ERGEG Interim Report on the lessons to be learned from the large disturbance in European power supply on 4 November 2006

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Executive summary

On Saturday, November 4, 2006 the UCTE power system was affected by a serious system disturbance originating from the North German transmission grid. The disturbance had its starting point in Germany, but subsequently large parts of the European power systems interconnected in the UCTE synchronous area suffered from it. After the tripping of many high voltage lines the UCTE grid was divided into three islands (West, North East and South East). This resulted in significant power imbalances and frequency deviations in each island.

ERGEG has undertaken a detailed analysis of the incident and established an Ad Hoc Working Group. Views in this ERGEG Interim Report are based on facts delivered by Transmission System Operators (TSOs) either directly to national regulatory authorities or within own published reports. Additionally, conclusions drawn here are rooted in an analysis of other recent large scale disturbances and blackouts; the 2005 ERGEG recommendations on the UCTE Operation Handbook which was published at the XI Florence Forum in September 2005, and an internal ERGEG report on the required cooperation and coordination between TSOs.

The interim report identifies a number of important lessons that can already be drawn. These lessons relate to the security and reliability of Europe's electricity network operations. They are to be considered of central importance. Conclusions call for an immediate and comprehensive response from the European institutions and from the TSOs together with the national energy regulators and CEER/ERGEG at European level.

The recommendations fall under two broad headings: (1) There is a need for an improved legal and regulatory framework to minimize the risk of future interruptions. (2) Measures by TSOs themselves to secure effective coordination and cooperation among each other are required. This must take place under strict regulatory oversight.

The Framework

The events of November 4 uncover again a major legal and regulatory gap in Europe's electricity market. The operational security rules of the interconnected electricity network are not embedded within a Europe-wide operational and legal framework. An integrated EU Grid requires such a legally binding framework based on fully effective compliance, monitoring and collaboration. Such a framework can only partially be achieved under Regulation (EC) 1228/2003, i.e. mainly in respect of TSO to TSO coordination and collaboration. Further to the Regulation, additional legal steps might be needed in implementing accordingly the provisions from the Electricity Directive 2003/54/EC and Security of Supply Directive 2005/89/EC. There exists particularly need for detailed and specific obligations placed on TSOs in relation to the coordinated operation of the networks across the Internal Energy Market and to provide for information exchange between TSOs. TSOs must be clearly accountable to regulators and also publicly in respect of the effective operation of the networks they run, and for the way in which networks interact.

The application of such framework including the legally binding operational security rules will be vital as a fully integrated electricity market emerges.

The role of TSOs

A second broad category that relates to the obligations on and actions required from the TSOs to enhance security to the operation of integrated power systems in Europe has also been identified. Actions are essential to resolve these concerns in order to meet the requirements of Article 9 c) and d) of the Electricity Directive 2003/54/EC and the Security of Supply Directive 2005/89/EC which deals (in Article 4) with operational network security, including the joint preparation of emergency plans with agreed protocols for coordinated actions and responsibilities by TSOs within a synchronous area. The development and regular testing of restoration plans should also be mandatory for all involved TSOs.

Much higher standards of coordinated real-time security assessment and control are needed from TSOs to facilitate secure network operation in synchronous areas. These rules will have to be precisely and uniformly defined. Implementation of these rules must be monitored by regulators. More effective communication and information exchange between TSOs will provide an essential platform to improve system operator situational awareness. They would also allow more effective operational planning, thereby enhancing the coordination of operational system security within the synchronous areas.

Exchange of real-time data among neighbouring TSOs must be precisely defined and duly implemented. This needs to be done in all the details, consistently, and in the most efficient way by all TSOs. The scope and quality of data exchanged should also allow the standard and state-of-the-art power system control applications to run reliably on a wider topology basis. Harmonization of data standards is also essential if the quality of information is to be improved thereby promoting swift and effective information exchanges between system operators. Joint operator training programs and decision support systems will further improve the operational security of the networks.

It should be ensured that there exists real-time information exchange and co-ordination between TSOs and DSOs about generators connected to distribution network.

This Interim Report will be followed by the Final Report in early February 2007. The 2007 Work Program of CEER and ERGEG sets out in more specific terms how CEER and ERGEG intend to go about delivering a properly researched and effective response to the challenges ahead.

1 Introduction

On Saturday, November 4, 2006 the UCTE interconnected grid was affected by a serious incident originating from the North German transmission grid. The disturbance had its starting point in Germany, but subsequently a major part of Europe suffered from it. After the tripping of many high voltage lines the UCTE grid was divided into three islands (West, North East and South East) and this resulted in significant power imbalances in each island.

A number of investigations have been undertaken so far. The TSO operating the grid where the incident originated undertook an immediate investigation and published a report on November 14, 2006.[1] Also, UCTE set up a tasks force to evaluate the events. The UCTE interim report has been published on November 30, 2006.[2] Additional national reports have been announced.

This report sets out ERGEG's preliminary view on the disturbance across the UCTE system on November 4, 2006. Data presented here have been collected by ERGEG members from TSOs and drawn from the reports already available publicly. Consequently, conclusions drawn here fully depend on the data delivered and/or presented by TSOs in the UCTE region. While there is no reason to doubt the corrected of TSOs this dependency has to be noted. ERGEG members did not perform independent audits to check the validity of the information provided by the TSOs.

In order to give a pan-European overview of the events, the events in most of the affected countries has been evaluated. This procedure allows for an in depth analysis of the incidents and the lessons to be learned from them. It is important to note that the goal of this ERGEG report is to reveal which consequences at a European level need to be drawn. ERGEG is fully aware that TSOs themselves have started investigations. Also, a number of national regulators are preparing their own evaluation and analysis of what happened during that night.

As several investigation projects have been started this report by ERGEG focuses on the European aspects of the disturbance. It is not the intention of this report to pre-empt or to replace any national report done by national regulatory authorities or other competent authorities. However, ERGEG believes that its contribution on this issue is valuable, particularly in view of the currently ongoing process of the strategic energy review started by the European Commission. ERGEG can give a truly independent view from a European perspective. Consequently, the report will present recommendations that focus on further actions at the European level.

The report is structured as follows. As a starting point the report summarizes the events on November 4, 2006. Based on this an assessment is given which shows that the current framework does not suffice to reliably prevent future disturbances. This leads to the final chapter which proposes changes to reduce the risk of pan-European blackouts or disturbances for the future.

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1 E.ON Netz Report on the status of the investigations of the sequence of events and causes of the failure in the continental European electricity grid on Saturday, Nov. 4, 2006 after 10:10 pm, Investigation status as of Tuesday, Nov. 14, 2006, 10:00 hours; http://www.eon-netz.com/Ressources/downloads/BerichtBNetzA_englisch.pdf

2 UCTE Interim Report, System Disturbance on 4 November 2006; http://www.ucte.org/pdf/News/IC-Interim-Report-20061130.pdf

2 Summary of the incident

The incident of November 4, 2006, is described in detail in the reports already published by Eon TSO and by UCTE. In terms of technical analysis, there seems to be no need for an additional appreciation of the sequences before, during, and after the disturbance by ERGEG. In order to understand the following assessment and the conclusion drawn based on this assessment, however, a brief summary of the events is useful and, consequently, presented in this main part of the report. A more thorough description can be found in Annex 1, including the necessary references to specific sources of data.

During the system disturbance the UCTE system split into three parts. In South-Western Europe frequency dropped to levels around 49 Hz and major parts of load were shed. In South Eastern Europe a slighter decrease in frequency down to 49.7 Hz was experienced. In North Eastern Europe a rather large increase in frequency up to 50.4 Hz could be seen.

