ERGEG Final Report

The lessons to be learned from the large disturbance in the European power system on the 4th of November 2006

Ref: E06-BAG-01-06
6 February 2007

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Executive summary

On Saturday, November 4, 2006 the interconnected power systems of the UCTE synchronous area were 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 areas (West, North East and South East). This resulted in significant power imbalances and frequency deviations in each area.

ERGEG established an Ad Hoc Working Group on the 7th November 2006 for a detailed analysis of the incident. Views in this ERGEG Final Report are based on facts delivered by Transmission System Operators (TSOs) either directly to national regulatory authorities or within their own published reports and on the UCTE final report from the 30th of January 2007. Additionally, conclusions drawn here are rooted in the analyses of other recent large scale disturbances and blackouts: in the 2005 ERGEG recommendations on the UCTE Operation Handbook which were published at the XII Florence Forum in September 2005 and in an internal ERGEG report on the required cooperation and coordination between TSOs which has been completed 2006.

The report identifies a number of important lessons that can be drawn. These lessons relate to the security and reliability of European electricity network operations and the need for more integrated and harmonised operational rules. Such issues were already raised by the regulators after the Italian blackout in September 2003 but have not yet been properly tackled. Recommendations included a 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 in order to help prevent similar incidents in the future or if disturbances occur to improve efficiency of remedial actions and restoration.

The report's 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 such as the 4th of November 2006
(2) Measures by TSOs themselves to secure effective coordination and cooperation among each other are required. This must take place under appropriate regulatory oversight.

The Framework

The events of November 4 uncover a 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. The current framework depends on voluntary measures, mostly to be taken by TSOs. However, interconnected electricity networks of Europe – "EU Grid" - require 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 on cross border exchanges of electricity. 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. A need particularly exists for detailed and specific obligations placed on TSOs in relation to the coordinated operation of the electric power 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 a framework including the legally binding operational security rules is vital for the emergence of a fully integrated electricity market.

The role and obligations of TSOs

The second broad category of recommendations relates to the obligations on and actions required from the TSOs to enhance security of the operation of integrated power systems in Europe. 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 The development and regular testing of restoration plans should also be mandatory for all involved TSOs.

More precisely and uniformly defined rules for coordinated real time security assessment and control (including but not limited to the steady state contingency analysis) are needed from TSOs to facilitate secure network operation in synchronous areas. 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. Harmonisation 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 coordination between TSOs and DSOs as well about generators connected to distribution network.

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 interconnected UCTE 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 several high voltage lines the UCTE grid was divided into three areas (West, North East and South East) and this resulted in significant power imbalances in each area.

A number of investigations have been undertaken so far. The TSO operating the grid where the incident originated – E.ON Netz GmbH (hereafter in this report referred to as E.ON Netz) – undertook an immediate investigation and published a report on November 14, 2006.[1] Also, the Union for the Coordination of Transmission of Electricity, UCTE, set up a task force to evaluate the events. The UCTE final report has been published on January 30, 2007.[2] Additional national reports have also been announced.

This report sets out ERGEG's view on the disturbance across the UCTE system on November 4, 2006. Data presented here have been collected by ERGEG members from the affected TSOs and, additionally, 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. Even if there is no reason to doubt the correctness of the information provided by the TSOs, this dependency has to be noted. ERGEG members have not performed independent audits to check the validity of the information provided by the TSOs. Note should also be taken on the fact that ERGEG members do not even have the powers to require or check information from other than their national TSOs and that mandate is solely based on their national regulatory powers.

In order to give a pan-European overview of the incident, the events in most of the affected countries have been evaluated. This procedure allows for an in-depth analysis of the events 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 need to be drawn at the European level. 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 pan-European aspects of the disturbance. It is not the intention of this report to pre-empt or to replace any national reports prepared 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 launched by the European Commission. ERGEG will deliver an independent view from a pan-European perspective. Consequently, the report presents recommendations that focus on further actions at the European level.

The report is structured as follows. As a starting point the report summarises the events on November 4, 2006. Based on this an assessment is given which shows that the current

[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 Final Report, System Disturbance on 4 November 2006; http://www.ucte.org/pdf/Publications/2007/Final-Report-20070130.pdf

framework does not suffice to reliably prevent future disturbances. This leads to the final chapter which proposes measures to reduce the risk of pan-European disturbances in the future or if disturbances occur to improve efficiency of remedial actions and restoration.

2 Summary of the incident

The incident of November 4, 2006, is described in detail in the reports already published by E.ON Netz and 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 conclusions drawn based on this assessment, however, a brief summary of the events is presented in this main part of the report. A more thorough description can be found in Annex 1 including the necessary references to the specific sources of data.

On September 18, 2006, the shipyard Meyerwerft located on the River Ems requested from E.ON Netz 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. The shutdown of the transmission lines is mandatory in such cases to prevent possible hazards when parts of a ship approach these lines. At Meyerwerft's request of November 3, 2006, E.ON Netz agreed to predate the opening of the Conneforde-Diele 380 kV double line by three hours to 10:00 pm on November 4.

At 09:29 pm on November 4, 2006, E.ON Netz performed a simulation calculation for the scheduled opening of the double line over the River Ems. This simulation was based on data of the current state of the grid and there was no signal of violations on any limit value in this case. Because of the empirical evaluation of the grid situation, E.ON Netz assumed that the N-1-contingency would be met in the system. A calculation of N-1-contingency of the network after the opening of the double line over the River Ems, however, was not performed. At 09:38 pm E.ON Netz opened the Conneforde-Diele 380 kV double line over the River Ems. As expected, the power flow was redistributed to other, more southern located lines which are also running in East-West direction.

At 10:07 pm, the safety limit value on the Landesbergen-Wehrendorf 380 kV line between RWE Transportnetz Strom and E.ON Netz was exceeded, and following this alarm, an immediate intervention was required to restore safe grid operation.

At 10:10 pm, E.ON Netz performed a topology change in the Landesbergen substation by coupling busbars. The Landesbergen-Wehrendorf 380 kV line tripped off two seconds later, by the automatic overload protection. The cascading effect continued towards the south and finally resulted in a separation of the entire UCTE grid into three partial sub-grids: Western, South Eastern and North Eastern areas.

The countries in the Western area were Spain, Portugal, France, Italy, Belgium, Luxemburg, the Netherlands, Switzerland, Slovenia, as well as parts of Croatia, Austria and Germany. Power deficiency of about 9,000 MW led to a frequency drop to about 49 Hz. This drop in frequency was stopped by automatic load-shedding and by tripping pumping storage units.

The countries in the South-Eastern area were the Former Yugoslav Republic of Macedonia, Montenegro, Greece, Bosnia and Herzegovina, Serbia, Albania, Bulgaria, Romania, as well as parts of Croatia and Hungary. In this area, there was a slighter deficiency of power, which led to a

frequency drop to about 49.7 Hz. Consequently, these countries were not seriously affected by the disturbance.

