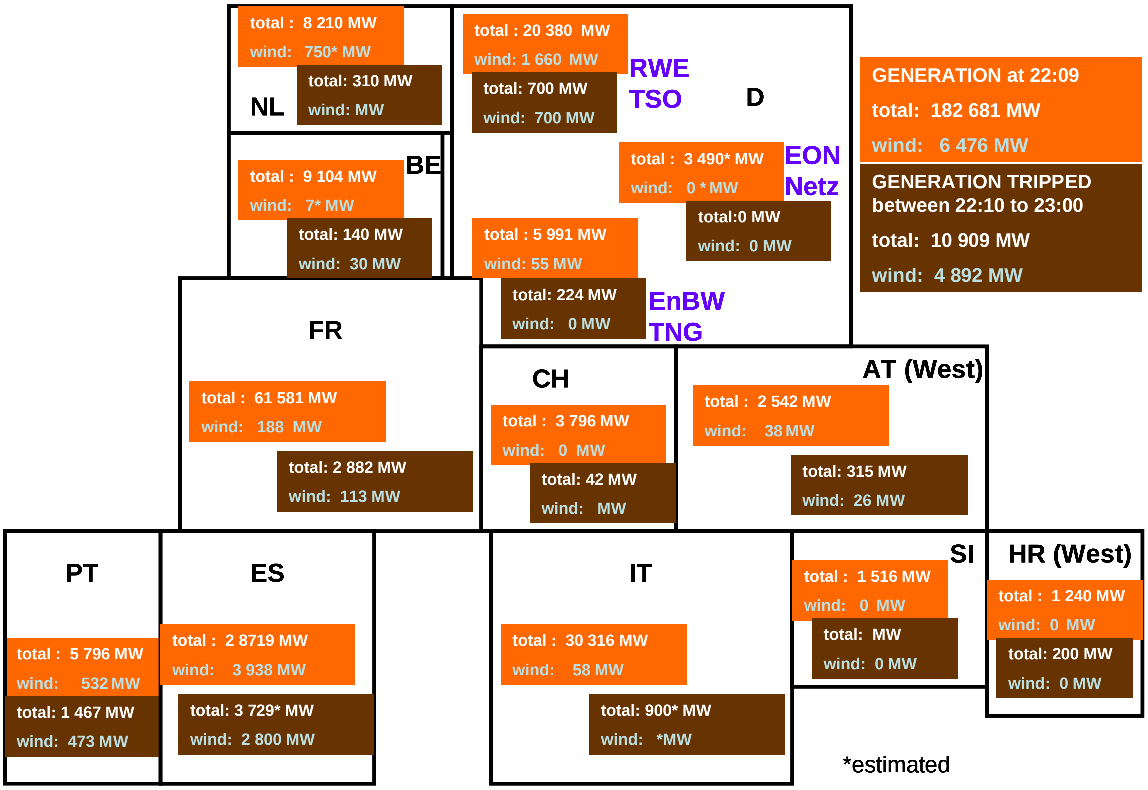

Figure 8: Map of generation tripped (total and wind)

The orange squares show the total of generation units in operation and the wind generation in operation just before the incident (22:09). The brown squares show the generation units tripped due to the frequency and voltage drop.

Generation automatically reconnected to the grid during the disturbance

The small power generation units such as combined-heat-and-power and wind generation which tripped after the frequency drop were automatically reconnected to the grid when the conditions of voltage and frequency were in the accepted range. However this occurred without any control from TSOs nor DSOs.
An example of the tripping and automatic reconnection of wind generation is given in Figure 13.

Generation started by TSOs to restore the frequency after the event

In order to quickly restore the frequency to its nominal value of 50 Hz, TSOs manually started generation units (mainly hydro ones). This action was done in accordance with the TSOs' restoration plans; no special co-ordination was undertaken at that time; each TSO acted according to its own rules.
A total of about 16 800 MW was started in the Western area while the tertiary reserve declared in this area was about 18 500 MW. That means that in the Western area, almost all available reserves were started.

The details of generation units started by TSOs are shown in the Figure 9.

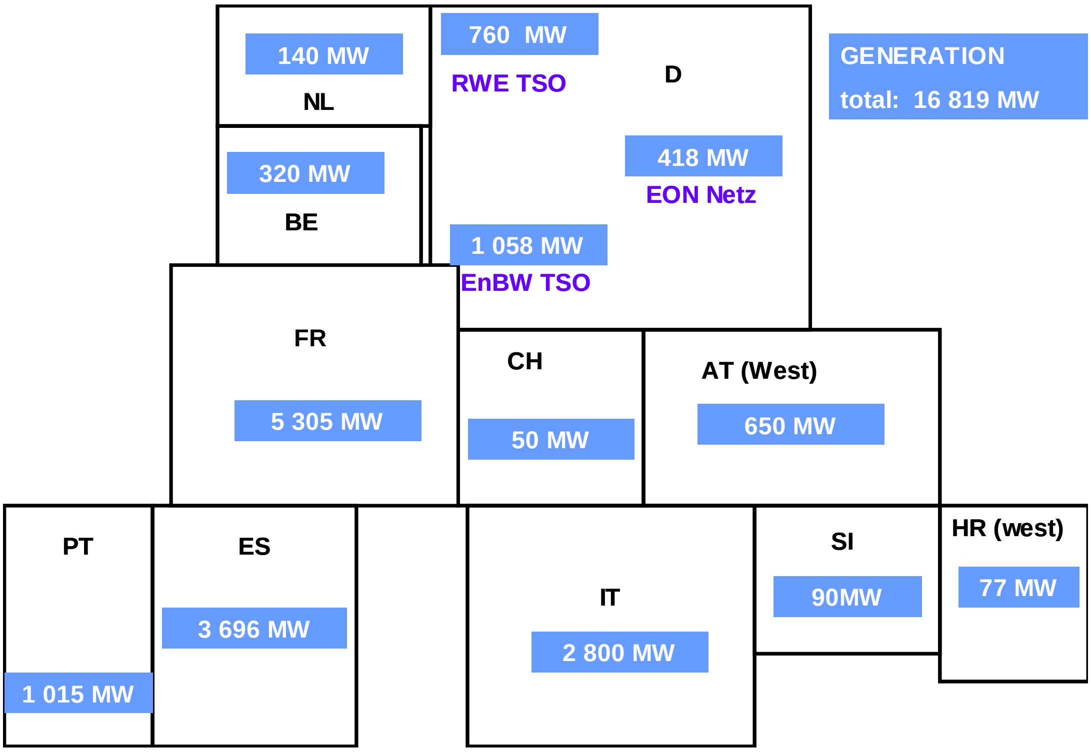

Figure 9: Generation units started by TSOs

The physical flows on the lines in the Western area induced by the system splitting, load shedding, generation tripping and starting, were significantly different from the ones forecasted for normal operation conditions.

TSO communication and co-ordination

Immediately after the frequency was automatically stabilized, TSOs started the exchange of information trying to identify the origins of the disturbance and the status of the whole interconnected system, however the complete picture was not known immediately.

During a few minutes after the incident, some TSOs stopped the load frequency control or it was stopped automatically (RTE, TERNA, E.ON Netz) in order to analyze the situation very quickly without endangering the system stability. Since the normal time range of secondary control actions is between 30s and 15 minutes after the frequency deviation, stopping the secondary load frequency for less than 1 minute helped the automatic generation control to stabilize and increase the frequency.
At 22:32, ETRANS suggested to RTE, TERNA and APG to change the secondary load frequency control into pure frequency mode.[8]

The re-energization of load (restoration of power supply for customers) in most of the countries has been done without co-ordination nor awareness of the split network.

Frequency analysis

For explanations of the frequency curve during the first minutes after the incident, see Figure 10 focusing on the time range from 22:10:20 to 22:13.

[8] LFC could be set in 3 modes:
1. Secondary load frequency control: $\Delta E = \lambda.\Delta F + \Delta Pi$
2. Secondary frequency control: $\Delta E = \lambda.\Delta F$ ($\Delta Pi = 0$)
3. Secondary load control: $\Delta E = \Delta Pi$ ($\lambda = 0$)
In case of quick frequency drop, setting the LFC in frequency mode allows to maintain the frequency regardless of the geographical location of the disturbance origin. This action needs to be done in co-ordination, in order to avoid further N-1 violation on borders.

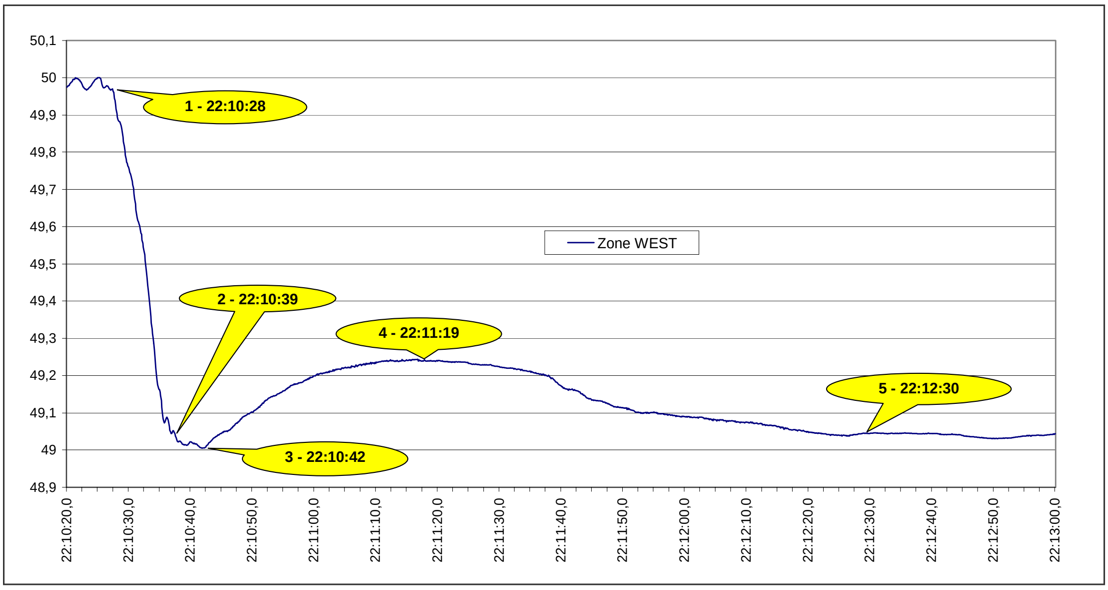

Figure10: Frequency in the Western area

① – 22:10:28, separation of the Western area from the Eastern part of UCTE
② – 22:10:39, stop of frequency decrease, mainly due to the activation of defense plans
③ – 22:10:42, beginning of frequency increase caused by additional primary reserve
④ – 22:11:19, frequency maximum at a value near 49.2 Hz
⑤ – 22:12:30 slow frequency raise to reach a normal value of 50 Hz at about 22:25

Range ① to ②
Due to the large imbalance in the Western area frequency decreased very quickly with a slope reaching up to 120-150 mHz/s. Moreover, the total imbalance was higher than the estimated primary reserve in the Western area. During this 11s time range, pumped-storage units tripped according to the defense plan but it was not high enough to face the total imbalance. Frequency still decreased.

Range ② to ③
During this time range, frequency stopped to decrease mainly due to the automatic load shedding carried out according to the defense plan of each TSO.

Range ③ to ④
Frequency started to increase and reached a value of about 49.2 Hz. Due to activation of the last primary reserves of thermal power plants the frequency stabilized at 49.2 Hz; 15 seconds after the incident most of the available primary reserve was activated which contributed to stabilize the frequency.

Range ④ to ⑤
During this time range, the frequency decreased again by about 0.2 Hz due to exhaustion of the primary or secondary reserve.

Range ⑤ and after
After 22:12, the frequency was stable and started to increase from 22:15 to reach a value near 50Hz at about 22:24. The time step of frequency increase correlates to the manual increase of generation and start of additional generation units by TSOs, taking into account that re-energization process has been started by some TSO or DSO, preventing the frequency to recover 50 Hz level in a shorter time delay.

3.2. North-Eastern area

After cascading trippings of overloaded lines leading to the splitting of the UCTE power system into three large separate areas, the North-East area (see Appendix 4 for composition of the area) faced severe imbalance conditions with a generation surplus of more than 10 000 MW (approx. 17% of total generation in this area before the splitting) leading to a situation of high over-frequency. The imbalance was attributable to the fact that before splitting there was a huge transit of electricity from this area towards the West and South of Europe. This is a typical load flow situation in this region, but on this day the volumes of flows were increased as compared to standard days due to high wind conditions in the North of Germany (see Figure 11).

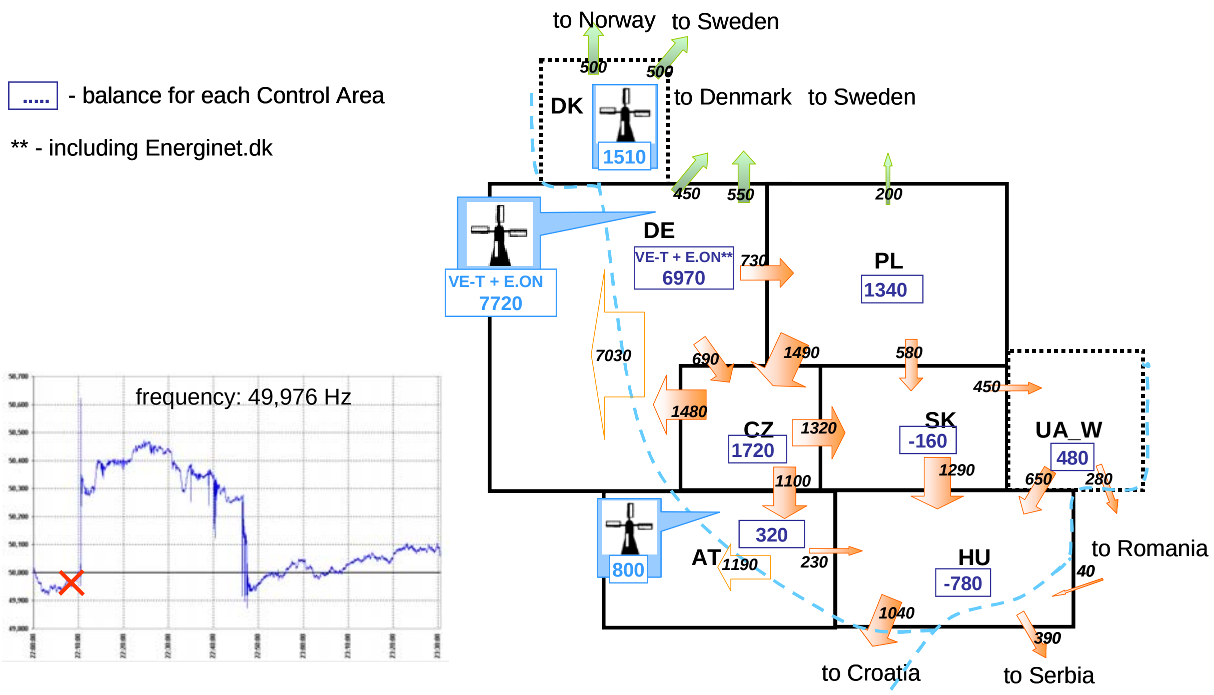

Figure 11: Intersystem power flows in area 2 at 22:09

This huge imbalance in the North-East area caused the rapid increase of frequency up to about 51.4 Hz reduced to the range of about 50.3 Hz by automatic pre-defined actions (primary control – standard and emergency range, activation of speed control of certain generating units) and automatic tripping of the generating units sensitive to high frequency value (mainly windmills). Tripping of wind generation with an estimated value of 6200 MW (approx. 5400 MW located in the North of Germany and 800 MW in Austria) played the crucial role in decreasing frequency during the first seconds of the disturbance. There were no trippings of windmills in Jutland (Western Denmark).

The new steady-state situation in area 2 established just after the splitting with the frequency of about 50.3 Hz resulted in power flows within area 2 within acceptable limits (see Figure 12) without the serious danger for power systems operation (except for the areas in the vicinity of tripped lines in E.ON Netz, APG and MAVIR control areas). At this stage of the disturbance, the dispatchers of E.ON Netz, APG and MAVIR were busy with recognizing the emergency situation and identifying the state of their power systems split internally, while TSOs not experienced by line trippings identified the situation only in terms of over-frequency. Part of the load frequency controllers (LFC) in the area 2 was properly switched (automatically or manually) from load and frequency control mode to pure frequency mode. This mode of LFCs' operation together with continuation of speed control on some generating units ensured continuation of proper automatic response on the generation side under the conditions of over frequency (300 mHz deviation is considered as not accepted being outside the 180 mHz steady deviation acceptable in normal operating conditions) during the first minutes after the disturbance.

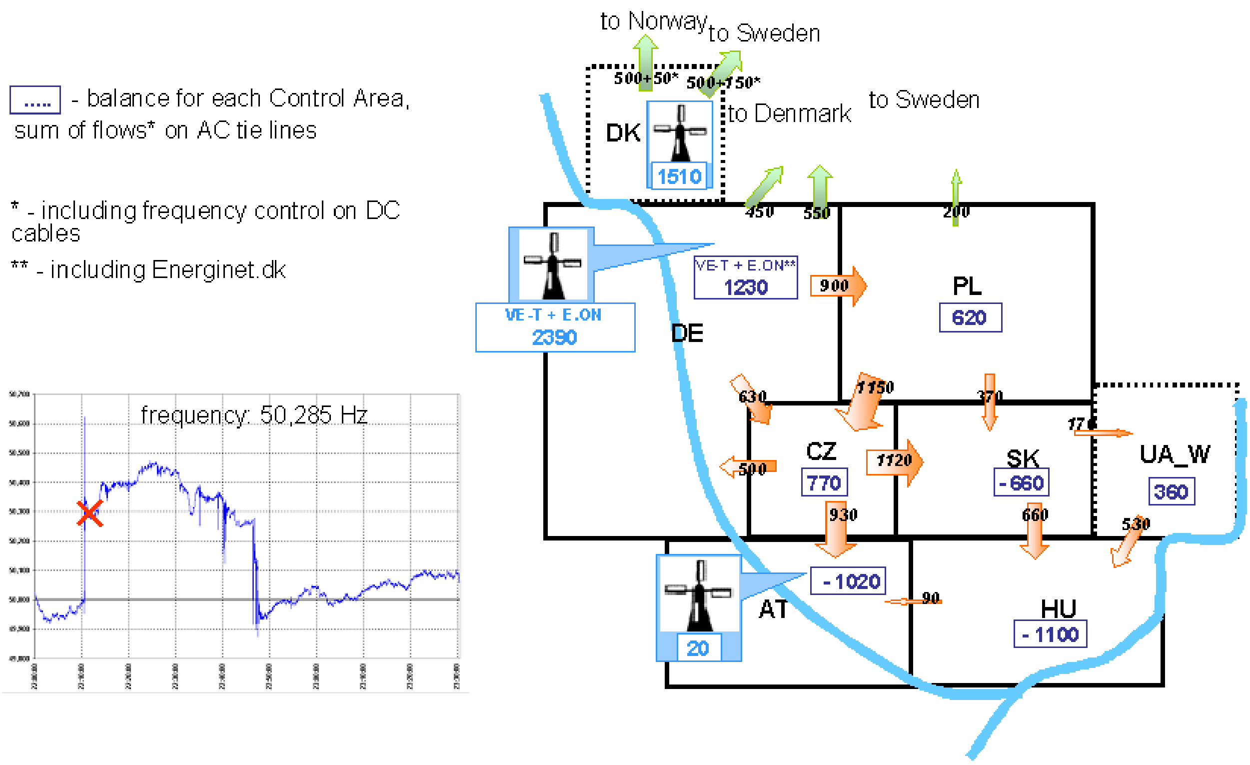

Figure 12: Intersystem power flows in area 2 at 22:12

On the other hand, at the same time (first minutes after the disturbance) the windmills, which tripped at 22:10 started being automatically reconnected to the power systems (in Germany and Austria) thus gradually increasing generation in these control areas (see Figure 13). This behavior of windmills was contrary to the required decrease of generation in the whole area 2. Since the volume of reconnected wind generation exceeded the volume of generation automatically reduced on other units (mainly thermal) the frequency began to slowly, but steadily increase starting from 22:13.