On September 18, 2006, the shipyard Meyerwerft, located on the River Ems, requested from Eon TSO the shutdown of the Conneforde – Diele 380 kV double line for the transport of the ship *Norwegian Pear* on the River Ems to the North Sea on November 5 at 01:00 am. The shutdown of the electric line is mandatory in such cases to prevent possible hazards when parts of a ship approach the electric line. At Meyerwerft's request of November 3, 2006, Eon TSO agreed to move forward the switch off of the Conneforde – Diele line by three hours to 10:00 pm on November 4.

At 09:29 pm on November 4, 2006, Eon TSO performed a simulation calculation for the scheduled switching off of the line over the River Ems. This simulation was based on data of the current state of the grid. The control system did not signal any limit value violations in this case. Because of the empirical evaluation of the grid situation, Eon TSO assumed that the N-1-contingency would be met in the system. A separate calculation of N-1-contingency of the network after the switch-off the line over the River Ems, however, was not performed. At 09:38 pm Eon TSO switched off the 380-kV Diele – Conneforde lines over the River Ems. As expected, the power flow was redistributed to other, more southerly located lines which are also running in East – West direction.

From the data presented by UCTE the power flow on the Landesbergen – Wehrendorf line increases over time beginning roughly at 10:01 pm. At 10:06 pm, the current on the line Landesbergen – Wehrendorf had increased to approx. 1900 A. Thus, the safety limit value of RWE TSO protection – 1,800 A as specified by RWE TSO – was exceeded on this line. At 10:07 pm, RWE TSO and Eon TSO jointly established after a call of RWE TSO that the safety limit value was exceeded and thus immediate intervention were required to restore safe grid operation.

Eon TSO immediately made an assessment of corrective switching measures. Coupling/interconnection of the busbars in the Landesbergen substation was considered suitable for this. At 10:10:11 pm, Eon TSO performed the coupling, without any further coordination with RWE TSO. The line Landesbergen – Wehrendorf was switched off two seconds later, at 10:10:13 pm, by the automatic protective device due to overload. The cascading effect continued towards the south and finally resulted in a separation of the entire UCTE grid into three partial sub-grids.

Many of the smaller generation units automatically reconnected to the grid when conditions of voltage and frequency were within the range of acceptance. As these small units typically are decentralized units, TSOs did not control the reconnection of these units. Apart from these problems, TSOs in Germany started 2.300 MW under their control.

In the over-frequency countries (Czech Republic, Poland, Slovakia, Ukraine, and parts of Hungary, Austria, and Germany) load and generation balance operational planning for November 4, 2006, did not indicate any problems. No congestions were found for the time of the disturbance during the operation planning phase. The network situation was N-1 secure, the planned disconnections did not cause any violation of the network security.

The maximum frequency occurred immediately after the disturbance, at 10:10 p.m. The value of the frequency was over 50.5 Hz most of the cases. It peaked at 51.4 Hz. For the following 30-40 minutes the involved areas worked with frequencies ranging from 50.3 to 50.4 Hz. Due to an increase in frequency in the North-Eastern “island” certain units feeding into the transmission system tripped as well as some generating units connected to the distribution network. The overloading and system instability caused line tripping in Austria which led to the split in Austrian transmission grids.

According to the UCTE interim report, restoration of the grid was hampered by the uneven absorption of the initial surplus of generation capacity in this area, mainly due to automatic reconnection of wind generation units in Northern Germany.

Two areas encountered an under-frequency situation. The countries in the Western area were Spain, Portugal, France, Italy, Belgium, Luxemburg, The Netherlands, Switzerland, Slovenia, and parts of Croatia, Austria and Germany. The countries in the South Eastern area were Yugoslav Republic of Macedonia, Montenegro, Greece, Bosnia and Herzegovina, Serbia, Albania, Bulgaria, Romania, as well as parts of Croatia and Hungary. As these countries were not seriously affected by the disturbance, no separate description of the sequence of events occurring in this area is included in this report.

The security analyses carried out by the TSOs of the Western area for November 4 have shown few violations of limit values. All the identified congestions could be managed using topologic changes or dispatching measures. Accordingly, the network situation was considered as N-1 secure by the concerned TSOs.

Just after the splitting of UCTE network into three areas, around 10:10 pm, it appeared that the Western area had a lack of power of about 9,000 MW. Consequently the frequency dropped to about 49 Hz. This drop in frequency was stopped by the triggering of automatic pumping storage units and load shedding. According to the national reports the minimum frequency may not have been exactly the same across the Western area: Spain reports a minimum of 48.95 Hz while the Netherlands points out that the frequency did not reach the threshold of 49 Hz.

It appears that not all power systems contributed to the restoration of the balance between generation and consumption in the Western area to the same extent. The tripping of generation units due to under-frequency has tended to increase the imbalance between generation and consumption. According to the UCTE interim report a total of about 10,700 MW (out of 182,686 MW) tripped in the Western area. A significant amount of generation connected to the distribution grid (i.e. wind generation and combined heat and power) tripped. Except for one thermal generation unit in Spain (about 700 MW) a few power generation units connected to the TSOs network tripped.

The Western and Eastern areas were reconnected at 10:47 pm after several attempts (no detail in the currently available regulators’ national reports). The resynchronization process was achieved at 10:49 pm. Full restoration of the UCTE synchronous area was achieved around 11:45 pm.

3 Assessment of the incident

Three core aspects of the failure can be drawn from the sequence of events as mentioned above. (1) The N-1 security rule was violated. (2) However, even in light of this violation the system disturbance might have been avoided if coordination among TSOs had been better. (3) The behaviour of many generators, particularly smaller ones and those connected at the DSO level cannot be controlled by TSOs. In addition to these three points that are covered separately in the following sections a number of other issues can be noted. These are collected in the final section of the chapter.

3.1 N-1 security rule

The first result to be noted is that after switching off the lines across the River Ems the system of Eon TSO was not N-1 secure any more as shown by the immediate triggering of the overload alarms after the line switching. It even appears that the system was very close to being not N-0 secure. The switch off would not have happened, had Eon TSO done a calculation on the N-1 contingency at that point of time. Concerning real time security analysis, TSOs behave differently throughout UCTE grid: For example, RTE and RWE TSO process a real time security analysis every 15 minutes. However, Eon TSO reports that its control centre staff evaluated the grid situation empirically. This raises the question why Eon TSO did not perform such a calculation. From the reports available so far, such a calculation is at the discretion of the grid control centre. The UCTE OH requires that “TSOs monitor at any time the N-1 criterion for their own system” (Policy 3, chapter A, requirement 1). It is a major deficiency of system security that a number of TSOs do not carry out real time security computation on a regular basis.

At the same time Eon TSO reduced the NTC value by 350 MW at the border with TenneT. It is unclear how this reduction was determined. Additionally, after moving forward the passage of the *Norwegian Pearl* the curtailment of available capacity for the first hours of November 5 did not fully match any more the time frame for the shutdown of the line across the River Ems.

At 9:39 pm, directly after the switching, Eon TSO received several alarm messages that currency values were reached. This means that the operators could have been aware that the system state was close to being not N-0 secure. This should have been followed by immediate actions. Assessment of possible corrective measures should have been done immediately. Redispatching of power plants within Germany (or counter-trading between the Eon TSO and RWE TSO areas) could have been considered. Even reconnection of the lines over the River Ems could have been an option.