The countries in the North-Eastern area were Czech Republic, Poland, Slovakia, Ukraine, and parts of Hungary, Austria, and Germany. This area encountered a surplus of generation. The value of the frequency was over 50.5 Hz in most of the cases and it peaked at 51.4 Hz.

The Western and Eastern areas were finally reconnected at 10:47 pm after several unsuccessful attempts. The resynchronisation 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 or monitored by TSOs. In addition to these three issues that are covered separately in the following sections, a number of other issues can be noted. These are presented in the final section of this chapter.

3.1 N-1 security rule

The first result to be noted is that after opening of the double 380 kV line across the River Ems the system of E.ON Netz was not N-1 secure any more since the loss of the Landesbergen-Wehrendorf 380 kV line led to a cascade of line trippings. If the opening of the double line had been cancelled and the passage of the ship would have also been postponed the disturbance would not have occurred.

Before opening of the Conneforde-Diele 380 kV double line, E.ON Netz reports that its control centre staff evaluated the grid situation empirically. This raises the question why E.ON Netz did not perform a N-1 security calculation. From the reports available, such a calculation is at the discretion of the grid control centre. The calculation of N-1 security by E.ON Netz could have shown that opening of the double line was not feasible.

Besides, TSOs behave differently across UCTE as regards real time security analysis. Unlike some other UCTE TSOs, E.ON Netz did not process regular real time security analysis. It is a major deficiency of system security that some TSOs do not carry out real time security analysis on a regular basis.

The UCTE Operation Handbook requires that "*TSOs monitor at any time the N-1 criterion for their own system*" (Policy 3, chapter A, requirement 1). ERGEG considers that this requirement implies that TSOs perform N-1 security analysis on a regular basis either automatically or manually and always when topology changes are planned or take place.

Before predating the passage of the *Norwegian Pearl*, E.ON Netz reduced the NTC value by 350 MW at the border with the Dutch TSO TenneT. It is unclear how this reduction was determined. After moving forward the passage of the ship the curtailment of available capacity for the first hours of November 5, 2006 did not match any longer the new time frame. At the point of time when the decision to predate the passage of the ship was taken, no exchange program reduction

was possible on the Dutch-German border, due to the agreed auction rules (capacity is considered as firm, except in the case of “force majeure”.

Immediately after opening of the Conneforde-Diele 380 kV double line E.ON Netz received several alarm messages warning that safety limit values were reached. It should have taken immediate corrective actions. Assessment of possible corrective measures should have been done immediately after the alarms or even assessed at the operational planning stage. Redispatching of power plants within Germany (or counter-trading between the E.ON Netz and RWE Transportnetz Strom areas) could have been considered. Even reconnection of the lines over the River Ems could have been an option as the analysis of the time sequence discloses that enough time would have been available for that.

In conclusion, two issues must be improved. Firstly, N-1 contingency analysis must be performed regularly by all the TSOs. A regular and appropriate security analysis in meshed UCTE grid requires also regular exchange of real time network information between relevant TSOs. Therefore exchange of information should also become mandatory. Secondly, there seems to be a need for a more formal procedure for conditions which call for an additional specific calculation (especially before and after planned opening of transmission lines). In order to allow for sufficient time for 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 Operation Handbook. Thus, national interpretations of the rule may differ and impede proper coordination between TSOs. In its position paper on the UCTE Operation Handbook ERGEG has stated that a more detailed and specific definition of the N-1 operational security criteria should be considered.[3]

3.2 TSO cooperation

Cooperation between TSOs is vital as soon as major interconnectors within the UCTE system are concerned. As described above, E.ON Netz undertook some effort to coordinate activities with neighbouring TSOs.

- In advance of the events, E.ON Netz had informed RWE Transportnetz Strom and TenneT about the planned opening of the double 380 kV transmission line.
- E.ON Netz, RWE Transportnetz Strom and TenneT also exchanged information ahead of time on predating the planned opening of the Conneforde-Diele 380 kV double line across the River Ems.
- After opening of the double line at 9:38 pm, the expected power flows essentially occurred. However, E.ON Netz received alarm messages from the Elsen-Twistetal and Bechterdissen-Elsen lines which drew the attention to the fact that the limit values for line currents were reached. E.ON Netz assumed that due to thermal reserves, which allowed a temporary overload of the transmission lines by up to 25 %, there was no immediate need for remedial action. Accordingly, at 9:41 pm E.ON Netz had an information exchange with RWE Transportnetz Strom on this issue. Within the scope of this telephone call, RWE Transportnetz Strom drew attention to the alarm value of 1,800 A on the line of

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

Landesbergen-Wehrendorf. Also, RWE Transportnetz Strom informed E.ON Netz about the protective tripping value of 1,990 A for this line.

However, lack of exchange of information can also be stated to aggravate the problem.

- E.ON Netz did not take into account the different settings of protection systems at the RWE Transportnetz Strom substation for the Landesbergen-Wehrendorf 380 kV line. This information was communicated by RWE Transportnetz Strom in advance. Ignoring this information while deciding on remedial actions has to be considered as another main cause of the event. Besides, it has to be noted that protection relay settings at both ends of each interconnectors should be defined in cooperation between the TSOs and settings for alarm and tripping should be jointly agreed.
- After RWE Transportnetz Strom and E.ON Netz jointly established that the safety limit value of the Landesbergen-Wehrendorf 380 kV line was exceeded, E.ON Netz performed the coupling of busbars at the Landesbergen substation. This action immediately triggered cascading tripping of numerous lines. E.ON Netz 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 this network situation. 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. In addition to the need for regular security calculations demonstrated by such an incident, the accuracy of simulation models has to be addressed, notably by taking into account the exact settings of protection systems when thermal limits of transmission lines are defined within the simulation model.
- According to the UCTE[4] final report, no counter trading measures between the Netherlands and Germany had been discussed. A common concept for – purely curative – counter trading measures might have helped to avoid the event. Apparently such measures have not been considered by the involved TSOs. UCTE should justify the lack of consideration of such measures to solve security problems[5].
- During the disturbance information about the reason for the disconnections and the consequences were scarce for TSOs. Many TSOs were not aware about the separation of the UCTE system into three areas, neither about the place of the disconnection, the borders of the areas formed, nor about the start and place of the recovery of the synchronous operation. Generally, however, the local information available to TSOs allowed for actions to limit the effects of the disturbance during the recovery time.
- Except the modification asked by the Swiss transmission system coordinator Swissgrid concerning secondary control, there is no indication of any real time coordinated action during the restoration phase.

On the basis of the points listed, a lack of coordination among TSOs must be stated. Independent of whether E.ON Netz did adhere to procedures required by the German Transmission Code or the UCTE Operation Handbook, it must be noted that more cooperation, better information

[4] UCTE final report, p. 21.