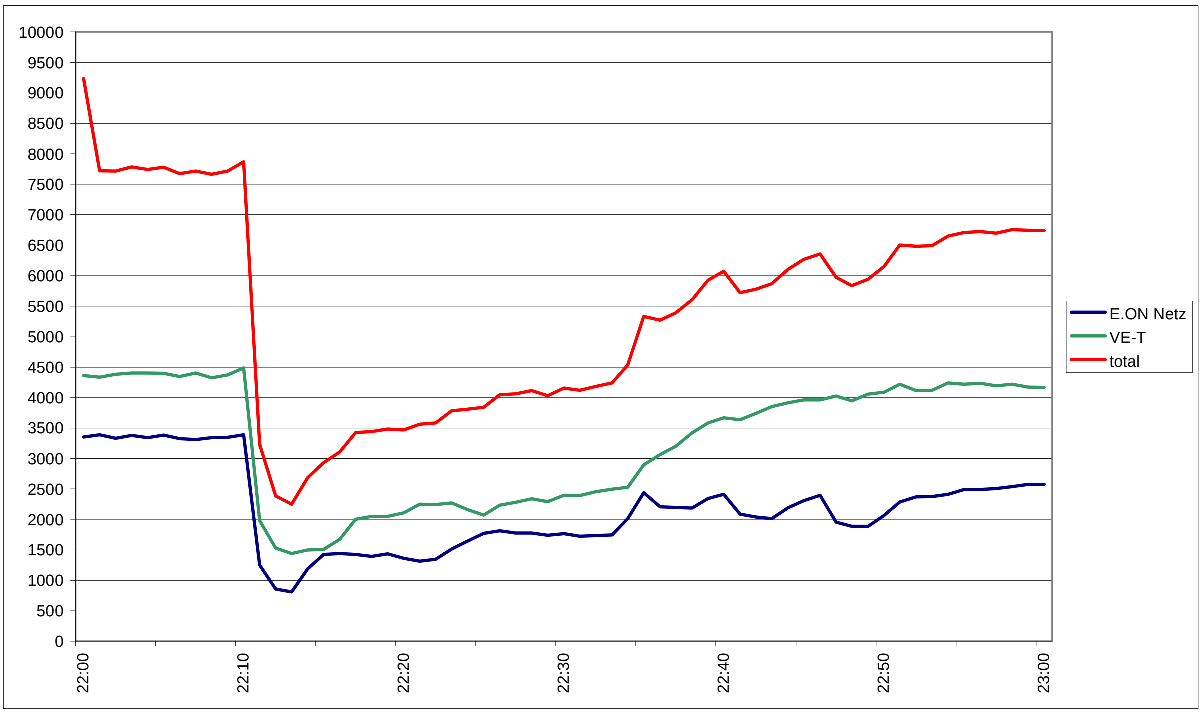

Figure 13: Output of windmills (VE-T, E.ON Netz, from 22:00 to 23:00

Having observed this frequency increase, the dispatchers of involved TSOs started manual actions in order to balance the whole area 2 and decrease the frequency to normal level. These actions included instructions for generating companies to decrease output of units, stopping some of them and starting pumps in pumped storage plants. These manual actions superimposed previous automatic ones and ensured steady decrease of generation in most of the thermal power plants of the region, which were able to decrease their output. This was not the case in many thermal units in VE-T control area, which operated close to their minimums already before the disturbance (due to high wind conditions) and thus were not able to contribute to frequency decrease after it. The dispatchers of PSE-O, acting as a CENTREL control block leader, apart from decreasing generation within Poland also approved other CENTREL TSOs (CEPS, SEPS, MAVIR, WPS) deviations from planned exchange programs instructing them at the same time to further decrease the generation within their control areas. In total, at 22:35 the CENTREL power systems together absorbed about 58% out of the initial overcapacity of approx. 10 000 MW in the whole area 2 (mainly PSE-O: 35%, CEPS: 20%), while the other power systems of area 2 absorbed together 32% (VE-T + E.ON Netz: about 23%, APG: 9%). The remaining initial overcapacity roughly estimated at about 10% resulted in an over-frequency of 50.37 Hz (the frequency slowly raised from 50.3 Hz at 22:13 up to 50.45 Hz at 22:28 and then slowly decreased to about 50.3 Hz before resynchronization – see Figure 14).

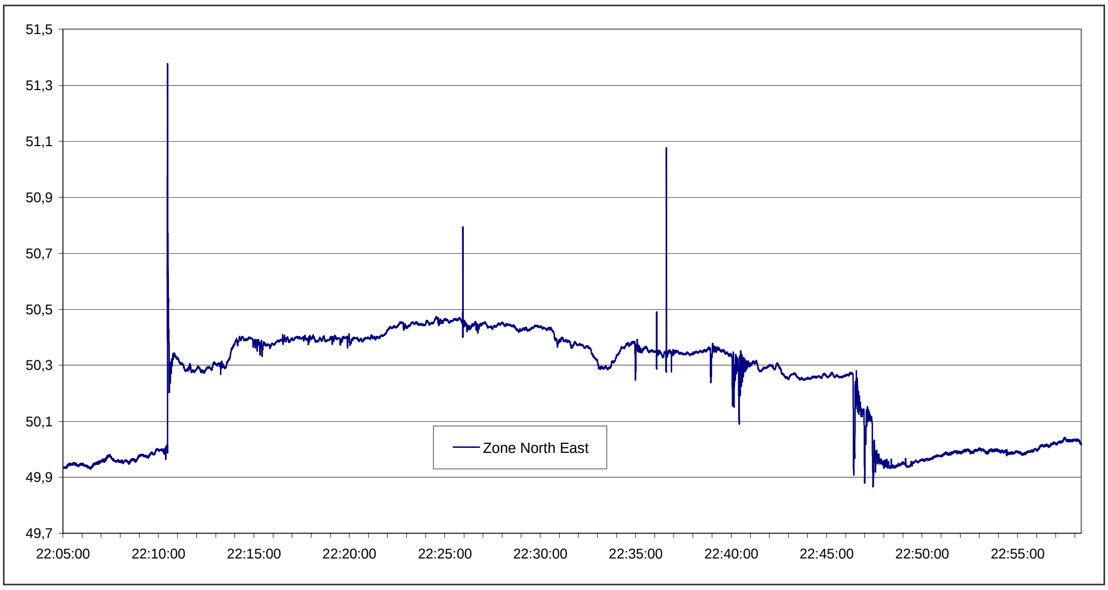

Figure 14: Frequency in area 2 (22:00 – 23:00)

This uneven absorption of the initial surplus of generating capacity within area 2, which mainly resulted from the reconnection of windmills in the North of Germany, led in turn to significant changes in power flows within area 2. As indicated above, the power flows established in a new steady state just after the disturbance were within acceptable limits but with the gradual increase of wind generation and decrease of thermal generation after 22:10 these flows started gradually to change. Generally the process was featured by an increase of generation in the North of Germany (windmills) and decrease of output of thermal plants in the whole area, but mainly in Poland and the Czech Republic resulting in increasing flows from VE-T to PSE-O and CEPS, while other tie-lines in the region experienced lower loadings than usual. Already at 22:20, the flows on VE-T/PSE-O and VE-T/CEPS profiles exceeded the transfer capacities on these borders acceptable in normal operating conditions[9] (see Figure 15) and continued to increase further till 22:35 when it reached unacceptable levels even for emergency conditions (see Figure 16 and Figure 17).

[9] at this time it was necessary to switch off manually the 400/220 kV transformer in Krajnik substation (north west of Poland), which overloading reached 147% and was still increasing.

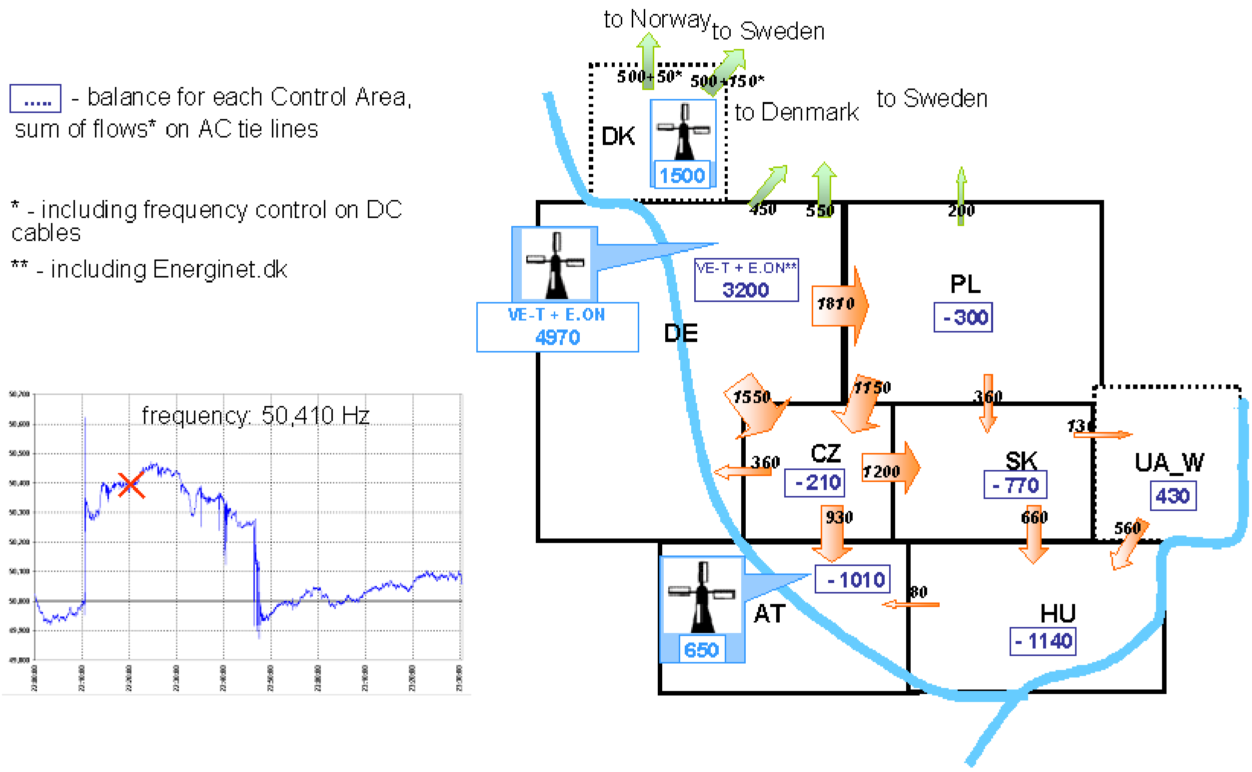

Figure 15: Intersystem power flows in area 2 at 22:20

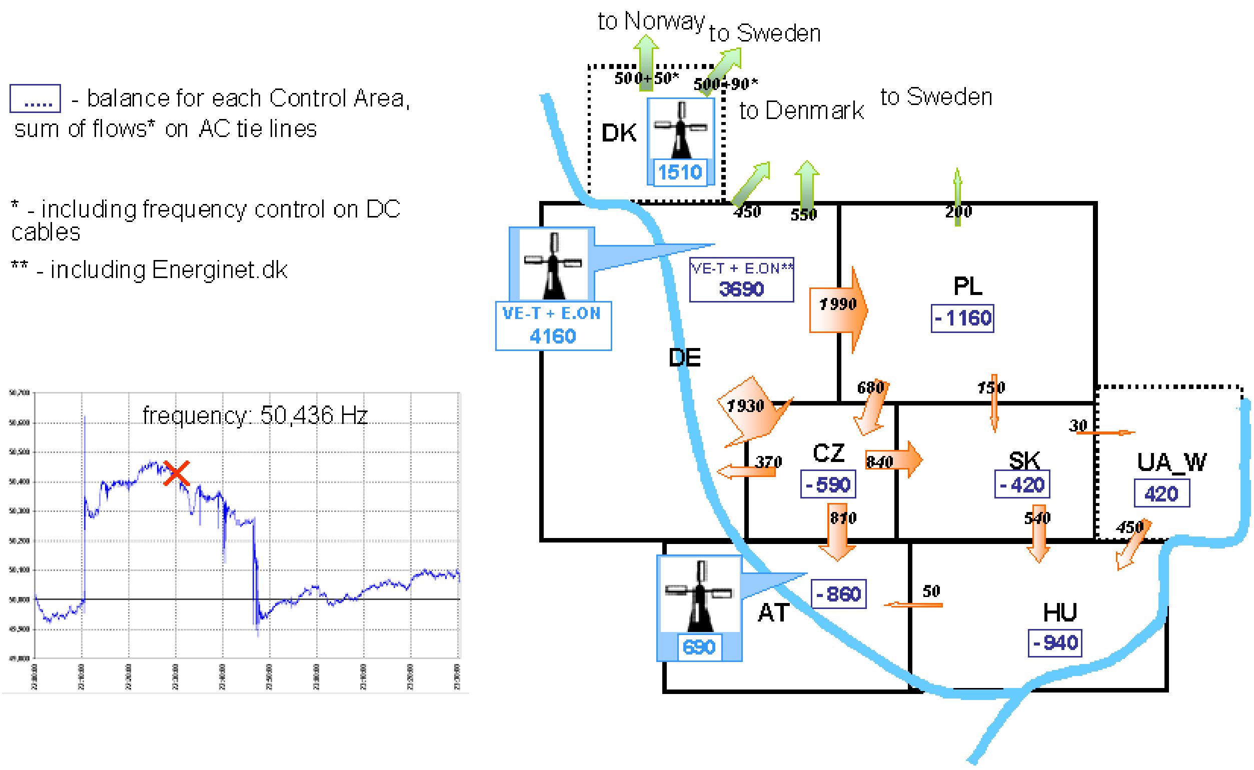

Figure 16: Intersystem power flows in area 2 at 22:30

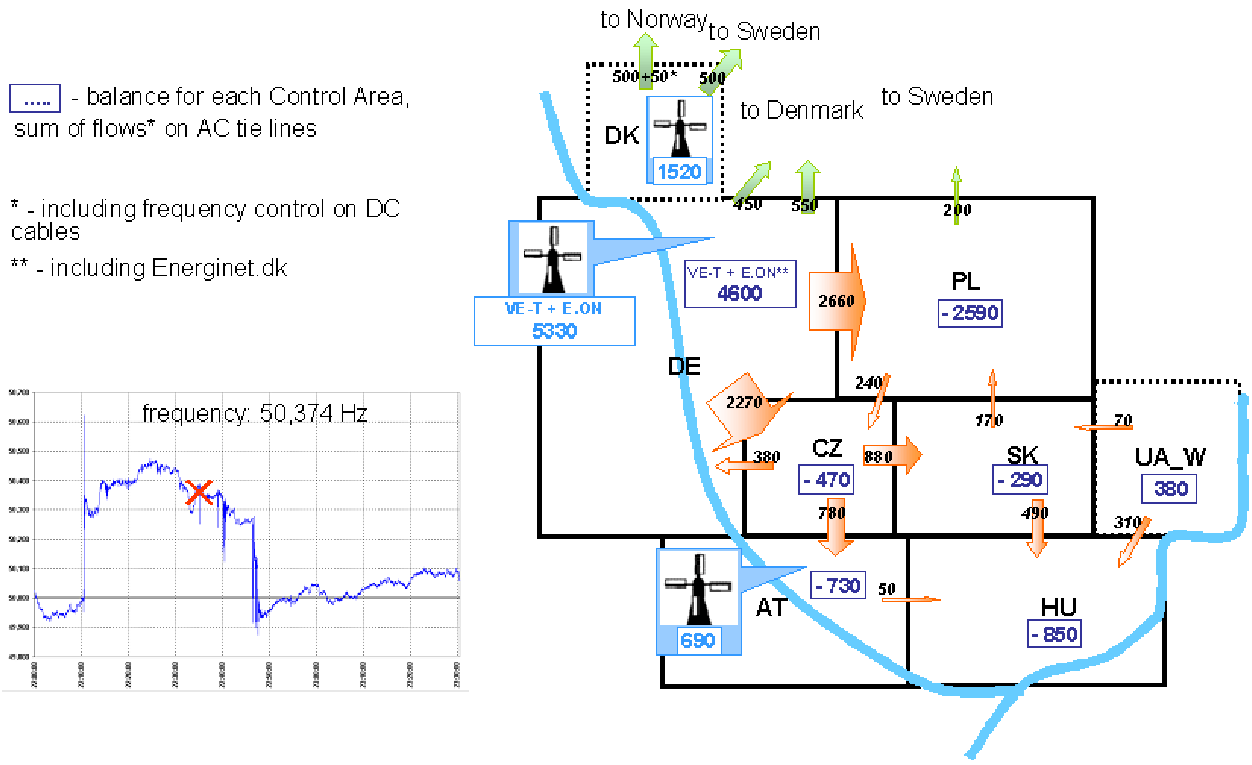

Figure 17: Intersystem power flows in area 2 at 22:35 (critical West East flow)

These flows led to overloading of internal lines in the south of the VE-T control area (double circuit 380 kV line Bärwalde - Schmölln for a few seconds up to 100 % of the permanent transport capability), southwest of Poland (400 kV line Mikulowa - Czarna was overloaded up to 120 %, both 400/220 kV transformers in Mikulowa substation were overloaded to more than 120%) and west of Czech Republic (400 kV line Hradec - Reporyje was overloaded up to 140 % - see Figures 18, 19 and 20).