At 10:07 pm, RWE TSO and Eon TSO jointly established that the safety limit value of the line Landesbergen – Wehrendorf was exceeded and thus immediate intervention were required to restore safe grid operation. Eon TSO immediately made an assessment of corrective switching measures. Coupling/interconnection of the busbars in the Landesbergen substation was considered suitable for this. The switching measure was intended for a reduction of the load flow on the line Landesbergen – Wehrendorf. Eon TSO assumed that the measure would result in a reduction of the load by about 50 MW (equivalent to 80 A). At 10:10:11 pm, Eon TSO performed the coupling. Ex-post control calculation with the last grid data record of 10:00 pm, however, shows an increase in the line load by 67 A which explains the immediately following protection triggering. Here again, a calculation of N-1 security after the switching measure might have helped. However, this late in the process with major time constraints and decisions mostly at the discretion of the grid control centre, this calculation was not performed.

In conclusion, two things must be improved. First, regular calculation of N-1 contingency every 15 minutes must be performed regularly by all TSOs. Second, there seems to be a need for a more formal procedure for conditions which call for an additional specific calculation. In order to allow for sufficient time of these calculations, the order of procedures needs to be predefined as far as possible.

However, in addition to procedural questions, ERGEG has already noted that the N-1 contingency rule is not clearly defined in the UCTE Operational Handbook. Thus, national interpretations of the rule differ an increase the difficulties of proper coordination between TSOs. In its position paper on the UCTE Operation Handbook ERGEG states that a more detailed and exact definition of the N-1 operational security criteria should be considered.[3]

3.2 TSO co-operation

Cooperation between TSOs is vital as soon as major tie lines within the UCTE system are concerned. As described above, Eon TSO undertook some effort to coordinate activities with neighbouring TSOs.

- In advance of the events, Eon TSO had informed RWE TSO and TenneT about the planned switch off.
- Eon TSO, RWE TSO and TenneT also exchanged information ahead of time on moving forward the planned switch off of the line across the River Ems.
- After switching off the line at 9:38 pm, the expected load flows essentially occurred. However, the Eon TSO received warning messages from the lines Elsen – Twistetal and Bechterdissen – Elsen which drew the attention to the fact that the current limit values were reached. Eon TSO assumed that due to thermal reserves which allowed a temporary overload of the equipment by up to 25% there was no immediate need for action. Accordingly, at 9:41 pm Eon TSO had an exchange with RWE TSO on this issue. Within the scope of this telephone call, RWE TSO drew attention to the warning value of 1,800 A on the line of Landesbergen – Wehrendorf. Also, RWE TSO informed Eon TSO about the protective tripping value of 1,990 A for this line.

However, serious lack of exchange of information can also be stated that aggravated the problem.

- Eon TSO did not take into account the differing settings of protection systems at the RWE TSO substation of the Wehrendorf – Landesbergen line. This information was communicated by RWE TSO in advance. Ignoring this information while deciding on specific measures has to be counted as main cause of the event. Here, the human factor plays an important role. However, it has to be noted that equal protection settings on all lines of all TSOs in the system may not have caused any coordination effort.
- At 10:07 pm RWE TSO and Eon TSO jointly established that the safety limit value of the line Landesbergen – Wehrendorf was exceeded and thus immediate intervention were required to restore safe grid operation. Eon TSO immediately made a qualitative

[3] ERGEG position and recommendations on the UCTE operation handbook, updated version, November 27, 2006, p. 3.

assessment of corrective switching measures. The switching measure at the Landesbergen substation was intended for a reduction of the load flow on the line Landesbergen – Wehrendorf. Eon TSO assumed that the measure would result in a reduction of the load by about 50 MW (equivalent to 80 A). At 10:10:11 pm, Eon TSO performed the coupling, without any further coordination with RWE TSO. This immediately triggered automatic tripping of numerous lines. Eon TSO states that, as a rule, intermeshing of the grid typically results in a more uniform load flow, which turned out to be a wrong assumption in case at hand. Obviously, the rules that provide guidance in the decision making process did not suffice to prevent the disturbance. Consequently, it is questionable whether more precise rules of procedures might have helped to avoid the incident.

- According to the UCTE[4] interim report no counter trading measures between the Netherlands and Germany had been discussed. Due to moving forward the switch off of the line this kind of measures may have been more useful than at the originally planned time of switch off. A common concept for – purely curative – counter trading measures might have helped avoiding the event. However, as the interconnectors between Germany and the Netherlands remained N-1 secure during the event, it is questionable whether counter trading between Germany and the Netherlands would have been effective. Counter trading measures between the Eon TSO and RWE TSO area seem to be potentially more effective. Apparently such measures have not been considered by the UCTE TSOs.
- During the disturbance information about the exact reason for the disconnections and the consequences were scarce for TSOs in the over-frequency region outside Germany. These TSOs were not aware about the separation of the system into 3 parts, neither about the place of the disconnection, the borders of the "islands" formed, nor about the start and place of the recovery of the synchronous operation. After focusing on controlling the situation the Polish TSO at 10:55 pm distributed information stating that "something" happened in Germany which caused huge disturbances.
- Except the modification asked by ETRANS concerning secondary control, there is no indication of any real time coordinated action during the restoration phase.

From the points listed a lack of coordination must be stated. Independent of whether Eon TSO did adhere to procedures required by the German Transmission Code or the UCTE Operational Handbook, it must be noted that more cooperation, better information exchange, and improved common decision making might have prevented the event. With its recommendations ERGEG wishes to assist TSOs particularly in this area.

TSOs in the UCTE area have developed the UCTE Operation Handbook (OH) in order to established harmonized rules for the operation of transmission networks. CEER and ERGEG have been analyzing the OH with respect possible and necessary improvements. The results of this study were presented by ERGEG at the XI Florence Forum in 2004,[5] and at the XII Florence Forum in 2005.[6] The regulators' position has been updated recently. The core elements of the OH

[4] UCTE interim report, p. 20.

[5] http://ec.europa.eu/energy/electricity/florence/doc/florence_11/ceer_security_rules.pdf

[6] http://ec.europa.eu/energy/electricity/florence/doc/florence_12/ergeg_position_op_handbook.pdf

that are of relevance in terms of the incidents under discussion here are summarized in Annex 2. The OH is a valuable contribution of TSOs that allows for better coordination among TSOs and more secure operation of the synchronous network.

It has to be noted that even though TSOs have established a process to monitor and ensure compliance with the OH, the OH is not legally binding in any way. Consequently, the only legally binding rules on the secure network operation currently are national.

3.3 Behaviour of generators

The tripping of small and/or distributed generation units due to under-frequency has increased the imbalance between generation and consumption. In many countries affected by the disturbance generation behaviour could not be controlled by TSOs. TSOs lack control and data about generation units as many of those are connected decentralized at the DSO level. Consequently, automatic tripping and automatic reconnection of these units may influence critical situations in a way that even increases hazards for the system altogether as TSOs do not have access to real time data of power units connected to distribution grids.

Generation from renewable energy sources and particularly wind generation is of special concern here. The systems introduced at national level are typically introduced in order to increase generation from renewable sources without creating too many barriers to entry for these units. Considering operational security of the system overall in many cases has been viewed as such a barrier to market entry. As the disturbance shows it is becomes more and more important that smaller and/or decentralized generators become part of the system security. Information provision by these generators and procedures for automatic tripping must be formulated in a way that guarantees system security and enables TSOs to control system state as far as possible.

3.4 Additional issues

In addition to the three main points mentioned above a number of other issues shall be noted here. First, the use of secondary control may have increased the imbalance between generation and consumption in some cases. Second, not all national systems contributed at the same level to restoration. Third, there are some inconsistencies in the reports available so far. From the data presented by UCTE the power flow on the Landesbergen – Wehrendorf line increases over time beginning roughly at 10:01 pm. However, sudden and unforeseeable movements in power flows[7] cannot be acknowledged, neither from the data given by Eon TSO itself[8] nor from information given by other TSOs.[9] Also, the indication that wind conditions were relatively high – as mentioned in the UCTE interim report[10] – is not supported by relevant data. Rather, these values are within the normal range. According to information provided by Eon TSO to the German regulatory authority, wind feed-in was above the average value in its balancing zone, however only 50% of the maximum was seen at that time.