[5] It is obvious that counter-trade will require the involvement of market participants, but the key concepts and requirements including technical prequalification rules will have to be proposed by the TSOs.

exchanges, 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 in order to establish harmonised rules for the operation of transmission networks. The European energy regulators have been analysing the Operation Handbook with respect to possible and necessary improvements. The results of this analysis were presented by ERGEG at the XI Florence Forum in 2004[6] and at the XII Florence Forum in 2005.[7] The regulators' position has been updated recently. The core elements of the Operation Handbook that are of relevance in terms of the incident under discussion are summarised in Annex 2. The Operation Handbook is a valuable contribution of TSOs that allows for better coordination among TSOs and more secure operation of the synchronous UCTE network. Nevertheless disturbance on the 4th of November 2006 demonstrated the need for a swift improvement of the Operation Handbook in order to make it appropriate and more precise.

It has to be noted that even though TSOs have established a process to monitor and ensure compliance with the Operation Handbook, it is not legally binding. Consequently, currently the only legally binding rules on the secure network operation are national. Nevertheless, in case of cross border incidents the TSO's liability remains insufficiently defined by the current inter-TSO agreements that has negative consequences for the protection of grid users' interests in almost all Member States. This issue was already raised during the XI Florence Forum in 2004 where it was noted that damages from non-compliance could go much wider than simply the signatories to the agreement and that there was a need to protect grid users. The need for independent oversight of the contents of the Operation Handbook, its implementation and enforcement is henceforth demonstrated.

3.3 Behaviour of generators

The tripping of small and/or distributed generation units due to under-frequency increased the imbalance between supply and demand. TSOs lack control and real time data about generation units as many of those are decentralised at the DSO level. Consequently, automatic tripping and uncontrolled reconnection of these units may influence in 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 nor at aggregated level for an area of the grid or a DSO.

Generation from renewable energy sources and particularly wind generation are of special concern here. At national level, incentives are introduced in order to increase generation from renewable sources without creating too many barriers to entry for these units. When decentralised generators begin to represent a significant part of the generation, these generators have to participate to the security of the grid in due proportion. Otherwise the centralised generation will not be able to mitigate the lack of decentralised generation participation to security measures. As the disturbance shows it becomes more and more important that smaller and/or decentralised generators become part of the system security. Information provision by these generators and procedures for automatic tripping and coordinated reconnection must be

6 http://ec.europa.eu/energy/electricity/florence/doc/florence_11/ceer_security_rules.pdf
7 http://ec.europa.eu/energy/electricity/florence/doc/florence_12/ergeg_position_op_handbook.pdf

formulated in a way that guarantees system security and enables TSOs to control system state as far as possible. This could also require additional measures concerning the real time network operation.

3.4 Additional issues

In addition to the three main issues mentioned above some other issues shall be noted here.

3.4.1 Contribution to the restoration of supply

All national systems have not contributed to the same extent to the restoration of supply through increasing generation. ERGEG notices that there was not enough coordination between network operators during the restoration phase. Besides, it seems that some DSOs started reconnecting loads without any coordination with their TSOs even though operating conditions were not yet back to normal state.

3.4.2 Automatic load-shedding

The current design of load-shedding plans implies that each system of the Western area did not contribute to the same extent to the restoration of the balance between supply and demand in case of a disturbance. ERGEG notes that the UCTE rules on load-shedding[8] are not sufficiently specific on this issue.

It appears that the ratio of load-shedding during the disturbance differ from one TSO to another. Several factors may explain these differences: in many countries the first step of load-shedding is activated when the frequency drops under 49 Hz, in some countries not only the frequency but also its derivative (velocity of frequency change) is used to define the amount of load to be shed at a given frequency level, etc. Here a question arises if the protection relay settings for load-shedding are sufficiently coordinated across the joint European network.

3.4.3 Frequency control

The UCTE final report reveals that TSOs changed to “pure frequency” mode at different times and in different conditions. In the North-Eastern and South-Eastern areas the automatic change to “pure frequency” mode performed by some TSOs contributed to the limitation of the increase, respectively, decrease of the frequency. In parts of Europe without this change of mode the secondary frequency control increased the imbalance between generation and consumption.

This specific operation mode contributed to accelerate the recovery of the network frequency regardless of the geographical location of the disturbance origin. Thus, the secondary reserve is used in the same conditions as the primary reserve. Nevertheless, this specific mode does not take into account the total power deviation of each TSO control area, highlighting the main drawback of this mode if no coordination between TSOs is performed. ERGEG notes that this mode is not defined in the UCTE Operation Handbook.

[8] UCTE Operation Handbook, Policy 1 (Chapter E, Requirement 1) and Policy 5 (Chapter A, Guidelines 6).

3.4.4 Inconsistencies in the reports

There are some inconsistencies in the reports available so far. From the data presented by UCTE the power flow on the Landesbergen-Wehrendorf 380 kV line increased over time beginning roughly at 10:01 pm. However, sudden and unforeseeable movements in power flows[9] cannot be acknowledged neither from the data given by E.ON Netz itself[10] nor from information given by other TSOs.[11] Also, the indication that wind conditions were relatively high – as mentioned in the UCTE final report[12] – is not supported by relevant data. Rather, these values were within the normal range. According to the information provided by E.ON Netz 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.

4 Recommendations

4.1 General

The event, which resulted in the splitting of the UCTE network into three areas and extremely low frequency values in a large part of the UCTE system, is unique in the history of the UCTE system. According to the UCTE final report, more than 15 million households[13] 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 measures are urgently necessary to avoid such disturbances in the future as far as possible.

Three main causes for the system disturbance have been identified. The first one is the non-fulfilment of the N-1 criterion after the disconnection of Conneforde-Diele 380 kV double line. Before the disconnection of the Conneforde-Diele 380 kV double line, the impact in terms of N-1 criterion fulfilment for the situation after opening of the double line was not checked by E.ON Netz via a numerical calculation.

The second main cause was inappropriate inter-TSO coordination during the event. The initial planning for switching-off the double line was duly prepared by the directly involved TSOs (E.ON Netz, RWE Transportnetz Strom and TenneT), but similar coordination was not adopted when actual opening of the double line was performed. Besides, the settings of protection devices on the both ends of Landesbergen-Wehrendorf 380 kV line are different and this was not given full attention by E.ON Netz. The event resulted in an uncontrolled splitting of the UCTE network into three areas, whereas at that time none of the TSOs had a full overview of the system situation. This conclusion calls for more cooperation and coordination among TSOs within a synchronous area.

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[9] Eon Netz report, p. 9.
[10] Eon Netz report, p. 27.
[11] For example, other German TSOs do not report any unusual development of power flows in their systems.
[12] UCTE final report, p. 30.
[13] UCTE final report, p. 6.

Thirdly, distributed generation units were not monitored or controlled appropriately by TSOs. The uncoordinated behaviour during the disturbance worsened the consequences and introduced a risk for more severe instability.

Furthermore, an improved cooperation scheme even calls for a critical review of the UCTE philosophy. The current UCTE philosophy is based on a decentralised approach, where each TSO is only responsible for its control area. There is no centralised supervisory system and there are no centrally coordinated emergency schemes to avoid spreading of disturbances over the whole UCTE system. It is clear that the current decentralised 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 generally recommended to analyse whether a somewhat more centralised approach to system operation, control and restoration structures could provide additional benefits.