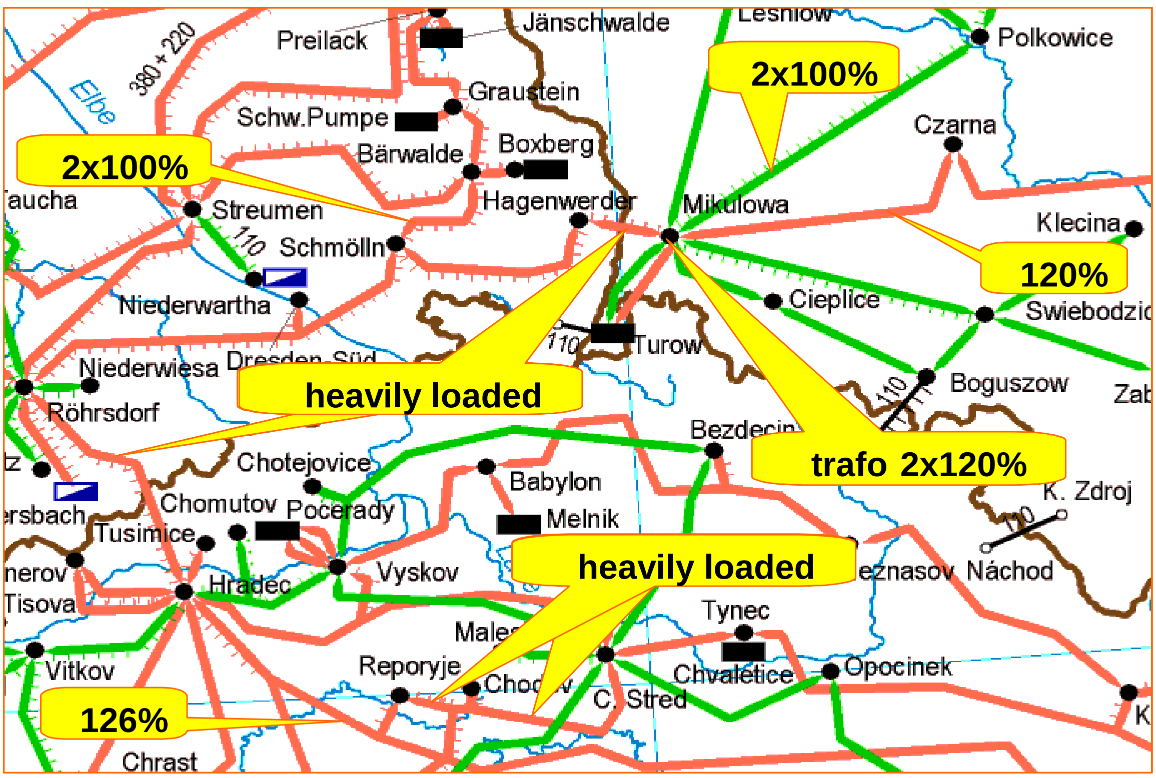

Figure 18: Overloaded elements in the region of VE-T/PSE-O/CEPS borders

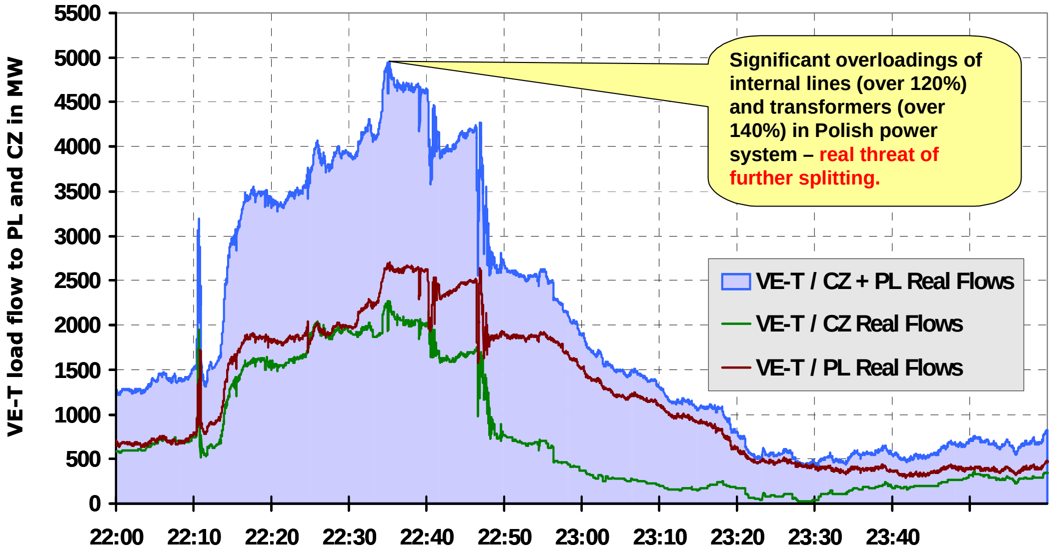

Figure 19: Example of critical load flows: VE-T / PL + CZ profile

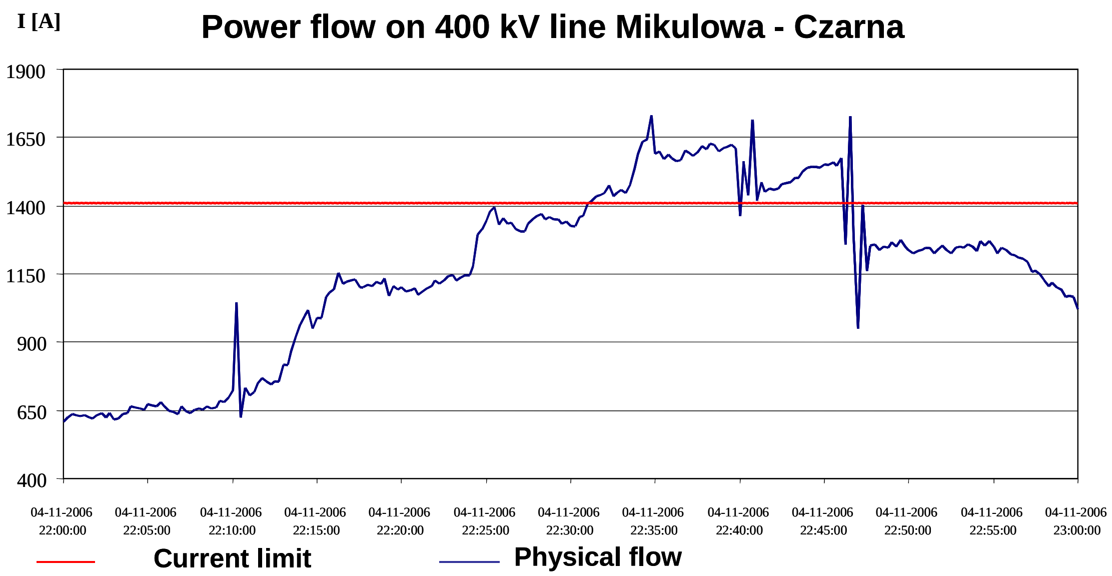

Figure 20: Overloads on the 400 kV Mikulowa-Czarna internal PSE-O line

At that time there was a real danger of further splitting of UCTE power systems. However, the cooperation between the control centers of involved TSOs allowed first to relieve the overloadings for some minutes (increase of generation in the southwest of Poland, usage of complex control on transformers in the Mikulowa substations, additional pumps started and thermal generation decreased in the VE-T control area) and then finally the successful resynchronization of area 1 with area 2 in Germany and Austria at 22:47 decreased the flows in this region to acceptable levels within half an hour (see Figure 21). At 23:30 the power systems in central Europe came back to normal operational conditions (see Figure 22)

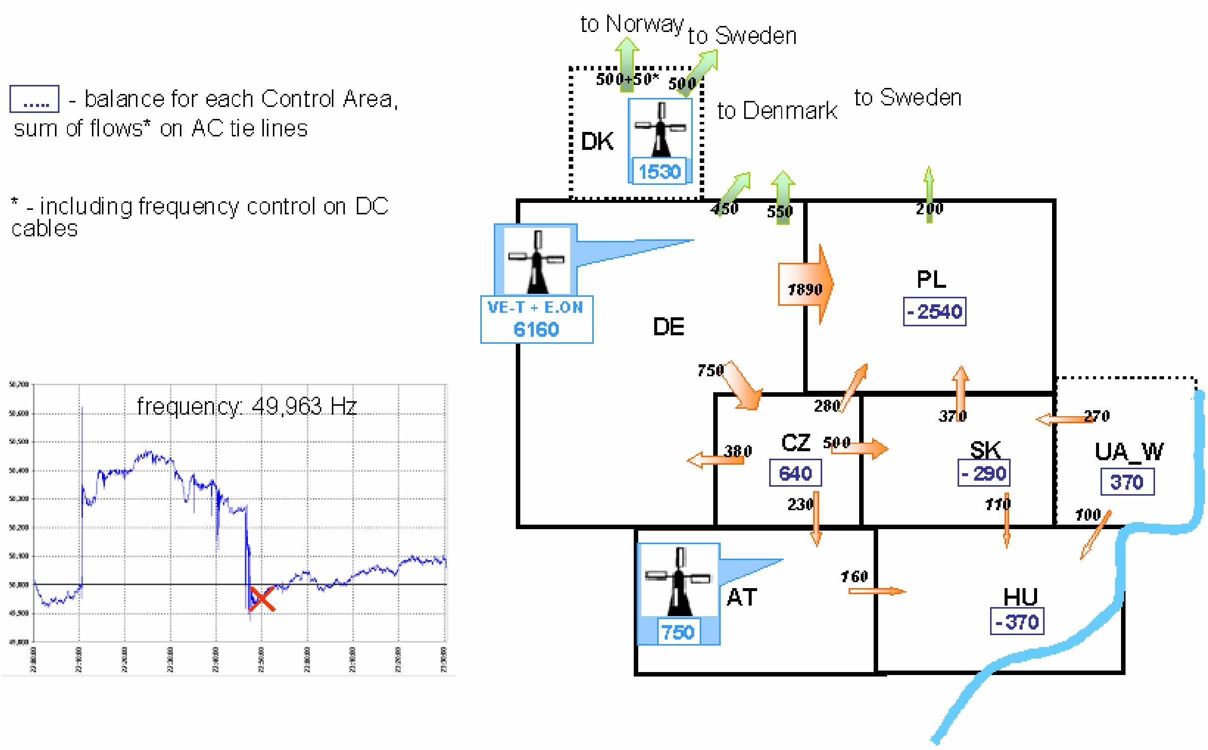

Figure 21: Intersystem power flows in area 2 at 22:50 (flow just after synchronization in DE and A; decrease of W-E flow)

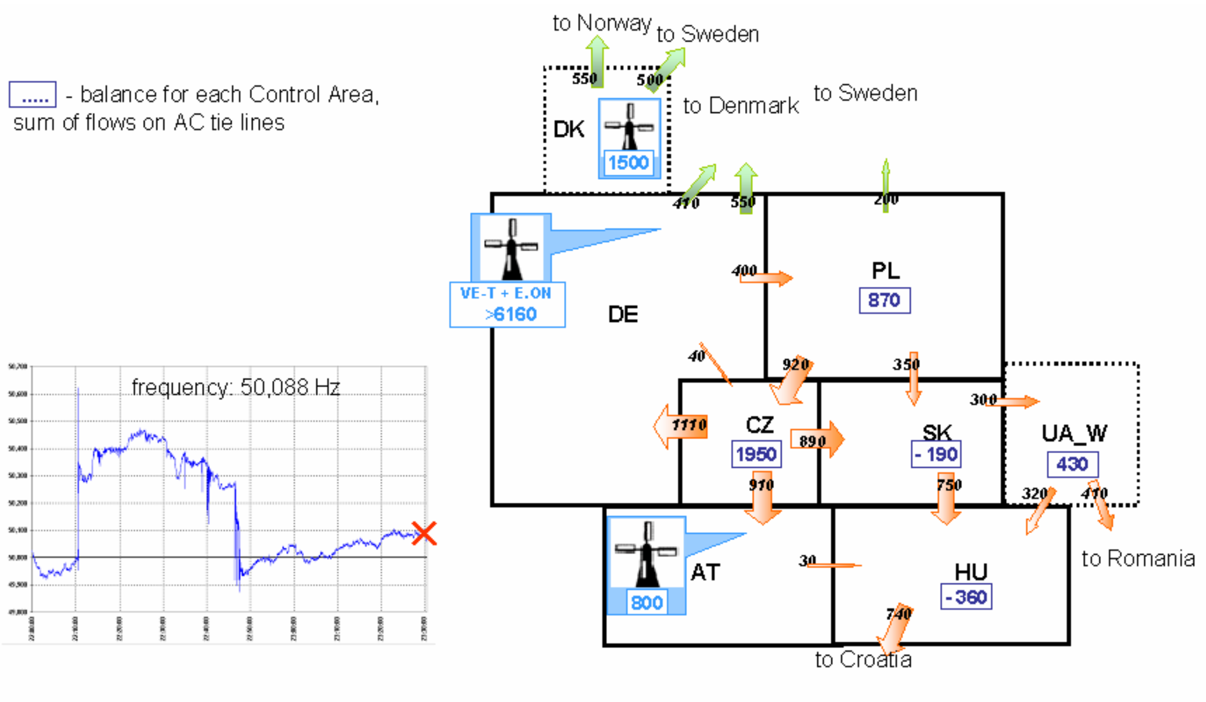

Figure 22: Intersystem power flows in area 2 at 23:30 (back to normal operational conditions)

3.3. South-Eastern area

After 22:10:29 an islanded area (hereby South-Eastern Europe – Area 3) was formed comprising the TSOs as listed in Appendix 4.

According to the information provided by relevant TSOs, the power balance estimated for Area 3 at 22:09 was the following[10]:
Total generation: 29 100 MW
Total load: 29 880 MW
Thus, the South Eastern Area had in fact very little power imbalance of around 770 MW.

The first indications of a disturbance were noted between 22:10:20 and 20:10:52 when severe power flow oscillations were observed on the following lines:

- Subotica 3 (RS) - Sándorfalva (HU)
- Mitrovica 2 (RS) - Ernestinovo (HR)
- Mitrovica 2 (RS) - Ugljevik (BA)
- Blagoevgrad (BG) - Thessaloniki (GR)

At 22:10:40, frequency dropped down to 49.79 Hz.

Unit 7 in TPP Kakanj station in Bosnia (BA) was automatically tripped at 22:10. The generation of this unit, prior to tripping, was 210 MW.

Since the frequency during the whole disturbance was significantly above the first threshold for load shedding **no other automatic actions or load shedding took place during the event**. Thus, the defense plans were not activated.
According to analyses, area 3 was N-1 secure during the whole event.

At 22:14:17, due to the low frequency, the automatic generation control mode of the HTSO (GR) was changed from load frequency control[11] to pure frequency control[12]. At 22:30, 2 hydro units in Croatia (HR) started up: Zakučac-220 kV with 47 MW and Zakučac-110 kV with 55 MW. Due to the automatic generation control of Greece, using the available secondary reserves and the additional increase of generation in Croatia, frequency was back in the acceptable range (49.982 Hz) as shown in Figure 23, at 22:40:36.

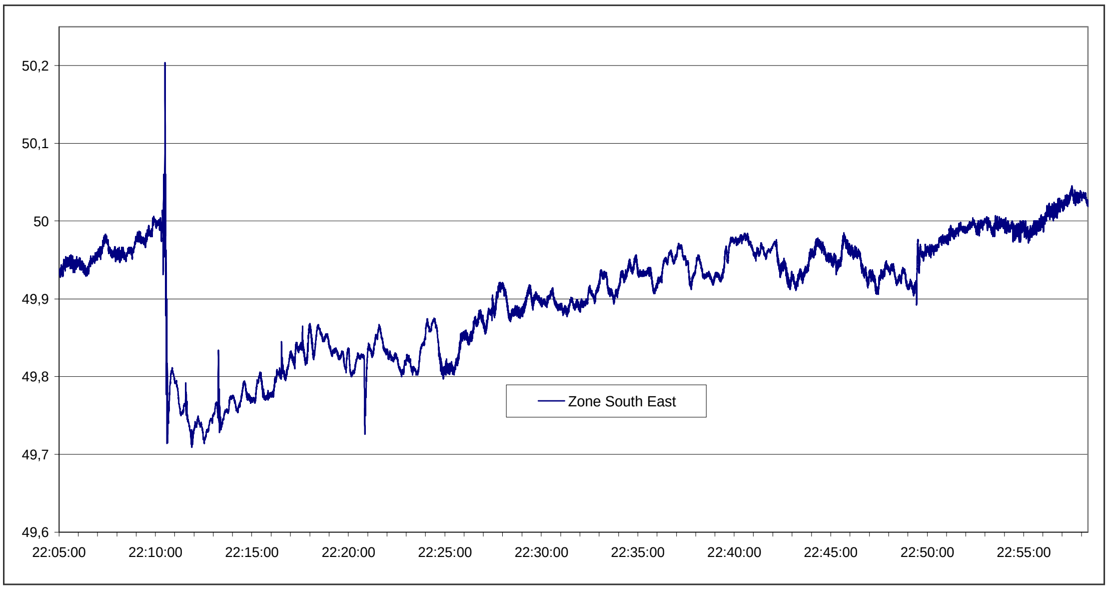

Figure 23: Frequency evolution in area 3 during the event (WAMS recording)

[10] KESH is not included
[11] Tie-Line Bias Control, i.e. the AGC adjusts the production so as to keep the scheduled program in the interconnectors
[12] Constant Frequency Control, i.e. the AGC adjusts the production so as to keep constant frequency (50 Hz)

At 22:40:36, the automatic generation control of HTSO (GR) was switched back to load frequency control.

During the event, TSOs actively communicated among themselves trying to identify the origins of the disturbance and exchanging information about the current status of the system conditions.

The power exchange on the DC link between Italy and Greece (capacity of 500 MW), scheduled at 312 MW towards Greece, was not interrupted during the whole event. Fortunately, there was no need from the Italian side to interrupt this program (in a different case, Greece would have faced an additional deficit of 310 MW). Moreover, the time frame of the event coincides with a period when load rapidly decreases in the Southeast area. An indicative example is given in Figure 24.

Figure 24: Evolution of consumption in the HTSO area during the event (no load shedding in the area)

3.4. Connections to other synchronous areas

Four TSOs of North-East area (E.ON Netz, Energinet.dk, VE-T and PSE-O) are connected to Nordel power systems via submarine DC cables (see figure 11). On November 4 at 22:10, just before the event, all of them were in operation transferring 2 200 MW in total from UCTE to Nordel area (total capacity of the cables 3500 MW). The splitting of UCTE system did not disturb their operation at all. However, the power flows on Skagerrak and Kontiskan cables (Denmark West/Energinet.dk to Norway/Stattnett and to Sweden/Svenska Kraftnat) were influenced by pre-defined automatic actions. These actions were triggered by long lasting frequency deviation on the UCTE side and consisted of increasing power flow from the surplus area - so called emergency frequency regulation (see Figures 12, 15, 16, 17). The maximum changes of power flows on these connections amounted to 50 MW and 150 MW for Skagerrak and Kontiskan respectively (comparing to 500 MW of scheduled flows in both cases).

Such an emergency measure is not active on the other three cables: Baltic, Kontek and SwePol so the power flows remained on them as scheduled during the whole event. Anyway, the available capacity of all these cables was almost fully used (transfer capacity from Poland to Sweden was limited due to internal network constraints in Polish transmission system on that day).

Summarizing the operation of the DC connections to Nordel was satisfactory during the event - helping slightly by exporting the surplus of capacity from the UCTE overfrequency area while not disturbing operation of Nordel power systems at all.

Concerning the West area, the power flow from Spain to Morocco before the incident amounted to 490 MW and there was a power flow of 56 MW from Morocco to Algeria. Due to the decrease of the frequency in the UCTE, the Spain-Morocco interconnection tripped at 49.5 Hz due to under-frequency protection at Melloussa (Morocco). Part of the power deficit in the Moroccan system was compensated by the Algerian and Tunisian power systems, which in turn caused a trip of the interconnection between Morocco and Algeria due to wattmeter protection (380 MW instantaneous). The isolated Moroccan power system experienced the under-frequency load shedding with about 300-350 MW load shed. On the other hand, the Algerian and Tunisian power systems remained connected, with a generation surplus what induced frequency rise to 50.16 Hz. Automatic primary regulation initiated a power flow to the Tunisian network which exceeded the threshold of load shedding control (SPS) on the 225 kV Tajerouine-Aouinet line (adjusted at: 150 MW, instantaneous) and activated an automatic load shedding of 31 MW in Tunisia.

The French to England DC interconnection “IFA” was used close to the total capacity with a flow of about 1 990 MW from France. The link neither tripped nor was impacted by the frequency drop. There is no automatic protection related to frequency variation but TSOs can manually reduce the flow very quickly if needed. Such an action was not started on the November 4 since the automatic load shedding occurred during less than one second and the available tertiary reserve was activated within few minutes.

3.5. Network frequency control during the incident

UCTE Operation Handbook sets the requirements and standards for different types of operational reserves to be maintained by TSOs in normal operating conditions (+/-180 mHz of deviation). In case of very serious disturbances (like the event on 4 November) the operating conditions are severely violated. In such situations the contribution of the activated primary control (to stabilize the frequency) and secondary control reserves (to recover the nominal frequency) constitutes only a minor share in covering the imbalance. In other words, the power activated through above mentioned types of operational reserves is not enough to bring the situation under control. Therefore, the individual TSOs have developed and implemented additional, extraordinary measures included in the emergency plans that are activated when a severe disturbance takes place.

However, these extraordinary measures were not sufficiently harmonized among TSOs.

Frequency stabilization after splitting

The estimated amount of primary control in the Western area was 2050 MW while the total imbalance of this area was close to 9 000 MW (approx. 22%), in the North-Eastern area it was 700 MW as compared to an imbalance of about 10 000 MW (approx. 7%) and in South-Eastern area it totaled 250 MW as against an imbalance of over 750 MW (approx. 35%). These figures show that primary control solely was not able to stabilize frequency in the Western and North-Eastern areas. Thus the extraordinary measures were automatically activated. In the Western area frequency was stabilized mainly by load and pumps shedding (approx. 18 600 MW to cover initial imbalance of approx. 9 000 MW as a result of splitting and further generation tripping of 10 900 MW) while in the North-Eastern area by wind generation tripping (approx. 6100 MW).

Load frequency control (secondary reserve)

In normal conditions TSOs operate load frequency control according to the non-intervention rule what means, that only the TSO affected by a sudden imbalance has to cover it, thus restoring the frequency to the nominal value. Obviously, during such severe disturbances as on 4 November it is not possible for TSOs directly involved to cover the occurring imbalance only by themselves. Therefore the non-intervention rule cannot be maintained anymore during severe emergencies and other TSOs shall assist with their secondary reserve to restore the frequency.

To this end, the LFC mode needs to be changed into frequency control. Since this can lead to overloading of tie-lines, it has to be carried out carefully in a co-ordinated way and special monitoring of tie-lines is necessary.

During the disturbance, some TSOs in all three areas took this measure, however not in a coordinated way.

Even the full activation of secondary control reserves was not sufficient to recover the nominal frequency (especially in the Western and North-Eastern areas) due to the volume of imbalances after splitting and automatic reactions of power system elements (primary control, load and pumps shedding, generation units tripping) This is why further measures were required to restore the frequency.

Generation rescheduling (tertiary reserve)

In case of Western area, additional activation of almost total tertiary reserves available in all control areas close to 17 000 MW, allowed to restore the frequency to the nominal value. This action was not sufficiently coordinated and fortunately no critical network overload occurred..

Due to relatively low imbalance in the South-Eastern area, the activation of tertiary reserve (approx. 100 MW) in Croatia together with LFC in frequency mode in Greece and a accompanying natural decrease of consumption in this area was sufficient to restore the frequency.

In view of the North-Eastern area, there was a need to decrease frequency mainly through a reduction of the generation level. This action was not coordinated: in two control areas a manual decrease of the generation level took place (allowing deviation of exchanges) while some others maintained the exchange as scheduled. The most critical factor was increasing of generation (the opposite action to the expected) observed in the German part of the North-East area (VE-T, north part of E.ON Netz) caused by uncontrolled reconnection of wind farms which tripped in the first moment after splitting. The frequency recovery close to the nominal value was in this case possible only by a very deep decrease of generation output in other control areas (critical network overloads were observed).