[7] Eon Netz report, p. 9.
[8] Eon Netz report, p. 27.
[9] For example, other German TSOs do not report any unusual development of power flows in their systems.
[10] UCTE interim report, p. 29.

4 Recommendations

The event, which resulted in the splitting of the UCTE-network and extremely low frequency values in a large part of the UCTE system is unique in the history of the UCTE-system. Many consumers were disconnected and it appears that the event could easily have led to more serious blackouts in some parts of the UCTE-system. It is worrying to note that this event was not triggered by technical failures or external events (like extreme weather conditions). Therefore it is concluded that measures are urgently necessary to avoid such disturbances in the future as far as possible.

The investigations so far have shown that a human factor played a decisive role. The effect of human factor during incidents like this should be further investigated. Three main causes for the system disturbance have been identified. The first one is the non-fulfilment of the N-1 criterion during the disconnection of Conneforde – Diele line. Before the disconnection of the Conneforde – Diele line the impact in terms of N-1 criterion fulfilment for the situation after switching off the double line was not checked by Eon TSO via a numerical calculation. The second main cause was lack of actions (before and) directly after the switching, as the system state appeared to be close to not N-0 secure. The third main cause was inappropriate regional inter-TSO coordination during the event. The initial planning for switching-off the double line was duly prepared by the directly involved TSOs (Eon TSO, RWE TSO and TenneT). However, the settings of protection devices on the both sides of Landesbergen – Wehrendorf line are different and this was not given fully attention by Eon TSO.

Generally, however, it has to be noted, that over and under frequencies caused by the incident have consequences even for a strong national network. The event resulted in an uncontrolled splitting of the UCTE network in three areas, whereas at that time none of the TSOs had a full overview of the system and none of the TSOs was aware of the amount of generation-load imbalance in its part of the system. This conclusion alone calls for more cooperation and coordination among TSOs within a single synchronous area. It even calls for a critical review of the UCTE-philosophy. The current UCTE-philosophy is based on a strong decentralized approach, where each TSO is only responsible for its control area. There is no centralized supervisory system and there are no centrally coordinated defence schemes to avoid spreading of disturbances over the UCTE-system. It is clear that the current decentralized approach has many advantages and it is also acknowledged that any changes in the operation and control philosophy of the UCTE system should be made with great prudence to avoid any worsening of the present situation. Therefore, it is recommended to analyze whether a somewhat more centralized approach to system operation and control structures could provide additional benefits.

4.1 Preliminary findings and recommendations

Based on the analysis of the sequence of the events and the assessment of problems during the incident ERGEG proposes a number of measures to decrease the probability of future blackouts and disturbances. In addition to the evaluation of the data regarding the system disturbance on November 4, 2006, ERGEG also takes into account work done in the past on related issues. The ERGEG Position and Recommendations on the UCTE Operation Handbook (XII Florence Forum 2005) has already been mentioned. Additionally, the ERGEG Electricity System Operation Task Force internal report on the required cooperation and coordination among the TSOs is of importance. Finally, lessons learned from the previous large disturbances and blackouts in Europe have been taken into account.

4.1.1 Measures for Transmission System Operators

- Operational rules should be made legally binding. Accordingly, the currently existing multilateral framework (e.g. Nordel agreement, UCTE Multilateral Agreement) should be improved. Furthermore, an efficient compliance monitoring and enforcement process is essential to strengthen the transparency and the credibility of TSO’s performance. Such a multilateral framework must contain a set of minimum standards on conflict resolution of important questions and details on the applied security criteria (such as N-1), primary and secondary load-frequency control, load shedding, coordination and cooperation, information exchange, etc.
- UCTE rules should be made more detailed and consistent to reduce the probability of future large disturbances and blackouts as far as possible. Lessons learned from recent large disturbances and blackouts should be taken into account in the revised UCTE Operational Handbook.
- TSOs in other synchronous areas, where appropriate, should revise their operational rules.
- Regular calculations of N-1 contingency shall be obligatory for all TSOs.
- The operational security rules should also include joint preparation of emergency plans with agreed protocols for coordinated actions and responsibilities by TSOs within a synchronous area. Finally, development and regular testing of restoration plans shall become mandatory for all the involved TSOs.
- Coordinated operational planning and security assessment during operational phase with network data and simulation models spanning across relevant TSOs is crucial. Coordinated real-time security assessment, and monitoring on a much higher level than today (e.g. possibly with dynamic assessments) are required among TSOs to allow secure network operation in the synchronous area.
- The UCTE philosophy of decentralized responsibility should be evaluated and the possibility to introduce more centralized and/or hierarchical system operation and control structures to support this decentralized responsibility should be analyzed. A starting point for this effort could be an improved structure for inter-TSO communication and information exchange. Effective communication and information exchange between TSOs is important. It provides an essential platform for improving system operator situational awareness. It also develops more effective coordinated operational planning and supports the coordination of operational system security, especially in synchronous areas spanning multiple control areas (TSOs). It is crucial that this exchanged information is also used in operational planning and security assessment within TSOs. Exchange of real time data among neighbouring TSOs must be specified in detail, implemented in the most efficient way and strictly followed by the TSOs and their staff involved. The scope and quality of data exchanged should also allow the standard power system control applications like state estimators, contingency analysis, etc. to run in a reliable way on a wider topology basis (i.e. including the consideration of neighbouring TSOs, too). Here, a centralized institution that provides online data on relevant aspects of the state of the grid, planned and unplanned measures at all times for all TSOs within a synchronous system may improve informational standards for all the TSOs concerned.
- Harmonisation of data standards is unavoidable to improve the quality of information, and promote effective and swift information exchange between system operators within a synchronous area.

- Joint operator training programs should be implemented. Performance of the training programs should be evaluated regularly. Training should provide approaches and methods for experienced operators (control centre staff) on how to keep the adequate level of cognitive capabilities and remain alert also during normal operational situations. An appropriate certification system should be introduced, implemented and reviewed for all TSOs.
- Finally, whereas existing for many years and e.g. in wide use in some electric power systems of Europe and USA, decision support systems for the control centre staff shall be systematically studied and accordingly implemented on a wider and standardized scale in the EU synchronous areas.

4.1.2 Legal framework and regulatory oversight

- An EU-wide formally binding legal framework for the multilateral agreements between the TSOs of the European synchronous areas mentioned above is needed in the today's electric power supply systems and markets.
- To complement the new legal instrument and the current UCTE Operation Handbook, operational security rules and a European Grid Code should be created to provide obligations on TSOs relating to:
    - coordinated operation of the networks across the Internal Electricity Market including operational planning, real time operation, emergency arrangements and inter-TSO co-operation and coordination, i.e. TSO-to-TSO rules,
    - connection rules for generation, consumption and DSOs when connected to the TSO's grid, i.e. TSO-customer rules.
- A proper regulatory oversight to enforce and oversee the legal framework and the European Grid Code should be ensured. The roles, responsibilities, and powers of national regulators should be duly organized as well as the coordination and cooperation among the national regulatory authorities when pursuing tasks related to TSO oversight and enforcement.
- In order to help TSOs overcome problems with uncontrolled generation, TSOs need improved information about availability of small generation data at TSO level. To facilitate this, rules and requirements on data submission from generators connected to distribution network to TSOs may need to be considered. This may also include the development of connection requirements for distributed generation should allow them to support power system in case of major disturbance.