Finally, it has to be noted that many of the recommendations described here have already been identified in CEER's response to the European Commission's Green Paper.[14] 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; and implementing a central institution that facilitates cooperation between TSOs at EU level.

4.2 Proposals for measures and follow-up

ERGEG proposals for measures based on the disturbance on the 4th of November 2006 can be divided into short term (one to three years) and medium term (over three years) actions. Proposals include both voluntary and legally binding measures.

ERGEG proposals for short and medium term actions with time frames and actors are summarised as follows:

Proposal for an action	Actor	When due
Short term actions		
Amendments UCTE Operation Handbook	UCTE	Follow-up end 2007
Guidelines on good practice for operational security (relevant to the CM guidelines within Regulation (EC) 1228/2003)	ERGEG	Q4 year 2007
Amendments to Regulation (EC) 1228/2003: Operational Security Rules according to the Article 8(4) of the Regulation ("4th Guidelines")	EC ERGEG advice	2008 – 2009 Q1 year 2008

[14] 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

Proposal for an action	Actor	When due
Implementation and oversight of Security of Supply Directive: Obligation on TSOs to harmonise emergency planning and restoration plans.	Member States	1st December 2007[15]
Medium term actions		
Proposal for a new legislation to deal with European Grid	EC ERGEG advice	2008 – 2010 Q4 year 2008
Guidelines on good practice for connection of distributed generation	ERGEG	Q4 year 2008
Connection rules for distributed generation as part of European Grid	EC ERGEG advice	2009 – 2010 Q4 year 2009

Actions proposed above are discussed in more detail in the following chapters. As a summary from the analysis on the disturbance on the 4th of November, the legally binding security rules based on harmonised objectives across Europe shall be goal for the longer term perspective. This can be achieved by harmonised EU regulation within the framework of European Grid.

4.2.1 Amendments to UCTE Operation Handbook and its framework

ERGEG has made a comparative overview of the operational security and reliability rules in the synchronous areas of the EU as presented in Annex 2 emphasising the issues of relevance for the UCTE area. Based on the considerations in this report, relying on the results of the analysis above and taking into account the previous lessons learned from large disturbances/blackouts, the list of necessary adjustments and improvements in the Operation Handbook and its framework is reported in this chapter.

The majority of issues below are applicable for voluntary improvement. The process of compliance monitoring and – even more important – compliance to the operational rules as set out in the UCTE Operation Handbook must be implemented consistently across the synchronous area. As UCTE membership is voluntary, ERGEG recognises that enforcing compliance is difficult. However, as the disturbances of the past show, non-compliance creates difficulties not only for the non-complying TSOs but across Europe. Consequently, the short term effort may be focused on issues like improved consistency of N-1 security rule definitions, harmonisation of emergency and restoration planning, coordinated cross-border dispatching, and improved exchange of data.

ERGEG proposes that UCTE prepares the work plan for implementing the amendments before July 2007 and first follow-up of implementation is at the end of year 2007.

[15] Date defined in Security of Supply Directive 2005/89/EC.

General Issues

Compliance and consistence in the national implementations: In order to ensure coordinated and coherent reaction throughout and between the synchronous areas in case of future disturbances, it is required to (i) identify the critical Operation Handbook components that have to be implemented without tolerance in all control areas and (ii) ensure the adequate implementation and monitoring/enforcement. The basis for (ii) should be laid down by a legally binding framework.

Modifying the Operation Handbook and related framework: Formal procedures need to be defined for requesting analysis of specific questions and modifications to the Operation Handbook and related framework including initiatives of market participants other than the UCTE members.

Experiences and lessons learned from large disturbances in the past: Amendments to the policies recommended by the UCTE Report on 28 September 2003 blackout in Italy are not yet fully implemented in the Operation Handbook. This has also been recognised by UCTE and the lessons learnt need to be further elaborated in the next release of the related Operation Handbook framework, notably Policy 3 and Policy 5.

Congestion Management Guidelines and Policy 4: The Operation Handbook Policy 4 relates to the CM Guidelines in many technical and organisational terms. Contradictions between these two documents are to be avoided, whereas the CM Guidelines, as already released and being part of the formally binding EU legislation, shall serve as a reference.

Further EU Framework on Security and Reliability: In the development and implementation of the Operation Handbook and related framework, the Operational Rules and the EU Grid Code (cf. Article 8(4) of the Regulation (EC) 1228/2003) need to be considered, too. These rules, since part of the Regulation, will be directly applicable to EU members within the areas of UCTE, Nordel, Ireland, Great Britain and the Baltic states. They could also apply to the area where an agreement with the EU is referring (or would refer) to the EU Acquis Communitaire on energy, like e.g. South East Europe

Technical Issues

N-1 Criteria (Policy 3): A detailed and unambiguous definition of the (N-1) operational security criteria at least in the following terms needs to be considered: (i) network elements to be considered, (ii) contingency analysis framework and (iii) time frame to return to normal state after disturbances.

Scheduling and accounting (Policy 2): It is proposed to develop data exchange standards as soon as possible since this is one of the key issues for e.g. coordinated congestion management and capacity calculation.

Interdependencies and information exchange: Whereas presently no detailed specifications of interdependencies in terms of operational security beyond Policy 3 exist and no specifications on information exchange between the TSOs themselves or TSOs and other parties are defined, these issues shall be considered accordingly and in due time as they significantly impact the IEM. Such an improved cooperation should firstly include an obligation to better inform other TSOs according to the predefined procedures. These procedures should cover scheduled unavailability of infrastructures but they should also cover swift information on unplanned events.

Coordinated Operational Planning (Policy 4): The Operation Handbook should require a minimum harmonisation of physical capacity assessment process among TSOs (including also any kind of "reliability margins" that need to be considered). Furthermore, a number of detailed technical issues have been identified by ERGEG where adaptations in Policy 4 are needed and have been agreed with UCTE, notably belonging to the areas of capacity calculation, N-1 security management.

Coordination on load-shedding and frequency control: The UCTE rules on load-shedding should be more specific. The national load-shedding plans should be made compatible within a synchronous area and they should be consistent with the performance of generation units, including also generation of smaller size. Coordinated load-shedding should allow a fair participation of all TSOs to the UCTE network security. Furthermore, the UCTE rules should describe the "pure frequency" mode of the load frequency control. Particularly, conditions under which TSO should switch to this mode (and return to "normal" mode) and the associated TSO coordination, should be defined in more detail.

Emergency Operations (Policy 5): Restoration plans shall become requirement and not just a guideline in the sense of Operation Handbook. Further, whereas it is recognised that training of the system operation staff is presently to a large extent the issue of each TSO, stronger coordination and possibly standardisation (certification, tests, etc.) should be required in the future. Common training sessions should be organised concerning operation of interconnections. This is reaffirmed taking into account lessons learned and experiences from the past large disturbances and blackouts. In particular, the announced Policy 8 shall take account of this requirement. Whereas operational security is indeed the responsibility of the TSOs, regulatory authorities will always be involved in any kind of global activities aimed at maintaining and improving general framework for the operational security that might be necessary. Therefore the consultation and approval of the respective framework by the EU regulatory authorities needs to be considered.