RESYNCHRONIZATION PROCESS 4

4. Resynchronization process

Resynchronization actions were performed in the networks of E.ON Netz and RWE TSO in Germany and APG in Austria, HEP in Croatia, TRANSELECTRICA in Romania and WPS in West-Ukraine. These TSOs started preparations to switch the tripped lines on immediately after having awareness about the splitting. They did it on their own with minimum co-ordination with other TSOs (decentralized approach).

The actions which finally allowed the resynchronization can be grouped into the following phases:

- Resynchronization trials which did not result in real interconnection,
- Resynchronization attempts which resulted in real interconnection but failed after a few seconds,
- Successful resynchronization process.

Classification of actions to the above grouping is based on the WAMS measurements of frequencies in split areas (each measurement point with exact GPS time stamp, 100 msec resolution) - see Figure 25.

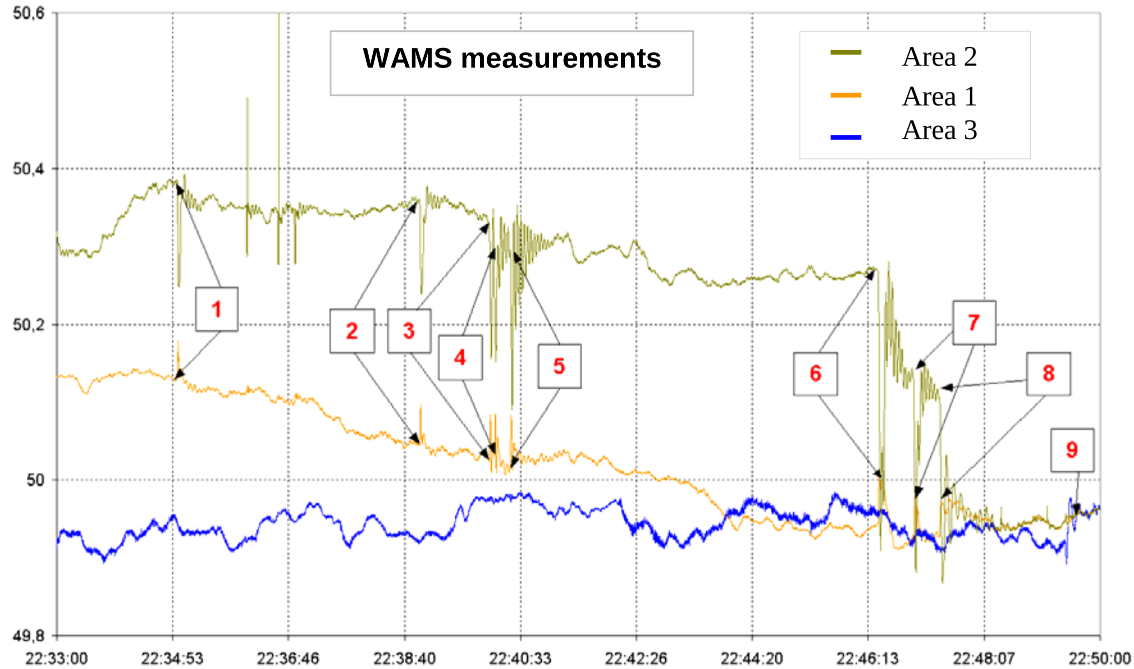

Figure 25: Frequency recordings for three areas

As a first step of a resynchronization process, the area 1 was synchronized with area 2 in Germany (E.ON Netz) and Austria (APG) and as a second step, the area 3 was synchronized with already interconnected areas 1 and 2 through the tie-line between Romania (TRANSELECTRICA) and West Ukraine (WPS). Those two steps were performed within overlapped timeframes i.e. the second one started before completing the first one.

The milestones of resynchronization were: first successful reconnection of tie-line between area 1 and area 2 done at 22:47, and first tie-line between already connected areas 1-2 and area 3 switched on at 22:49.

Preparatory actions

The preparations to reconnect tripped lines started immediately after 22:10 but due to the huge differences of frequencies, successful switching on the lines required extraordinary measures. There were several attempts of unsuccessful actions to re-close the open lines.
To connect asynchronous areas E.ON Netz and APG used respectively semi-automatic and automatic devices dedicated for this purpose. Parallel switching devices (PSD) used by E.ON Netz automatically recognize different frequency areas and connect them at an optimal point of time if there is compliance

with pre-set parameters (permissible frequency difference 500 mHz, voltage difference +/- 15 kV, angle difference 10 degrees). The dispatcher's action is to start that procedure and to wait for 45 seconds during which the parallel switching devices, check the compliance with the pre-set parameters and complete the procedure by closing circuit breaker. The 400 kV tie-line between Transelectrica and WPS was switched on manually by the dispatcher of the latter TSO when the conditions at both ends of the line reached acceptable level according to the relevant procedure (permissible frequency difference 100 mHz, voltage difference +/- 20 kV, angle difference 20 degrees). All the other lines, which tripped during the disturbance, were switched on back to operation in normal procedure for closing open rings (there were no separate asynchronous areas anymore).

Resynchronization of area 1 and area 2

Resynchronization trials which did not result in real interconnection

22:34:57 - trial switching-on of the 380 kV Oberhaid-Grafenrheinfeld line which tripped due to strong oscillations [1].

22:38:54 - trial switching-on of the 380 kV Oberhaid-Grafenrheinfeld line which tripped due to strong oscillations [2].

22:40:04 (E.ON Netz time: 22:40:03, RWE TSO time: 22:40:09, order to PSD was sent at 22:39:58 – E.ON Netz time) - trial switching-on of the 380 kV Landesbergen-Wehrendorf line which tripped due to strong oscillations (difference of frequencies was 300 mHz) [3].

22:40:09 (E.ON time: 22:40:08, order to PSD was sent at 22:39:58 – E.ON Netz time) – trial switching-on of the 380 kV Conneforde–Diele red line which tripped due to strong oscillations [4]

22:40:25 (E.ON time: 22:40:24, order to PSD was sent at 22:40:12 – E.ON Netz time) - trial switching-on of the 380 kV Conneforde-Diele white line which also tripped due to oscillations (difference of frequencies was 300 mHz) [5].

Resynchronization attempts which resulted in real interconnection but failed after a few seconds

Taking into account the experiences from the trials mentioned above (the reconnection of the second circuit took too long) E.ON Netz decided to try to connect as many circuits as possible within a short range of time. Such an approach increased the probability of successful reconnection of the second circuit before the first one trips. To do so the dispatchers had to start PSDs one after another much quicker than previously.

22:46:23 - 22:46:27.3 (E.ON Netz time: 22:46:23 – 22:46:28, order to PSD was sent at 22:46:14) switching-on both circuits of the 380 kV Conneforde-Diele line, which again caused oscillations, ended up after 4 seconds with trippings of both 380/220 kV transformers in the Conneforde substation, the 380 kV line Unterweser-Conneforde and opening of the 220 kV busbar coupling in the Conneforde substation (moving the border line eastwards). The difference of frequencies was about 300 mHz [6].

22:46:57.3 - 22:47:00.6 (E.ON Netz time: 22:46:57 - 22:47:05, RWE TSO time: 22:47:03 - 22:47:09, order to PSD was sent at 22:46:53) switching-on of the 380 kV Landesbergen-Wehrendorf line which tripped due to oscillations after 3 seconds (the difference of frequencies was about 150 mHz) [7].

1. **22:34:57 - trial switching-on of the 380 kV Oberhaid-Grafenrheinfeld line**
2. **22:38:54 - trial switching-on of the 380 kV Oberhaid-Grafenrheinfeld line**
3. **22:40:04 (E.ON time: 22:40:03, RWE: 22:40:09) trial switching on of the 380 kV Landesbergen - Wehrendorf line**
4. **22:40:09 (E.ON time: 22:40:08) trial switching-on of the 380 kV Conneforde – Diele red**
5. **22:40:25 (E.ON time: 22:40:24); trial switching on of the 380 kV Conneforde – Diele white**
6. **22:46:23 – 22:46:27 (E.ON time: 22:40:24 – 22:46:29); switching on both of the 380 kV Conneforde – Diele which again caused oscillations ended up after 4 s with trippings of both 380/220 k V transformers in Conneforde substation, 380 kV line Unterweser-Conneforde and opening 220 kV busbar coupling in Conneforde substation**
7. **22:46:57 – 22:47:00 (E.ON time: 22:46:57 – 22:47:05, RWE: 22:47:03 – 22:47:09); switching on of the 380 kV Landesbergen – Wehrendorf**

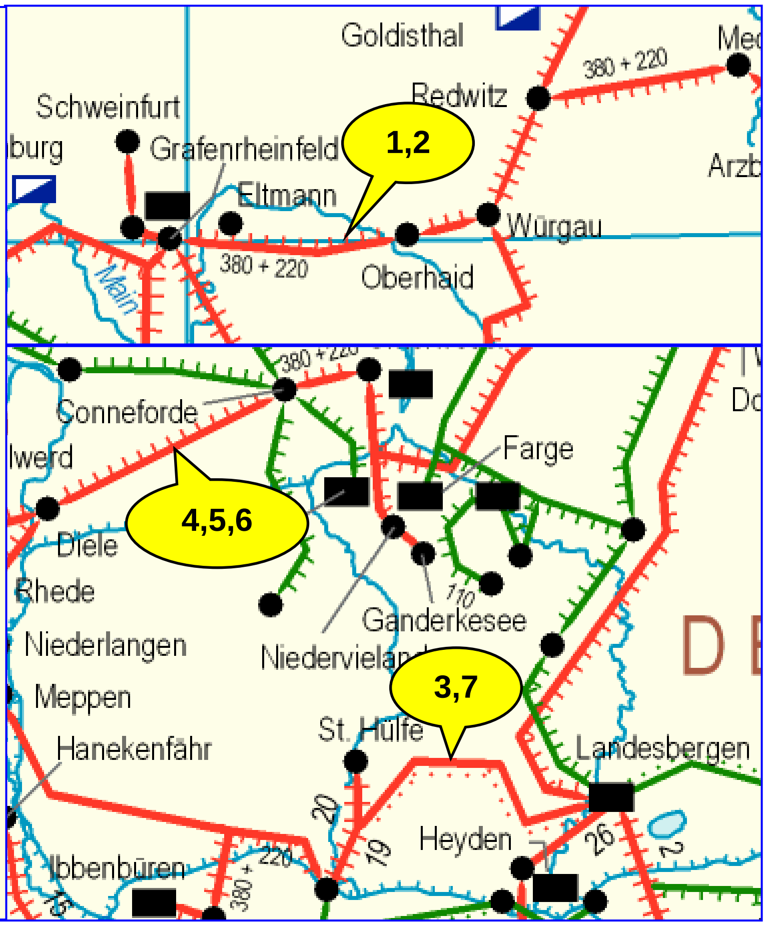

Figure 26: Unsuccessful resynchronization trials and attempts

Successful resynchronization process

Finally at 22:47:23.4 (E.ON Netz time: 22:47:23, order to PSD was sent at 22:47:11) successful resynchronization took place first on the 380 kV line Bechterdissen-Elsen (circuit 2) [8]. The recorded difference in frequencies before this connection was about 180 mHz and the phase angle difference on the line's ends was less than 10°. It is remarkable that this line is much shorter than lines in the North of Germany which failed before, and is located closer to the generation area in the western part. Further lines were switched-on very quickly and after 6 minutes (at 22:53) already nine 380 kV and four 220 kV lines on the border between area 1 and area 2 were in operation in Germany and in Austria. The restoration sequence was finally finished in Germany at 23:24:39 with 17 transmission elements re-closed (in Austria re-closure of all six lines was completed already by 22:51). Details of this phase are presented on Figure 27.

1. **22:47:23; 380 kV Bechterdissen – Elsen 2**
2. **22:48:00; 380 kV Dipperz – Großkrotzenburg1**
3. **22:48:16; 380 kV Dipperz – Großkrotzenburg2**
4. **22:48:23; 380 kV Dürnrohr – Ernsthofen (Austria)**
5. **22:48:47; 380 kV Etzersdorf – Ernsthofen (Austria)**
6. **22:48:55; 380 kV Unterweser - Conneforde**
7. **22:49:00; 220 kV Bisamberg – Ybbsfeld 1,2 (Austria)**
8. **22:51:00; 220 kV Ternitz - Hessenberg 1,2 (Austria)**
9. **22:50:48 (RWE time); 380 kV Wehrendorf – Dummersee - Sud – Landesbergen 1**
10. **22:52:27; 380 kV Sk Raitersaich - Redwitz**
11. **22:53:39; 380 kV Oberhaid - Redwitz**
12. **22:55:00; 220 kV Bechterdissen-Paderborn-Süd4**
13. **22:56:10; 380 kV Etzenricht - Redwitz**
14. **23:02:06; 380 kV Redwitz - Würgau**
15. **23:02:55; 380 kV Etzenricht - Schwandorf**
16. **23:04:16; 380 kV Mechlenreuth - Schwandorf**
17. **23:05:30; 380 kV Pleinting - Schwandorf**
18. **23:10:40; Conneforde: 220 kV busbar coupling**
19. **23:11:29; Conneforde: T 422 380/ 220-kV**
20. **23:12:04; Conneforde: T 421 380-/220-kV**
21. **23:24:39 (RWE time: 23:27:57); 220 kV Gütersloh – Bielefeld**

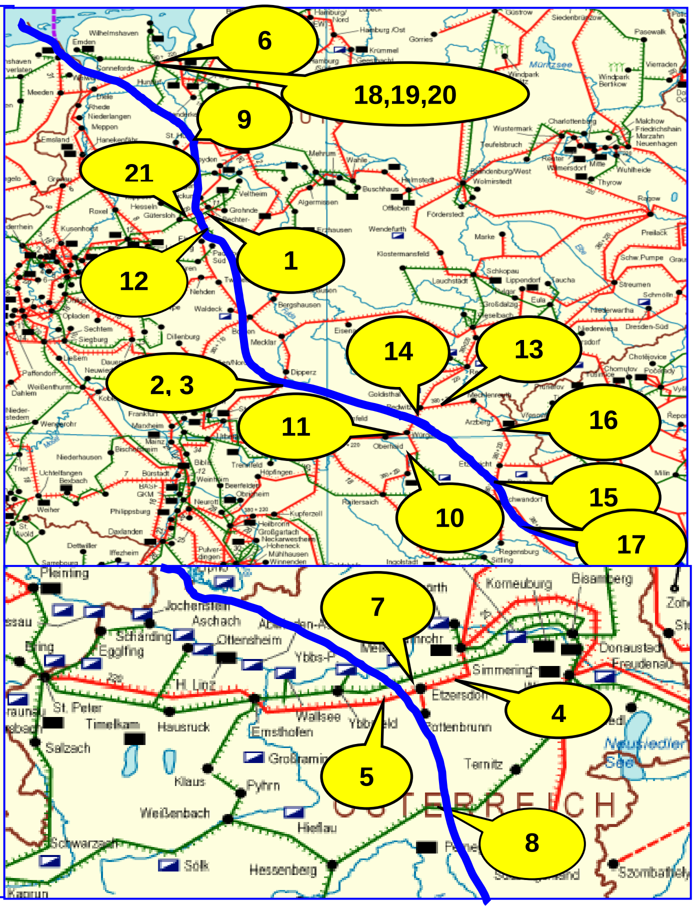

Figure 27: Resynchronization of areas 1 and 2 in Germany and Austria

Resynchronization of area 1+2 and area 3

The resynchronization process started immediately after successful reconnection of areas 1 and 2 with switching-on of the 400 kV line Mukachevo-Rosiori at 22:49:35 [9]. At that time, area 1 and area 2 were synchronously connected by four lines in Germany and four lines in Austria. Prior to connection, the difference of frequencies between area 1-2 and area 3 was in the range of 40 mHz. Within the next 13 minutes, four lines connecting area 3 to the rest of UCTE were switched on (two internal lines in Croatia, one circuit of the Croatian-Hungarian tie-line). The resynchronization sequence was finished at 23:57 when the last 400 kV line between Croatia and Hungary was switched on.
Details of the resynchronization phase in Croatia, Hungary, WPS with geographical reference are presented on Figure 28 Resynchronization of area 1+2 with area 3 in Croatia, Hungary, Romania and West Ukraine.

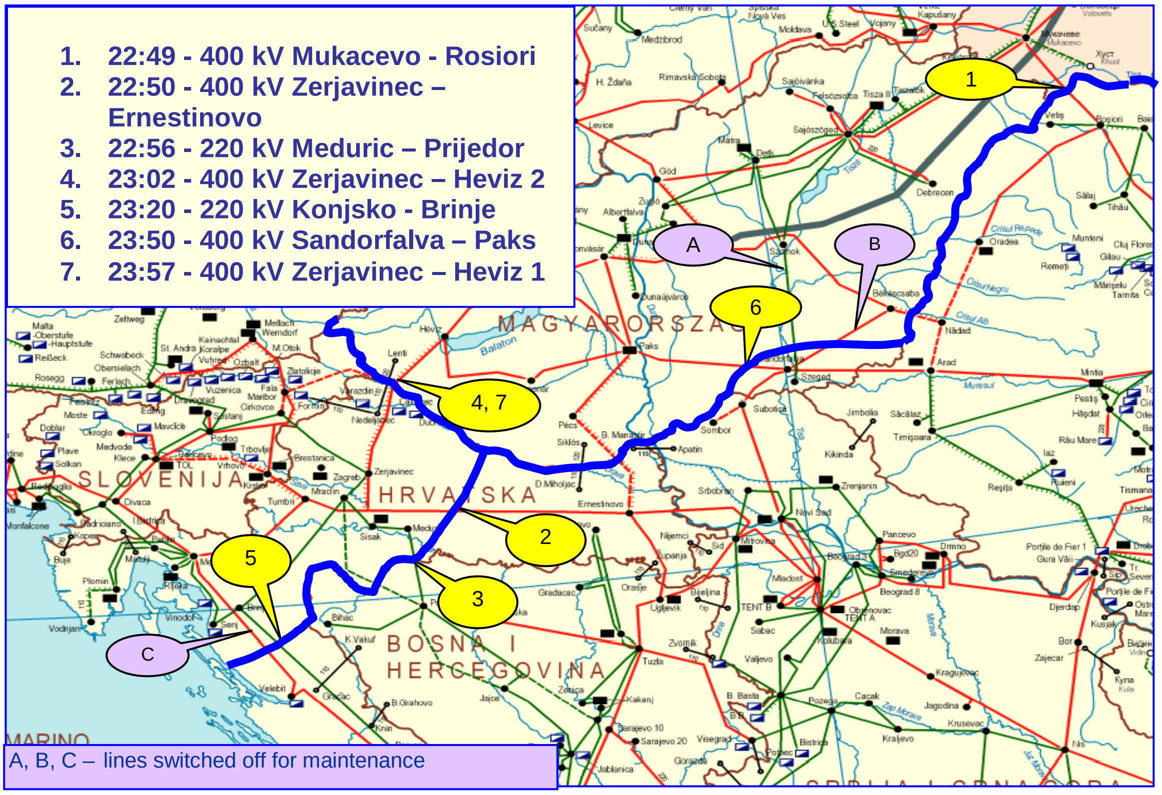

Figure 28: Resynchronization of area 1+2 with area 3 in Croatia, Hungary, Romania, West Ukraine

5 ANALYSIS OF MAIN CAUSES

5. Analysis of main causes

MAIN CAUSE 1: Non fulfillment of the « N-1 » criterion

The N-1 criterion is a basic operation principle in UCTE; it is of major importance to prevent disturbances. This rule requires that any single loss of transmission or generation element should not jeopardize the secure operation of the interconnected network, that is, trigger a cascade of line trippings or the loss of a significant amount of consumption.

On November 4, after switching-off the 380 kV double circuit line Conneforde-Diele, the E.ON Netz grid (including some of its tie-lines) was not in "N-1" secure conditions.

After disconnection of Conneforde-Diele line the resulted physical flow on the 380 kV Landesbergen (E.ON-Netz)-Wehrendorf (RWE TSO) line was so close to the settings of protection system in Wehrendorf substation (RWE TSO) that even a relatively small power flow deviation (which is not unusual in the highly meshed network) could start the cascade of lines tripping. Between 22:00 and 22:10, as the power flow on the Landesbergen-Wehrendorf line increased, it triggered the cascade tripping of the lines what proved the non fulfillment of the N-1 criterion.

The violation of the N-1 criterion is confirmed by simulations carried out by the Investigation Committee. Just after switching-off the Conneforde-Diele line (i.e. 21:40[13]), in case of unexpected outage of the 380 kV Bechterdissen-Elsen line or of the 380 kV Elsen-Twistetal line, the power flow on the 380 kV Landesbergen-Wehrendorf line exceeds not only the alarm threshold on the E.ON Netz side (i.e. 2000 A) but also the threshold of the protection device on the RWE TSO side (i.e. 2100 A). In case of outage of one of these two lines, the Landesbergen-Wehrendorf line would have tripped immediately.

