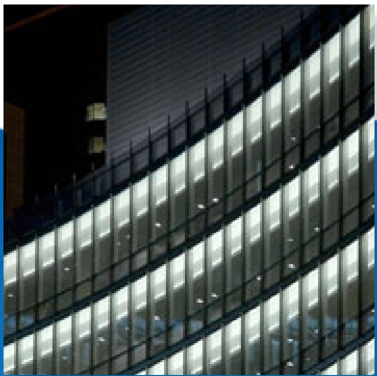
UCTE



Interim Report
System Disturbance on 4 November 2006

union for the co-ordination of transmission of electricity

TABLE OF CONTENTS

Disclaimer

The following Interim Report, based on the present state of the investigation and information available concerning the power system disturbances of 4 November 2006, is prepared by the Investigation Committee and is issued by UCTE according to the agreed-upon Terms of Reference of the said Committee.

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 Interim Report is a result of the first phase of the investigation process and presents facts and preliminary findings of the events and the root causes only. It is not in the intention of UCTE to draw any conclusions or do judgments which may be relevant concerning the 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 do not intend to be applied in general to the involved TSOs.

EXECUTIVE SUMMARY

Executive Summary

As far as the number of involved TSOs and the amplitude of the registered frequency deviation are concerned, the events on 4 November 2006 constitute the most severe disturbance in the history of UCTE.

After the tripping of many high voltage lines that started in the North Germany, the UCTE grid was divided into three islands (West, North East and South East). This resulted in significant power imbalances in each island. 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.

In both under-frequency areas (West and South East), sufficient generation reserves and load shedding allowed restoring the normal frequency in a relatively short time. In the over-frequency area (North East), the lack of control over generation units (quick reduction of schedules and automatic reconnection of wind generation) contributed to the deterioration of system conditions in this area (long lasting over-frequency with severe transmission lines overloading).

Generally, the uncoordinated operation of generation units (mainly wind and combined-heat-and-power) during the disturbance complicated the process of re-establishing normal system conditions.

The resynchronization of the three islands was performed after several unsuccessful attempts. The full resynchronization was completed within 38 minutes after the system split. Although the individual TSOs did not have a complete and clear picture at any moment of the unexpected and exceptional events, a normal situation in all European countries was re-established in less than 2 hours.

However, the decentralized spread of responsibilities among TSOs demonstrated its efficiency: appropriate measures were taken against further deterioration of the situation and thus avoided a blackout on the entire European continent.

The investigations identified so far two root causes as well as five critical factors.

Essential root causes

Non fulfillment of the N-1 Criterion
The evaluation of N-1 secure conditions was not based on results of a N-1 numerical analysis. It was also not based on the analysis of possible changes in the system conditions for the following hours. The impact in terms of N-1 criterion fulfillment of the triggering sequence of events in the evening of 4 November (the outage of the Conneforde-Diele line and the topology change in Landesbergen substation) were not checked by E.ON Netz via a numerical simulation. Only an empirical evaluation of the situation was performed.
The results of the preliminary security calculations performed in the course of this investigation confirm that the N-1 criterion was not fulfilled in the E.ON Netz grid and on some of its tie-lines to the neighboring TSOs.

Inappropriate regional inter-TSO co-ordination during this event
The initial planning for switching-off the 380 kV Diele-Conneforde line foreseen on 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 of this switching maneuver was communicated by EON Netz to the other directly involved TSOs very late and was not prepared and checked in order to ensure the secure operation of the system in this area. 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.

Further critical factors

1. Generators related issues

During the disturbance, a significant amount of generation units tripped due to the frequency drop in the West area of UCTE system. This certainly 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 East island, the uncontrolled reconnected of generation units induced very severe conditions and additional time to recover a secure system operation.

2. Limited range of action available to dispatchers for handling grid congestions

German TSOs have to take different kind measures as stated in the German Energy Law and transposed to internal procedures: grid related measures, market related measures and other adjustments for the management of emergency situations. The adequacy and effectiveness of such measures will need to be further investigated.

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

In some control areas, re-energizing customers started without proper knowledge of the situation of the overall UCTE system. Some Distribution System Operators (DSOs) started to reconnect customers without co-ordination with their TSOs. This worsened the conditions for TSOs action in order to restore normal system conditions.

4. Inappropriate co-ordination of resynchronization procedures during this event

Actions taken by TSOs during the resynchronization process were not coordinated in all cases There have been several unsuccessful attempts to put lines back into operation and to resynchronize the 3 different system areas with only a partial view of the status of the whole grid.

5. Training of dispatchers to be improved

Two aspects have to be examined: procedures and tools and inter-TSO co-ordination and consultation under normal and emergency conditions.

The Investigation Committee will provide in the Final Investigation Report a more comprehensive analysis of the sequence of events and recommendations for the improvement of procedures at UCTE and individual TSOs level as well as of specific security standards at UCTE level.

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 3 islands.

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 is 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 include:

- 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] is chaired by the Chairman of the UCTE Steering Committee, Gerard A. Maas (TenneT, The Netherlands). IC members are nearly all UCTE member companies (see Appendix 1).

The working structure of the Committee consists 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** is chaired by Mrs. Clotilde Levillain (RTE, France) and members of this group include TSOs from Germany, The Netherlands, Belgium, France, Spain, Portugal, Italy, Switzerland, Slovenia, Croatia and Austria.

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

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

This **Interim Report** is the result of the first phase of the investigation process and presents facts and preliminary findings on the root causes of the disturbance.

The **Final Report** is expected in January 2007 and will include final conclusions and recommendations.

UCTE AS A STANDARD SETTING ORGANIZATION AND TSO COORDINATION PLATFORM

2

2. 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 in continental Europe. It aims at providing a reliable market base 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 2500 TWh. The UCTE system covers 23 European countries with some 220.000 km of 400 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 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 quality of supply were continuously improved.

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 re-setting 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.

One actual example of changing generation patterns is due to the rapid development of wind generation characterized by a short term predictability: within a few hours, the production of wind farms can change from minimum to maximum and conversely. This can only be mastered with an adequate transmission infrastructure and a more and more complex management of interconnected networks. In reality, many UCTE TSOs face increasing difficulties to build new network infrastructures (lines, substations, etc.) This puts more than ever before pressure on all TSOs to be able to rely on each other via closer co-ordination mechanisms as those stated among UCTE standards.

This is why UCTE – supported by the European Commission and all relevant stakeholders - developed from 2002 on 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.

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 a 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

3 SYSTEM CONDITIONS BEFORE THE DISTURBANCE

3. 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:

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

On the borders between the separated areas:

- 380 kV line Sandorfalva – Békéscaba (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 2 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 operating situation..

Power balance between the three “virtual” areas

The data about generation is partial and provisional as TSOs do not have the same level of information on the generation, in particular in the distribution grid.

Generation in the whole UCTE system at 22:09 is estimated 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

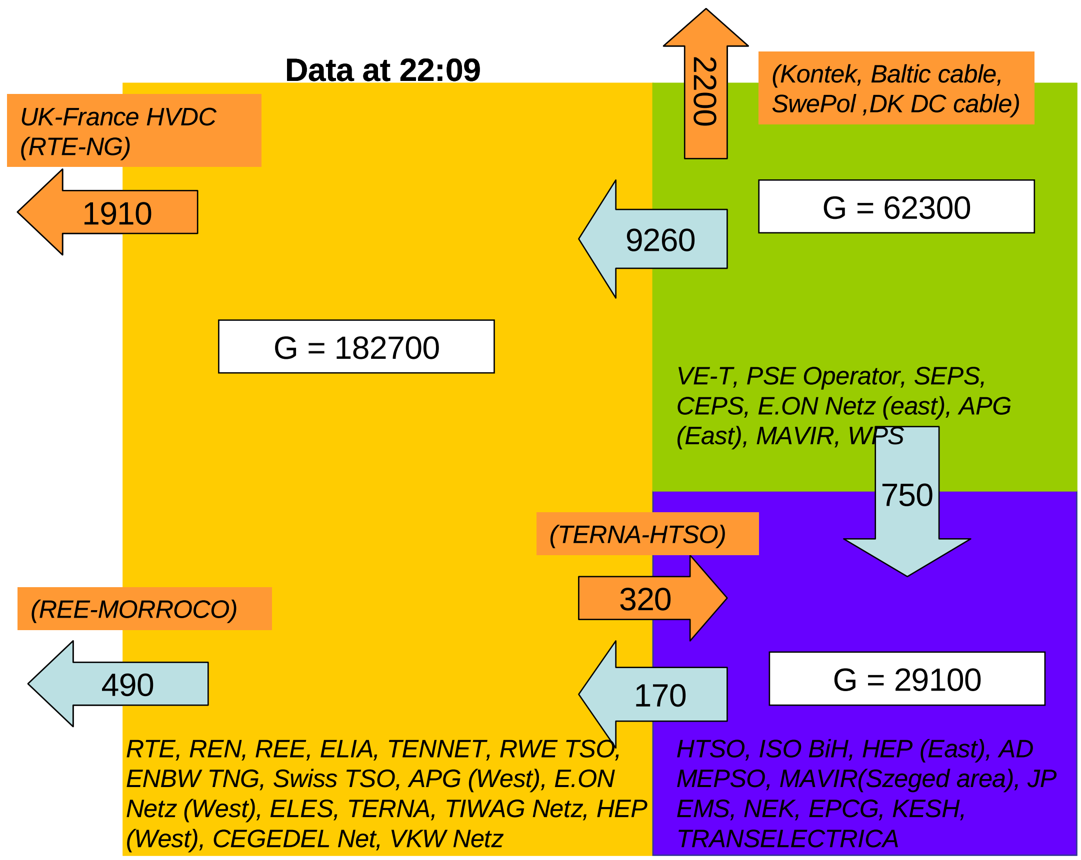


Figure 1: Generation and power flows between the 3 areas just before splitting 4 November 22:09

<u>Frequency</u>

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

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

The power flows in a meshed grid are the result from 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 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 East Europe (starting point of the disturbance) is the high flow from Germany to The Netherlands and Poland due to the high wind generation.

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

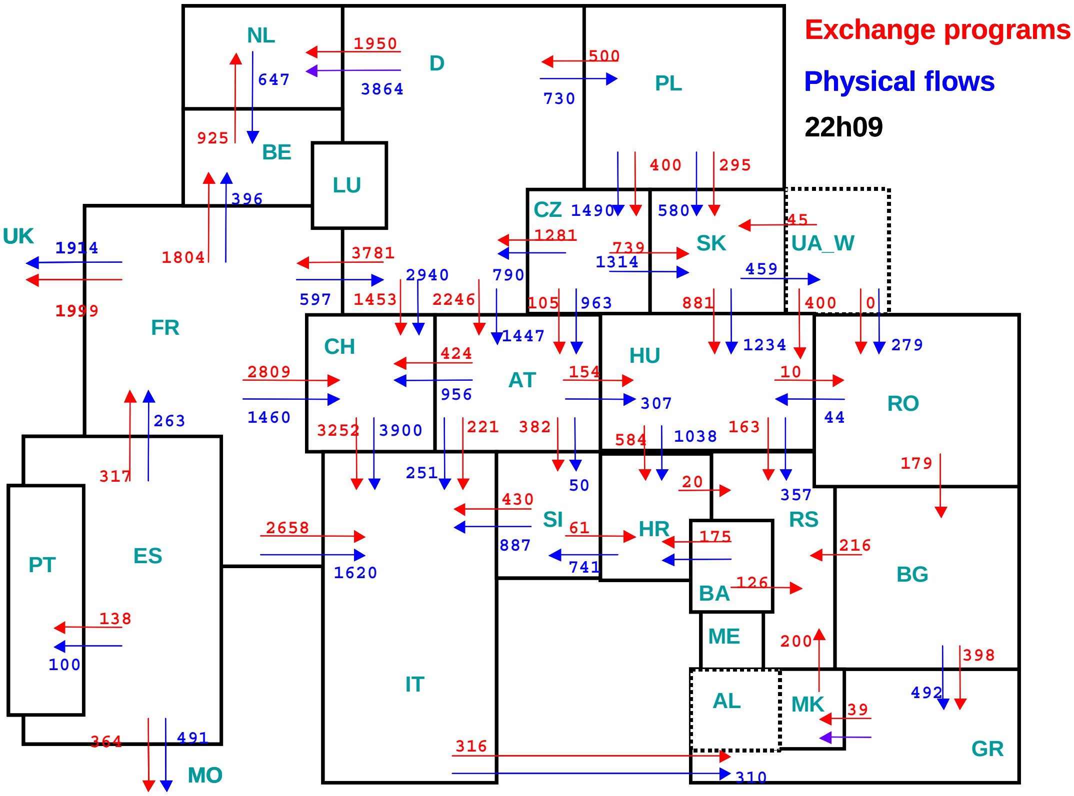


Figure 2: Exchange programs (red) and physical flows (blue) on 4 November at 22:09

Planning for the Diele-Conneforde 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 Diele-Conneforde 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 27th 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 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 to The Netherlands amounted to 3 091 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 neigbouring TSO.

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, although E.ON Netz already provisionally agreed to advance the outage of the line, 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 transformer 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 the TenneT and RWE TSO grid would be secure, TenneT and RWE TSO gave its agreement to the outage.

[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.

FACTUAL SEQUENCE OF EVENTS 4

4. Factual sequence of events

This chapter presents the events starting at 21:29 on 4 November.

4.1. Evolution of system conditions before 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 the N-1 criterion would be met in the system.
At 21:30, just before the opening of the Diele Conneforde line, RWE TSO made a load flow calculation and an N-1 analysis with the outage of the Diele Conneforde 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 remedial actions which can be implemented within the available time to maintain secure operation.

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 Diele-Conneforde.