Validity and Applicability

Multi Lateral Agreement: It is important to carefully examine the MLA applications and consequences for the market in order also to be able to propose any necessary adjustments. In the current context three options can be considered for the enforcement of the defined operational standards in general: (i) MLA alone; (ii) European-wide legislation (e.g. Security and Reliability Guidelines according to Article 8(4) of the Regulation (EC) 1228/2003); (iii) Enforcement through national regulatory framework. Whereas each of these three options has certain advantages and drawbacks, ERGEG considers that the option (i) needs to be supplemented with options (ii) and (iii) above.

Compliance monitoring and enforcement process (CMEP): At the XIII Florence Forum, the UCTE announced that a pilot phase of CMEP has been launched since the beginning of 2006. ERGEG considers that this process is essential since it aims to strengthen the transparency and credibility of TSO's performance within the community as well as towards stakeholders. Therefore ERGEG considers that regulatory authorities will have to be involved where necessary in order to fulfil this goal.

4.2.2 Guidelines on Operational Security

ERGEG recognises that enforcing compliance within UCTE area may be difficult as UCTE membership is voluntary. The past disturbances show that non-compliance has introduced

problems not only for the non-complying TSOs but also across Europe. Furthermore, other synchronous systems in the EU such as Nordel, Great Britain, Ireland and Baltic States, have to be taken into account when operational security rules are considered, in order to also guarantee equal and non-discriminatory treatment of all the participants in the Internal Energy Market. Consequently, this should lead to adjustments in the EU legal framework, where at least an EU wide formally binding legal framework between the TSOs of the European synchronous areas should be introduced.

To introduce such a legal instrument the Article 8(4) of the Regulation (EC) 1228/2003 makes it possible to establish Guidelines on Operational Security. However, these Operational Security Guidelines could include only issues relevant for cross border exchanges of electricity, such as coordinated operation of the networks across the Internal Electricity Market including joint operational planning, joint real time operation, coordinated emergency and restoration arrangements, and inter-TSO co-operation and coordination. These Guidelines could improve the coherence of the enforcement at a national level of the Article 5(2) of the Regulation (EC) 1228/2003 that requires an approval by the regulatory authorities of the schemes for the calculation of the total transfer capacity and the transmission reliability margin. These schemes must be based upon the electrical and physical features of the network and included in the safety, operational and planning standards used by transmission system operators. They cannot be coherent at the European level if the related standards are not so.

The legal framework should ensure a proper regulatory oversight, where roles, responsibilities, and powers of regulators should be duly organised as well as the coordination and cooperation among the national regulators when pursuing tasks related to joint TSO oversight and enforcement. The most appropriate option for delivering such a legal framework could be to combine improved multilateral agreements (e.g. UCTE MLA, Nordel) notably with regard to the TSOs' liability for insufficient reliability of power transmission with Operational Security Guidelines according to the Article 8 of the Regulation (EC) 1228/2003. This approach exploits efficiently the experiences from present UCTE Operation Handbook and other operational agreements.

Such EU 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 Operation Handbook) 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.

But even the development of guidelines will take time, as they will have to be consulted widely and will have to undergo the comitology process according to Regulation (EC) 1228/2003. Consequently, short term solutions rely on voluntary measures by the TSOs as requested in chapter 4.2.1.

ERGEG will, according to the Work Programme 2007, continue to work on main contents of operational security rules according to Article 8 of Regulation (EC) 1228/2003. The work starts with an analysis of the need and ways to proceed towards harmonised or at least compatible rules for adequate TSO interworking and cooperation in terms of operational security within IEM. To speed up the harmonised approach across Europe for operational security, ERGEG will work first on guidelines of good practice on operational security during the year 2007. After ERGEG advice in year 2008 these guidelines are proposed to be made legally binding.

4.2.3 Implementation of Security of Supply Directive

The analysis of the incident on the 4th of November 2006 shows that national operating rules may not be consistent at the European level. Particularly, emergency and restoration plans have been developed to ensure as far as possible the secure operation of each power system in emergency or critical conditions. In this respect these rules may not incorporate pan-European issues, even if they are appropriate at national level. However, the disturbance on the 4th November 2006 demonstrates that interconnected power systems are deeply interdependent and, consequently, emergency measures and restoration phase must be coordinated.

In this respect, Article 4 (Operational network security) of Security of Supply Directive 2005/89/EC calls for consultation with neighbours, with which interconnection exists, when developing national operational rules. It notably states that "*Member States shall ensure that curtailment of supply in emergency situations shall be based on predefined criteria relating to the management of imbalances by transmission system operators. Any safeguard measures shall be taken in close consultation with other relevant transmission system operators, respecting relevant bilateral agreements, including agreements on the exchange of information"*.

Accordingly, European considerations should play a role in national plans as well as national rules should contribute to the secure operation of European interconnected grid. This creates the legal basis for common emergency plans across borders and common restoration plans after a possible disturbance or blackout. Furthermore, the Directive does not specifically ask TSOs to consult with neighbouring TSOs. Rather, it opens this consultation to all relevant actors in neighbouring countries. ERGEG urges that TSOs and national regulators are included in this consultation process.

It has to be noted though, that Article 4 of Security of Supply Directive only requires Member States to implement these operational rules on a national basis. As a consequence, this solution will most likely not lead to optimal results, particularly in terms of enforcement. Besides, this will not necessarily provide a consistent and harmonised European framework. However, Article 7 of the Directive requires Member States to ensure that the report referred to in Article 4 of Directive 2003/54/EC covers the overall adequacy of the electricity system to supply current and projected demands for electricity, comprising also operational network security. Then, in the short term, the European Commission notably with the technical support of ERGEG and relevant TSO associations could detect possible discrepancies and ask the concerned Member States for the appropriate modifications to inappropriate national operational rules.

As a conclusion, the provisions of the Security of Supply Directive should lead to an improvement of coordination between neighbouring TSOs with regard to operational network security if implemented within Member States in a consistent and harmonised manner. National regulators should evaluate how appropriate these national provisions are in the European context. However, because of national implementation the provisions may be insufficient to ensure consistent and harmonised operational rules at the European level. This requirement would rather require a European wide approach instead of a national one.

To supplement the Security of Supply Directive, ERGEG considers that the current European legal framework should be complemented or amended to set consistent operational security rules that would be enforceable at the European level.

4.2.4 New legislation on European Grid

New legislative proposals have been raised in the recent publication by the European Commission on the Strategic Energy Review (SER). With regard to this Review CEER proposes to define European Grid accompanied by European operation and security rules. To ensure regulatory oversight a system of ERGEG*plus* as an appropriate EU level regulatory organisation to oversee collective European obligations is proposed by ERGEG[16].