This violation of the N-1 criterion has been identified by the Investigation Committee as the first main cause of the disturbance.

According to Policy 3 of the UCTE Operation Handbook ("Operational Security"), each TSO has to monitor the N-1 criterion fulfillment in its own control area and some defined parts of adjacent systems at any time. The procedures described in this policy include two types of analysis:

- forecast analyses based on hypotheses for power exchanges, generation pattern and system topology,
- online analyses based on real-time data of the system state[14].

On November 4, the violation of the N-1 criterion could have been avoided if appropriate analyses as mentioned in Policy 3 had been performed. Only analyses based on numerical simulations are suitable to check the compliance with the N-1 criterion. The following facts confirm that the best-practice principles were neglected at several stages of the process.

- On November 3, when E.ON Netz gave its provisional agreement to bring forward the disconnection of the Conneforde-Diele line to November 4 at 22:00, a contingency analysis was not deemed necessary by E.ON Netz. Only an empirical load flow evaluation was made and it was assumed that the N-1 criterion would be met in the E.ON Netz grid.

- On November 3, RWE TSO and TenneT were not informed about this new timing, therefore no special security analyses were carried out. They were informed only on November 4 at 19:00.

- The DACF (Day Ahead Congestion Forecast)[15] data file distributed by E.ON Netz to all UCTE TSOs on November 3 at 18:00 did not take into account the disconnection of the Conneforde-Diele line. These data files allow each TSO to carry out day-ahead security analyses on a regional basis, larger than their own grid.

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[13] In fact, this contingency analysis has been done using the last available snapshot file of the whole UCTE system that is 21:30, thus assuming that nothing changed between 21:30 and 21:40 except the switching off of the Conneforde-Diele line

[14] see Operation Handbook Policy 3, Chapter A, Procedure 2

[15] DACF data files are prepared by each UCTE TSO every day at around 18:00 for the coming day.

- On November 4 at 21:30, i.e. just before the opening of the Conneforde-Diele line, no security computations (N-1 analysis) of the planned situation taking into account the opening of the line were carried out by E.ON Netz. This type of analysis was not deemed necessary. Here again, only an empirical evaluation was made and it was assumed that the N-1 criterion would be met in the grid.

- No security computation was carried out by E.ON Netz after opening of the line. Unlike most of UCTE TSOs, E.ON Netz does not carry out contingency analyses at regular time interval. E.ON Netz has no automatic online contingency analysis tool integrated in its SCADA/EMS system in the control centre in Lehrte.

- RWE TSO carried out a security computation just before and after the opening of the Conneforde-Diele line. The analysis performed by RWE TSO showed that the tripping of the line Landesbergen – Wehrendorf would not lead to cascading outages in the internal RWE TSO grid and on the tie-lines of RWE TSO with its neighbors.[16] However, since currently there is no specific UCTE requirement defining the region which should be considered in the n-1 security analyses, this analysis did not take into account the contingencies in the E.ON Netz grid.

It is worth underlining that, on November 4, due to construction work in the 380 kV Borken substation (E.ON Netz), the substation was operated in a two-busbar mode. The Borken substation is usually operated in only one-busbar mode. This configuration means that power flows were not possible from East to West in this region. It is clear that this particular configuration at the Borken substation on November 4 was an unfavorable factor.

The Landesbergen-Wehrendorf tie-line between E.ON Netz and RWE TSO was the most heavily loaded line, but it was not the only one. Simulations show that several other lines of the E.ON Netz grid were heavily loaded:

- In particular, the 380 kV East-West axis Mecklar (E.ON Netz) – Dipperz (E.ON Netz) – Grosskrotzenburg (E.ON Netz) – Dettingen (RWE TSO) – Urberach (RWE TSO),
- And the 380 kV Redwitz (E.ON Netz) - Remptendorf (VE-T) line.

In both cases, the outage of one circuit of these lines would have led to exceed the alarm threshold on the other circuit (in some cases the overload is higher than 25%). The operating rules, currently in force at the E.ON Netz control centre, allow dispatchers to accept that the power flows exceed the alarm threshold (by a maximum of 25%) during a short period of time, in order to apply remedial measures to come back to an acceptable situation.

Despite, the system state was not N-1 secure and the situation was tight, no immediate remedial actions were taken to reduce the power flow on the Landesbergen-Wehrendorf line. Between 22:02 and 22:10, this power flow gradually increased by about 130 MW (see Figure 3 in Chapter 2.2). This increase can be explained mainly by transient variation of the power exchanges between Germany and The Netherlands. Appendix 7 shows the power exchange deviations[17] (i.e. the difference between the actual power exchanges and the scheduled power exchanges) for TSOs from West and North East area from 21:50 till 22:10. These transient deviations are the result of a global shift in physical power flows within the UCTE synchronous area due to changes in generation programs and exchange programs around 22:00. These curves show a situation which is rather normal and typical at that time.

The continental grid situation on November 4 was marked by large long-distance load flows from North-Eastern to South-Western Europe (close to 10 000 MW; see Chapter 2.1), resulting from the international transactions the day before. Between 22:00 and 22:10, the variation of physical power exchanges between Germany and The Netherlands was about 340 MW (from Germany to the Netherlands). A sensitivity analysis assessing the impact of this variation on the Landesbergen-Wehrendorf line shows that this deviation leads to an increase of about 70 MW of the power flow on this line. It is clear that on November 4 the absence of the Conneforde-Diele line contributed to this

[16] since the 400 kV Landesbergen-Wehrendorf line and the 220 kV Bielefeld/Ost-Spexard line are electrically interdependent, tripping of the 400 kV line causes an immediate tripping of the 220 kV line which cannot carry the load. Therefore, those two lines are considered as one element in the N-1 security computations of RWE TSO.
[17] the scheduled export out of the E.ON Netz control area increased by 150 MW from 1635 MW to 1785 MW. The scheduled export from E.ON Netz to RWE TSO decreased by 50 MW from 695 MW to 645 MW.

increase. The sensitivity analysis was focused on the area around the Landesbergen-Wehrendorf line (E.ON Netz, RWE TSO, TenneT).

Furthermore, between 22:00 and 22:10, some units increased their production in the E.ON Netz grid. Three of them, due to their localization, have a direct impact on the Landesbergen-Wehrendorf power flow (Erzhausen, Wilhelmshaven, Heyden). Simulations show an additional increase in the power flow on this line of about 30 MW. It is worth noting that a slight increase of wind generation in Germany (connected to E.ON Netz and VE-T grids) during this period of time (see Figure 13) was not significant enough to explain a further increase of the power flow on this line.

Considering that the variation of physical power exchanges is not an unusual phenomenon, especially around 22:00, the security margin on the Landesbergen-Wehrendorf line was not sufficient.

Finally, at 22:10:11 E.ON Netz dispatchers decided to change the topology in the Landesbergen substation. They expected that coupling the two busbars in the substation would lead to a reduction of the power flow on the Landesbergen-Wehrendorf line. However this manoeuvre had an opposite effect and the line was automatically tripped by the distance protection in the Wehrendorf substation what initiated a cascade of line trippings, starting with the 220 kV Bielefeld/Ost-Spexard line and continuing within the E.ON Netz grid. This decision, taken in a rush, cannot be considered as a cause of the disturbance, while the situation of the E.ON Netz grid was not secure before.

This topology change was decided on the basis of an empirical assessment of the consequences, without any simulation. Simulations[18] performed by the Investigation Committee confirm that this manoeuvre leads to an increase in the load of the Landesbergen-Wehrendorf line of about 50 MW (67 A). Figures 30 and 31 below show the power flow configuration at the Landesbergen substation before and after coupling both busbars.

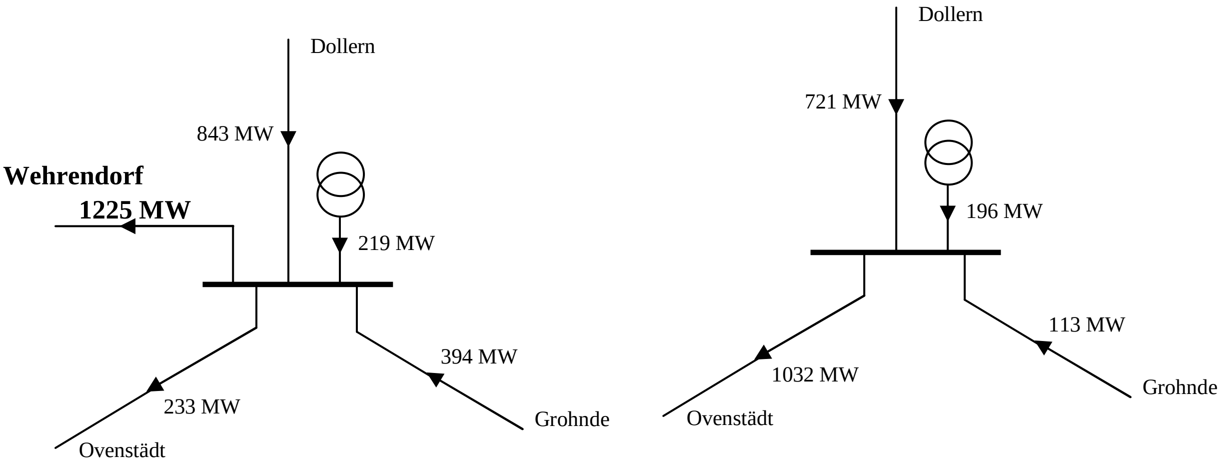


Figure 30: Landesbergen substation - Before coupling

[18] These simulations have been done using the last available snapshot file of the whole UCTE system, that is 22:00.

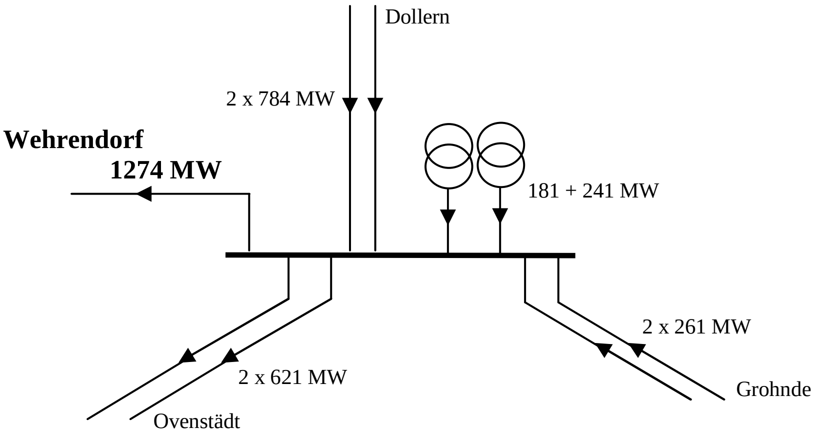


Figure 31: Landesbergen substation - After coupling both busbars

MAIN CAUSE 2: Insufficient inter-TSO co-ordination

Inter-TSO co-ordination is crucial to maintain the security of the system. This co-ordination is exercised at different time horizons: from long term planning to real time operation. The co-ordination actions of E.ON Netz towards neighboring TSOs were not sufficient after the outage of the Conneforde-Diele line was rescheduled.

This insufficient co-ordination was identified by the Investigation Committee as a second main cause of the disturbance.

The initial planning for switching-off the 380 kV Conneforde-Diele line scheduled on 5 November from 01:00 to 5:00 was duly prepared by the TSOs involved. However, the change of this switching time was communicated by E.ON Netz very late to the TSOs concerned and was not properly prepared and checked in the operational planning phase in order to ensure a secure operation of the system in this area.
No efficient remedial actions were prepared by E.ON Netz with neighboring TSOs in order to keep a sufficient security margin on the Landesbergen-Wehrendorf line after switching-off the Conneforde-Diele line.

The protection settings in the Wehrendorf substation (RWE TSO) defining the tripping current value was not taken into account by E.ON Netz. This specific issue was critical regarding the very high flow on this line.

Although RWE TSO, TenneT and E.ON Netz expected high flows on the grid after switching-off the Conneforde-Diele, no emergency situation was expected. Despite the warning made by RWE TSO at 21:41 about the tight security margin in the Wehrendorf substation, an emergency situation was not recognized therefore no immediate remedial actions were taken by E.ON Netz to re-establish the sufficient security margin.
Just before the busbar coupling in the Landesbergen substation, due to the necessary rush, neither co-ordination nor consultation was performed by E.ON Netz towards directly involved TSOs.

ANALYSIS OF OTHER CRITICAL FACTORS 6

6. Analysis of other critical factors

6.1. Generation-related issues

The description of the course of events of November 4 shows clearly the important role of generation in the power system performance. This role was crucial in different ways during all stages of the event, especially in the Western and North-Eastern areas.

First of all, some TSOs do not have sufficient information available from generation units connected to the transmission grid: generation programs (including intra-day changes) and online data. Ignoring the amount and precise location of power injection in the TSO grid leads to improper grid monitoring and system security assessment.

Immediately after split of the UCTE system

The requirements for disconnection of generation units connected to the distribution grid (especially wind generation and CHP) are usually less strict than for the units connected to the transmission grid, i.e. they are disconnected at a smaller frequency deviation. When the frequency deviation reaches the threshold values of the units' protection, they are automatically disconnected from the grid as happened in both above-mentioned areas where units had tripped due to under-frequency in the Western area and due to over-frequency in the North-Eastern area. Such a behavior worsened the situation in the Western area (increased imbalance) while in the North Eastern area this reaction reduced power imbalance during the first seconds after the splitting.

After UCTE system split

Recovering the frequency to its nominal value required an increase of generation output in the Western area and a decrease of generation output in the North-Eastern area. After a few minutes, wind farms were automatically reconnected to the grid, being out of the TSOs' control. This unexpected reconnection had a very negative impact, preventing the dispatchers in both areas from managing the situation.
Additionally, certain TSOs in the North-Eastern area were not able to reduce the power output from generation connected to the transmission and distribution grid in a sufficiently short time necessary for the frequency restoration.

These are examples of insufficient TSO control over the generation behavior. The TSO control usually applies to generation connected to the transmission grid since traditionally the generation connected to the distribution grids has not had a significant impact on the power system as a whole. However, the recent rapid development of dispersed generation, mainly wind farms, has changed the situation dramatically. The wind generation in some areas significantly influences the operation of the power system due to its high share in the generation and intermittent behavior dependent on weather conditions.
The negative role of wind generation performance on November 4 was evident. Due to uncontrolled behavior of wind generation it was not possible to maintain a sufficient power exchange balance in some German control areas (VE-T, East part of E.ON Netz) after split. Fortunately, these control areas were connected to control areas of Poland and the Czech Republic where the absorption of the "unintentional" wind generation was possible by decrease of the power output of thermal generation (however creating additional critical network problems).

6.2. Range of possible actions for the dispatchers to handle grid congestions

To remove a constraint and restore a secure operation of the grid with regard to the N-1 criterion, TSOs have to manage a number of actions defined in the national regulations and internal procedures: grid-related measures, market-related measures and other special actions for the management of emergency situations.
The adequacy of such measures that have to be duly identified and prepared in advance must be evaluated in terms of the remaining safety margin in the grid, variable factors (such as changes of cross-border exchange schedules, generation pattern changes) and finally the time needed for the

TSOs to implement these different measures. A specific measure is only relevant if its efficiency to fix the problem, the context (normal operation or emergency situation) and the time needed for implementation are taken into consideration.

Where an N-1 violation or a security problem is detected, German TSOs are obliged to examine first no direct cost actions (grid-related measures), and then actions with financial consequences (market-related measures). This second kind of actions is based on inter-TSOs or TSOs-market actors contracts.

In the planning phase (from year ahead to Day – 2), there is quite a wide range of possible actions for these TSOs to handle grid congestion. The TSOs concerned stated that they make security analysis and simulation at each stage from yearly, monthly, weakly and Day – 2 (Monday to Friday) time horizons. However, from Day – 2 to real time, the range of possible actions is smaller, in particular for cross-border capacity reduction and for redispatching of generation and counter-trading.

For TenneT, RWE TSO and E.ON Netz, cross-border schedules cannot be reduced after morning (around 8:00) of D – 1 and in real time except in case of emergency situations (violation of system security, imbalance within a control area).
Activation of redispatching and counter-trading is based on the existing contracts. In the course of the investigation, it became known that E.ON Netz has such a contract with one trader covering most of the power plants connected to its EHV grid. However, this redispatching measure takes at least 15 minutes to be activated which can be too long a period in case of sudden changes of flow patterns in a highly loaded grid.
E.ON Netz can address a request to a specific power plant only if the former actions are not efficient. Thus, the need for a relevant sense of emergency is critical, especially when operating the system close to the security limits.

6.3. Defense and restoration plans

Defense plans

The UCTE Operation Handbook specifies the following requirements for TSOs:

- Each TSO is responsible for the development of a detailed step-plan for load shedding.
- In order to prevent a collapse of the whole interconnected system, load shedding has to be started automatically.
- Automatic load shedding due to a large drop of frequency should be implemented starting from 49 Hz with disconnection of 10% to 20% of consumption in steps for any progressive stages e.g. of 0.3-0.5 Hz frequency drop with the lowest value of 47.5 Hz.
- Earlier shedding of pumped storage units can be started at a frequency higher than 49 Hz.

The defense plan set up by each TSO in the Western area (except Swiss TSOs for which a load shedding plan is under implementation) generally showed the expected, satisfactory performance.
After the splitting of the UCTE power system, load shedding allowed to stop the frequency drop in the Western area and to find a new balanced condition of the power system.

However, the registered amount of load shedding on November 4 differed significantly from one TSO to another (from 3% for The Netherlands to 19% for Portugal). Several reasons can explain these differences:

- The rate and threshold of load shedding are different among TSOs and countries as they are defined in different documents: laws, grid codes, internal rules.
- Defense plans are defined to manage power imbalance and the related frequency drop referring to the consumption of each country. The UCTE Operation Handbook does not specify obligations for TSOs to coordinate their defense plans.
- Due to technological differences, frequency measuring devices activating the load shedding have different accuracy. The tolerance of the frequency measurement varies between 0.005 Hz and 0.15 Hz. Bearing in mind that the frequency fell close to 49 Hz (and not significantly below this value) some relays did not trigger due to the tolerance margin.
- The load-shedding relays are installed mainly in the distribution grid and national framework in terms of control of the proper implementation and functioning of this equipment differs from country to country.

These points in addition to some dysfunctions of the equipment explain the differences in the load shedding share for different TSOs. These differences however are not inevitably prejudicial for the safety of the UCTE electric system.

Restoration and re-energization

The restoration principles (re-energization of the load) differ also from one country to another. Some DSOs re-connected the load without co-ordination with their TSO, thus without taking into account the condition of the interconnected electric system whereas the frequency was still significantly below 50 Hz.

These actions caused further imbalance and prolonged the restoration process and could have endangered the security of the electric system.

However, in some cases these actions were based on national rules which allow re-energization at a frequency higher than the first threshold of load shedding (and not 50 Hz) and voltages above the given limits, not taking into account the overall situation of the interconnected electric system.

6.4. Resynchronization process

The resynchronization process was completed within 40 minutes after splitting. This enabled the interconnected UCTE system to be brought back to normal operation in less than two hours. In view of the seriousness of the disturbance, this result is to be considered as a remarkable achievement. The resynchronization process was carried out in a fully decentralized way, sometimes without knowing the exact conditions in the interconnected system. A good example of co-ordination of the resynchronization process was switching on of the 400 kV line between Romania and West Ukraine (i.e. the first line between the South-Eastern area and the rest of UCTE) just two minutes after resynchronization of the West and North-Eastern areas.

It should be noted that, in spite of some embedded risk, only this decentralized approach allowed to achieve reconnection in such a short time which was very important for the North-Eastern area suffering from high overloading of transmission network elements. An analysis showed that co-ordination of this process could have led to significant extension of the resynchronization time (needed for necessary communication and agreements among TSOs) what, in turn, could have led to further splitting in the North-Eastern area.

6.5. Training of dispatchers

The Investigation Committee has analyzed two training items directly related to the disturbance on November 4: the defense operation and the restoration process. An analysis concerned with the planning phase and normal operation showed no critical factors.

The analysis showed that incidents originating from external networks and affecting a TSO's own network are not always trained. Joint simulation training with neighboring TSOs is not a common practice today, however an exchange of experience and discussion on procedures do happen.