At 21:38, E.ON Netz switched off first circuit of the 380 kV line Diele-Conneforde, so called Diele-Conneforde red.
At 21:39 E.ON Netz switched off second circuit of the 380 kV line Diele-Conneforde, so called Diele-Conneforde 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 RWE TSO network.

In the course of investigations, the Committee was informed that the protection settings on both sides of the Landesergen-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. Exact possible actions to reduce the flow on the Landesbergen-Wehrendorf line evaluated by those TSOs have to be further investigated.

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 (see chapter 7) 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 critical 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 1200 MW close to the secure limit for RWE TSO. At around 21:50, a small decrease (about 100 MW) can be observed, however at around 22:02 the loading gradually increased. The line tripped immediately after coupling the busbars in Landesbergen. This tripping led to cascading line trippings all over the UCTE area. All lines tripped due to overloading that triggered distance protection. These line trippings are listed in Appendix 3.

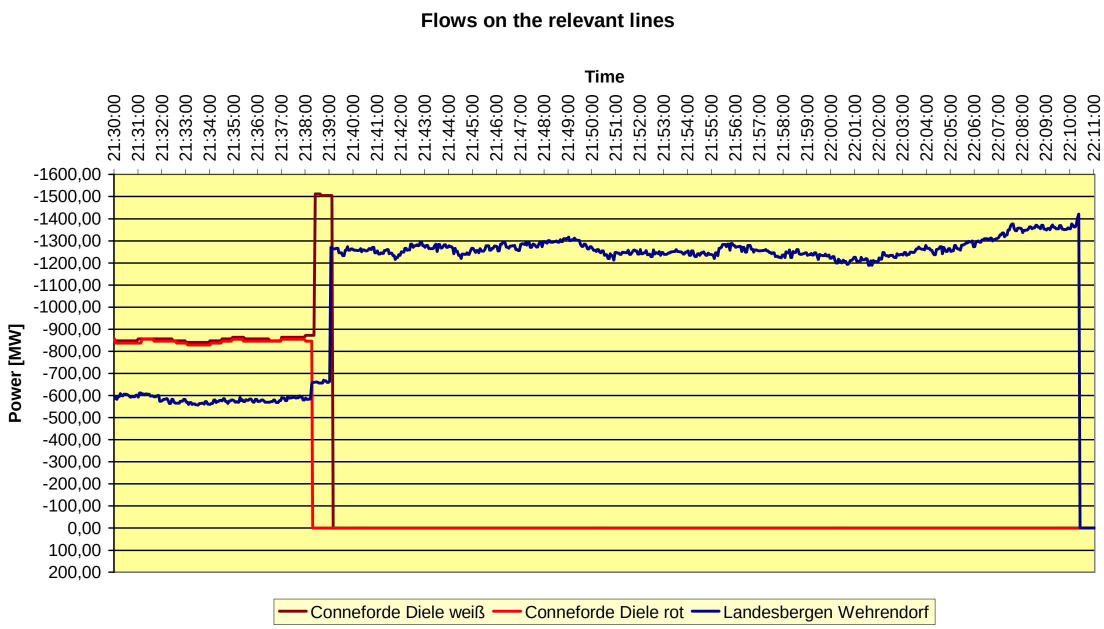


Figure 3: Power flow on the Landesbergen-Wehrendorf line before and after Conneforde-Diele switching off

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 22:10, E.ON Netz assumed that there was no immediate need for re-dispatching.

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 reduce the flow on the Diele-Meeden interconnector) and would not decrease the flow on the Landesbergen-Wehrendorf line. Re-dispatching would require the increase of power in 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 Diele-Conneforde, no counter trading measures between The Netherlands and Germany were discussed in real time because all grid analyses performed by all TSOs for their own grids showed that the grid situation after the outage was secure even if lines were highly loaded in the whole area of RWE TSO, TenneT and E.ON Netz.

4.2. Separation of the UCTE system.

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.

---

[5] 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 neighbouring 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.

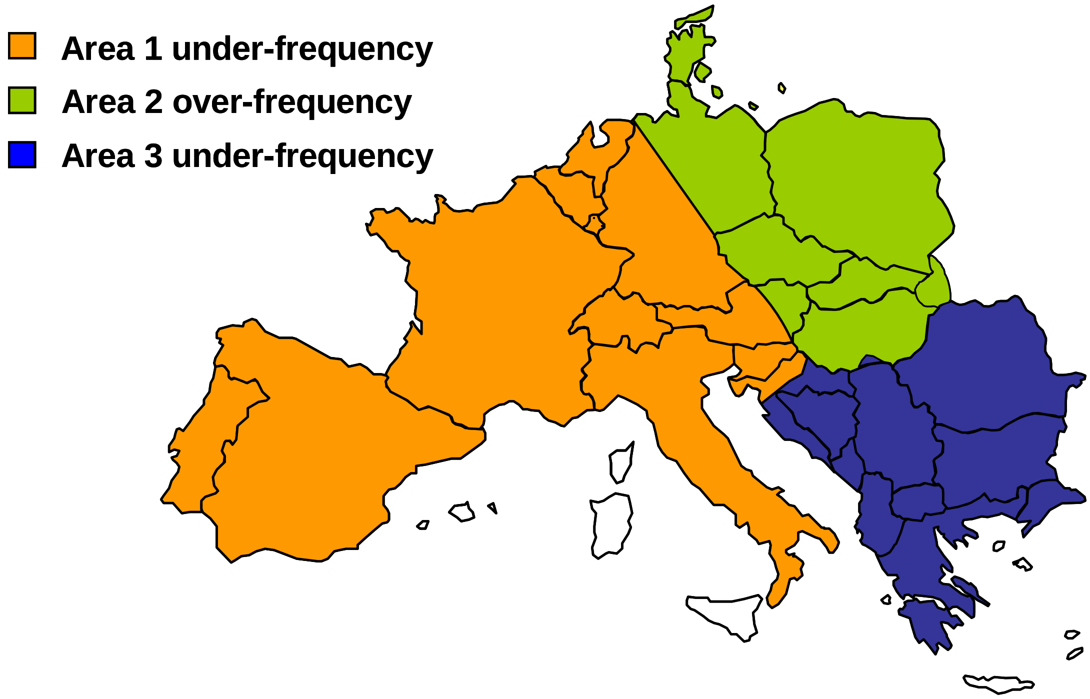


Figure 4: Schematic map of UCTE area split into three areas

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

Figure 5 (below) 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.

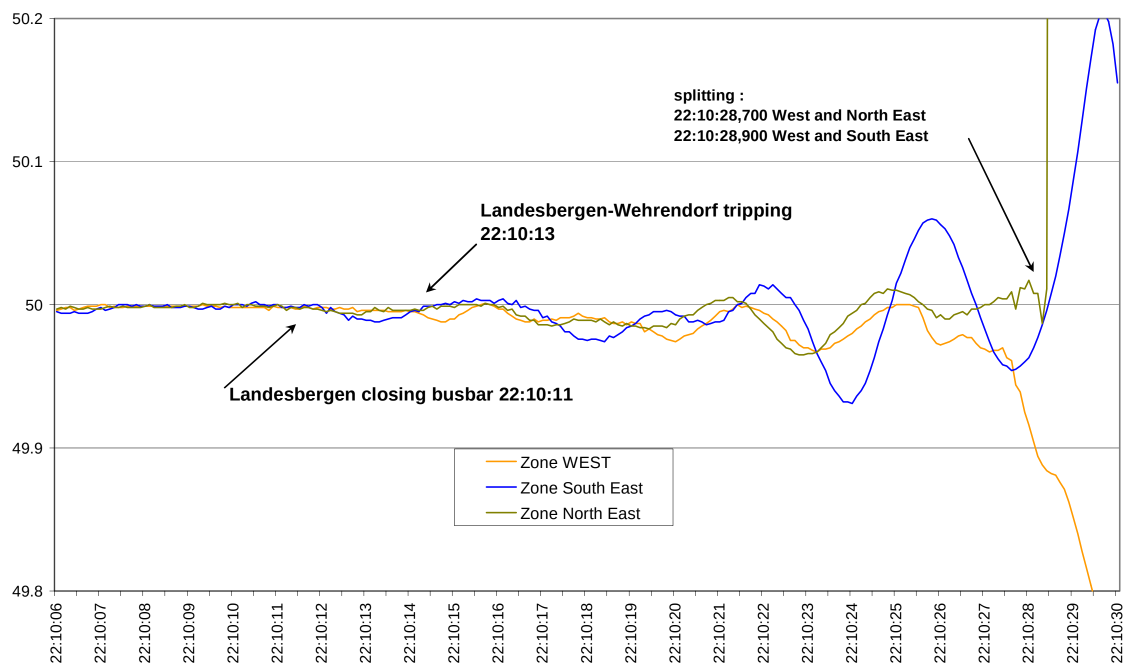


Figure 5: Frequency recordings until area splitting

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

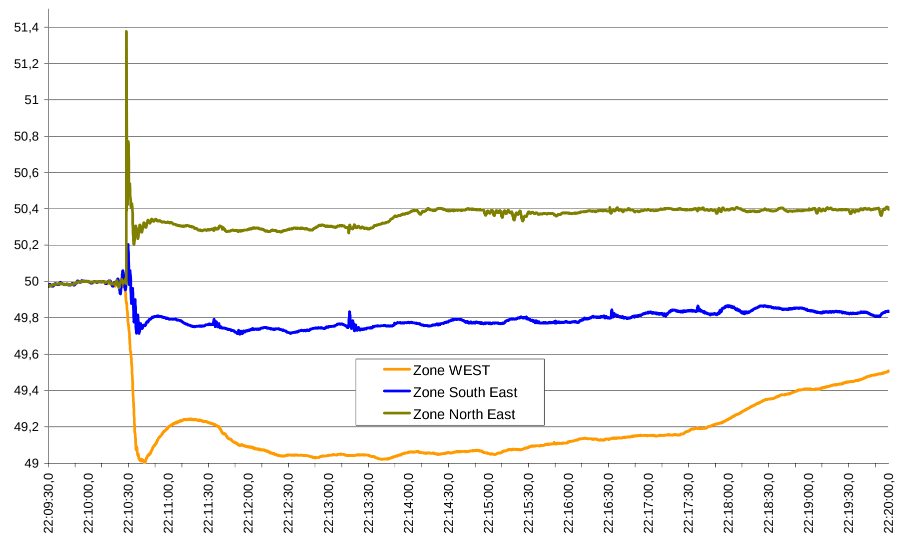


Figure 6: Frequency recordings after the split

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 zone 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.

SYSTEM STATUS AND DEFENSE ACTIONS IN INDIVIDUAL ISLANDS

5

5. System status and defense actions in individual islands

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.

5.1. Western Europe

5.1.1. Evolution of system conditions

After cascading overloads and tripping leading to the splitting of Europe 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 7 and 8).

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 defense plans concerning load shedding and pumped storage unit shedding of each TSO located in the Western area is included in Appendix 5.

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 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 (see map below in Figure 7).

[7] values are rounded at 100 MW step

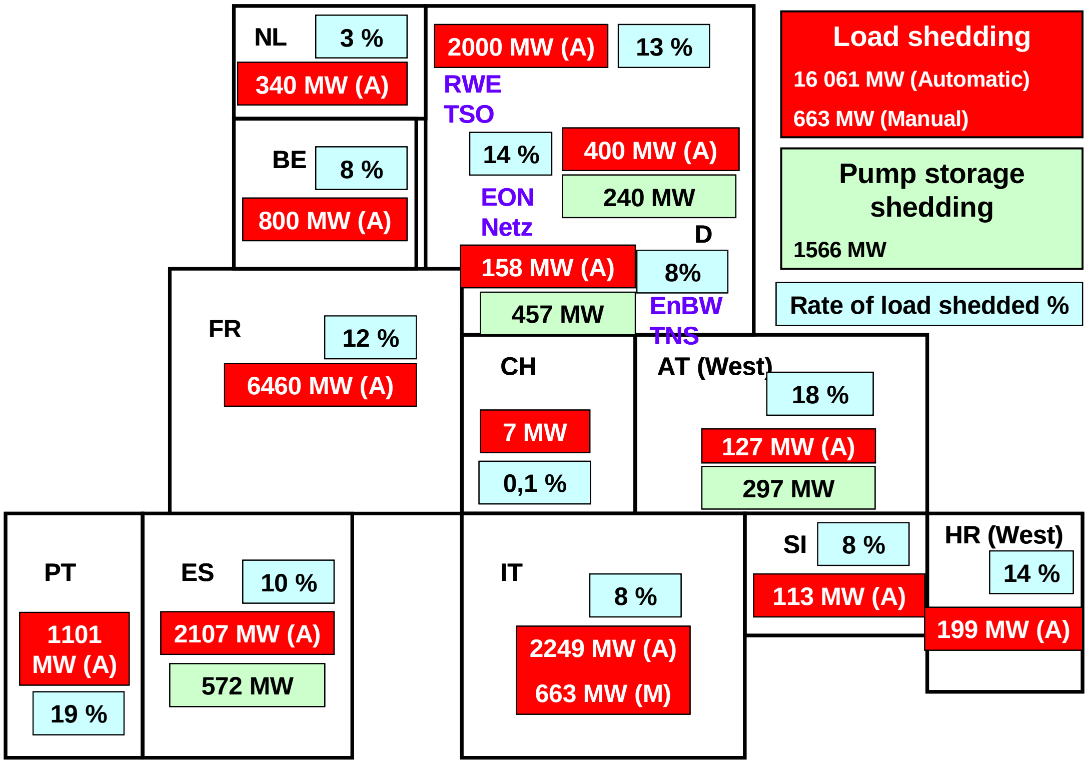


Figure 7: Map of load and pumped-storage shedding by TSOs

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. However, it has to be further investigated and checked by comparing to what was expected from TSOs defense plan. In fact, the large difference of load shed for each TSO related to estimated total load has to be understood.