4.1.3 Remaining national issues

In addition to the measures named above, some need for national improvements remains. The specifics of these national improvements need to be determined by national legislators and/or national regulators.

- Regulators and TSOs must check whether the existing national rules are sufficient. One of the issues here may also be information about and coordination with decentralized generation units. According to the UCTE TSOs lacked information about the amount of generation and the sequence of disconnection and reconnection of these units during the disturbance. Also the rules for tripping of generators in case of low frequencies should be assessed. During the disturbance, a significant amount of generation tripped in the under-frequency area, which worsened the situation considerably. This particularly applied to smaller sized, dispersed, generators. This topic is likely to become even more important because of the increasing share of such type of generators.

- Regulators must analyze compliance with existing national rules regarding issues as secure system operation, primary and secondary control, load shedding, generator tripping due to under-frequency, and system restoration.
- Apparently there is a lack of coordination between the setting of the load shedding relays and the intervention of protection of distributed generation.

The issue of information about generation of units will be solved to some extent in due time as the newly in force Guidelines on Congestion Management require that TSOs publish information on forecast and actual load.[11] The specifics of this new requirement are currently under discussion in several ERGEG Regional Initiatives. Additionally decentralized generation has to contribute to avoid or restore a critical situation and, in the case of generation connected to distribution grid, its reconnection has to be coordinated between DSOs and TSOs. Here, national TSOs need to take action to ensure also real time information exchange and coordination with DSOs. ERGEG may provide guidance on how this task might be tackled.

4.2 Final remarks

Integrated and harmonized rules for the electric power system operation are required to ensure the operational security and secure supply of the European power systems and the functioning of the Internal Electricity Market. These issues were already raised by the regulators after the Italian blackout of September 2003 without a reaction from UCTE. The recent events confirm that solving these issues is necessary for meeting of the requirements contained in the article 9 c) and d) of the Directive 2003/54/EC. Such more detailed operational rules could not only result from TSOs consensus. They might also be made legally binding. In the absence of new legislation, the most appropriate option for delivering such a framework could be to combine improved multilateral agreements (e.g. UCTE MLA) notably with regard to the TSOs' liability for insufficient reliability of power transmission with operational security rules according to the Article 8 of the Regulation (EC) 1228/2003.

Such rules (as integrated part of the Regulation, they would become immediately applicable national law in all EU member states) could set the EU-wide framework for the coherent and common operational rules and standards for interworking of the European TSOs throughout all the synchronous areas, whereas the specific technical rules (like e.g. improved UCTE OH) would then be used at the synchronous area level and made binding through the reference in the rules. It follows therefore that the rules should be based on the existing technical standards and should take into account the needs of markets and operational security.

[11] Commission Decision (2006/770/EC) of November 9, 2006, no. 5.5 (h) and 5.7.

To complement the new legal instrument, a European Grid Code should be created to provide obligations on TSOs relating to the grid access, development and maintenance of the European networks to specified harmonized standards.

Tension associated with the competing objectives of maximizing capacity for trade and maximizing contingency reserves to ensure transmission system security as already required by article 6(3) of the Regulation (EC) 1228/2003 may need to be addressed in this context. The appropriate decisions should be taken within the time allotted (by 24 Feb 2008) for the implementation of the Directive 2005/89/CE where article 4 deals with operational network security.

A proper regulatory oversight to enforce and oversee the legal framework and the European Grid Code should be ensured. The roles, responsibilities and powers of national regulators should be duly organized as well as the co-ordination and co-operation among the national regulatory authorities when pursuing tasks related to TSO oversight and enforcement. Implementation of integrated and coordinated system operation in the European transmission grids is likely to raise organizational, legal, technical and local challenges, particularly across synchronous areas spanning several jurisdictions.

Finally, it has to be noted that many of the recommendations have already been identified in CEER's response to the European Commission's Green Paper.[12] Here, a number of detailed actions were identified, including placing European obligations on TSOs to develop and have in place standards, approved by regulators; developing a European Grid Code to specify the responsibilities of TSOs including standards on development, maintenance and operation of the networks as well as information sharing and information control; implementing a central institution that facilitates cooperation between TSOs at EU-level.

This shows that regulators are fully aware that the issues at hand are not new and that they need to be tackled immediately. CEER and ERGEG will continue to put considerable effort into the necessary improvements. An ERGEG Electricity Transmission Networks Task Force has been established in the ERGEG Work Program 2007[13] to deal with the electricity internal market issues such as European Grid from the horizontal (i.e. TSO-to-TSO cooperation) perspective of the security rules (Security and Reliability Guidelines according to the Article 8 of the Regulation) and the vertical (i.e. grid access) perspective with the development of the EU Grid Code.

Deliverables from this work will be an analysis of the need and ways to proceed towards harmonized or at least compatible rules for grid access and for adequate TSO interworking and cooperation in terms of operational security within the context of the Internal Electricity Market. Here the scope and details of the framework for the EU Grid Code and main contents of operational security rules cf. Article 8 of the Regulation 1228/2003/EC will be elaborated. The EU Grid Code will consist of the set of coherent and common grid access rules to be used EU-wide. The operational security rules will include the objectives and scope for, and set of coherent and common operational rules and standards for the interworking of the European TSOs, based on the existing technical standards and taking into account the needs of the market and operational security.

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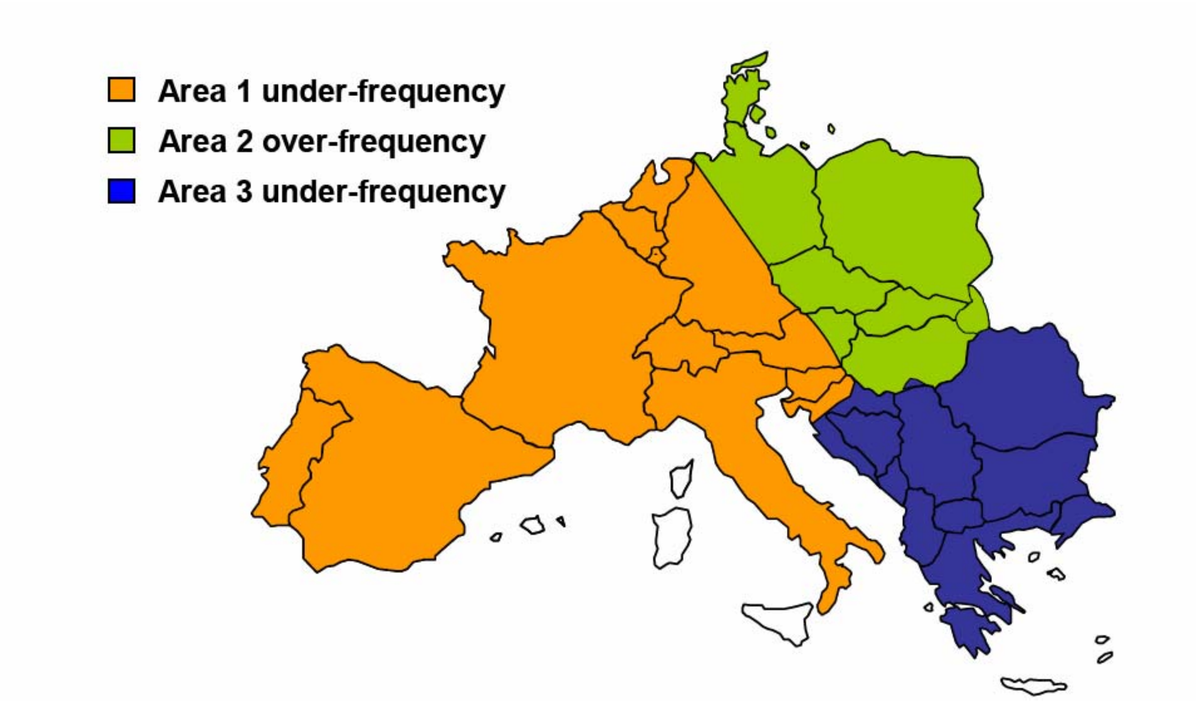
12 CEER response to the Energy Green Paper, July 11, 2006; http://www.ceer-eu.org/portal/page/portal/CEER_HOME/CEER_PUBLICATIONS/CEER_DOCUMENTS/CEER-ResponseToGP_2006-07-11.pdf

13 http://www.ergeg.org/portal/page/portal/ERGEG_HOME/ERGEG_DOCS/ERGEG_WORK_PROGRAMME/C06-WPDC-06-04_CEER-ERGEG_WP2007_Public.pdf

Annex 1: Analysis of planned and real time operation during the event

This more detailed description of events is based on information gathered from TSOs and from publicly available documents. ERGEG has not independently checked the correctness of the data presented by TSOs.