6.6. Communication among TSOs

The communication among UCTE TSOs was proceeded in a way expected in emergency situations taking into account the current framework of co-operation, the scope of responsibilities of individual TSOs and on-line data available at individual control centers. Usually, the first period of approx. 15 minutes after the disturbance is necessary for dispatchers to recognize the situation in their own grid and to undertake first necessary countermeasures to avoid spreading of the disturbance. This period is a very hectic one for the staff on the shift and obviously there is nothing to communicate by the TSO affected by the disturbance before it has itself enough information.

On the other hand, initiation of some remedial actions (such as changing the load frequency mode) should in principle require general information about the current status of the system.

On November 4, the knowledge of the actual situation of the UCTE system after splitting was not available quickly to all TSOs. The splitting between the Western and Eastern part of UCTE was known first only to a few involved TSOs from the Western part around 10 to 20 minutes after the event. The information on splitting of UCTE into 3 parts was available to most of the TSOs on November 5.

As the frequency severely dropped and automatic load shedding occurred at 22:10 in the Western area, TSOs of this area expected that a severe disturbance would happen. Dispatchers initiated a number of phone calls to identify the source of the problem and system status in the neighboring countries; however, it was not possible to make a precise and efficient diagnostic within a relatively short time due to the lack of information.

Furthermore, the recommendation from ETRANS to a few TSOs to change the load-frequency control mode at 22:32 (from power and frequency control to pure frequency mode) was initiated without having a clear and total picture of the exact situation of the whole UCTE system (at this time, the splitting of the German grid into 2 parts was known only to German TSOs and TenneT for the Western area).

RECOMMENDATIONS 8

7. Conclusions and recommendations

General context

This chapter provides recommendations for technical and organizational issues which should be implemented by UCTE or relevant stakeholders on a national or European level.

The general performance of the UCTE system (automatic actions) as well as actions taken by TSOs allowed to restore normal system conditions within a relatively short time. However, the investigation underlined a need for enhancement of UCTE standards and their application by TSOs. Specific attention is requested from relevant European stakeholders in terms of harmonization of legal and regulatory frameworks across Europe. These two complementary sets of improvements shall contribute to a more secure operation of the interconnected system.

Today, the UCTE Operation Handbook defines the standards and requirements which set up the basic principles for secure operation of the synchronously interconnected system. These standards are obligatory via the inter-TSO agreement and according to UCTE's Articles of Association.

It is the basic responsibility of each TSO to duly follow the existing rules.

The Operation Handbook is being continuously improved; the first revision process was initiated by UCTE regardless of the disturbance on November 4. In this context, it should be highlighted that current analyses do not confirm fundamental deficiencies in the current rules. The analysis of this major disturbance will be of prime importance to indicate the necessary clarification and complement of Operation Handbook Policies. The following recommendations related to the Operation Handbook should be rather read as a direction for the enhancement and improvement of the rules.

UCTE has already recognized the importance of compliance monitoring and in 2006 started a pilot procedure for Policies 1, 2 and 3 based on the TSOs self assessments. In the meantime, a special Working Group was created and the process became a regular UCTE activity. In 2007, the compliance procedure will be extended to Policies 4-7.

UCTE commits itself to provide at the end of 2007 a report informing about the status of implementation of the recommendations.

N-1 criterion

As already stated in chapter 5, the violation of the “N-1” criterion should have been avoided by appropriate security analyses and application of pre-defined remedial actions. The UCTE Operation Handbook (Policy 3, Subsection A) requires that UCTE TSOs have to monitor at any time the “N-1” criterion for their own system through observation of the interconnected system (their own system and all relevant parts of adjacent systems) and carry out security computations.

The disturbance of November 4 has highlighted that the compliance with the “N-1” criterion cannot be evaluated by a TSO regardless of the situation of its neighbors. Due to the increase of power exchanges within UCTE, the assessment of security is more and more interdependent.
Furthermore, the quickly changing system conditions require numerical calculations to assess the security of the system.

Recommendation #1
The application of the N-1 criterion in Policy 3 of the UCTE Operation Handbook has to be reviewed in terms of the following aspects:

- **Definition of the relevant part and specific conditions in the adjacent systems which have to be taken into account in TSOs security analyses.**
- **Simulation of contingencies (tripping of power system elements) located outside the TSO's own control area.**
- **Mandatory and regular online contingency analysis (N-1 simulations) connected to the alarm processing system.**
- **Preparation and regular check of the efficiency of remedial actions through numerical simulations.**

"Master Plan" for managing UCTE-wide or regional disturbances
The conditions for operating the system have also changed quite significantly. Nowadays, the interconnected power system is operated closer and closer to its limit and all national system are more and more interdependent. It implies a specific attention to the impact on cross-border disturbances or consequences of national disturbances to the whole interconnected system. A number of issues in the context of TSOs behavior have to be pre-defined and harmonized within TSOs. UCTE should define possible scenarios, procedures and principles which have to be followed by TSOs to prevent any incident or, in emergency conditions, to allow a quick restoration.

At least the following issues shall be included:

- co-ordination of national defense plans, especially load-shedding criteria
- management of over-frequency conditions
- harmonization of re-energization criteria
- resynchronization principles
- co-ordination of load-frequency control management
- co-ordination and communication procedures.

Coordination of defense and restoration plans
The defense plans have usually been designed to manage power imbalance and related frequency drops at country level. Usually, the defense and restoration plans involve DSOs, industrial customers and generators. However, the liability and the regulatory and legal framework are not always clearly defined in each country and are not homogeneous throughout UCTE. Therefore, a clear contractual or regulatory framework must be defined to determine the liability and role of each partner in the defense plan more precisely: TSO, DSO, generators, industrial customers, public authorities.
The UCTE Operation Handbook, which already gives certain principles on this subject, must be refined in order to guarantee coherence and adequacy of each TSO's defense and restoration plans at the UCTE level.

Resynchronization
Taking into account that each next hypothetical splitting of the UCTE interconnected power systems would happen along different border line(s) which are difficult to predict, it is not possible to develop relevant, universal co-ordination procedures applicable to different various scenarios. Thus, the decentralized approach seems to be preferable, even if it inherently includes the risk of unsuccessful attempts, which imply a certain danger for the power systems due to oscillations triggered by them (which was also the case on November 4th). This risk is unavoidable if the resynchronization is supposed to be realized quickly.
However, it is recommended that all TSOs ensure that their most important substations are equipped with relevant synchronizing devices preferably remotely controlled from TSO control centre directly.

Load-frequency control management
The Operation Handbook does not yet define principles for the different load-frequency management modes. However, in disturbances involving several TSOs, coordination of the frequency mode might have a significant influence on the rapidity of system restoration. Therefore, the benefits and possible

impacts of these different modes have to be thoroughly analyzed and their application should be pre-defined. UCTE should propose principles and define strategies for the different modes of frequency control with a special attention to the pure frequency mode for LFC.

Recommendation #2
Policy 5 ("Emergency Operations") has to be extended with a "Master Plan" defining principles of operation and TSOs' responsibilities to manage UCTE-wide or regional disturbances. Additionally the following aspects have to be considered:

- **TSOs have to reconsider their defense plans and load shedding philosophy and rating taking into account significant amounts of generation tripped during disturbances with large frequency deviation**
- **The restoration and re-energization process has to be explicitly coordinated by TSOs regarding DSOs actions and the related responsibilities and duties of involved parties must be clarified within a national framework**

Regional TSOs coordination

Enhancement of exchanges of data and results of security analysis
Although different data is already broadly exchanged among TSOs, the disturbance of November 4 clearly underlined that present practices are not robust and wide enough. The exchange of information about internal elements which influence significantly cross-border flows is not common.
The exchange of on-line data among TSOs is not always sufficient to manage securely the grid and the interconnected system.
The adequate evaluation of the system security in real time also strongly depends on real-time data exchange. Development of on-line data exchanges should be addressed by all TSOs in order to provide all relevant data for real-time security analysis and on-line simulations. Exchange of on-line data about consumption and generation of at least first guard ring (for any EHV nodes) should be mandatory for each TSOs, as well as the topology and status of all devices in substations (busbars coupling, circuit breaker position, tap changers position, etc.).
In order to enhance system security evaluation on a highly meshed grid with increasing influence of transits between TSOs and regions, TSOs should share more details for each relevant time frame, results of their security analysis on their grid and possible counter-measures.

Joint training
UCTE shall define a standard framework for training in order to provide reasonable assurance that the dispatchers have and hold up the knowledge and skills enabling them to operate the power system in a safe and reliable manner under all conditions and at all time. The common framework for training of operating and supervisory personnel shall contribute to develop personnel competency in normal and insecure system conditions. Due to bigger and more volatile market transactions, there is a stronger interrelation of security issues in the meshed network, and possible risks are enhanced. Thus, it is of utmost importance to develop a framework for joint training actions focusing on specific situations in order to ensure that coordinated actions will be performed with a due quality by means of visits, workshops, or on shift cross periods or bilateral/multilateral common training sessions on Dispatcher Training Simulator (DTS) depending on the level of mutual interference of the neighboring systems and the corresponding level of risks. The implementation of these solutions through TSO-TSO agreements must also be tested during joint training sessions of TSOs dispatchers.

Recommendation #3
UCTE has to develop standard criteria for regional and inter-regional TSOs co-ordination approach aiming at regional security management, from operational planning to real time, in terms of joint training, enhancement of exchanges of data, results of security analyses and foreseen remedial actions.

UCTE-wide awareness system

During the first minutes of disturbances, dispatchers should focus their actions on the restoration of normal conditions. On the other hand, the information about localization of the source of the disturbance and overall system conditions is necessary for other TSOs in order to act accordingly and efficiently. On November 4, this was true more than ever – the information about the split of the system into three areas was available to some operators with significant delay. This issue might be solved via a dedicated central server collecting the real-time data and making them available to all UCTE TSOs.
In this way, each TSO will obtain within a few minutes essential information about disturbances. beyond their own control area.

Recommendation #4
UCTE has to set up an information platform allowing TSOs to observe in real time the actual state of the whole UCTE system in order to quickly react during large disturbances.

Generation behavior and control

During the disturbance, a significant amount of generation units tripped due to a frequency drop in the Western area, which resulted in an increased imbalance. Most of those units were connected to the distribution grid (especially wind power and combined-heat-and-power units).
This behavior of generation units, which are disconnected when the frequency falls below 49.5 Hz, has certainly prevented an earlier increase of frequency after automatic load shedding.

Additionally, certain TSOs do not have the latest generation schedules available even for generation units connected to their own grid which might lead to improper system security assessments. The increased flexibility given to market players by the regulatory framework has to be associated with the obligation for generators to provide to TSOs their generation schedules in due time.

Additionally, most TSOs do not have available real-time data on the power generated in the distribution grids. In view of the rapidly growing share of such generation, this has multi-dimensional consequences:

- no real-time knowledge of the total national balance between supply and demand,
- no real-time knowledge of the generation started in DSO grids and possible tripping/reconnection in case of a frequency or voltage drop,
- no real-time knowledge of generation started in DSO grids and possible impact on grid congestion in the high voltage grid.

Additionally, certain TSOs have no control over the generation (e.g. cannot reduce or stop wind power generation). Bearing in mind the growing amount of installed power of wind generation, this situation could lead to serious power balance problems especially in over-frequency areas.

Recommendation #5
The regulatory or legal framework has to be adapted in terms of the following aspects:
- **TSOs should have the control over generation output (changes of schedules, ability to start/stop the units)**
- **Requirements to be fulfilled by generation units connected to the distribution grid should be the same in terms of behavior during frequency and voltage variations as for the units connected to the transmission network. These requirements should be applied also to units already connected to transmission and distribution grids.**
- **Operators of generation units connected to the transmission grid must be obliged to inform the TSO about their generation schedules and intra-day changes of programs prior to their implementation.**
- **TSOs should receive on-line data of generation connected to DSOs grids (at least 1-minute data)**

APPENDIXES 10

8. Appendixes

Appendix 1 – Investigation Committee

Appendix 2 – Planned non-availabilities of EHV tie-lines and internal lines

Appendix 3 – Sequence of tripped lines

Appendix 4 – List of TSOs in each area

Appendix 5 – Summary of load shedding actions in West area

Appendix 6 – Dynamic stability analyses

Appendix 7 – Power exchange deviations in West and North East area

Appendix 8 – List of abbreviations

Appendix 1 - Investigation Committee

UCTE representatives	
IC chairman	Gerard A. Maas (TenneT, The Netherlands)
UCTE Secretary General	Marcel Bial (UCTE)
IC Secretary	Jakub Fijalkowski (UCTE)
Subgroup convenors	
Western Europe (area 1)	Clotilde Levillain (RTE, France)
North Eastern Europe (area 2)	Jerzy Dudzik (PSE-Operator, Poland)
South Eastern Europe (area 3)	Yannis Kabouris (HTSO/Desmie, Greece)

Represented countries and TSOs

Country		Company
Austria	AT	APG
Bosnia Herzegovina	BA	ISO BiH
Belgium	BE	Elia System Operator
Bulgaria	BG	NEK
Switzerland	CH	SWISSGRID
Serbia	RS	JP EMS
Czech Republic	CZ	CEPS
Germany	DE	E.ON Netz
		Vattenfall Europe Transmission
		EnBW TNG
		RWE Transportnetz Strom
Spain	ES	REE
France	FR	RTE
Greece	GR	HTSO/DESMIE
Croatia	HR	HEP-OPS
Hungary	HU	MAVIR
Italy	IT	Terna
FYROM	MK	AD MEPSO
The Netherlands	NL	TenneT
Poland	PL	PSE Operator
Portugal	PT	REN
Romania	RO	Transelectrica
Slovenia	SI	ELES
Slovak Republic	SK	SEPS

Appendix 2 – Planned non-availabilities of EHV tie-lines and internal lines

1. E.ON Netz (DE)

Substation A	Substation B	Number of circuits	Voltage
Borken		Split off in two parts (for renewal of the station): Eastern part with the lines Mecklar and Bergshausen, western part with the lines Twistetal/Nehden and Gießen-Nord	380 kV
Oberbachern	Oberbrunn	1	380 kV
Gütersloh	Bechterdissen - Paderborn/Süd	4 (only in Gütersloh)	220 kV
Godenau	Hardegsen	1	220 kV
Göttingen	Hardegsen	1	220 kV

2. RWE TSO (DE)

Substation A	Substation B	Number of circuits	Voltage
Gronau	Polsum	1	380 kV
Oberzier	Niederstedem	1	380 kV
Gütersloh	Bechterdissen/Paderborn	1	220 kV
Gersteinwerk	Lippborg	1	220 kV
Gronau	Kusenhorst	1	220 kV
Garenfeld	Koepchenwerk	1	220 kV
Niederrhein	Utfort	1	220 kV
Niederhausen	Otterbach	1	220 kV
Gronau, Phaseshifter		1	380 kV / 380 kV
Niederstedem, Transformer 421		1	380 / 220 kV

3. VATTENFALL EUROPE TRANSMISSION (DE)

Substation A	Substation B	Number of circuits	Voltage
Hamburg-Ost	Krümmel	1	380 kV

4. EnBW TNG (DE)

NONE

5. APG (AT)

NONE

6. RTE (FR)

Substation A	Substation B	Number of circuits	Voltage
GAUDIERE	VERFEIL	1	400 kV
CRENEY	REVIGNY	1	400 kV
MAMBELIN	SIERENTZ	1	400 kV
REVIGNY	VIGY	1	400 kV
ANSEREUILLES	LA PIERETTE	1	225 kV
CROIX ROUSSE	CHARPENAY	1	225 kV
AOSTE	GRENAY	1	225 kV
AOSTE	MIONS	1	225 kV
MIONS	GRENAY	1	225 kV
DOMLOUP	PIQUAGE DE KERLAN	1	225 kV
PONT-JEROME	ROUGEMONTIER 1	1	225 kV

7. TERNA (IT)

Substation A	Substation B	Number of circuits	Voltage
PORTOTOLLE	FORLI'	1	380 kV
POGGIO A CAIANO	SUVERETO	1	380 kV
PATRIA	S. SOFIA	1	380 kV
LATINA	GARIGLIANO	1	380 kV

8. ELIA (BE)

Substation A	Substation B	Number of circuits	Voltage
Meerhout	Maasbracht	1	400 kV

9. TENNET (NL)

Substation A	Substation B	Number of circuits	Voltage
Maasbracht (NL)	Meerhout (B)	1	380 kV

10. REE (ES)

Substation A	Substation B	Number of circuits	Voltage
CASTRELO	CARTELLE	2 (only 1 circuit opened)	220 kV
C.T.COMPOSTILLA	MONTEARENAS	1	220 kV
MUDARRA	MONTEARENAS	1	220 kV
ALONSOTEGUI	GÜEÑES	1	220 kV

VALLADOLID	ZARATAN	2 (only 1 circuit opened)	220 kV
S. JUST	VILADECANS	1	220 kV
CASTELLET	LA GONAL	2 (only 1 circuit opened)	220 kV
RUBI	MEQUINENZA	1	400 kV
ALMARAZ	J.M. ORIOL	1	400 kV
CASA CAMPO	NORTE	1	220 kV
LITORAL	ASOMADA	1	400 kV
LUCERO	BOADILLA	1	220 kV
LA ELIANA	LA PLANA	2 (only 1 circuit opened)	400 kV
CASA CAMPO	MAZARREDO	1	220 kV
CATADAU	TORRENTE	1	220 kV
GUADAME	TAJO ENCANTADA	1	400 kV
SANTIPONCE	TORREARENILLAS	1	220 kV
DOS HERMANAS	QUINTOS	1	220 kV
CARTUJA	D. RODRIGO	1	220 kV

11. REN (PT)

Substation A	Substation B	Number of circuits	Voltage
Carrapatelo	Torrão	1	220 kV
Mogadouro	Valeira	1	220 kV
Palmela	Monte da Pedra	1	150 kV
Caniçada	Vila Fria	1	150 kV

12. PSE Operator (PL)

Substation A	Substation B	Number of circuits	Voltage
Połaniec	Kielce	1	400 kV
Tucznawa	Tarnów	1	400 kV
Tucznawa	Rzeszów	1	400 kV
Zamość	Dobrotwór	1	220 kV
Halemba	Byczyna	1	220 kV
Halemba	Kopanina	1	220 kV

13. WPS (WEST UKRAINE)

NONE

14. CEPS (CZ)

Substation A	Substation B	Number of circuits	Voltage
Opočinek	Čechy Střed	1	220 kV
Čechy Střed	Bezděčín	1	220 kV

Tisová	Vítkov	1 (Power Station Line)	220 kV
Babylon	Bezděčín	1	400 kV

15. MAVIR (HU)

Substation A	Substation B	Number of circuits	Voltage
Sándorfalva	Békéscsaba	1	400 kV
Szeged	Szolnok	1	220 kV
Felsőzsolca	Sajóivánka	1	400 kV

16. SEPS (SK)

Substation A	Substation B	Number of circuits	Voltage
Sucany	Horna Zdana	1	440 kV

18. ISO BiH (BA)

Substation A	Substation B	Number of circuits	Voltage
TPP Kakanj V	Zenica 2	1	220 kV

19. NEK

Substation A	Substation B	Number of circuits	Voltage
Kozloduy NPP	Sofia West s/s	1	400 kV
Kozloduy NPP	Mizia s/s	1	400 kV

20. JP EMS (RS)

Substation A	Substation B	Number of circuits	Voltage
Djerdap 1	Portile de Fier (RO)	1	400 kV

21. HTSO (GR)

Substation A	Substation B	Number of circuits	Voltage
ACHELOOS	DISTOMO	2 (Only one circuit out of operation)	400 kV

22. HEP (HR)

Substation A	Substation B	Number of circuits	Voltage
Melina	**Velebit**	**1**	**400 kV**

23. AD MEPSO (MK)

NONE

24. TRANSELECTRICA (RO)

Substation A	Substation B	Number of circuits	Voltage
Portile de Fier	Djerdap	1	400 kV
Constanta N	Cernavoda	1	400 kV
Lacu Sarat	Smardan	1	400 kV
Rosiori	Oradea	1	400 kV
Mintia	Alba Iulia	1	220 kV