Defining a European grid will lead to the development European Operational Security Rules and European Grid Code. This will further yield the TSOs that have dual responsibility – for the management of the national networks, and for the participation of their networks in the European Grid. The European Operational Security Rules and the European Grid Code will provide further obligations to TSOs relating to the uniform and non-discriminatory grid connection, operations, development and maintenance. In order to fulfil these tasks, TSOs will have to organise in a way that allows for collective action. In its response to the European Commission's Communication "An Energy Policy for Europe", ERGEG proposes a body that may be called ETSO*plus*, as the current (voluntary) association of European TSOs seem the most appropriate predecessor for an organisation for collective, binding action of TSOs. Moreover, since the European Grid should rather be based on the concept of common services and applications at the transmission level, rather than on some specific network elements[17], it is anticipated that this new ETSO*plus* will have to perform a number of technical and operational tasks like e.g. centralized capacity calculation and forecast, centralised information management and transparency implementation.

In this framework one of the core tasks of ERGEG*plus* will be to monitor the compliance of the European Operational Security Rules and with the European Grid Code. These works would in such a system be subject to approval by ERGEG*plus*. Consequently, the European Operational Security Rules and European Grid Code would be legally binding. Compliance by all TSOs would be required.

As the measures described above will only be available in the long term, faster solutions such as 4.2.1 and 4.2.2 need to be envisaged.

Disturbance on the 4th of November 2006 implies e.g. that harmonised connection rules for distributed generation are important for operational security and they should be included in the European Grid Code.

Harmonised connection rules for distributed generation

During frequency variations in the predefined range around 50 Hz, generators are normally required to remain connected to the grid for some time and, in this range, to contribute in frequency regulation of the power system. During the disturbance on the 4th of November 2006 a large amount of distributed generation, mainly wind and combined heat and power (CHP) units,

[16] ERGEG's response to the European Commission's Communication: "An Energy Policy for Europe", published in February 2007.

[17] It is noted that in the synchronous areas of e.g. Nordel and UCTE, the "European grids" operating with common frequency have already existed for many decades, but the way of operation and especially dealing with the requirements of the electricity market, does not correspond any more to the challenges and changed, liberalised environment.

was automatically disconnected in the under-frequency area, as well as automatically reconnected in the over-frequency area.

This behaviour, which worsened the consequences of the disturbance, e.g. in terms of number and duration of consumer disconnections, is not unexpected since it derives, in most cases, from the present national connection rules and technical characteristics of the plants, having performance standards less stringent than for conventional power plants.

The increasing diffusion of distributed generation therefore calls for a better control at least during disturbances and abnormal operation of the power system.

ERGEG recommends that the possibility during abnormal operating conditions for the distributed generators and groups of them (e.g. wind farms) should be studied:

- To contribute as far as possible to network frequency and voltage control as it applies to conventional power plants.
- To avoid too early tripping, uncoordinated with automatic load-shedding, in under-frequency conditions and to avoid inappropriate reconnections in over-frequency conditions.
- To provide TSOs with adequate monitoring capabilities of distributed generation through information provided by DSOs.

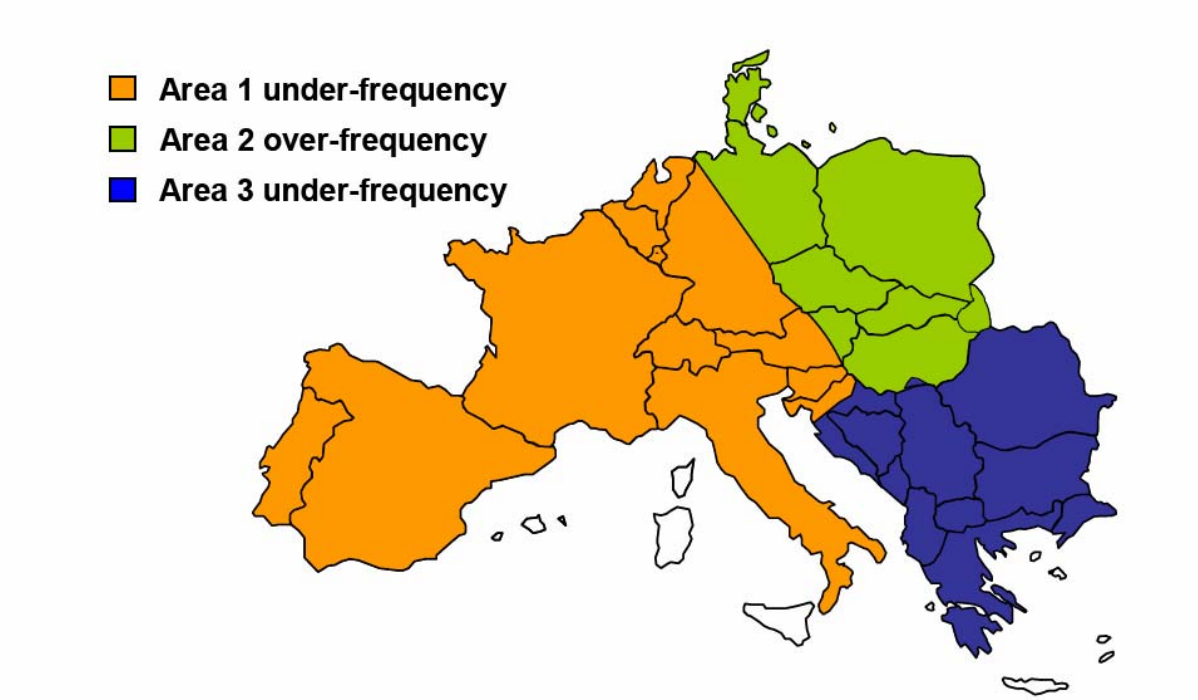
Some of the above measures should be immediately implemented, giving priority to the larger power plants (or group of them) connected to the HV network. For the others a gradual approach should be followed, namely for those plants that are connected to MV radial feeders, where considerations related to safety suggest a more prudent approach.

The relevant implementation procedure could start from a document of good practise guidelines from regulators and to be followed by more legally binding requirements within European Grid Code.

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 areas. In 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 final report, p. 21)*

1 The situation in Germany[18]

1.1 Operational planning before the event

On September 18, 2006, the shipyard Meyerwerft, located on the River Ems, sent a written request to E.ON Netz regarding the opening 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

[18] This part mainly draws on the report published by E.ON Netz, http://www.eon-netz.com/Ressources/downloads/BerichtBNetzA_englisch.pdf.

am.[19] The opening of the electric lines is mandatory in such cases to prevent possible hazards when parts of a ship approach these lines. On October 27, 2006, the requested opening was provisionally approved by E.ON Netz. This decision was based on an analysis of the load situation using a standard planning data record. According to E.ON Netz 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 opening of the double 380 kV line was subject to a further analysis of the grid situation immediately before the opening of the double line. E.ON Netz had coordinated the decision with neighbouring grid operators. Also, E.ON Netz 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. At Meyerwerft's request of November 3, 2006, E.ON Netz agreed to predate the opening of the Conneforde-Diele 380 kV double line by three hours to 10:00 pm on November 4.