During the system disturbance the UCTE system split into three parts. In South-Western Europe frequency dropped to levels around 49 Hz and major parts of load were shed. In South Eastern Europe a slighter decrease in frequency down to 49.7 Hz was experienced. In North Eastern Europe a rather large increase in frequency up to 50.4 Hz could be seen. For clarity of analysis, the consequences of these different developments are presented and evaluated separately. Additionally, the situation within Germany is described in more detail. While moving through the event in terms of the sequence of the events, this geographical separation of analysis will be maintained.



Source: UCTE interim report, p. 21

1 The situation in Germany[14]

1.1 Operational planning before the event

On September 18, 2006, the shipyard Meyerwerft, located ton the River Ems, sent a written request to Eon TSO regarding the shutdown of the Conneforde – Diele 380 kV double line for the transport of the ship *Norwegian Pearl* on the River Ems to the North Sea on November 5 at 01:00 am.[15] On October 27, 2006, the requested switch off was provisionally approved by Eon TSO. This decision was based on an analysis of the load situation using a standard planning data record. According to Eon TSO the analysis – based on the information available at that time – did not reveal any indication of a violation of the N-1 contingency. Thus the final approval of the switch off was subject to a further analysis of the grid situation immediately before the switch off of the electric line. Eon TSO had coordinated the decision neighbouring grid operators. Also, Eon TSO had reduced capacity on its interconnector to Tennet for November 5 between 00:00 and 06:00 am, obviously in order to alleviate possible problems. On November 3, 2006, Meyerwerft requested to move forward in time the passage of the ship by three hours to 10:00 pm on November 4. Eon TSO agreed to this.

According to the report publish by Eon TSO,[16] approximately 13,700 MW of electricity were consumed in Eon TSO's area around 09:30 pm. Generation amounted to a total of approximately 14,100 MW, 3,200 MW of which from wind. Transits were at a level of approximately 7,300 MW. Wind power feed-in was expected to increase continuously to 4,500 MW at 03:00 am on November 5. The power flows took place predominantly in the south-westerly direction. Additionally, single electric lines as well as equipment in Eon TSO's substations were switched off at this time to enable the performance of building work for grid reinforcements. These measures were known at Eon TSO and taken into account in the simulation calculations in online operation.

1.2 Sequence of events

At 09:29 pm, Eon TSO performed a simulation calculation for the scheduled switching off of the line over the River Ems. This simulation was based on data of the current state of the grid. No limit value violations were indicated from this simulation in this case. Because of the empirical evaluation of the grid situation, Eon TSO assumed that the N-1-contingency would be met in the system. A separate calculation of N-1-contingency of the network after the switch-off the line over the River Ems, however, was not performed. In a telephone call at 9:30 pm both Eon TSO and RWE TSO established that the results of the respectively performed simulation calculations did not provide a reason for not performing the switching. In another telephone call at 09:33 pm, additional coordination was established with TenneT.

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[14] This part mainly draws on the report published by Eon TSO, http://www.eon-netz.com/Ressources/downloads/BerichtBNetzA_englisch.pdf.

[15] According to Eon TSO, the switch off of the electric line is mandatory in such cases to prevent possible hazards when ships approach the electric line. The distance between the line and the ship is too close to allow safe passage of any ship of this size underneath a line in operation. There were no other reasons for switching off the electric line. According to Eon TSO the line has been switched off over the River Ems for Meyerwerft ship transportations a total of fourteen times since 1995.

[16] Eon Netz report, p. 8.

Afterwards, at 09:38 pm Eon TSO switched off the 380-kV Diele – Conneforde line over the River Ems. As expected, the power flow was redistributed to other, more southerly located lines which are also running in East – West direction. According to Eon TSO[17] the actual flows of the grid in the region were essentially in accordance with the expectations on the basis of the simulation calculation.

At 09:39 pm, i.e. immediately after the switching, Eon TSO received several warning messages from the lines Elsen – Twistetal and Elsen – Bechterdissen that currency limit values were reached. Thermal reserves allow a temporary overload of the equipment by up to 25% according to Eon TSO internal rules. Accordingly no immediate need for action was assumed.

In a telephone call between Eon TSO and RWE TSO at 09:41 pm RWE TSO pointed out the safety limit value of 1,800 A on the line Landesbergen – Wehrendorf, the line which later was the first to fail. RWE informed of its protective limit value of 1,990 A at the Wehrendorf substation. At that time, the load of the line Landesbergen – Wehrendorf was approx. 1,780 A. At 09:42 pm Eon TSO issued the so-called disposition permission for the transfer of the ship.

Additional telephone calls between Eon TSO, RWE TSO and Vattenfall Europe TSO at 09:46 pm, 09:50 pm and 09:52 pm, did not bring about any other result. The situation was considered tense. According to Eon TSO there was no immediate need for action. Yet, possible reactions were discussed in case of a further aggravation of the situation.

Until 10:06 pm the current on the line Landesbergen – Wehrendorf had increased to approx. 1,900 A. Thus, the safety limit value of RWE TSO protection (1,800 A) was exceeded on this line. At 10:07 pm, RWE TSO and Eon TSO established that immediate intervention was required to restore safe grid operation. Eon TSO assessed possible corrective switching measures. Coupling/interconnection of the busbars in the Landesbergen substation was considered suitable for this. Eon TSO assumed that the measure would result in a reduction of the load by about 50 MW (equivalent to 80 A). At 10:10:11 pm, Eon TSO performed the coupling, without any further coordination with RWE TSO.

According to the Eon TSO report,[18] the line Landesbergen – Wehrendorf tripped two seconds later, at 10:10:13 pm, by the automatic protective device. The resulting additional power flow shifts lead to an overload of the 220 kV line Bielefeld/Ost – Gütersloh of RWE TSO which was also switched off automatically with delay of another two seconds. Another four seconds after that, at 10:10:19 pm, the automatic protective devices of the 380 kV line Bechterdissen – Elsen were triggered. The cascading effect continued towards the south and finally resulted in a separation of the entire UCTE grid into three parts.

Within the Western part of Germany, which was part of the under-frequency block about 2,400 MW were automatically shed. Additionally, Eon TSO shed about 240 MW of pump storage. A number of smaller generation units tripped immediately after the initial fall of frequency. According to the UCTE report, roughly 40% of these units were wind power units.

[17] Eon Netz report, p. 15.
[18] Eon Netz report, p. 10.

1.3 Restoration of the grid

Many of the smaller generation units automatically reconnected to the grid when conditions of voltage and frequency were within the range of acceptance. As these small units typically are decentralized units, TSOs did not control the reconnection of these units. Apart from these problems, TSOs in Germany started 2,300 MW under their control.