Appendix 3 – Sequence of tripped lines

Nr	HOUR	COUNTRY	TSO	EVENTS	CAUSE OF EVENT
1	22:10:13	DE	RWE TSO - E.ON Netz	380 kV Wehrendorf-Landesbergen tripped by automatic protection systems	Overload – Distance Protection (2120 A)
2	22:10:15	DE	RWE TSO - E.ON Netz	220 kV Bielefeld/Ost-Spexard tripped by automatic protection systems	Overcurrent – Distance Protection
3	22:10:19	DE	E.ON Netz	380 kV Bechterdissen-Elsen tripped by automatic protection systems	Overcurrent – Distance Protection
4	22:10:22	DE	E.ON Netz	220 kV Paderborn/Süd-Bechterdissen/Gütersloh tripped by automatic protection systems	Overcurrent – Distance Protection
	22:10:22	DE	E.ON Netz	380 kV Dipperz-Großkrotzenburg 1 tripped by automatic protection systems	Overcurrent – Distance Protection
5	22:10:25	DE	E.ON Netz	380 kV Großkrotzenburg-Dipperz 2 tripped by automatic protection systems	Overcurrent – Distance Protection
6	22:10:27	DE	E.ON Netz	380 kV Redwitz-Raitersaich tripped by automatic protection systems	Overcurrent – Distance Protection
	22:10:27	DE	E.ON Netz	380 kV Oberhaid-Grafenrheinfeld tripped by automatic protection systems	Overcurrent – Distance Protection
	22:10:27	DE	E.ON Netz	380 kV Redwitz-Oberhaid tripped by automatic protection systems	Overcurrent – Distance Protection
	22:10:27	DE	E.ON Netz	380 kV Redwitz-Etzenricht tripped by automatic protection systems	Overcurrent – Distance Protection
	22:10:27	DE	E.ON Netz	220 kV Würgau-Redwitz tripped by automatic protection systems	Overcurrent – Distance Protection
	22:10:27	DE	E.ON Netz	380 kV Etzenricht-Schwandorf tripped by automatic protection systems	Overcurrent – Distance Protection
6	22:10:27	DE	E.ON Netz	220 kV Mechlenreuth-Schwandorf tripped by automatic protection systems	Overcurrent – Distance Protection
	22:10:27	DE	E.ON Netz	380 kV Schwandorf-Pleinting tripped by automatic protection systems	Overcurrent – Distance Protection

7	22:10:28	AT	APG	380-kV-line Etzersdorf-Ernsthofen (434A) tripped by distance protection	Loss of Synchronism – Distance Protection
	22:10:28	AT	APG	380-kV-line Dürnrohr-Ernsthofen (433) tripped by distance protection	Loss of Synchronism – Distance Protection
	22:10:28	AT	APG	220-kV-line Ternitz-Hessenberg (225A) tripped by distance protection	Loss of Synchronism – Distance Protection
	22:10:28	AT	APG	220-kV-line Ternitz-Hessenberg (226A) tripped by distance protection	Loss of Synchronism – Distance Protection
8	22:10:29.025	HR	HEP	400kV Zerjavinec-Ernestinovo tripped	Distance Protection
	22:10:29.766	HU-HR	MAVIR-HEP	400 kV Heviz-Zerjanivec tripped (2 circuits)	Distance Protection
	22:10:29.303	HR	HEP	110kV Rab-Novalja tripped	Distance Protection
	22:10:29.417	HR	HEP	220kV Konjsko-Brinje tripped	Distance Protection
	22:10:29.911	HR	HEP	110kV Otocac-Licki Osik tripped	Distance Protection
	22:10:29	UA-W-RO	WPS-TEL	400 kV Mukacevo (Western UA) - Rosiori (RO) tripped in Mukacevo	
	22:10:29	HU	MAVIR	400 kV Sándorfalva-Paks tripped A consumers' island of 120 MW around Sandorfalva connected to the 3rd area was split from the Hungarian system	Distance Protection
	22:10:29	HU-RS	MAVIR-JP EMS	400 kV Sándorfalva-Subotica tripped and successfully reclosed, continuing to supply the consumers' island of 120 MW around Sándorfalva	No tripping – Distance Protection – Successful reclosing
	22:10:29.390	RO	TEL	400 kV Arad-Mintia tripped in Arad	Out of step protection
	22:10:29.460	HU-RO	MAVIR-TEL	400 kV Sándorfalva-Arad tripped in Arad	Distance threepole protection
9	22:10:31	AT	APG	220 kV Bisamberg-Ybbsfeld tripped by distance protection. At this moment the Austrian grid split into two parts: East: Vienna, major part of lower Austria and Burgenland (overfrequency) West: small part of lower Austria and rest of APG control area (underfrequency)	Loss of Synchronism – Distance Protection

10	22:10:32	ES-MOROCCO	REE	400 kV PTO.CRUZ – MELLOUSSA tripped by low frequency	Low frequency
11	22:11:29.372	HR-BA	HEP – ISO BiH	220kV Meduric-Prijedor tripped	
	22.11.29.574	HR	HEP	110 kV Daruvar-Virovitica	Distance Protection
	22.11.33.182	HR	HEP	Pozega-Nova Gradiska	Distance Protection

Appendix 4 – List of TSOs in each area

AREAS	TSOs included
West part	APG West (Austria) CEGEDEL Net (Luxemburg) E.ON West (Germany) ELES (Slovenia) Elia (Belgium) EnBW (Germany) HEP *West* (Croatia) REE (Spain) REN (Portugal) RTE (France) RWE TSO (Germany), Swiss TSOs (Switzerland) TenneT (The Netherlands) TERNA (Italy) TIWAG Netz (Austria) VKW Netz (Austria)
North East Part	APG East (Austria) CEPS (Czech Republic) E.ON East (Germany, including Jutland) MAVIR (Hungary) PSE – Operator (Poland) SEPS (Slovakia) VATTENFALL EUROPE TRANSMISSION (Germany) WPS (Ukraine)
South East Part	AD MEPSO (FYROM) EPCG (Montenegro) HEP *East* (Croatia) HTSO (Greece) ISO BiH (Bosnia and Herzegovina) JP EMS (Serbia) KESH (Albania) MAVIR South (Hungary) NEK (Bulgaria) TRANSELECTRICA (Romania)

Appendix 5 – Summary of load shedding actions in West area (as part of the defense plans)

The rates of load shedding refer to the installed relays and are theoretical values calculated by TSOs on the basis of the estimated country load.

Country	TSO Name	Defense Plan Description
Portugal	REN	49.5 Hz : Tripping of pumped- storage units 49.0 Hz : 15.6% of load shedding – no delay 18.1% of load shedding – 150 ms delay 0.7% of load shedding – 500 ms delay 48.8 Hz : 3.9% of load shedding – 150 ms delay 48.6 Hz : 1% of load shedding – 150 ms delay 48.5 Hz : 9.9% of load shedding – no delay 9.1% of load shedding – 150 ms delay 9.6% of load shedding – 500 ms delay 48.4 Hz : 2.3% of load shedding – 150 ms delay 47.9 Hz : 0.6% of load shedding – no delay
Spain	REE	49.5 Hz : Tripping of 50 % of pumped-storage units 49.3 Hz : Tripping of 50 % of pumped-storage units 49.0 Hz : 15% of load shedding – no delay 48.7 Hz : 15% of load shedding – no delay 48.4 Hz : 10% of load shedding – no delay 48.0 Hz : 10% of load shedding – no delay
France	RTE	49.2 – 49.6 Hz : Tripping of pumped-storage units 49.0 Hz : 20% of load shedding – no delay 48.5 Hz : 20% of load shedding – no delay 48.0 Hz : 20% of load shedding – no delay 47.5 Hz : 20% of load shedding – no delay
Belgium	ELIA	49.8 Hz : Start TurboJets, 5% voltage decrease 49.7 Hz + 49.4 Hz + 49.1 Hz + 49.0 Hz : 8% of load shedding – no delay
Netherlands	TENNET	49.0 Hz : 15% of load shedding – no delay 48.7 Hz : 15% of load shedding – no delay 48.4 Hz : 20% of load shedding – no delay
Germany	RWE	49.0 Hz : 10 to 15% of load shedding – no delay 48.7 Hz : 10 to 15% of load shedding – no delay 48.4 Hz : 15 to 20% of load shedding – no delay
	EON	49.0 Hz : 10 to 15% of load shedding – no delay 48.7 Hz : 10 to 15% of load shedding – no delay 48.4 Hz : 10 to 20% of load shedding – no delay
	ENBW	49.5 Hz : Tripping of pumped-storage units 49.0 Hz : 10 to 15% of load shedding – no delay 48.7 Hz : 10 to 15% of load shedding – no delay 48.4 Hz : 15 to 20% of load shedding – no delay
Switzerland	Swiss TSOs	49.5 Hz : Tripping of pumped-storage units no load shedding, according to the addenda to the UCTE policy 5.

Austria	APG	49.6 Hz : Tripping of pumped-storage units 49.0 Hz : 20% of load shedding – no delay 48.6 Hz : 20% of load shedding – no delay 48.2 Hz : 20% of load shedding – no delay
Slovenia	ELES	49.2 Hz : 10% of load shedding – no delay 48.8 Hz : 15% of load shedding – no delay 48.4 Hz : 15% of load shedding – no delay 48.0 Hz : 15% of load shedding – no delay
Italy	TERNA	From 49.6 to 48.9 Hz: tripping of pumping storage units 49.0Hz: 3% of load shedding – no delay 48.8Hz: 5% of load shedding – no delay 48.7Hz: 5% of load shedding – no delay 48.6Hz: 4% of load shedding – no delay 48.5Hz: 4% of load shedding – no delay 48.4Hz: 4% of load shedding – no delay 48.3Hz: 4% of load shedding – no delay 48.2Hz: 3% of load shedding – no delay 48.1Hz: 4% of load shedding – no delay 48.0Hz: 3% of load shedding – no delay 47.9Hz: 2% of load shedding – no delay 47.8Hz: 2% of load shedding – no delay 47.7Hz: 2% of load shedding – no delay
Croatia	HEP	49.2 Hz : 10% of load shedding – 50 ms delay 48.8 Hz : 15% of load shedding – 50 ms delay 48.4 Hz : 15% of load shedding – 50 ms delay 48.0 Hz : 15% of load shedding – 50 ms delay

Appendix 6 – Dynamic stability analyses

Power System Configuration

According to the load flow situation reconstructed from the snapshots provided by the TSOs, for the evening hours of November 4 the UCTE power system was characterised by a highly loaded power transfer corridor situation from the north-east to the south-west of Europe. The voltage phase angle difference between the middle of Poland to the middle of Spain had a value of 65 degrees.

The opening of the 380 kV double circuit transmission line between Diele and Conneforde resulted in a voltage phase angle step between these two substations from 5 degrees to 34 degrees.

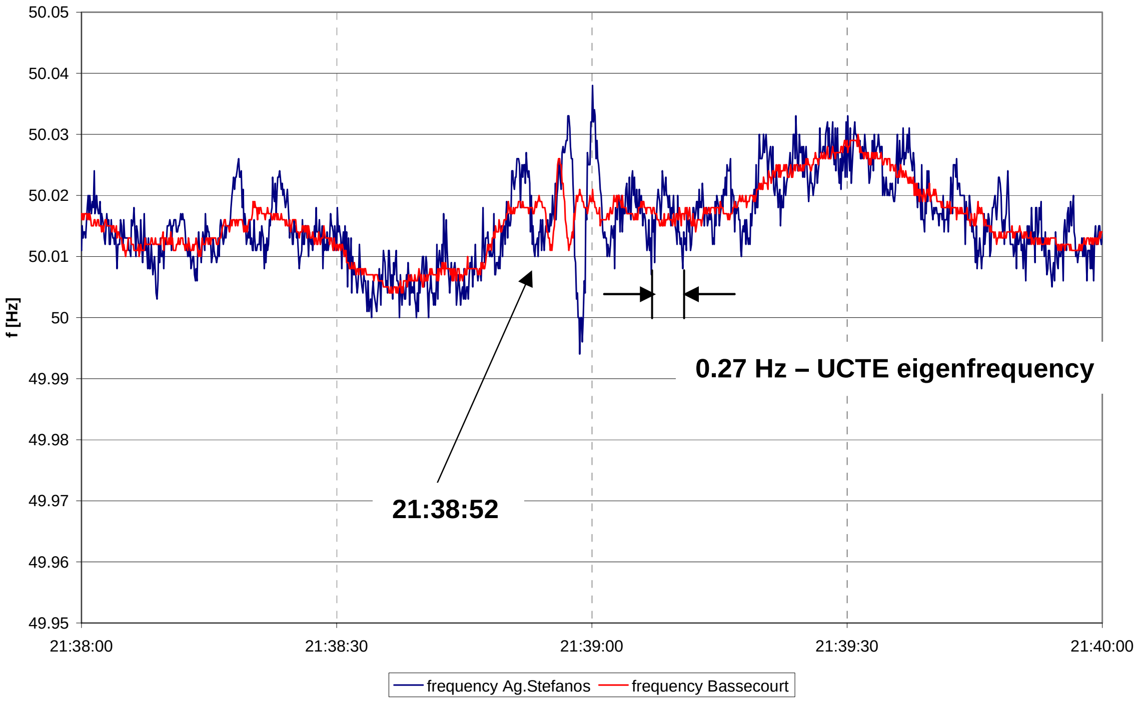
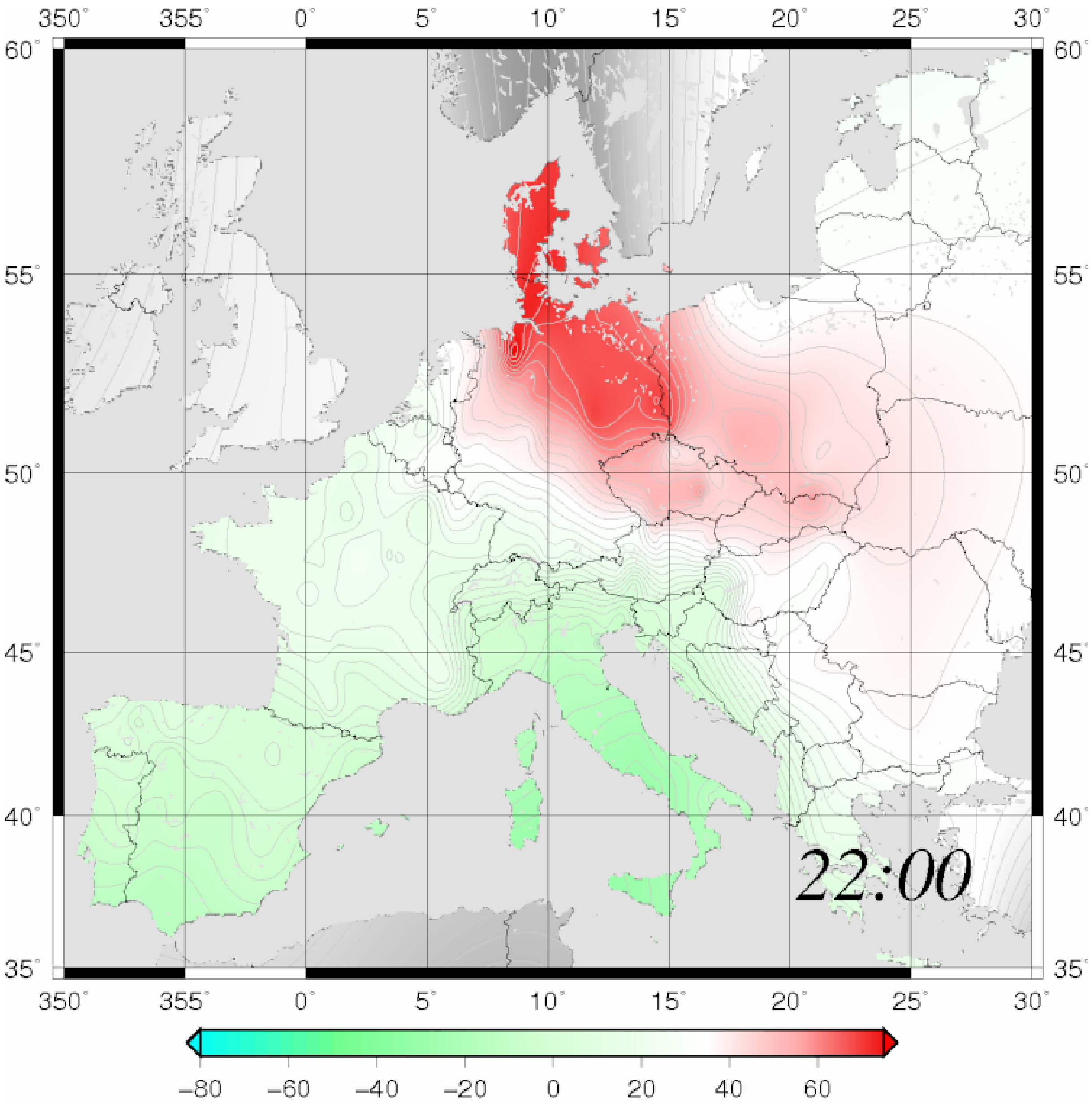


Fig. D1: Frequency of Switzerland and Greece at 21:39

The fact that the highly loaded corridor was seriously weakened by this action shows the increase of the calculated voltage phase angle difference between the centre of Poland and Spain respectively, which increases from 65 to 74 degrees after opening this line.

Notwithstanding the system damping of inter-area oscillations was still satisfactory, see **Fig. D1** showing the frequencies of Bassecourt (Switzerland) and Ag. Stefanos (Greece) as recorded by the WAMS.

Fig. D1a illustrates the voltage phase angle within the whole UCTE power system in a comprehensive way. The red area in the northern part of the system shows a high concentration of power generation in that area. Secondly the very dense lines in the northern part of Germany show the high voltage phase angle gradient and consequently the high power flow in that region. This figure is a graphical representation of load flow calculation results based on the UCTE snapshot 22:00 including the opening of the Conneforde-Diele double circuit line. The individual colours represent the voltage phase angle difference between the individual substations of the system.



Phase Angle (º)

Fig. D1a: Voltage phase angle differences in the UCTE system at 22:00 /ELES/

Description of System Separation

In order to characterise the exact separation sequence, several WAMS measurements acquired from geographically far located substations have been used. **Fig. D 2** shows the frequency of substations located near the first separation lines. The individual peaks describe the cascading transmission line disconnections which took place.

Detailed disturbance recordings based on digital protection equipment documents show the following sequence of events:

- **22:10:14-22:10:28** cascading trips of transmission lines by overload (distance protection 2-5 s back-up time) starting from the northern part of Germany up to the Main river in the middle of Germany. Those lines were tripped by the distance protection maximum operating time overcurrent function.
- **22:10:28** loss of synchronisms

- **22:10:28-22:10:30** system separation into three areas, lines tripping by distance protection (high-speed first zone tripping) due to rapid voltage drop on both sides of the tripped lines. The separation continued in north-south direction. The distance protection operates as high speed tripping due to protection against asynchronous operation along the electrically middle of a line by detecting a corresponding fictive fault.

Fig. D3 illustrates in exactly the same scaling the frequency of three substations located in the three areas to be separated. In these graphs the individual transmission line openings could be observed by means of abrupt gradient changes.

One of the main questions concerning system stability is, where exactly is the "point of no return", that means the precise time and system configuration where the system stability of the whole interconnected system was lost. It is a fact that the separation of the interconnected system in three areas has saved the entire grid from severe subsequent events. The recorded voltage phase angle difference between one substation in Switzerland and different substations of the three areas gives therefore a quite good indication of how the "big masses" of the three areas start to separate from each other. **Fig. D4** describes in the same time scale as for Fig D2, D3 the deterioration of the system stability in a comprehensive way.