In some TSOs (Italy and Austria), the automatic load shedding was completed by manual load 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 zone, a significant amount of units tripped on 4 November.
About 40% of the total generation units which tripped during the incident were wind power units. Moreover, 60 % of the wind stations connected to the grid at 22:09 tripped just after the frequency drop.

Similarly, 30% of combined-heat-and-power 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 unit connected to the TSO network tripped.

In the Western area, a total of about 10 700 MW tripped (see details in Figure 8).

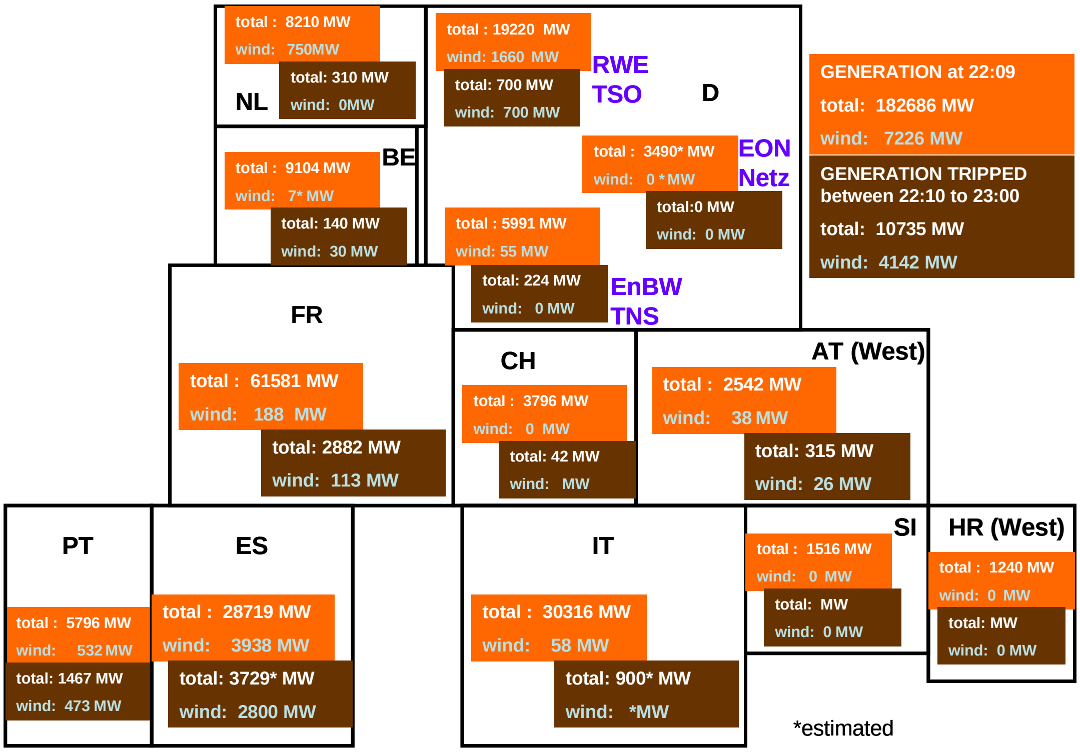


Figure 8: Map of generation tripped (total and wind)

The orange squares show the total of generation units started and the wind generation started 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 or 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 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 16 400 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.

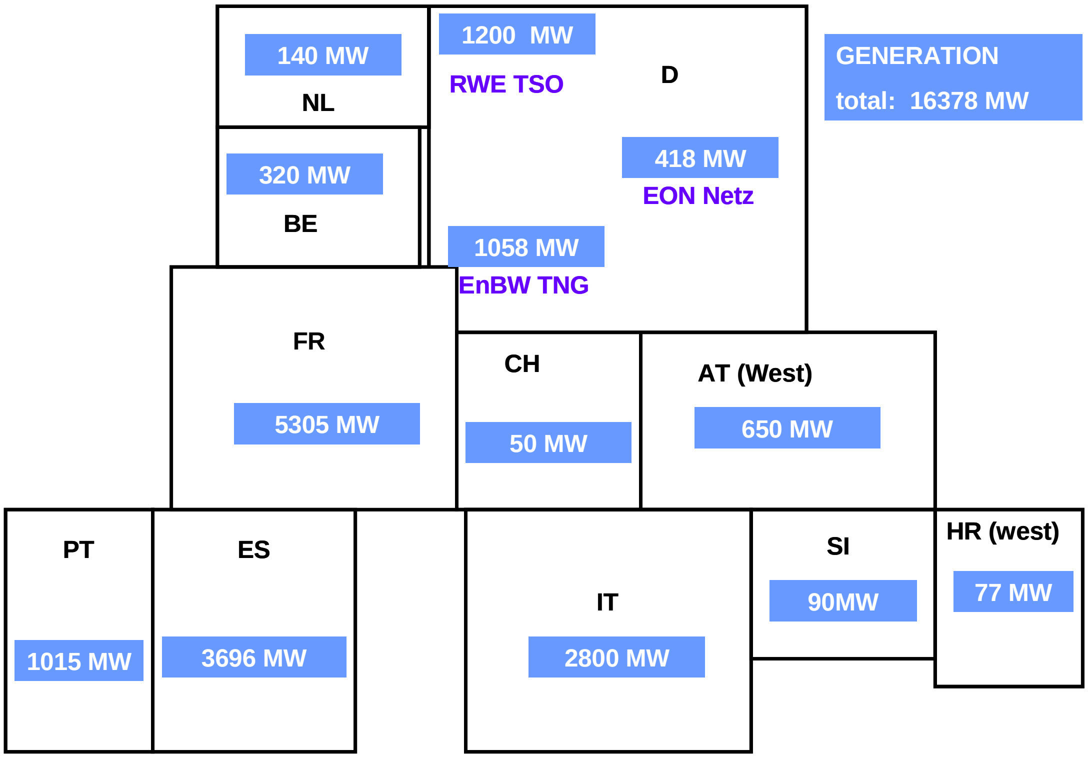


Figure 9: Generation units started by TSOs

The physical flows on the lines in the Western zone induced by the system splitting, load shedding, generation tripping and starting, were significantly different from the ones forecasted for normal operation conditions.
Immediately after the events and in the following several minutes, the N-1 criterion was not respected in some areas, especially on some tie-lines. That means that an additional fault on the relevant line of the grid could have a severe impact on system conditions (further separation of the area).
This “out of range” event induced huge physical flows which exceeded total transfer capacity values for a few borders (e.g. France-Spain).

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 (RTE, EnBW TNG, TERNA) 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 requested EnBW TNG, 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.

[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.

Preliminary frequency analysis

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

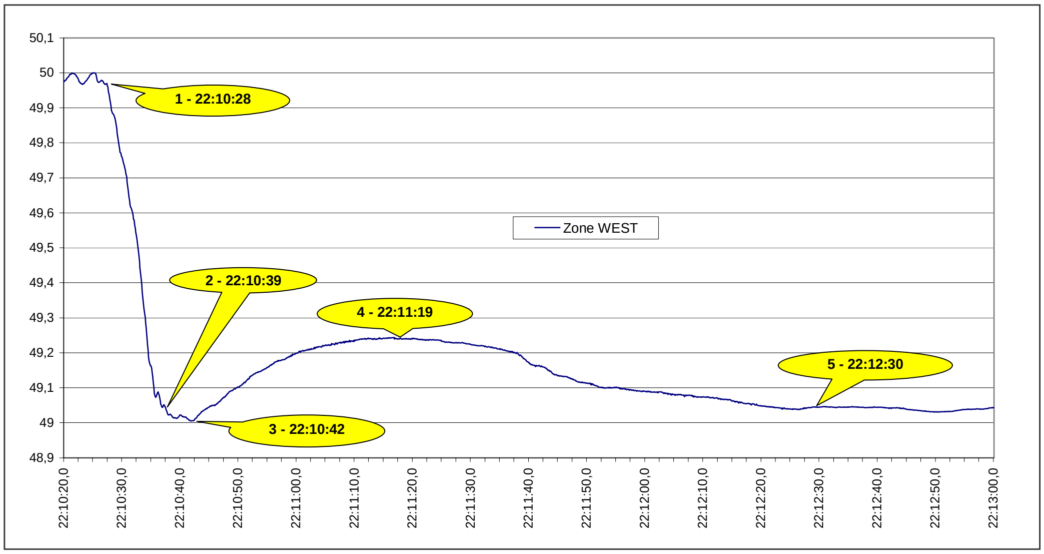


Figure10: Frequency in the Western area

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 action of defense plan
③ – 22:10:42, beginning of frequency increase caused by 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 (see chapter 4.1.1) 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 within thermal power plants the frequency stabilized at 49.2 Hz. According to the first estimations, 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 for the following reasons (preliminarily assumed): exhaustion of the primary reserve, re-energization started slowly in some TSOs, and generation units tripped.

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 stamp of frequency increase correlates to the manual increase of generation and start of additional generation units by TSOs.

5.2. North-Eastern Europe

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: Intersystem power flows in area 2 at 22:09).

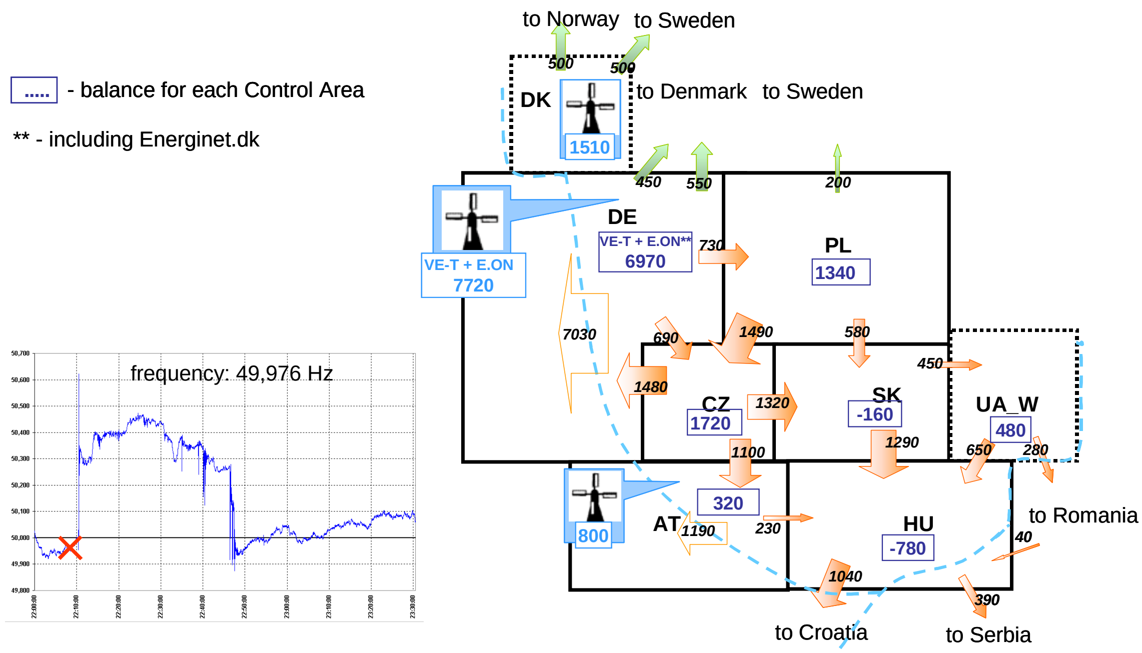


Figure 11: Intersystem power flows in area 2 at 22:09

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 intentional actions (primary control – standard and emergency range, activation of speed control of certain generating units) and automatic tripping of the generation 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 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 Intersystem power flows in area 2 at 22:12) 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 the dispatchers of other area 2 TSOs not experienced in 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.

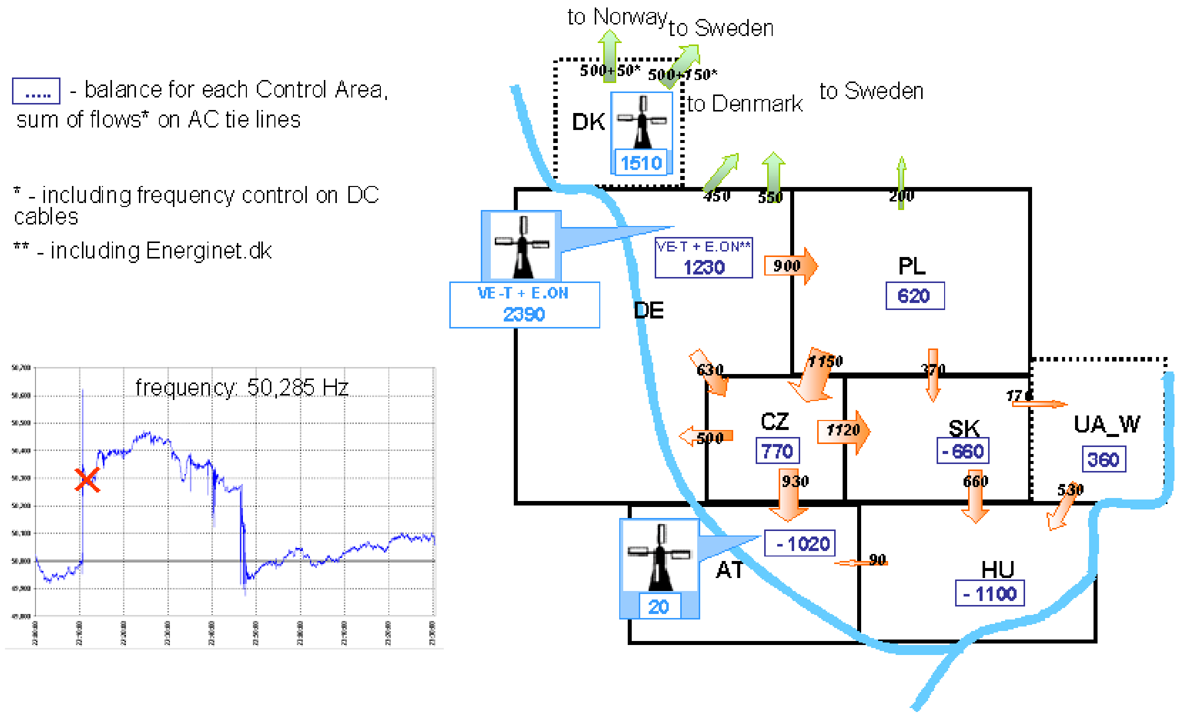


Figure 12: Intersystem power flows in area 2 at 22:12

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 behaviour 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.