Reconnection of the lines that shut out did not go ahead without problems. As the information provided by Eon TSO shows, it took two attempts to reconnect the Conneforde – Diele and the Wehrendorf – Landesbergen lines.[19] The Western under-frequency region and the Eastern under-frequency region were finally resynchronized at 10:47 pm.

2 The situation in the over-frequency countries affected20

The over-frequency countries are Czech Republic, Poland, Slovakia, Ukraine, and parts of Hungary, Austria, and Germany. Rather than analyzing the event on a country-by-country presentation, a summary of all the countries involved is presented here.

2.1 Operational planning before the event

In terms of the load and generation balance operational planning for November 4, 2006, did not indicate any problems. Sufficient power reserves were planned throughout the day. Also, the output in primary, secondary and tertiary control, quick-start, and operating reserve was sufficient from the perspective of the TSOs of the surplus area.

The contingency analysis performed in some cases was based on the Day Ahead Congestion Forecast (DACF) models (on the common UCTE database). This analysis did not indicate any problems for the interval of time in which the failure then occurred.

No congestions were found for the time of the disturbance during the operation planning phase. The network situation was N-1 secure, the planned disconnections did not cause any violation of the network security.

2.2 Sequence of events

The maximum frequency occurred immediately after the disturbance, at 10:10 pm. The value of the frequency was over 50.5 Hz most of the cases. It peaked at 51.4 Hz.[21] During the following 30-40 minutes the involved areas worked with frequencies ranging from 50.3 to 50.4 Hz.

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[19] Eon Netz report, p. 37.

[20] This section mainly draws on reports on the disturbance collected by national regulators from respective TSOs and assembled and merged by ERGEG.

[21] UCTE interim report, p. 29.

Due to an increase in frequency in the North-Eastern "island" certain units feeding into the transmission system tripped (in Czech Republic 611 MW, in Hungary 595 MW, in Austria around 1,500 MW, in Slovakia 515 MW), also some generating units connecting to the distribution network.
Due to an increase in frequency in the North-Eastern "island" certain units feeding into the transmission system tripped (in Czech Republic 167 MW, in Hungary 595 MW, in Austria around 1,500 MW, in Slovakia 515 MW), also some generating units connecting to the distribution network (in Czech Republic 444 MW)

There was no need for consumers' restriction. Loss of some limited consumers' supply was caused by frequency increase and fail operation of distribution network.

2.3 Restoration of the grid

According to the UCTE interim report, restoration of the grid was hampered by the uneven absorption of the initial surplus of generation capacity in this area, mainly due to automatic reconnection of wind generation units in Northern Germany.[22] Finally, at 11:30 pm the power systems in this part of Europe came back to normal operational conditions.

3 The situation in the under-frequency countries affected23

Two areas encountered an under-frequency situation. The countries in the Western area were Spain, Portugal, France, Italy, Belgium, Luxemburg, The Netherlands, Switzerland, Slovenia, and parts of Croatia, Austria and Germany. The countries in the South Eastern area were Yugoslav Republic of Macedonia, Montenegro, Greece, Bosnia and Herzegovina, Serbia, Albania, Bulgaria, Romania, as well as parts of Croatia and Hungary. As these countries were not seriously affected by the disturbance, no separate description of the sequence of events occurring in this area is included in this report.

3.1 Operational planning before the event

The security analyses carried out by the TSOs of the Western area for November 4 have shown few violations of limit values. All the identified congestions could be managed using topologic changes or dispatching measures. Accordingly, the network situation was considered as N-1 secure by the concerned TSOs. Security studies take into account the possible contingencies affecting the TSOs own network including tie lines. External lines are sometimes considered by TSOs in case their failure may cause security problems on their own network. Sufficient active power reserves were planned throughout the day according to the TSOs.

Besides, TenneT reports having taken action (using a phase shifter) to retain an N-1 situation on an interconnection without specifying if a real time security analysis had been performed prior to this decision.

[22] UCTE interim report, p. 31.

[23] This section mainly draws on reports on the disturbance collected by national regulators from respective TSOs and assembled and merged by ERGEG.

3.2 Sequence of events

Because of the tripping of the line Wehrendorf-Landesbergen between RWE TSO and Eon TSO further lines were overloaded and tripped in cascade. This lead to a split of the UCTE interconnected network. In Germany, 2 lines tripped between RWE TSO and Eon TSO and 12 inside the Eon TSO network. In Austria, 5 lines tripped inside the APG network. As a result the networks of Eon TSO and APG were split. 2 lines tripped between Hungary and Croatia. Besides, 2 lines tripped inside Croatia, and 1 line tripped between Bosnia Herzegovina and Croatia. As a result the UCTE network was split in 3 areas.

Concerning the interconnection with other systems, the two 400 kV transmission lines between Spain and Morocco tripped due to under-frequency protection setting off in Morocco. Also, the AC link between Italy and Sicily tripped while the DC links from France to UK, from Italy to Sardinia, and from Italy to Greece remained in operation. No other line tripping has been reported by the TSOs of the Western area.

Just after the splitting of UCTE network into three areas, around 10:10 pm, it appeared that the Western area had a lack of power of about 9,000 MW. Consequently, the frequency dropped to about 49 Hz. This drop in frequency was stopped by the triggering of automatic pumping storage units and load shedding. It seems that the minimum frequency may not have been exactly the same over the Western area: Spain reports a minimum of 48.95 Hz while the Netherlands points out that the frequency did not reach the threshold of 49 Hz.

The active power reserves required by UCTE rules are reported to have been available just before the disturbance. However they were insufficient to cover the power imbalance. On the whole, primary control has behaved as expected. However, the UCTE requirements for primary response are based on a single outage of 3,000 MW. In this event, there was an imbalance of 9,000 MW for only a part of the UCTE-system. Also, the implementation of the rules on primary reserve is not fully identical across the UCTE members.

Secondary control, however, in some cases tended to reduce the output of power plants. RTE, for example, switched the frequency-secondary-control to “pure frequency mode” just after the disturbance and used secondary reserve in the same conditions as the primary reserve.

Typically, pumped-storage units trip at a frequency of 49.5 Hz. According to the UCTE report[24] around 1,600 MW of pumped storage was shed:

Country (TSO)	Pumped-storage shedding
Austria(West)	297 MW
Germany (EnBW TSO)	457 MW
Germany (Eon TSO)	240 MW
Spain (REE)	156 MW (auto) 414 MW (manual)
France (RTE)	0 MW (no pump was functioning)

[24] UCTE interim report, p. 25.

In order to re-establish the balance between generation and consumption, automatic load-shedding was performed as well. According to UCTE rules, load-shedding should start step by step at the frequency of 49 Hz. The figures as given in the UCTE interim report[25] are as follows:

Country (TSO)	Load shed	% of consumption (incl. pumped-storage shedding)
Austria	127 MW	5.4 % (18 %)
Belgium (ELIA)	700 MW	8 %
Croatia (HEP)	199 MW	14 %
France (RTE)	6,260 MW	11 %
Germany (EnBW TSO)	158 MW	2 % (8 %)
Germany (Eon TSO)	400 MW	8.75 % (14 %)
Germany (RWE TSO)	2,000 MW	13 %
Italy (Terna)	2,350 MW (auto) 700-800 MW (manual)	6.6 %
Luxembourg (Sotel operated by ELIA)	120 MW	
Netherlands (TenneT)	190 MW	1.9 %
Portugal (REN)	1,101 MW	19 %
Slovenia (ELES)	113 MW	8 %
Spain (REE)	2,100 MW	7.64 % (10 %)
Switzerland (ETRANS)	7 MW	0.1 %
Total	**15,825 MW (auto)**	

The amounts of load shed sometimes slightly differ between ERGEG national reports and the UCTE interim report. It seems that UCTE values may also include loads that have tripped due to under-frequency protection (for example 150 MW for TenneT).