According to the report publish by E.ON Netz,[20] approximately 13,700 MW of electricity were consumed in E.ON Netz'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-western direction. Additionally, single transmission lines as well as equipment in E.ON Netz's substations were switched off at this time to enable the performance of building work for grid reinforcements. These measures were known at E.ON Netz and taken into account in the simulation calculations in online operation.

1.2 Sequence of events

At 09:29 pm on November 4, 2006, E.ON Netz performed a simulation calculation for the scheduled opening of the Conneforde-Diele 380 kV double 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, E.ON Netz assumed that the N-1-contingency would be met in the system. A calculation of N-1-contingency of the network after the opening of the double line over the River Ems, however, was not performed. In a telephone call at 9:30 pm both E.ON Netz 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.

Afterwards, at 09:38 pm E.ON Netz opened the Conneforde-Diele 380 kV double line over the River Ems. As expected, the power flow was redistributed to other, more southern located lines which are also running in East-West direction. According to E.ON Netz[21] the actual flows of the grid in the region were essentially in accordance with the expectations on the basis of the simulation calculation.

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[19] According to E.ON Netz, 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 E.ON Netz the line has been switched off over the River Ems for Meyerwerft ship transportations a total of fourteen times since 1995.

[20] Eon Netz report, p. 8.

[21] Eon Netz report, p. 15.

At 09:39 pm, i.e. immediately after the opening of the double line, E.ON Netz received several alarm messages from the Elsen-Twistetal and Elsen-Bechterdissen lines that current limit values were reached. Thermal reserves allow a temporary overload of the lines by up to 25% according to E.ON Netz internal rules. Accordingly no immediate need for action was assumed.

In a telephone call between E.ON Netz and RWE Transportnetz Strom at 09:41 pm RWE Transportnetz Strom 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 maximum accepted value of 1,990 A of that line at the Wehrendorf substation. At that time, the load of the Landesbergen-Wehrendorf 380 kV line was approx. 1,780 A. At 09:42 pm E.ON Netz issued the so-called disposition permission for the transfer of the ship.

Additional telephone calls between E.ON Netz, RWE Transportnetz Strom 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 E.ON Netz there was no immediate need for action. Yet, possible measures were discussed in case of a further aggravation of the situation.

From the data presented by UCTE the power flow on the Landesbergen-Wehrendorf 380 kV line increased over time beginning roughly at 10:01 pm. At 10:06 pm the current on the Landesbergen-Wehrendorf 380 kV line had increased to approx. 1,900 A. Thus, the safety limit value of RWE Transportnetz Strom protection (1,800 A) was exceeded on this line. At 10:07 pm, RWE Transportnetz Strom and E.ON Netz established that remedial actions were required to restore safe grid operation. E.ON Netz assessed possible corrective switching measures. Coupling of the busbars in the Landesbergen substation was considered suitable for this. E.ON Netz assumed that this measure would result in a reduction of the load by about 50 MW (equivalent to 80 A) on the Landesbergen-Wehrendorf 380 kV line. At 10:10:11 pm, E.ON Netz performed the coupling of the busbars at the Landesbergen substation, without any further coordination with RWE Transportnetz Strom.

According to the E.ON Netz report,[22] the Landesbergen-Wehrendorf 380 kV line tripped two seconds later, at 10:10:13 pm, by the automatic protective relays. The resulting additional power flow changes lead to the overloading of the Bielefeld-Ost-Gütersloh 220 kV line of RWE Transportnetz Strom which was also disconnected automatically with delay of another two seconds. Another four seconds after that, at 10:10:19 pm, the automatic protective relays of the Bechterdissen-Elsen 380 kV line opened that 380 kV line. The cascading effect continued towards the south and finally resulted in a separation of the UCTE grid into three areas.

Within the Western part of Germany, which was part of the under-frequency area about 2,400 MW were automatically shed. Additionally, E.ON Netz 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.

[22] 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 resynchronisation. As these small units are typically decentralised, TSOs did not control or monitor their reconnection. Apart from these problems, TSOs in Germany started 2,300 MW under their control.

Reconnection of the lines that were disconnected did not go ahead without problems. As the information provided by E.ON Netz shows, two attempts were needed to reconnect the Conneforde-Diele and the Wehrendorf-Landesbergen lines.[23] The Western under-frequency area and the Eastern under-frequency area were finally resynchronised at 10:47 pm.

2 The situation in the over-frequency countries affected[24]

The over-frequency area included Czech Republic, Poland, Slovakia, Ukraine, and parts of Hungary, Austria, and Germany. Rather than analysing the event on a country-by-country basis, 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 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 and 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.[25] During the following 30-40 minutes the involved areas operated with frequencies ranging from 50.3 to 50.4 Hz.

Due to an increase in frequency in the North-Eastern area some 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 connected to the distribution network tripped (in Czech Republic 444 MW).

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[23] Eon Netz report, p. 37.

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

[25] UCTE Final report, p. 30.

There was no need for load-shedding. Loss of some consumers' supply was caused by frequency increase and failed operation of distribution network.

According to the UCTE final report, part of load frequency controllers was switched (automatically or manually) from load and frequency control mode to "pure frequency" mode.

2.3 Restoration of the grid

According to the UCTE final 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.[26] 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 affected[27]

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 Former Yugoslav Republic of Macedonia, Montenegro, Greece, Bosnia and Herzegovina, Serbia, Albania, Bulgaria, Romania, as well as parts of Croatia and Hungary. As these countries in the South Eastern area 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.

3.2 Sequence of events

Because of the tripping of the Wehrendorf-Landesbergen 380 kV line between RWE Transportnetz Strom and E.ON Netz 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 Transportnetz Strom and E.ON Netz and 12 inside the E.ON Netz network. In Austria, 5 lines

[26] UCTE final report, p. 32.

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

tripped inside the APG network. As a result the networks of E.ON Netz and APG were split. Two 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.

Load frequency control

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 seems to have behaved as expected. However, the UCTE requirements for primary response across the whole UCTE area are based on the simultaneous outage of 3,000 MW. In this event, there was an imbalance of 9,000 MW for only a part of the UCTE system.

Concerning the secondary control, the UCTE final report reveals that power controller units switched to “pure frequency” mode at different times and in different conditions.

Around 10:30 pm, ETRANS (as frequency control coordinator) asked TSOs of the Western area (including RTE (France), EnBW TNG (Germany), Terna (Italy) and APG (Austria)) to switch the secondary control from load-frequency mode to “pure frequency” mode. This seems to be very late, as the frequency has already restored to around 50 Hz. Some TSOs, including Tennet, report that the late switch to “pure frequency” mode leads to deepen the lack of production.

As the frequency control was unable to stop the frequency decline in the West area, other emergency measures were necessary.