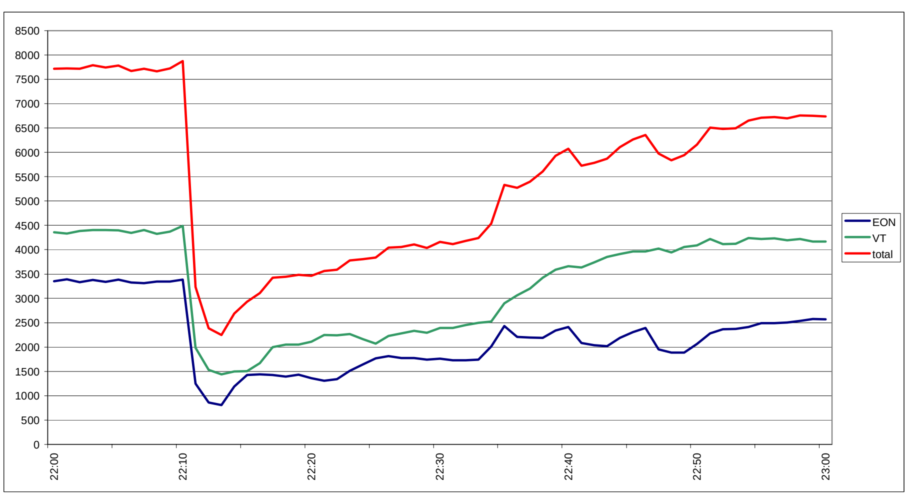


Figure 13: Output of windmills (VE-T, E.ON Netz, from 22:00 to 23:00

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 pumpedstorage 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 – chart of frequency in area 2).

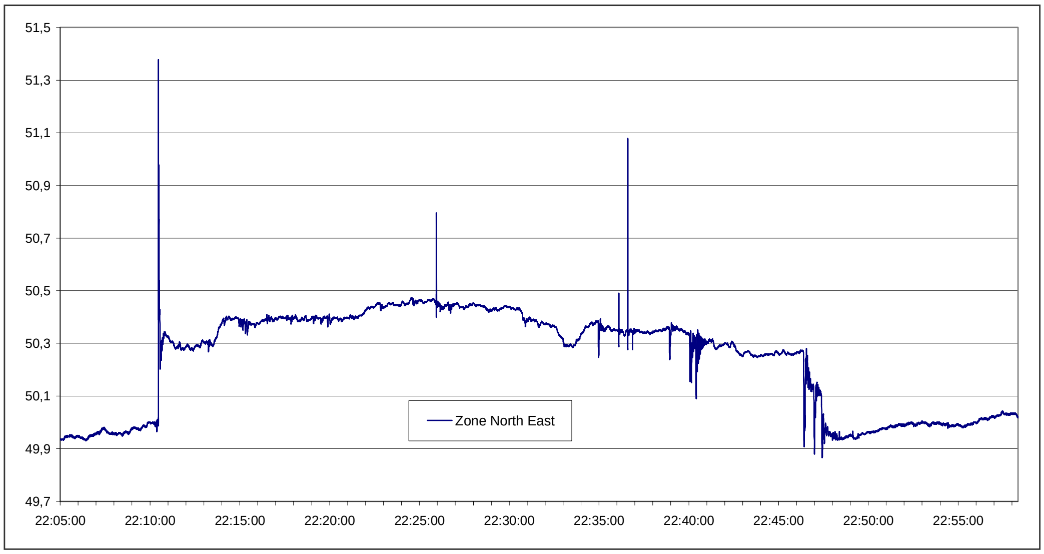


Figure 14: Frequency in area 2 (22:00 – 23:00)

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 Intersystem power flows in area 2 at 22:20) and continued to increase further till 22:35 when it reached unacceptable levels even for emergency conditions (see Figure 16: Intersystem power flows in area 2 at 22:30 and Figure 17: Intersystem power flows in area 2 at 22:35).

[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.

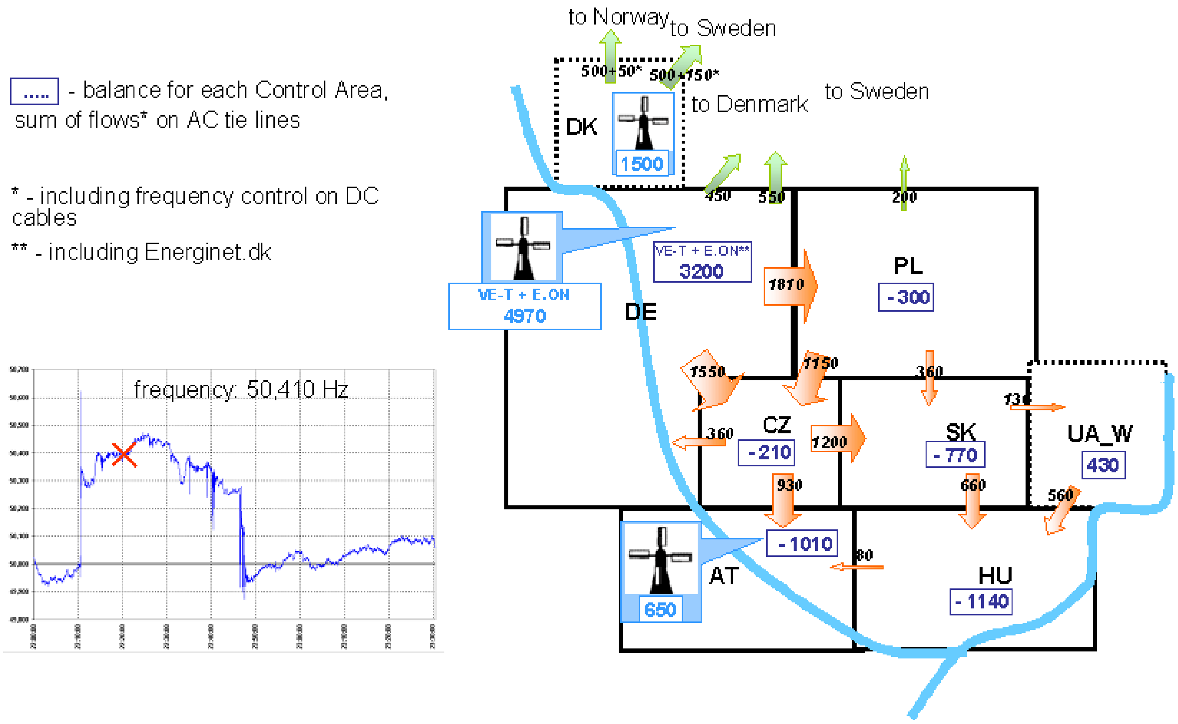


Figure 15: Intersystem power flows in area 2 at 22:20

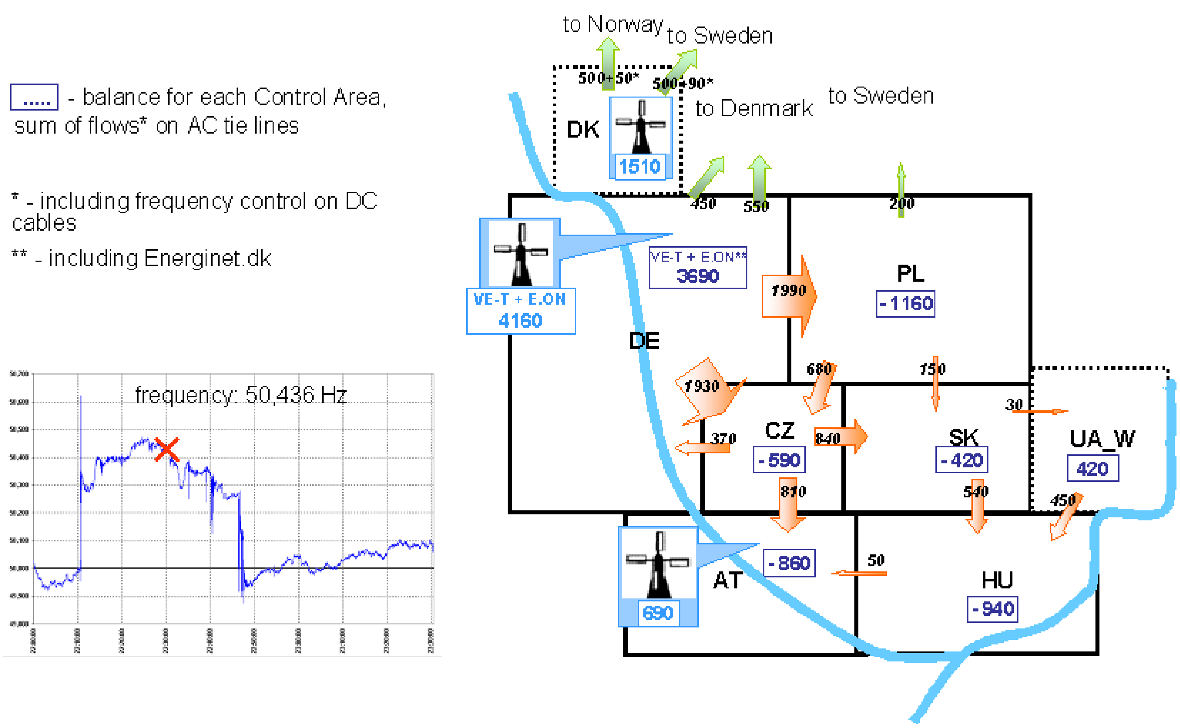


Figure 16: Intersystem power flows in area 2 at 22:30

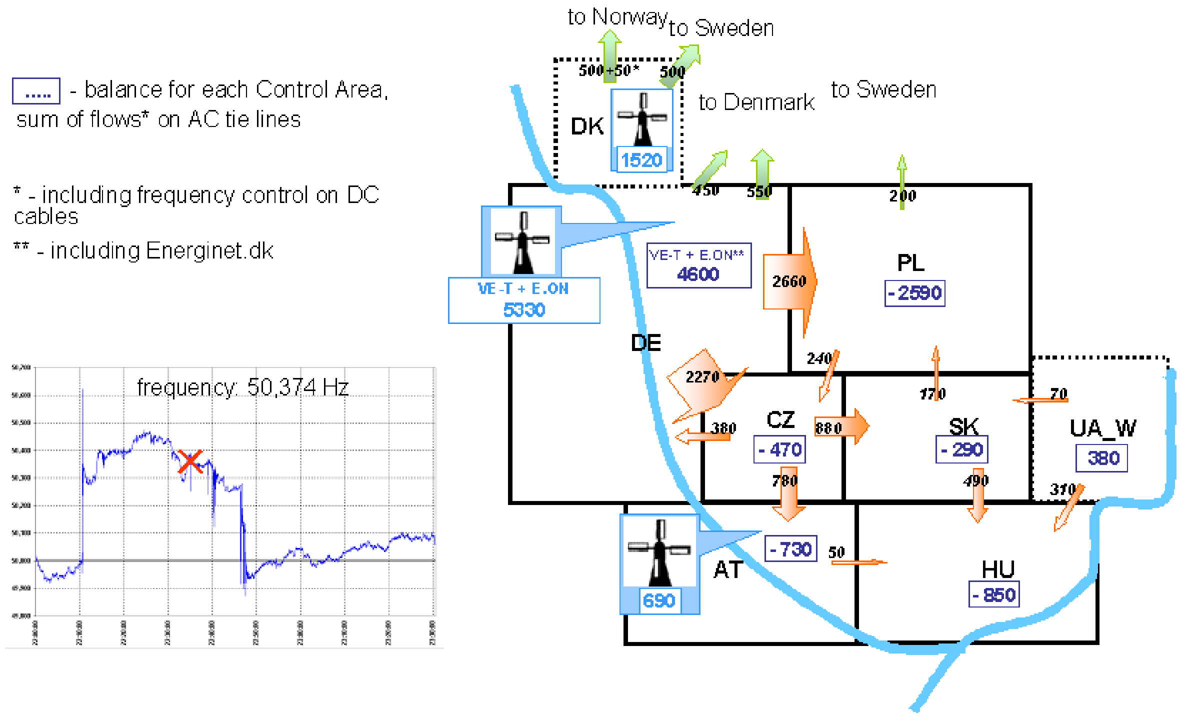


Figure 17: Intersystem power flows in area 2 at 22:35

These flows led to overloading of internal lines in the south of the VE-T control area (double circuits of 380 kV line Barwalde - Schmolln for a few seconds up to 126 % 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 Figure 18: Overloaded elements in the region of VE-T/PSE-O/CEPS borders and Figure 19: Example of critical load flows: VE-T / PL + CZ profile and Figure 20: Overloads on 400 kV Mikulowa-Czarna internal PSE-O line).