The tripping of generation units due to under-frequency has tended to increase the imbalance between generation and consumption. UCTE reports that a total of about 10,700 MW (out of 182,686 MW) tripped in the Western area.[26] A significant amount of generation connected to the distribution grid (i.e. wind generation and combined-heat-and-power) tripped.

Except for one thermal generation unit in Spain (about 700 MW) no high power generation unit connected to the TSOs network tripped. In synthesis, at the end of the automatic response of the system when the fall of the frequency ceased, the following power balance (in round figures) held:

- 9,000 MW of import from east area,
- 10,000 MW of generation lost when the frequency reached 49.5 Hz;

[25] UCTE interim report, p. 25.
[26] UCTE interim report, p. 26.

- 16,000 MW of shed load and pumping loads;
- 3,000 MW from primary regulation of generators and load self-reduction.

3.3 Restoration of the grid

The Western and Eastern areas were reconnected at 10:47 pm after several attempts (no detail in the currently available regulators' national reports). The full resynchronization process was achieved at 10:49 pm. Supply has been restored gradually thanks to the generation units started by the TSOs after the event (in particular hydraulic generation). According the UCTE interim report, the following amounts of generation were started:[27]

Country (TSO)	Generation units started
Austria	650 MW
Belgium (ELIA)	320 MW
Croatia (HEP)	77 MW
France (RTE)	4,955 MW
Germany (EnBW TSO)	1,058 MW
Germany (Eon TSO)	418 MW
Germany (RWE TSO)	1,200 MW
Italy (Terna)	2,800 MW
Netherlands (TenneT)	140 MW
Portugal (REN)	1,015 MW
Slovenia (ELES)	90 MW
Spain (REE)	3,696 MW
Switzerland (ETRANS)	50 MW
Total	**16,094 MW**

In the Western area full restoration was achieved at 11:45 pm.

[27] UCTE interim report, p. 27.

Annex 2: Rules and Procedures of the UCTE Operation Handbook

Within the scope of workshops and discussions with UCTE on Operation Handbook (OH) in 2004 and 2005 and in preparation of the ERGEG Position and Recommendations on the necessary improvements in the OH presented at the XII Florence Forum in September 2005[28] ERGEG has made a comparative overview of the operational security and reliability rules in the synchronous areas of the EU. Whereas this overview was an ERGEG internal work and has not been published, the key aspects of the UCTE synchronous area are summarized below using the results of that overview.

Security and reliability rules / aspects	Implementation in the UCTE OH and other UCTE framework
Transmission planning - principles	*No direct equivalent in the OH*
Transmission capacity – definition of capacity	OH Policy 4 B → Capacity assessment
Transmission planning for interconnections between regions	*No direct equivalent in the OH*
Dimensioning criteria for planning of transmission network - principles for planning	- UCTE System Adequacy Forecast (to some extent) - OH Policy 3 A → N-1 criterion
Methods, models and tools for system analysis	OH Policy 3 D and F → Stability calculation, Information exchange for power system computation;
Operational security standards	OH Policy 3 A → N-1 security criterion OH Policy 3 C → Network fault clearing OH policy 1 A, B & C → load frequency control OH Policy 3 B → voltage control and reactive power management OH Policy 4 B → Capacity assessment
Balancing - Requirements - Regulation price - Balance power exchanged between the subsystems - Supportive power	OH policy 1 C → tertiary control (*only technical principles*) *Market and economic aspects associated with balancing are out of the scope of the UCTE OH or other UCTE framework* - "Agreement on Mutual Balance Support"

[28] ERGEG position and recommendations on the UCTE operation handbook; http://ec.europa.eu/energy/electricity/florence/doc/florence_12/ergeg_position_op_handbook.pdf; updated version, November 27, 2006, p. 3.

Security and reliability rules / aspects	Implementation in the UCTE OH and other UCTE framework
Information to be exchanged between TSOs - Technical information about the power systems - Outage planning - Operational information - Information to market players	OH Policy 3 F → information exchanges between TSOs for operation, information exchange for power system computation OH Policy 4 C → DACF, Day-Ahead Congestion Forecast, real model of all 750kV, 380kV and 220kV elements OH Policy 4 A *Outage scheduling information to be exchanged are defined according to each policy, notably for:* OH Policy 2 → Scheduling and accounting (exchange programs) and OH Policy 3 F → Information exchanges between TSOs for security of system operation
Automatic countermeasures	OH Policy 5 A → System operation in insecure conditions
System services - Description and Requirements - Procurement	OH policy 1 A, B & C → load frequency control OH Policy 3 B → voltage control and reactive power management OH policy 5 B → blackstart capabilities (*no implementation survey*) *Procurement is out of the scope of UCTE OH*
Joint operation within region	OH Policy 1 E → provisions for emergency assistance shall be declared in operational agreements, load-shedding must be co-ordinated during emergency situations. OH Policy 3 A → Possible support from adjacent system (TSOs) to comply with the N-1 criterion (guideline) OH Policy 3 B → Joint action at boundaries for reactive power management; (*no implementation survey*)
Management of transmission limitations between subsystems in the region	OH Policy 4 C & D → DACF (planning phase), N-1 security management (operational congestion management); *Market mechanism and Economic aspects linked to congestion management are out of the scope of UCTE rules, these are defined in the Congestion Management Guidelines*
Power shortages	OH Policy 5 B → System operation in insecure conditions
Joint operation with other synchronous systems	*No direct equivalent in the OH*
System restoration after collapse	OH Policy 5 B → System restoration after collapse
Training	OH Policy 5 A → Dispatching operator's training has to be performed on regular basis OH Policy 8 (projected) → Operational training
General requirements and statements	*(Only general specifications)* OH policy 1 → nominal frequency, definition of operating conditions (frequency ranges); OH Policy 3 → range of voltage values in normal conditions; (*Mainly defined in TSOs' grid codes or national regulation*)

Security and reliability rules / aspects	Implementation in the UCTE OH and other UCTE framework
Conditions for power plants connection	(Only general specifications) OH policy 1 → load frequency controller characteristic; OH policy 5 → Blackstart capabilities, household operation *(Mainly defined in each TSOs' grid codes or national regulation*)
Communication infrastructure	OH Policy 6
Rules to handle the data	OH policy 7
Data agreement between TSOs	Policy4 URTICA Architecture

Furthermore and beyond the overview of the specific implementation of operational security and reliability rules in the UCTE OH, the ERGEG Electricity System Operation Task Force has also conducted an initial benchmark of the contents of the first three policies of the UCTE OH as they were practically implemented before the OH entered into force, including also some non-UCTE countries in order to produce a more wider and better comparable results.

17 countries have been covered by that benchmark: Austria, Belgium, Czech Republic, Denmark (west), Estonia, Finland, France, Italy, Luxemburg, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain and United Kingdom. Whereas this implementation benchmark might have changed slightly after the first release of the OH, the discrepancies in the implementation largely still remain. The results of the overview are not presented here in detail, but the conclusions on the areas of necessary improvements are summarized briefly:

1. Provisions for and implementation of the load-frequency control requirements
2. Security criteria in general and (N-1) security criterion in particular
3. Stability aspects
4. Information exchange between the control area managers (TSOs)
5. Coordination and cooperation in emergency and critical[29] operational states
6. Restoration procedures

These areas are related to the issues of high priority for the operational security of the electric power system in which significant and unjustified discrepancies have been identified in their implementation in the different control areas.

[29] According to the widely accepted Fink & Carlsen definition of the power system operational states, which includes normal, alert, emergency, critical and restoration.