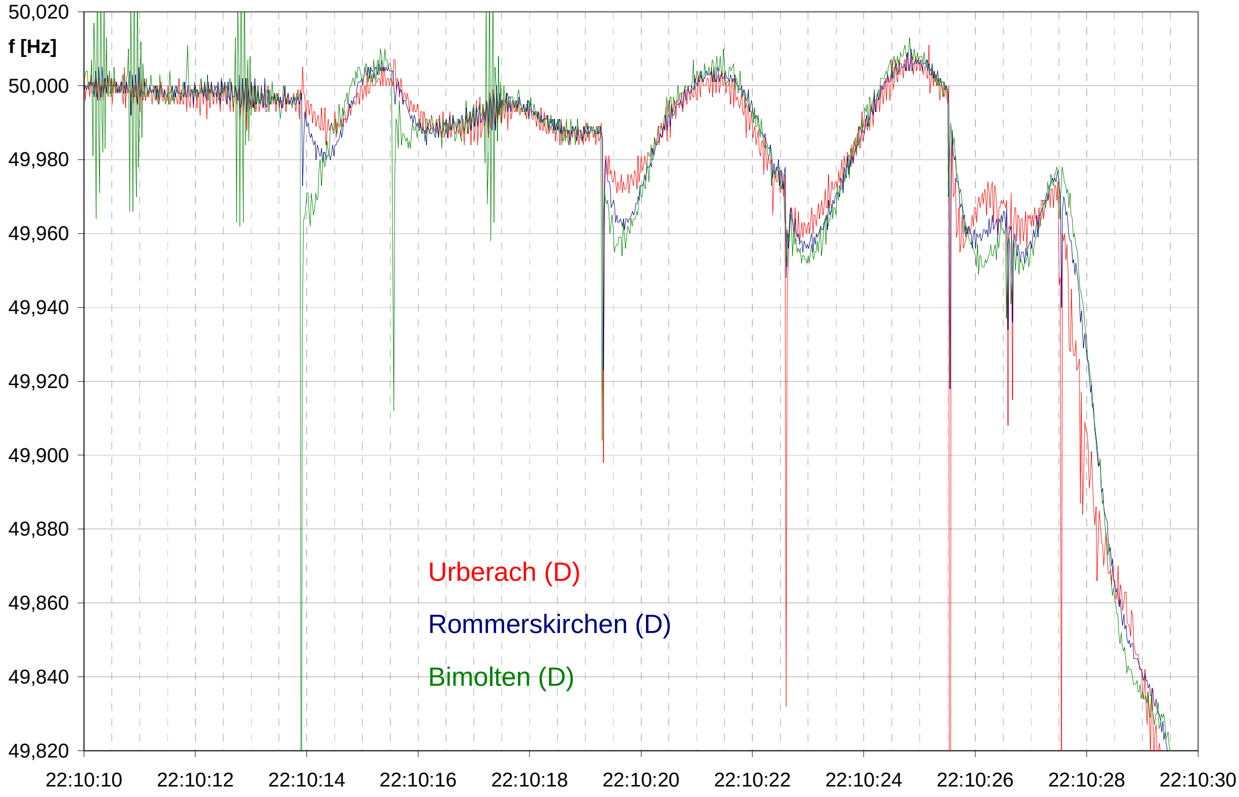


Fig. D2: Frequency of German substations during the system separation

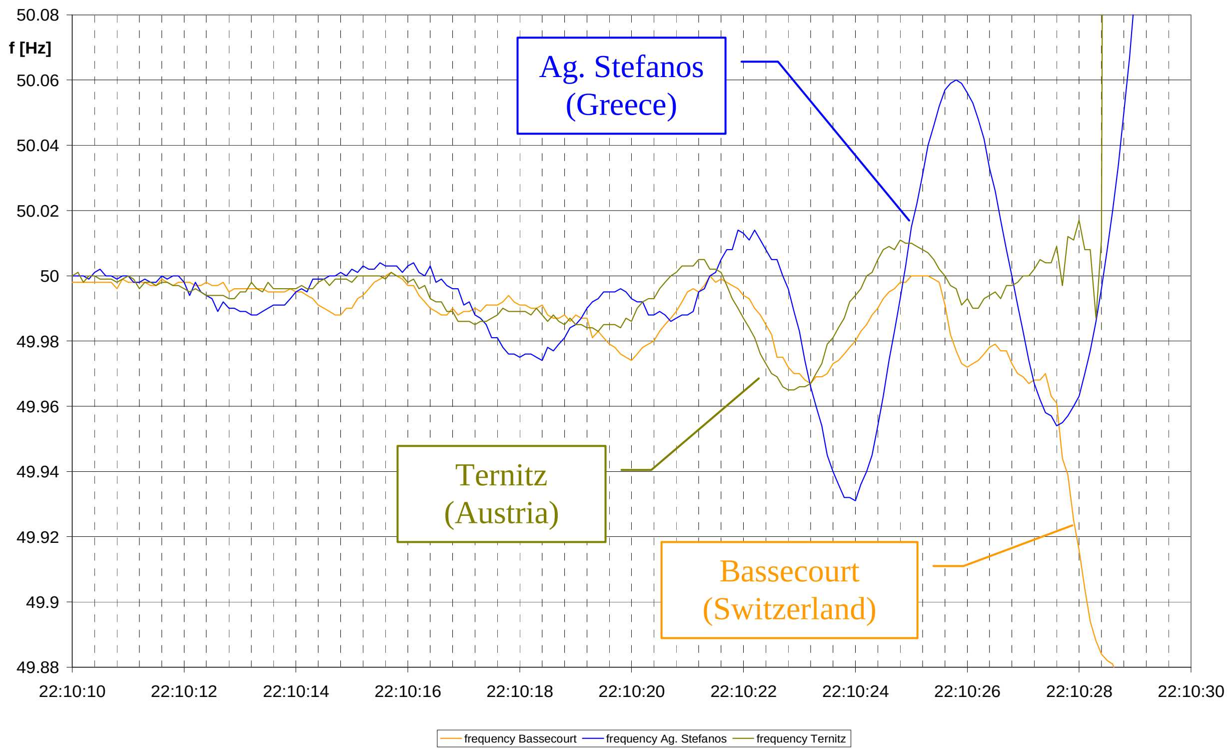


Fig. D3: **Frequency of the three areas (Bassecourt-CH, Ag. Stefanos-GR, Ternitz-A during the system separation**

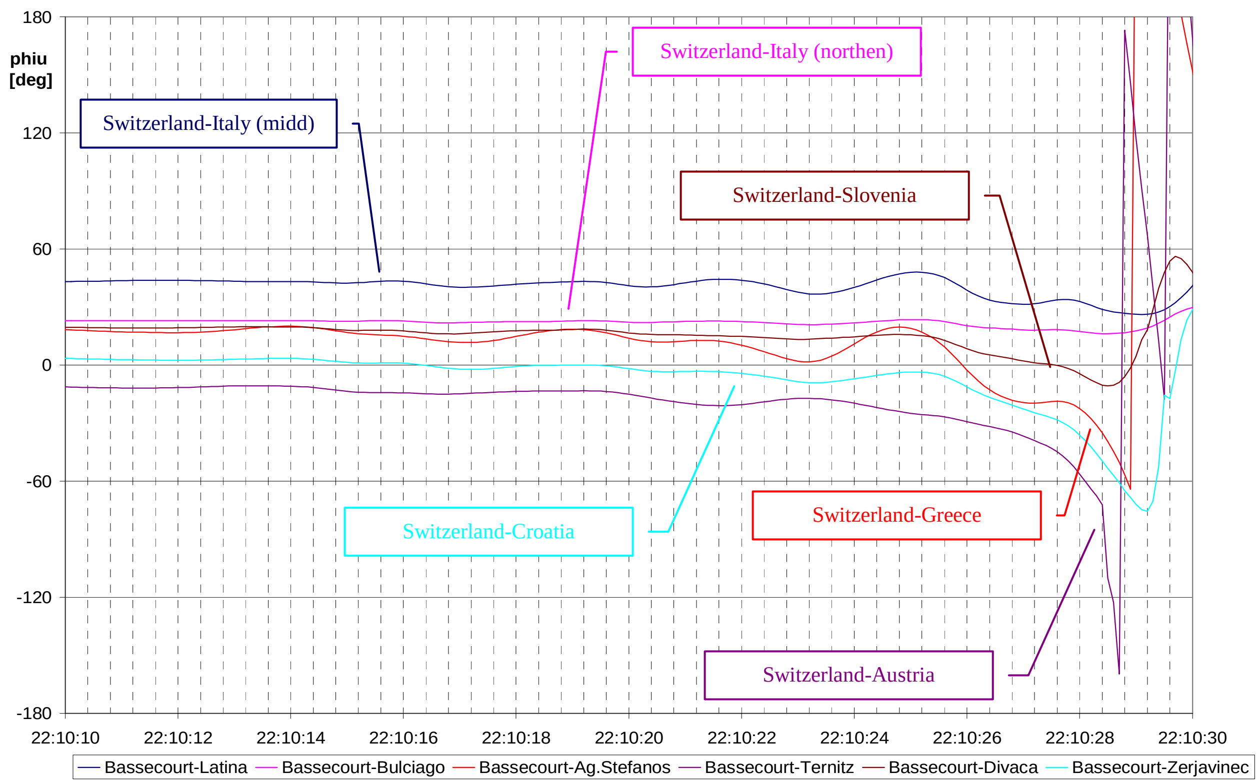


Fig. D4: Voltage phase angle differences of the three areas during the system separation (Bassecourt – CH, Latina - midd I, Bulciago-northern I, Ternitz – A, Divaca – SLO, Zerjavinec HR)

Due to the fact that only east-west voltage phase angle difference recordings were available, the whole picture could unfortunately not be exactly reflected in this figure. Starting from 22:10:11 the voltage phase angle differences started to increase permanently. It could be observed how the synchronising torque between the areas started to decrease more and more with each additional line trip.

The increasing voltage phase angle difference from Switzerland fortunately through northern and middle of Italy or Croatia and Slovenia illustrates how an additional oscillation mode has started, but due to the other earlier disconnections the further splitting was avoided.

Recordings of voltage measurements illustrate the way how the protection equipment has separated the system.

Fig. D5 shows the voltage of three substations in Germany located very near the first northern separation line.

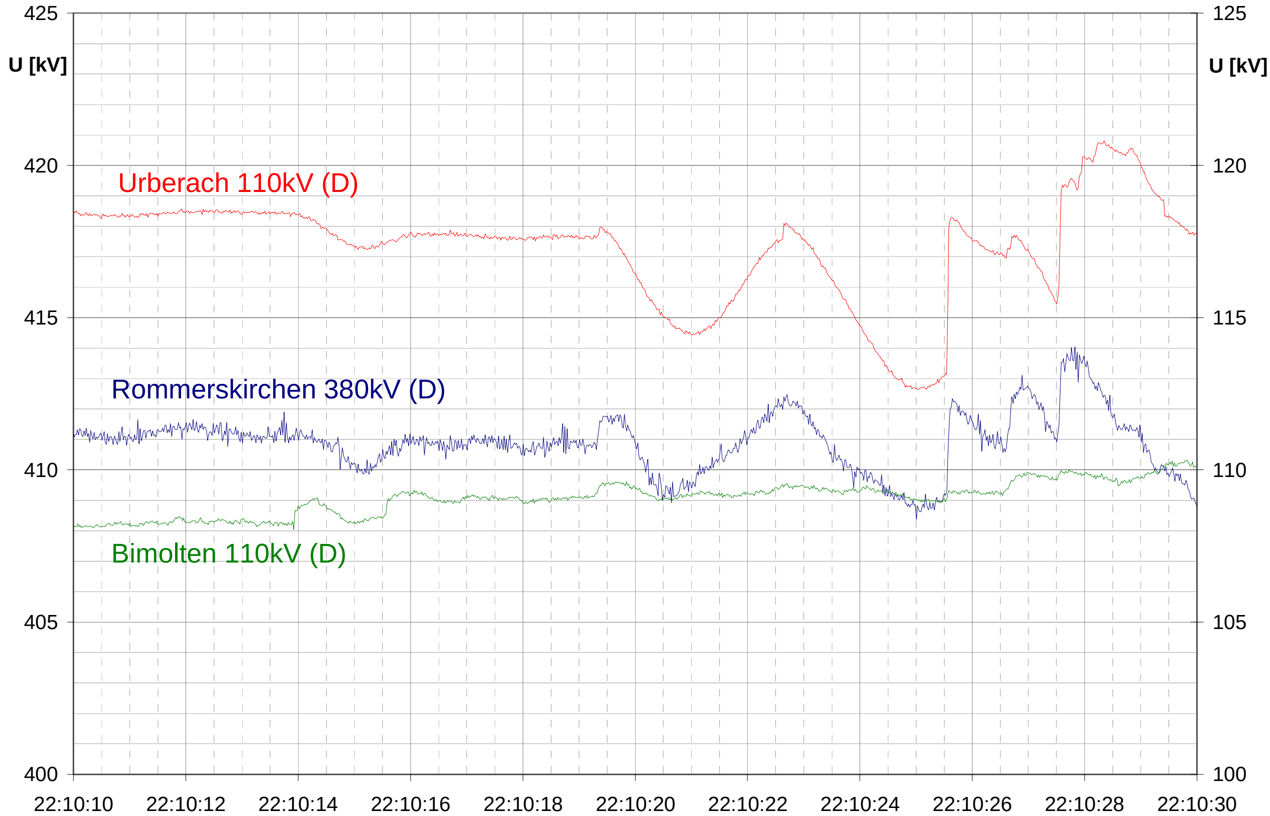


Fig. D5 Voltages Urberach, Rommerskirchen, Bimolten

In contrast to the quite stable voltage on the east-west separation line, the voltages on the north-south separation showed a significant drop before the last lines disconnected, see **Fig. D6**.

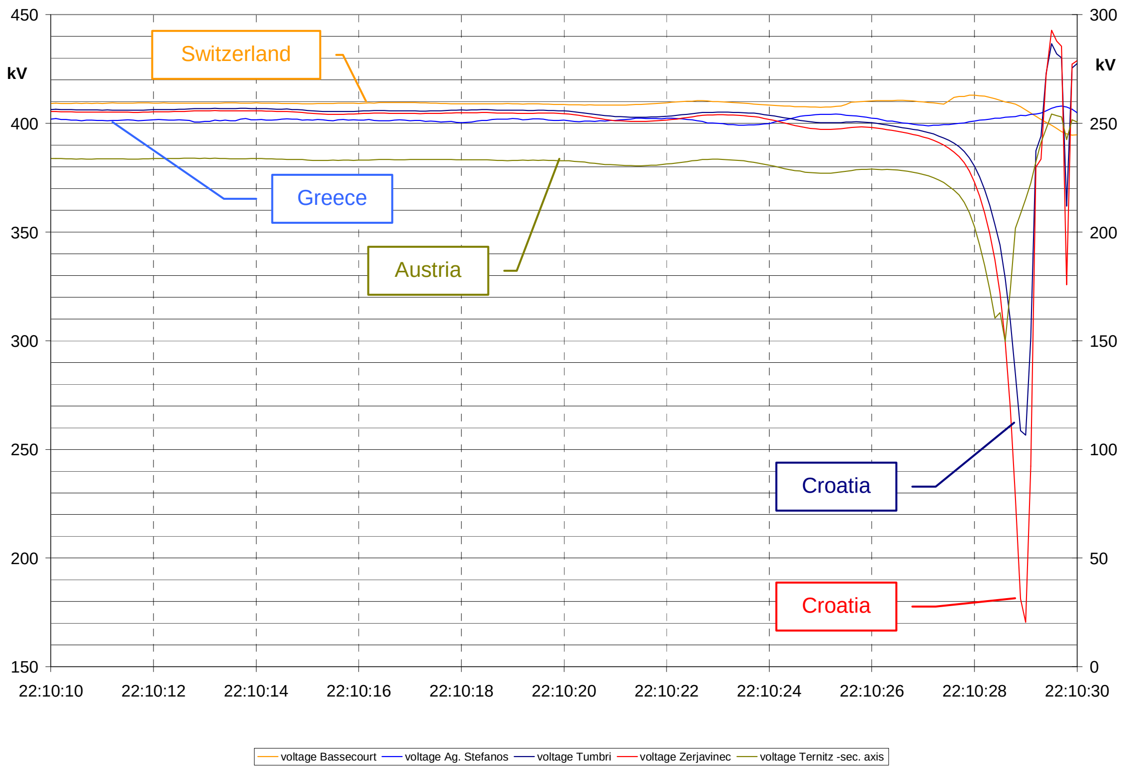
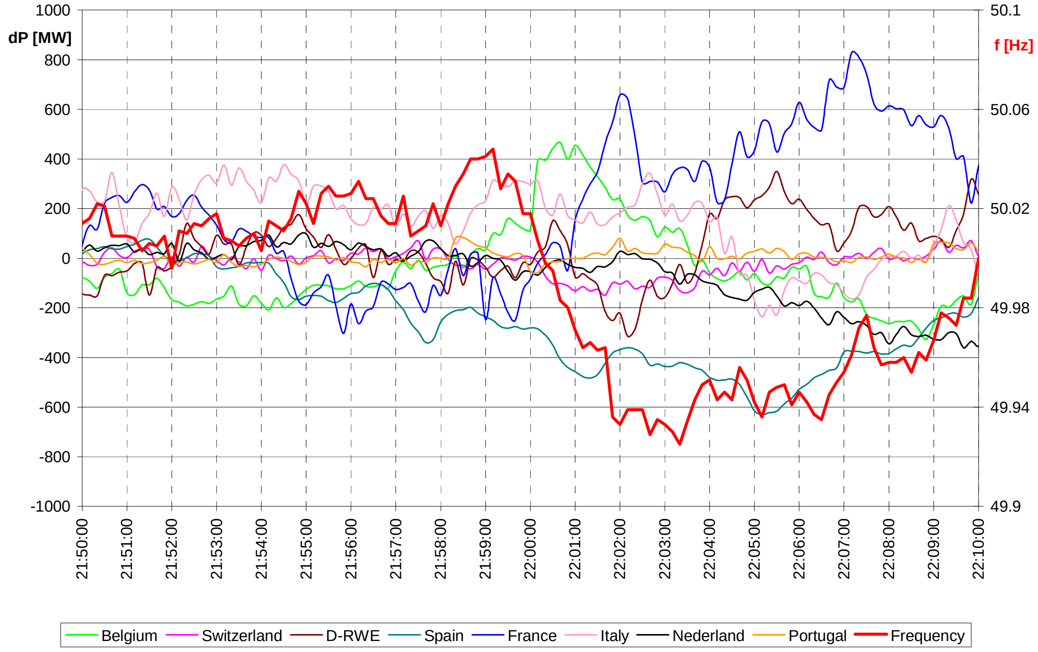
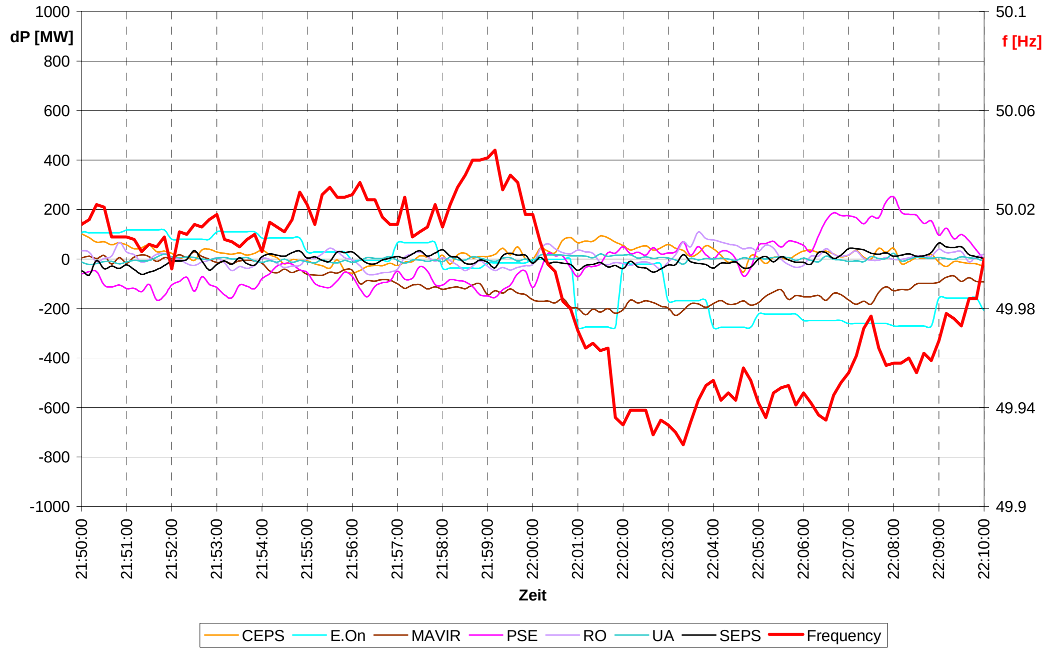


Fig. D6 **Voltages far and near the North-South separation line during the system separation,(Bassecourt – CH, Ag. Stefanos – GR, Tumbri – HR, Zerjavinec – HR Ternitz - A**

Appendix 7 – Power exchange deviations in West and North East area



Power exchange deviations in West area



Power exchange deviations in North East area

Appendix 8 – List of abbreviations

A	*Amperes*
CENTREL	*Regional group of Transmission System Operator s from Czech Republic, Hungary, Poland and Slovakia*
CHP	*Combined heat and power (plant)*
DC	*Direct current*
DSO	*Distribution System Operator*
EHV	*Extra high voltage (220 kV; 400 kV)*
GPS	*Global Positioning System*
HVDC	*High voltage direct current*
Hz	*Hertz*
IC	*Investigation Committee*
kV	*Kilovolt*
LFC	*Load - Frequency Control*
mHz	*Milihertz*
MW	*Megawatt*
NG	*National Grid (TSO of England)*
NORDEL	*Organization of Transmission System Operators in the Nordic countries (Denmark, Finland, Iceland, Norway and Sweden)*
OH	*Operation Handbook*
PSD	*Parallel switching devices*
TSO	*Transmission System Operator (see Appendix 1 for the names of companies)*
UCTE	*Union for Coordination of Transmission of Electricity*
WAMS	*Wide Area Measurement System*

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