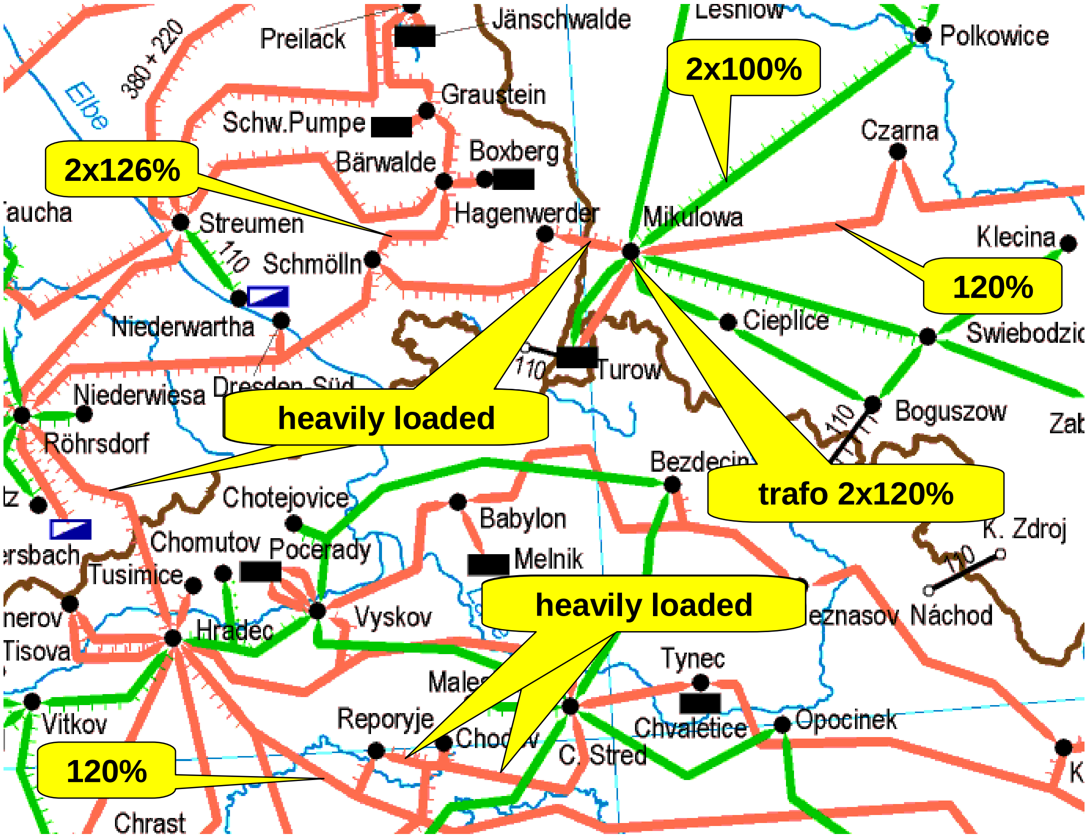


Figure 18: Overloaded elements in the region of VE-T/PSE-O/CEPS borders

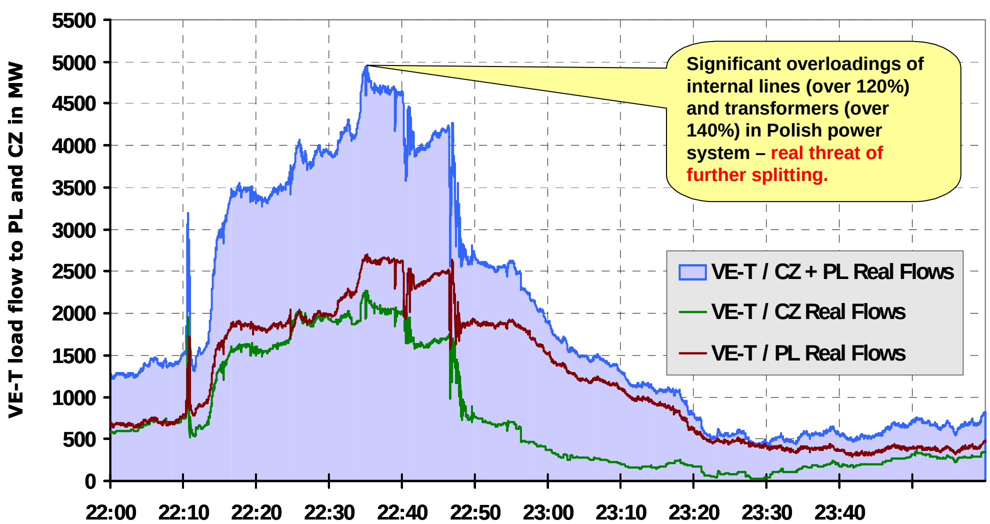


Figure 19: Example of critical load flows: VE-T / PL + CZ profile

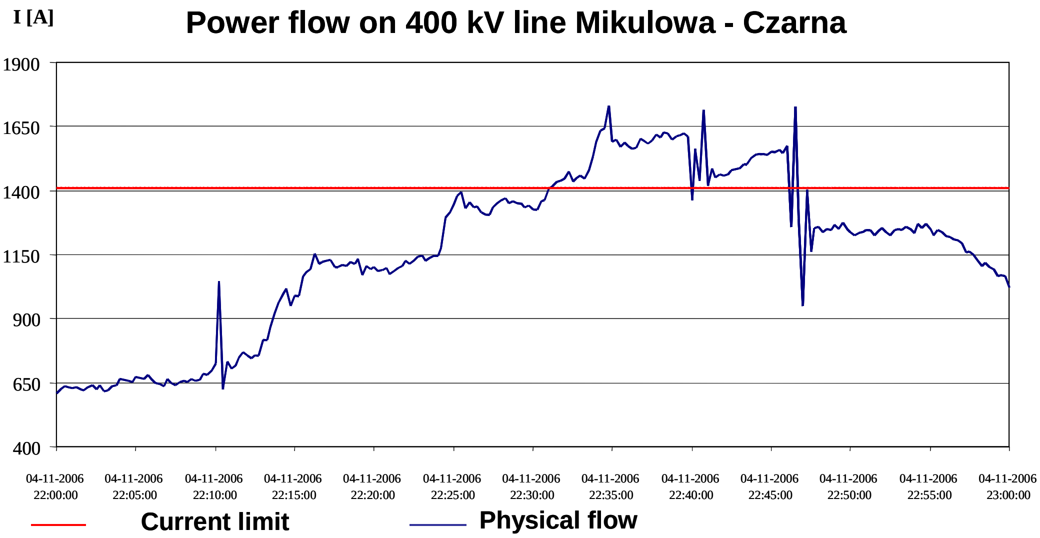


Figure 20: Overloads on the 400 kV Mikulowa-Czarna internal PSE-O line

The N-1 rule was not fulfilled at that time in this region of VE-T/PSE-O/CEPS borders and tripping of any element in this region (especially overloaded ones) would lead to further overloading and possible cascading tripping. This 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: Intersystem power flows in area 2 at 22:50 (critical W-E flow just after synchronization in Germany and Austria; decrease of W-E flow). At 23:30 the power systems in central Europe came back to normal operational conditions (see Figure 22: Intersystem power flows in area 2 at 23:30 (back to normal operational conditions)

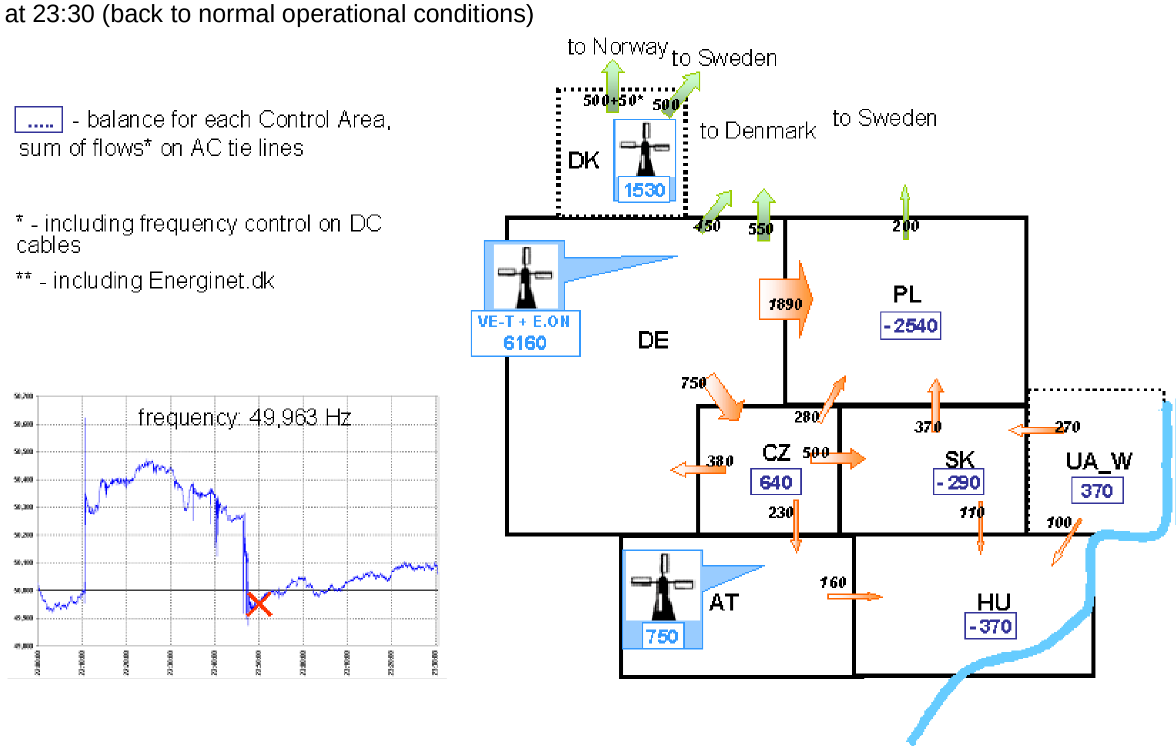


Figure 21: Intersystem power flows in area 2 at 22:50 (critical W-E flow just after synchronization in DE and A; decrease of W-E flow)

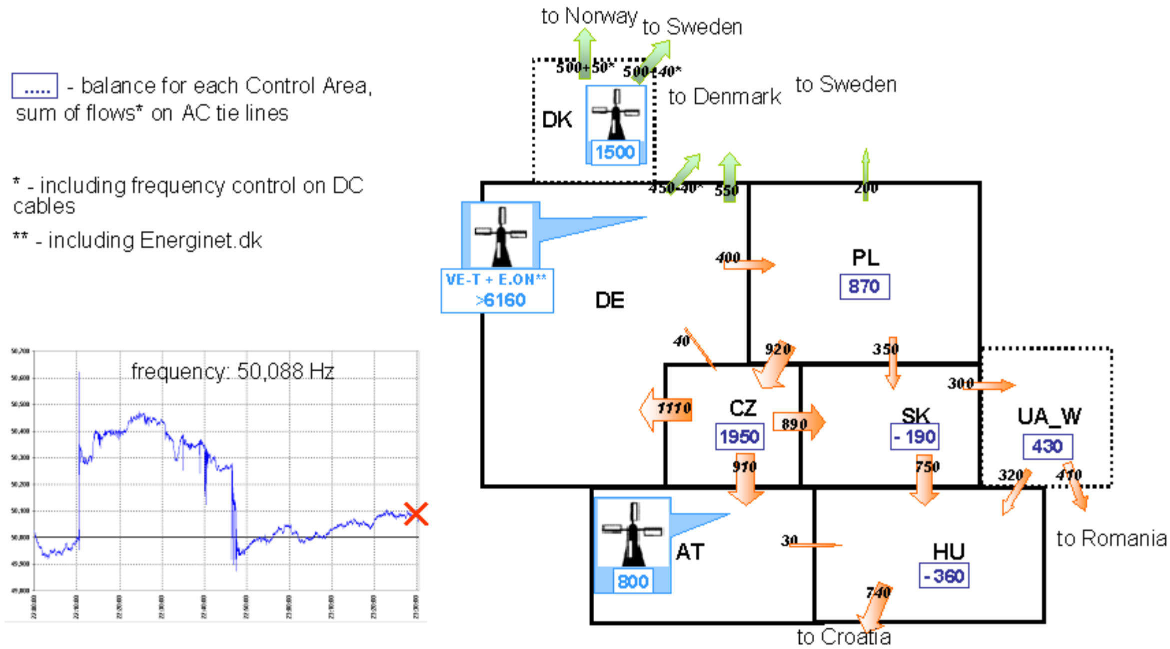


Figure 22: Intersystem power flows in area 2 at 23:30 (back to normal operational conditions)

5.3. South-Eastern Europe

5.3.1. Evolution of system conditions

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, except KESH (Albania), 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 (CS) - Sandorfalva (HU)
- Mitrovica 2 (CS) - Ernestinovo (HR)
- Mitrovica 2 (CS) - 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 nor load shedding took place during the event**. Thus, the defense plans were not activated.
According to preliminary 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: HE Zakučac-220 kV with 47 MW and HE 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.

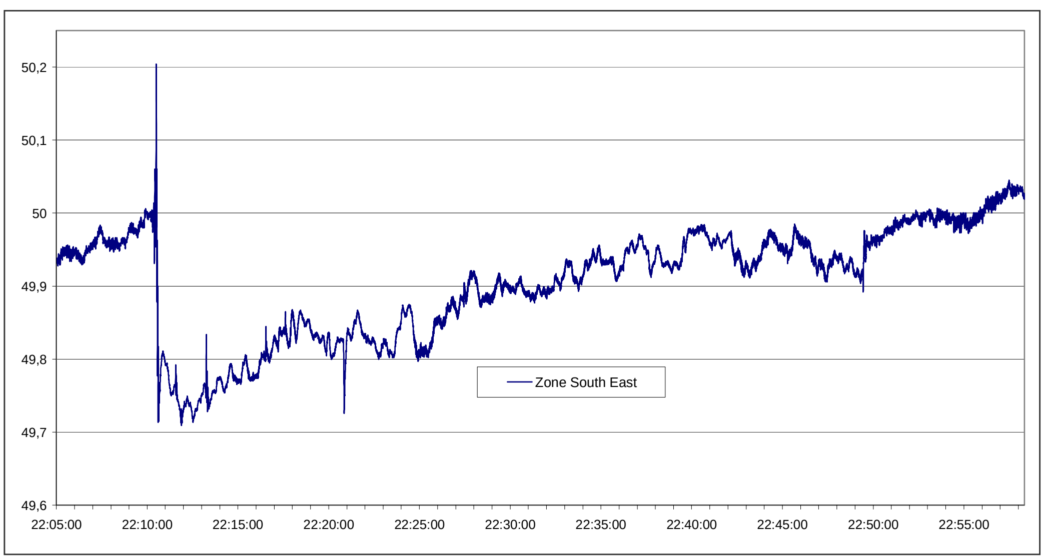


Figure 23: Frequency evolution in area 3 during the event (WAMS recording)

[10] KESH and EPCG are 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 (total consumption in HTSO area during the event).

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

RESYNCHRONIZATION OF ISLANDS 6

6. Resynchronization of islands

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.

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

- Preparatory actions,
- 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 Frequency recordings for three areas.

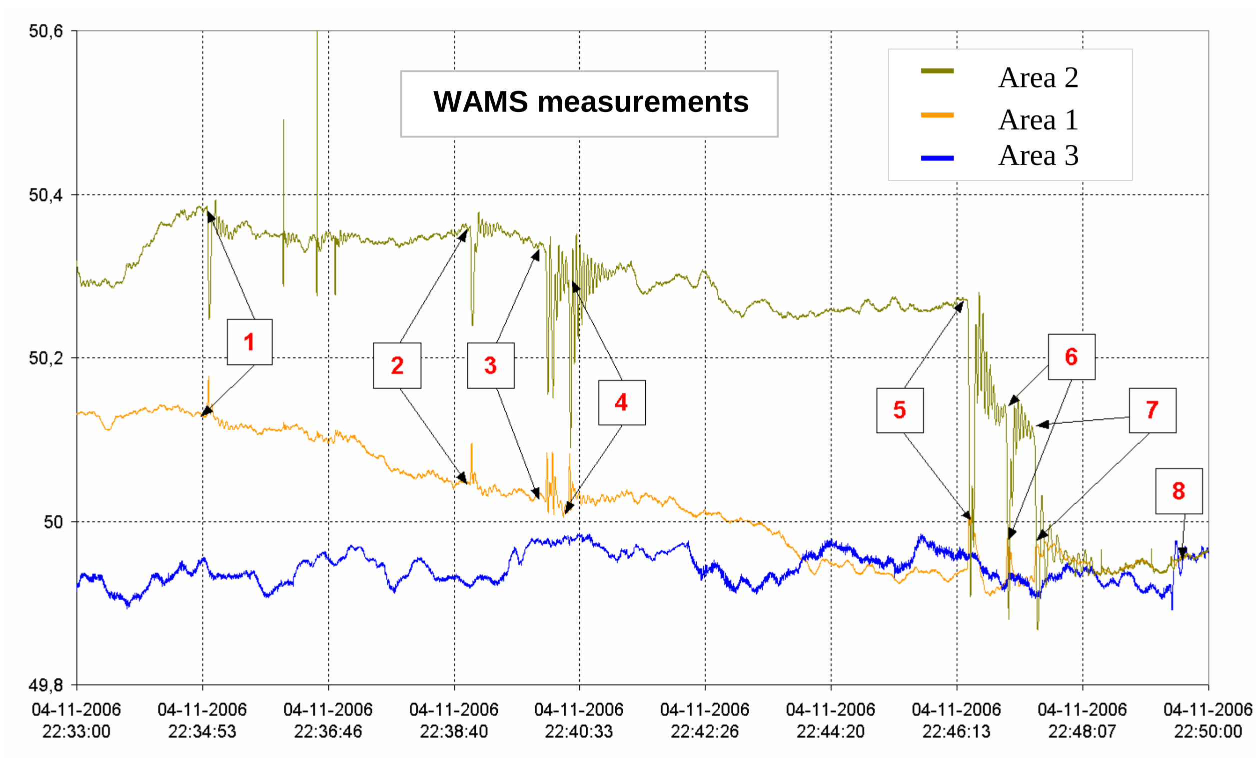


Figure 25: Frequency recordings for three areas

As a first step of a resynchronization process, the area 1 was synchronised with area 2 in Germany and Austria and as a second step, the area 3 was synchronised with already interconnected areas 1 and 2. Those two steps were performed within the 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 22:47:11, 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. The areas where the trial switchings were performed are not fully identified.

Resynchronization of area 1 and area 2

Resynchronization trials which did not result in real interconnection

22:34:59.5 (APG time: 22:36:05) trial switching-on of the 220 kV line Ternitz-Hessenberg in Austria which tripped immediately (difference of frequencies was over 250 mHz) [1].

22:38:57.1 (APG time: 22:36:35) trial switching-on of the 220 kV line Ternitz-Hessenberg in Austria which tripped immediately (difference of frequencies was about 240 mHz) [2].

22:40:06 (E.ON Netz time: 22:40:03, RWE TSO time: 22:40:09) - trial switching-on of the 380 kV Landesbergen-Wehrendorfline which tripped due to low voltage and high current (difference of frequencies was 300 mHz) [3].

22:40:27 (E.ON time: 22:40:25) - trial switching-on of the 380 kV Conneforde-Diele line which also tripped due to oscillations (difference of frequencies was 300 mHz) [4].

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

22:46:23 - 22:46:27.3 (E.ON Netz time: 22:46:24 – 22:46:29) switching-on 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 [5].

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) 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) [6].

1. **22:34:59 (APG time: 22:36:05); trial switching-on of the 220 kV Ternitz – Hessenberg line, tripped immediately due to ∆f = 250mHz**

2. **22:28:57 (APG time: 22:36:35); trial switching-on of the 220 kV Ternitz – Hessenberg line; tripped immediately due to ∆f = 240mHz**

3. **22:40:06 (E.ON time: 22:40:03, RWE: 22:40:09) trial switching-on of the 380 kV Wehrendorf – Landesbergen line; tripped due to oscillations**

4. **22:40:27 (E.ON time: 22:40:25); trial switching-on of the 380 kV Conneforde – Diele line; tripped due to oscillations**

5. **22:46:23 – 22:46:27 (E.ON time: 22:46:24 – 22:46:29); switching-on of the 380 kV Conneforde – Diele line, which again caused oscillations, ended up after 4 s with trippings of both 380/220 kV transformers in the Conneforde substation, the 380 kV line Unterweser-Conneforde and opening of**

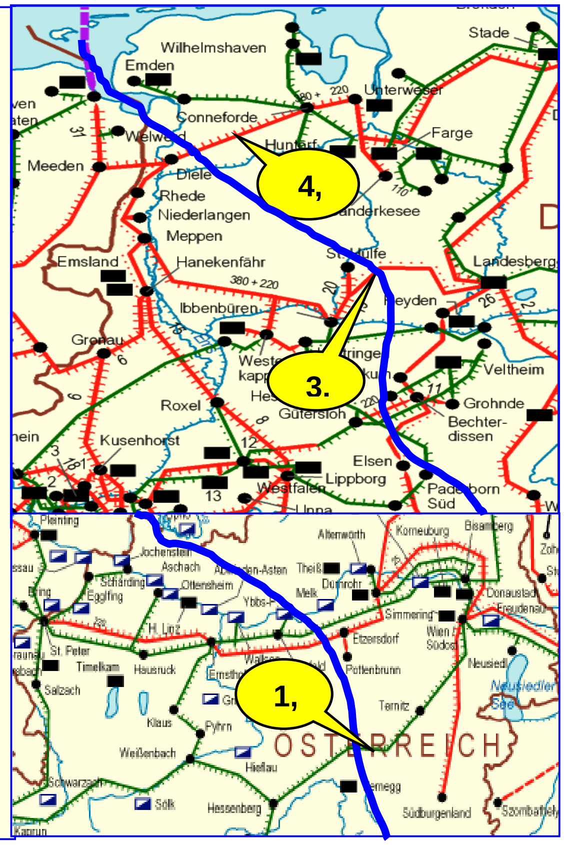


Figure 26: Unsuccessful resynchronization trials and attempts

Successful resynchronization process

Finally at 22:47:23.4 (E.ON Netz time: 22:47:11) successful resynchronization took place first on the 380 kV line Bechterdissen-Elsen (circuit 2) [7]. 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. Following that successful trial, 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 Resynchronization of areas 1 and 2 in Germany and Austria.

1. **22:47:23 (E.ON time: 22:47:11); 380 kV Bechterdissen – Elsen 2**
2. **22:48:00; 380 kV circuit Dipperz – Großkrotzenburg 1**
3. **22:48:16; 380 kV circuit Dipperz – Großkrotzenburg 2**
4. **22:48:23; 380 kV Dürnrohr – Ernsthofen (Austria)**
5. **22:48:47; 380 kV Etzerdorf – Ernsthofen (Austria)**
6. **22:48:55; 380 kV circuit 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 circuit Wehrendorf - Landesbergen1**
10. **22:52:27; 380 kV Sk Raitersaich - Redwitz**
11. **22:53:39; 380 kV circuit Oberhaid - Redwitz**
12. **22:55:00; 220 kV circuit Bechterdissen-Paderborn-Süd4**
13. **22:56:10; 380 kV circuit Etzenricht - Redwitz**
14. **23:02:06; 380 kV circuit Redwitz - Würgau**
15. **23:02:55; 380 kV circuit Etzenricht - Schwandorf**
16. **23:04:16; 380 kV circuit Mechlenreuth - Schwandorf**
17. **23:05:30; 380 kV circuit 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 circuit Gütersloh – Bielefeld**

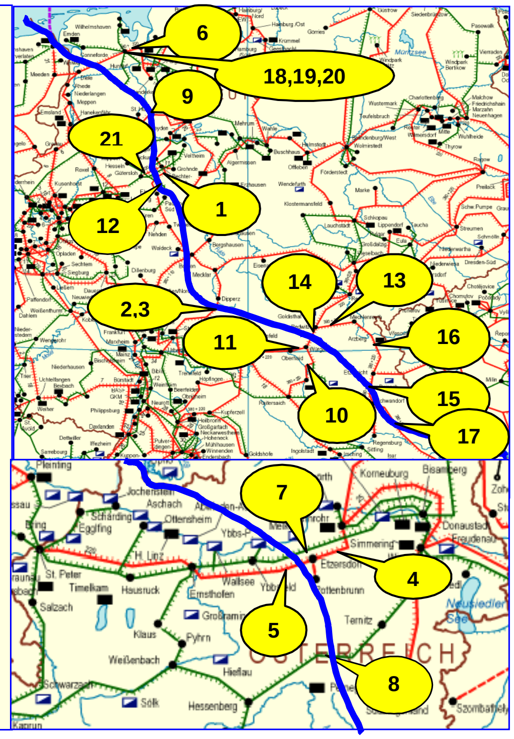


Figure 27: Resynchronization of areas 1 and 2 in Germany and Austria

Resynchronization of area 1+2 and area 3

Successful resynchronization process

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 [8]. At that time, area 1 and area 2 were synchronously connected by four lines in Germany and three 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, West Ukraine.

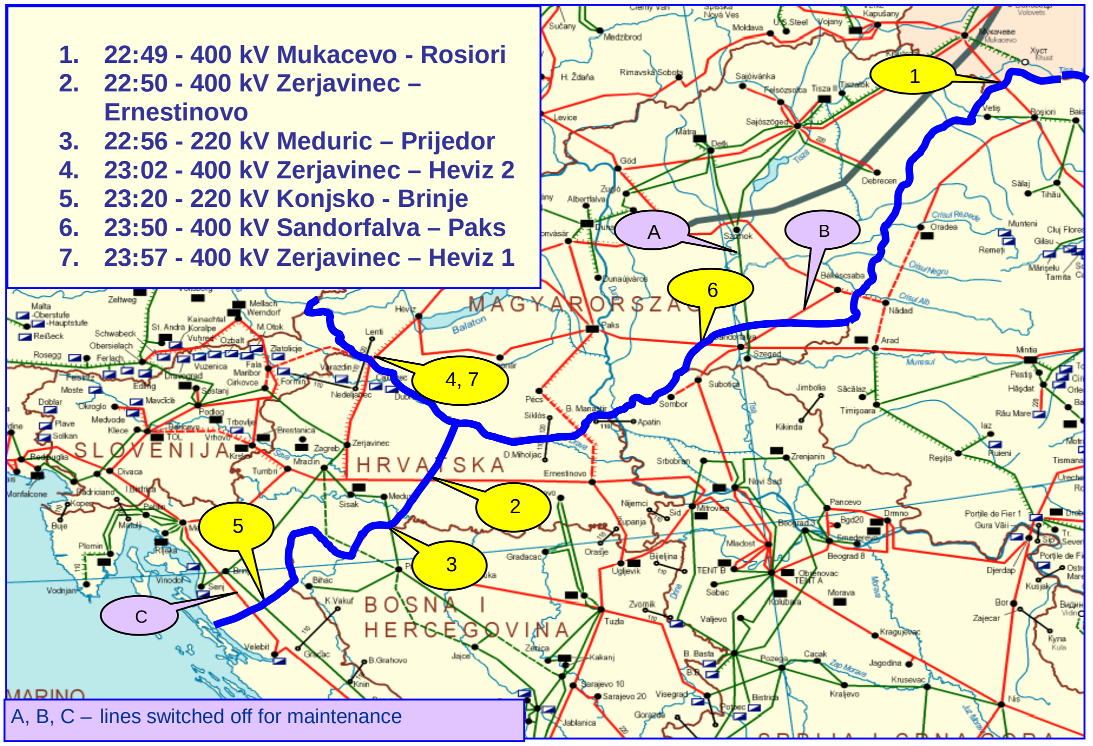


Figure 28: Resynchronization of area 1+2 with area 3 in Croatia, Hungary, Romania, West Ukraine

7

FIRST RESULTS OF THE STEADY-STATE SIMULATIONS

7. First results of the steady-state simulations

The power system behaviour can be simulated using the models which reflect the network configuration, generation and consumption. It means that the power system state, understood as the configuration of power flows over all the lines at a given moment in the past, can be reconstructed today. These power flows are computed by using the values of generations and consumptions as input data.

Once the power system state is reconstructed, it is possible to simulate some events such as the outage of one line or a topology change in a substation, in order to analyse the consequences of these events. In this exercise the sequence of events that happened on 4 November, from the switching-off of the Conneforde - Diele[13] line until the cascade of line trippings that led to the splitting of the UCTE grid was reproduced (except the very last moments before the splitting that require different simulation tools taking into account dynamic phenomena).

More precisely, the simulations which were carried out are the following:

i. Simulation of the power system state at 21:30: « N-1 » criterion check
ii. Simulation of the power system state at 21:40 i.e. after the switching off of the 380kV double circuit line Conneforde - Diele: « N-1 » criterion check
iii. Simulation of the power system state at 22:00: « N-1 » criterion check
iv. Simulation of the power system state at 22:10 i.e. just before the topology modification carried out by E.ON Netz dispatchers aimed at reducing the power flow over the Landesbergen-Wehrendorf line (coupling of the two busbars in the Landesbergen substation)
v. Simulation of the power system state at 22:10:11 i.e. just after the topology modification
vi. Simulation of the cascade of line trippings within the E.ON Netz grid from 22:10:13 (i.e. tripping of the Landesbergen-Wehrendorf line) till 22:10:25 (i.e. just before splitting of the UCTE system).
vii. The impact of the unavailability of some equipment in the E.ON Netz grid on 4 November for maintenance work was also evaluated. In particular, the consequences of an unusual topology in the Borken substation (the coupling of the two busbars on that day was impossible), was assessed.

All the data that are necessary for the simulations have been collected from all the UCTE TSOs. These data have been provided in a common format, called the « UCTE format ». Two data sets have been collected, one corresponding to a snapshot at 21:30 and the other one to a snapshot at 22:00.

Then a validation of these data has been performed. In particular, the computed power flows on all the interconnection tie lines between TSOs have been compared to the measurements made by these TSOs at 21:30 and 22:00.

Although the validation of data is not complete (in particular within the Balkan area), the simulations of the above list have been already carried out. At this stage, the first findings which are described below must be considered as provisional.

i. Simulation of the power system state at 21:30

The « N-1 » contingency analysis shows that :

- The East-West axis Mecklar - Dipperz – Grosskrotzenburg – Dettingen (RWE TSO) – Urberach (RWE TSO) is particularly loaded. This axis consists of 380 kV double circuit lines. The unexpected outage of one circuit would lead to exceed the alarm threshold on the other circuit.
- The double circuit line Redwitz-Remptendorf (VE-T) is also particularly loaded. The unexpected outage of one circuit would lead to exceed the alarm threshold on the other circuit.

The operating rules, currently in force at the E.ON control center, allow operators to accept that the power flows exceed the alarm threshold (by a maximum of 25%) during a short period of time, in order

[13] Unless otherwise indicated, all the substations mentioned in this Chapter are located in the E.ON grid.

to apply remedial measures to come back to an acceptable situation. In the two previous cases, these remedial measures have not been simulated yet.

ii. Simulation of the power system state at 21:40 (just after the switching off of the 380 kV double circuit line Conneforde-Diele)

In fact, this simulation has been done using the previous situation at 21:30, thus assuming that nothing has changed during 10 minutes, except the switching off of the Conneforde – Diele line.
This simulation shows that the most loaded line within the E.ON Netz grid is the 380 kV Landesbergen-Wehrendorf line (85% of the alarm threshold).
The contingency analysis shows that the « N-1 » criterion was not satisfied at 21:40:
In case of unexpected outage of the 380 kV Bechterdissen-Elsen line or of the 380 kV Elsen-Twistetal line, the power flow over the Landesbergen-Wehrendorf line exceeds not only the alarm threshold 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.

Furthermore, the contingency analysis shows that:
As expected, the East-West axis Mecklar - Dipperz – Grosskrotzenburg – Dettingen (RWE TSO) – Urberach (RWE TSO) is more heavily loaded at 21:40 than at 21:30. The outage of one circuit of any segment of this axis would lead to exceed the alarm threshold (in some cases the overload is higher than 25%).
The 380 kV Redwitz-Remptendorf (VE-T) line is also more heavily loaded at 21:40 than at 21:30. The outage of one circuit of this line would lead to exceed the alarm threshold on the other circuit.
In case of unexpected outage of one line in the area around the 225 kV Farge and Sottrum substations, power flows in this area would exceed alarm thresholds.

iii. Simulation of the power system state at 22 :00

The situation of the power system at 22:00 is similar to the situation at 21:40 from a security point of view. The “N-1” criterion was not satisfied for the same reasons.

iv. Simulation of the power system state at 22:10 (before the topology modification in the Landesbergen substation)

Between 22:00 and 22:10, measurements show that a progressive increase of the power flow over the Landesbergen-Wehrendorf line occurred. As the origins of this increase have not been identified so far, the situation of the power system at 22:10 has not been simulated yet.

v. Simulation of the power system state at 22:10:11 (just after the topology modification in the Landesbergen substation)

The topology manœuvre done by E.ON Netz dispatchers at 22:10:11 has been simulated using the data set of the 22:00 situation. This manoeuvre consisted in coupling the two busbars of the 380 kV Landesbergen substation. It was aimed at reducing the power flow over the Landesbergen-Wehrendorf line, but it had an opposite effect. Simulations show that the power flow increased by about 50 MW (67 A).
The Figures 29 and 30 below show the power flow configuration at the Landesbergen substation before and after coupling both busbars (as if this manœuvre had been done at 22:00).

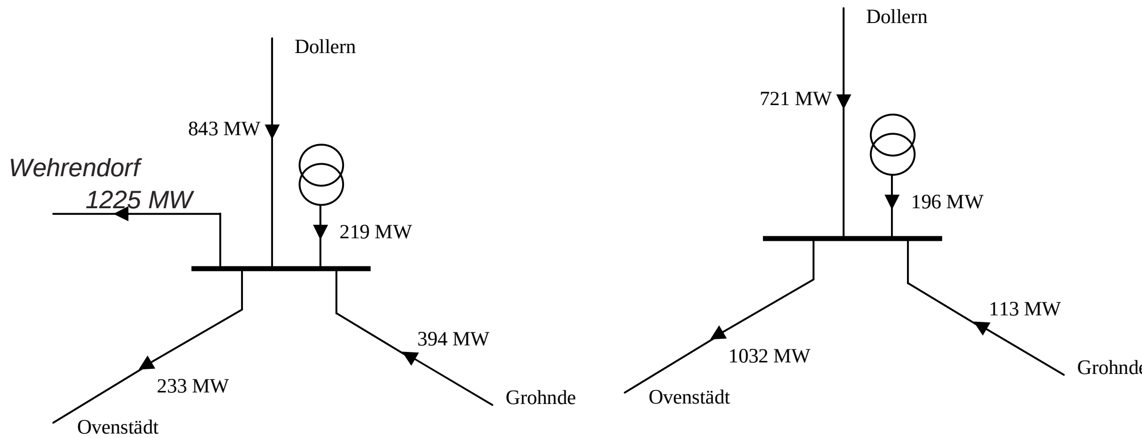


Figure 29: Landesbergen substation - Before coupling

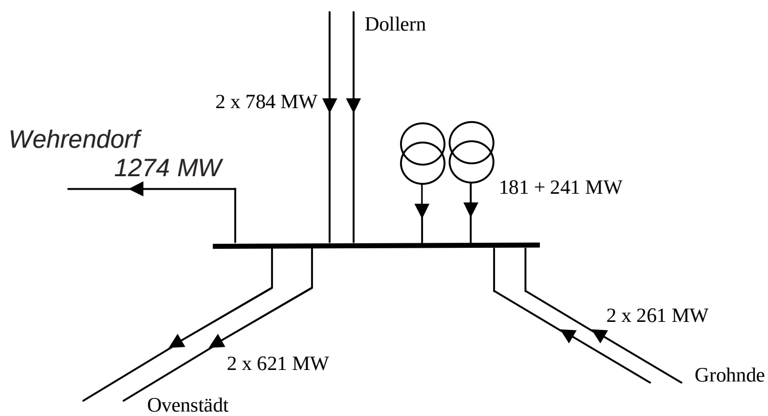


Figure 30: Landesbergen substation - After coupling both busbars

vi. Simulation of the cascade of line trippings within the E.ON Netz grid from 22:10:13 (tripping of the Landesbergen-Wehrendorf line) until 22:10:25

It has been possible to reproduce the beginning of the cascade of line trippings within the E.ON Netz grid from 22:10:13 (tripping of the Landesbergen-Wehrendorf line) until 22:10:25 using the dataset of 22:00 situation. This simulated cascade of line tripping is in line with the observed sequence as listed in Appendix 3.

vii. Impact of the topology at the Borken substation

The Borken substation is usually operated in only one busbar mode. On 4 November, because of construction works in this substation, the two busbars were not coupled, the substation was operated in two busbar mode. This configuration means that the power flows were not possible in the East to West direction.
In order to assess the impact of this topology in the Borken substation, a fictitious situation has been simulated. The coupling of the two busbars has been simulated just after the switching-off of the Conneforde – Diele line (at 21:40).

This simulation shows that the power system state is much better. The power flow over the Landesbergen-Wehrendorf line is reduced by 157 MW (221 A), that is about 13%. It is clear that this particular configuration at the Borken substation on 4 November was a very unfavourable factor.
This simulation also shows that in case of outage of the Bechterdissen–Elsen line or of the Elsen–Twistetal line, the power flow over the Landesbergen-Wehrendorf line does not exceed the alarm threshold any more.

RESULTS AND GENERAL CONCLUSIONS 8

8. Results and interim conclusions

8.1. Background

The events in the evening of 4 November 2006 have been the most severe disturbance in the more than 50-year history of UCTE regarding the number of involved TSOs and the amplitude of the registered frequency deviation. However, the decentralized responsibilities exercised by the UCTE member TSO's for the secure operation demonstrated its efficiency: the appropriate countermeasures in order to prevent further deterioration of the situation were taken and thus avoided a blackout on the European continent.

After cascade tripping of a considerable number of high voltage lines, the UCTE grid was divided into three islands (West, North East and South East) which resulted in significant power imbalances in each island. The power imbalance in the Western area induced a severe frequency drop which caused an interruption of power supply for more than 15 million West European households.

In both under-frequency areas (West and South East), sufficient generation reserves allowed restoring the normal frequency in a relatively short time. In the over-frequency area (North East), the lack of control over generation units (quick reduction of schedules and automatic reconnection of wind generation) contributed to deterioration of system condition in this area (long lasting over-frequency with severe transmission lines overloading). Generally, the uncontrolled behavior of generation (mainly wind farms and combined-heat-and-power) during the disturbance complicated the process of re-establishing normal system conditions.

Resynchronization of the three islands was performed after several unsuccessful attempts. The full resynchronization was completed within 38 minutes after the system split. Although the individual TSO's did not have a complete and clear picture at any moment of the unexpected and exceptional event, normal situation in all European countries was re-established in less than 2 hours.

8.2. Preliminary root causes analyses

The preliminary analyses indicate that the root causes of the disturbance can be grouped around two points:

- N-1 criterion security rule
- inter TSO co-ordination

N-1 criterion security rule

The N-1 security rule requires that a single incident should not jeopardize the secure operation of the interconnected network. Such incidents are for example tripping of a generation unit, a transmission line or transformer. In particular, the N-1 principle aims at avoiding cascading effects.

Considering the first event of the sequence, switching off the 380 kV Diele - Conneforde line resulted in non N-1 secure conditions in the E.ON Netz grid and on some of its tie-lines to the neighboring TSOs. The evaluation of N-1 secure conditions after the switching action was not based on results of numerical analyses. It was also not based on the analysis for the following hours of possible changes of the system conditions.
Only an empirical evaluation of the situation was performed.

Concerning the high load on the 380 kV line Landesbergen-Wehrendorf which appeared at 22:08, RWE TSO drew the attention on this urgent situation but E.ON Netz did not take efficient remedial actions.

Influence of the topology change in the substation Landesbergen on the power flow on the line was not checked by numerical anaylysis due to the necessary rush. In fact the results of the switching were opposite to the expectations of operators and led to the tripping of the line Wehrendorf – Landesbergen. This tripping initiated the cascading tripping of many lines which resulted in the splitting of UCTE in 3 areas.

The results of the preliminary security calculations performed in the course of this investigation confirm that the N-1 criterion was not fulfilled in the E.ON Netz grid and on some of its tie-lines to the neighboring TSOs.

Inter TSO co-ordination

The initial planning for switching-off the 380 kV Conneforde Diele foreseen on 5 November from 01:00 to 5:00 was prepared by the involved TSOs.

The change of this switching maneuver on the 380 kV Conneforde Diele line was communicated by EON Netz to the other directly involved TSOs very late and was not prepared and checked in the planning phase in order to ensure a secure operation of the system in this area.

In spite of the fact that the network was highly loaded at that time, no efficient remedial action was prepared by E.ON Netz in order to keep a minimum safety margin and to prevent a possible increase of the flow due to changes in generation (especially wind power), in consumption and in cross border exchanges for the following hours.

Just before the triggering event at the Landesbergen substation due to the necessary rush neither co-ordination nor consultation was performed by E.ON Netz towards directly involved TSOs.

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. This specific issue was critical regarding the very high flow on this line (close to the tripping limit in the RWE TSO Wehrendorf substation).

8.3. Other critical facts

The following sections summarize the preliminary findings on the critical facts that occurred during the disturbance: generation related issues, range of the possible actions for the dispatchers to handle grid congestions, defense and restoration plans, resynchronization process and training of dispatchers.

These issues will be further investigated in order to evaluate their specific effect and consequences on the disturbance.

Generation related issues
During the disturbance, a significant amount of generation units tripped due to the frequency drop in the system which resulted in the increased imbalance. Most of this generation is connected to the distribution grid (especially wind and combined-heat-and-power).

In a similar way, the uncontrolled reconnection of generation units was causing further imbalance in the area with a power surplus.

This situation certainly had an influence on the frequency behavior during the first seconds and minutes after the splitting of the UCTE system and it contributed to the deterioration of system conditions.

Additionally, most of the TSOs do not have the real time data of the power units connected to the distribution grid.

The restoration of the frequency after activation of the defense plans requires sufficient means for rescheduling generation in individual control areas (resources, procedures).

However the automatic restarting of a considerable amount of wind generation in the North part of Germany was not immediately compensated by a corresponding amount of decreased generation in thermal or hydro power plants.

During the incident, the growing surplus of generation in Germany balanced by the decrease of generation in other countries in the North - East area (mainly in Poland and the Czech Republic) induced significant additional problems in the transmission grid (overloading of some lines). The insufficient rescheduling of generation output was a main reason for long lasting frequency deviations in the East-North area and for re-synchronisation failures.

Range of possible actions for the dispatchers to handle grid congestions

To remove a constraint and restore a secure operation of the grid and the N-1 criterion, German TSOs have to manage a number of actions defined in the German Energy Law and internal procedures: grid related measures, market related measures and other “adjustments” for the management of emergency situations.

The adequacy of such measures that have to be duly prepared will need to be further investigated taking into account the remaining safety margin in the grid, variable factors such as changes of exchange programs, generation changes and finally the time needed for dispatchers to implement a given measure.

Defense and restoration plans

In some control areas, the re-energization process of the customers started without proper knowledge of the situation of the overall UCTE system. Some DSOs started to reconnect customers without co-ordination with TSOs. These actions worsened the conditions for TSOs in order to restore normal system conditions.

Resynchronization

Actions taken by TSOs during the resynchronization process were not sufficiently coordinated. There were several unsuccessful attempts to a) put lines back into operation and b) to resynchronise the 3 different system areas with only a partial view of the status of the whole grid. The protection devices performed correctly and prevented further negative consequences.

Training of dispatchers

Further investigation is necessary to determine the accuracy and completeness of dispatchers training. Two aspects have to be examined in terms of:

- procedures and tools and
- inter-TSO co-ordination and consultation under normal and emergency conditions.

9 FURTHER WORK OF THE INVESTIGATION COMMITTEE

9. Further work of the Investigation Committee

The Committee's further work will address amongst others, the following issues:

Capacities for N-1 criterion fulfilment by directly involved TSOs

- Current means for security analysis and simulations from the planning period to real time
- Range of available actions and measures to be taken in collaboration with neighbouring TSOs to handle grid congestions
- Regional areas taken into account for the security simulations and analysis
- Accuracy of the security simulation models taking into account the actual system components and system parameters

Coordination between TSOs

- Exchanges of data and results of security analysis in terms of possible constraints and adequate remedial actions (from the planning horizon to real time)
- How are the different protection settings on lines taken into account by TSOs from the planning period to real time
- Awareness of TSOs about the generation located outside each TSO control area that has an influence on the physical flows and security issues
- Awareness of the splitting and of the actual situation of the UCTE system after the splitting
- Resynchronization process in each control area

Compliance with Operation Handbook Policies

- Difference between security standards and actual performance

Defence plan actions

- Criteria for load shedding and pumped-storage tripping in case of under-frequency
- Comparison between defined actions and actual behavior

Re-energization

- Procedures and criteria for re-energization of the customers after load shedding
- Analyses of the applied procedures

Frequency management

- Coordination and information exchange between TSOs
- Security analysis of the impact of any change in frequency mode management
- Delays for action

Generation behaviour

- Criteria for generation islanding in case of frequency deviations
- Level of compliance of generation units with currently applicable standards

Coordination between TSO and the generators connected to its grid

- Awareness of the program schedules before and during operation time: information from generators about their programs and modifications for the following hours
- Capabilities of modulation of the generation programs by the TSO
- Possibilities of modulation of wind power under emergency conditions
- Level of real time information and control over the generation connected to the distribution grid

Stability conditions of the UCTE system before the sequence of events on 4 November

Training of dispatchers
Determination of the accuracy and completeness of dispatchers training in terms of:

- procedures and tools
- co-ordination with neighbouring TSOs

Recommendations for improvement of procedures at the level of individual TSOs and security standards at the level of UCTE

APPENDIXES 10

10. 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 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
AT	APG
BA	ISO BiH
BE	Elia System Operator
CH	ETRANS
CS	JP EMS
CZ	CEPS
DE	E.ON Netz
	Vattenfall Europe Transmission
	EnBW TNG
	RWE Transportnetz Strom
ES	REE
FR	RTE
GR	HTSO/DESMIE
HR	HEP-OPS
HU	Mavir
IT	Terna
MK	AD MEPSO
NL	TenneT
PL	PSE Operator
PT	REN
RO	Transelectrica
SI	ELES
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

17. ELES (SI)

Substation A	Substation B	Number of circuits	Voltage
Gorica	Vrtojba	1	110 kV
Pekre	Maribor	1	110 kV
Maribor	Sladki Vrh	1	110 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/Güterslo h 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	
	22:10:29.417	HR	HEP	220kV KONJSKO-BRINJE tripped	Distance Protection
	22:10:29.911	HR	HEP	110kV Otocac-Licki Osik tripped	
	22:10:29	UA-W-RO	WPS-TEL	400 kV Mukacevo (UA) - Rosiori (RO) tripped (line of Western Ukraine)	
	22:10:29	HU-CS	MAVIR-JP EMS	400 kV Sandorfalva-Subotica tripped and successfuly reclosed	No tripping – Distance Protection – Successful reclosing
	22:10:29	HU	MAVIR	400 kV Sandorfalva-Paks tripped	Distance Protection
	22:10:29	HU-RO	MAVIR-TEL	400 kV Sandorfalva-Arad tripped and re-energized by reclosure of line Subotica	No tripping – Distance Protection – Successful reclosing
	22:10:29	RO	TEL	400 kV Arad-Mintia tripped	Distance 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 zone (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	

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 East (Szeged area) 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.

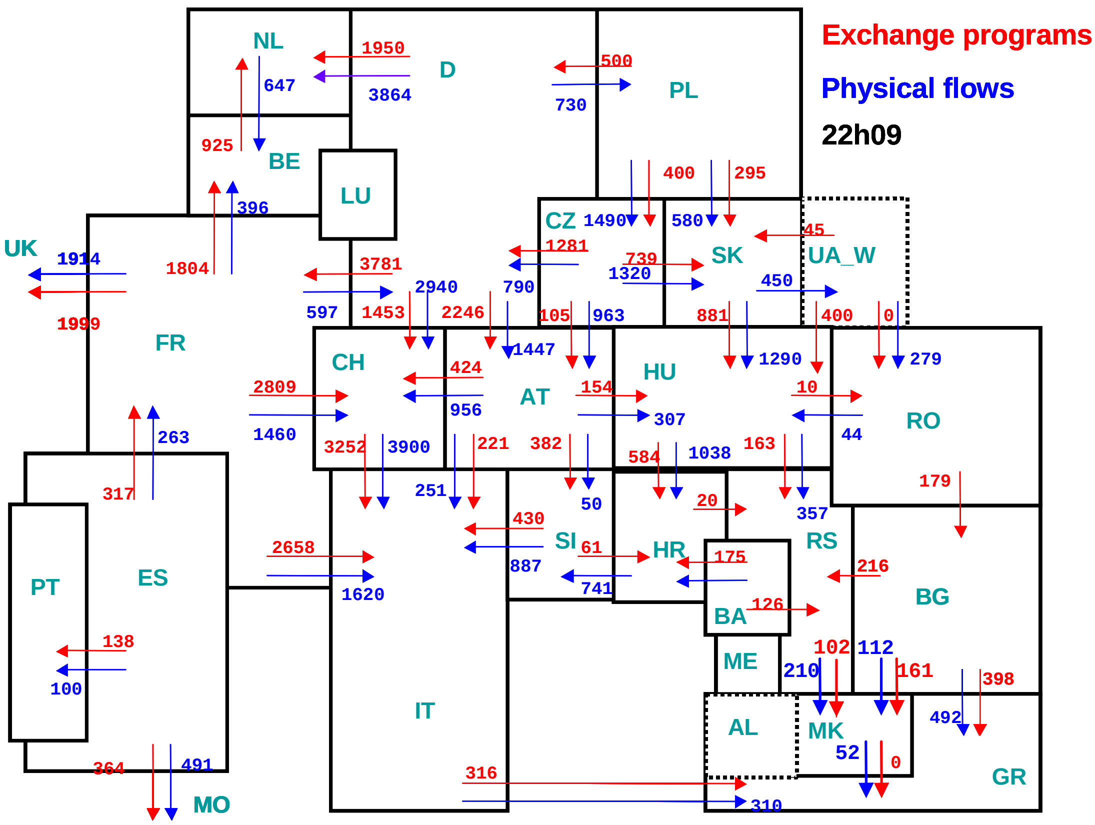
Country	**TSO Name**	**Defense Plan Description**
Portugal	REN	49.5 Hz : Tripping of pumped- storage units 49.0 Hz : 15.6% of load shedding – no delay 18.1% of load shedding – 150 ms delay 0.7% of load shedding – 500 ms delay 48.8 Hz : 3.9% of load shedding – 150 ms delay 48.6 Hz : 1% of load shedding – 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

Erratum

7 December 2006

page 15, Figure 2 should be replaced with the following:



page 26, Figure 8
to be added: Generation tripped in HR (West): 200 MW;
and accordingly: Generation tripped, total: 10 935 MW

page 26
is: A total of about 16 400 MW was started…
should be: A total of about 16 800 MW was started…

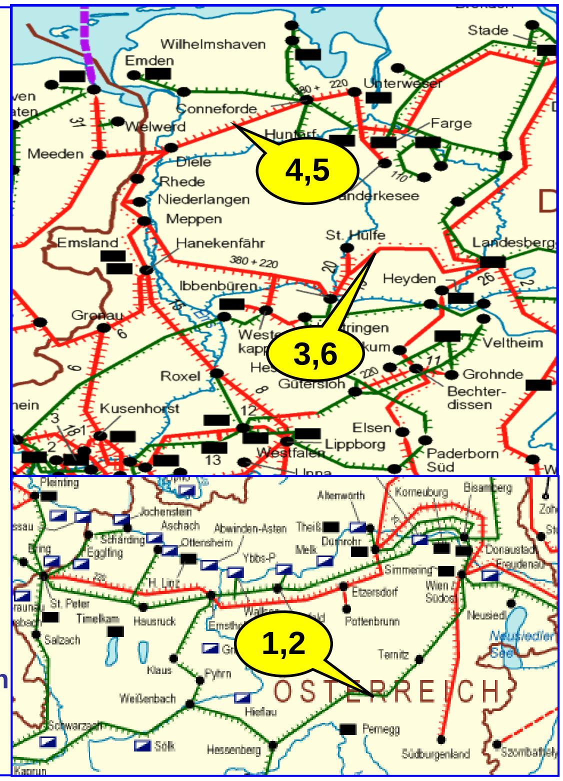
page 27, Figure 9
is: GENERATION total: 16 378 MW
should be: GENERATION total: 16 819 MW

page 33
is: (double circuits of 380 kV line Barwalde - Schmolln for a few seconds up to 126 % of the permanent transport capability)
should be: (single circuit of 380 kV line Remptendorf - Röhrsdorf 574 for a few seconds up to 126 % of the permanent transport capability)

page 37, reference 10
is: KESH and EPCG are not included
should be: KESH is not included

page 42, Figure 26 should be replaced with the following:

1. **22:34:59 (APG time: 22:36:05); trial switching on of the 220 kV Ternitz – Hessenberg, tripped immediately due to Δf = 250mHz**
2. **22:28:57 (APG time: 22:36:35); trial switching on of the 220 kV Ternitz – Hessenberg; tripped immediately due to □f = 240mHz**
3. **22:40:06 (E.ON time: 22:40:03, RWE: 22:40:09) trial switching on of the 380 kV Wehrendorf – Landesbergen; tripped due to oscillations**
4. **22:40:27 (E.ON time: 22:40:25); trial switching on of the 380 kV Conneforde – Diele; tripped due to oscillations**
5. **22:46:23 – 22:46:27 (E.ON time: 22:40:24 – 22:46:29); switching on 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**
6. **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 Wehrendorf – Landesbergen; tripped due to oscillations after 3 s.**



page 50 (cover page)
is: RESULTS AND GENERAL CONCLUSIONS
should be: RESULTS AND INTERIM CONCLUSIONS

Appendix 1, represented countries and TSOs
to be added: BG NEK

Appendix 3
position 8 in the table should be replaced with the following:

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 (UA) - Rosiori (RO) tripped (line of Western Ukraine)	
	22:10:29	HU	MAVIR	400 kV Sandorfalva-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-CS	MAVIR-JP EMS	400 kV Sandorfalva-Subotica tripped and successfully reclosed, continuing to supply the consumers' island of 120 MW around Sandorfalva	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

position 11 should be completed with following items:

11	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
is: MAVIR East (Szeged area)
should be: MAVIR

Contact

Boulevard Saint-Michel, 15
B-1040 Brussels – Belgium
Tel +32 2 741 69 40 – Fax +32 2 741 69 49

info@ucte.org
www.ucte.org