Pumped-storage shedding

Typically, pumped-storage units trip at a frequency of 49.5 Hz. According to the UCTE final report[28] around 1,600 MW of pumped storage was shed:

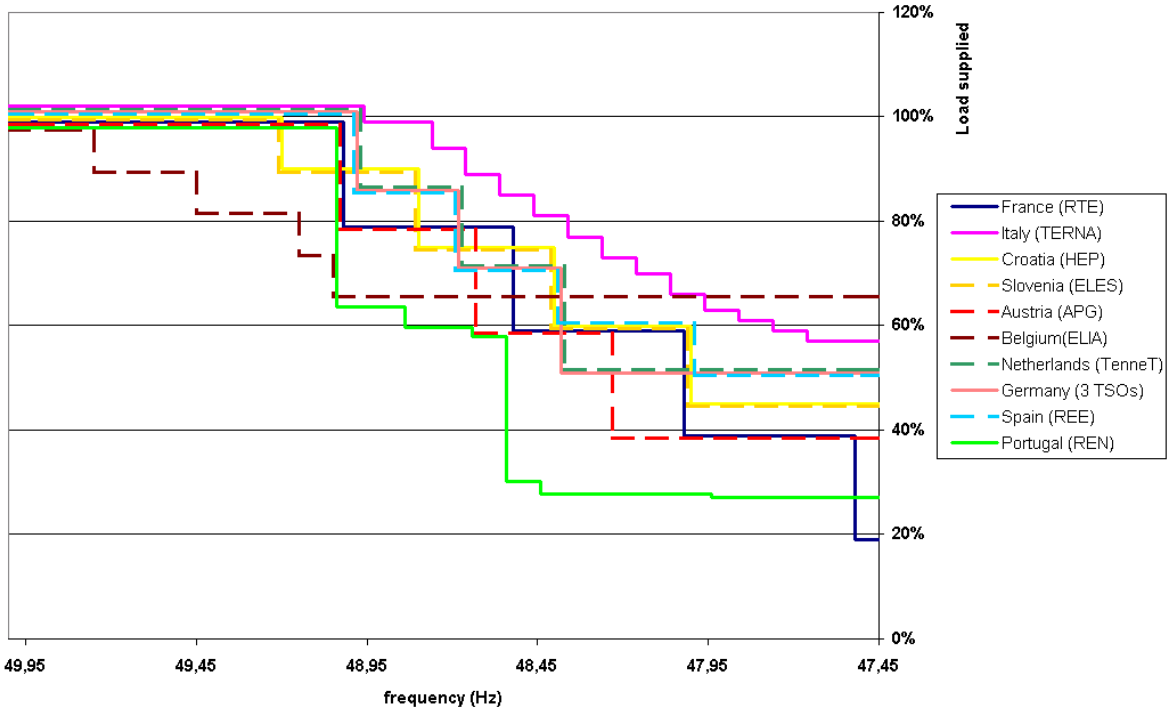
[28] UCTE final report, p. 26.

Country (TSO)	Pumped-storage shedding
Austria (West)	297 MW
Germany (EnBW TNG)	457 MW
Germany (E.ON Netz)	240 MW
Spain (REE)	572 MW
France (RTE)	0 MW (no pump was functioning)

Automatic load-shedding

In order to re-establish the balance between supply and demand, 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 current design of load-shedding implies that each country would not contribute to the same extent to the restoration of the balance between generation and load in case of a disturbance in the UCTE.



Current design of load-shedding vs frequency in the western area countries (Source: UCTE final report[29])

[29] UCTE final report, p. 75-76

The Swiss TSO (Swissgrid) has not yet implemented automatic load-shedding system. The figures of load-shedding as given in the UCTE final report[30] are as follows:

Country (TSO)	Load shed	% of consumption (incl. pumped-storage shedding)
Austria (West)	127 MW	18 %
Belgium (ELIA)	800 MW	8 %
Croatia (HEP)	199 MW	14 %
France (RTE)	6,460 MW	12 %
Germany (EnBW TNG)	158 MW	8 %
Germany (E.ON Netz)	400 MW	14 %
Germany (RWE Transportnetz Strom)	2,000 MW	13 %
Italy (Terna)	2,249 MW	8 %
Netherlands (TenneT)	340 MW	3 %
Portugal (REN)	1,101 MW	19 %
Slovenia (ELES)	113 MW	8 %
Spain (REE)	2,107 MW	10 %
Switzerland (ETRANS)	7 MW	0.1 %
Total	**16,061 MW (auto)**	

The ratio of load shed differs from one TSO to another. Besides, the figures given in the table above are not consistent with the current design of load-shedding given by UCTE. For instance, Belgium should have shed 30% of its load after the decline in frequency to 49 Hz.

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

Generation behaviour

The tripping of generation units due to under-frequency has tended to increase the imbalance between generation and load. UCTE reports that a total of about 10,900 MW (out of 182,681 MW) tripped in the Western area.[31] 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 large 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 indicative power balance held:

[30] UCTE final report, p. 26.
[31] UCTE final report, p. 27.

- 9,000 MW of import from Eastern area no longer available,
- 10,000 MW of generation lost when the frequency reached 49.5 Hz;
- 16,000 MW of shed load and pumped storage;
- 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. The full resynchronisation 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 hydro generation). According to the UCTE final report, the following amounts of generation were started:[32]

Country (TSO)	Generation units started
Austria (West)	650 MW
Belgium (ELIA)	320 MW
Croatia (HEP)	77 MW
France (RTE)	5,305 MW
Germany (EnBW TNG)	1,058 MW
Germany (E.ON Netz)	418 MW
Germany (RWE Transportnetz Strom)	760 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	**16,379 MW**

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

During restoration of supply, it appeared that some DSOs started reconnecting loads without any coordination with their TSOs.

[32] UCTE final report, p. 28.

Annex 2: Rules, Procedures and Implementation 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 Operation Handbook presented at the XII Florence Forum in September 2005[33] 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 summarised below using the results of that overview concentrating the operational issues.

Security and reliability rules / aspects	Implementation in the UCTE Operation Handbook and other UCTE framework
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"
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

[33] 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 Operation Handbook and other UCTE framework
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*)
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 Operation Handbook, the ERGEG Electricity System Operation Task

Force has also conducted an initial benchmark of the contents of the first three policies of the UCTE Operation Handbook as they were practically implemented before the Operation Handbook 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 Operation Handbook, the discrepancies in the implementation largely still remain. The conclusions on the areas of necessary improvements are

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[34] operational states
6. Restoration procedures

These issues have high priority for the operational security of the electric power system. Therefore, the significant discrepancies which have been identified in their implementation in the different control areas are considered unjustified and potentially dangerous for the system security and integrity, as illustrated in the detailed tables below for some security criteria.

Table A2-1: Definition of the N-1 operational security criteria in:

Country	AUT	BEL	CZ	DK	ES	FR	LUX	NL	PL	PT	SK
Grid code	✓		✓		✓			✓	✓		✓
TSO own rules		✓				✓	✓			✓	
Other agreement				✓							

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

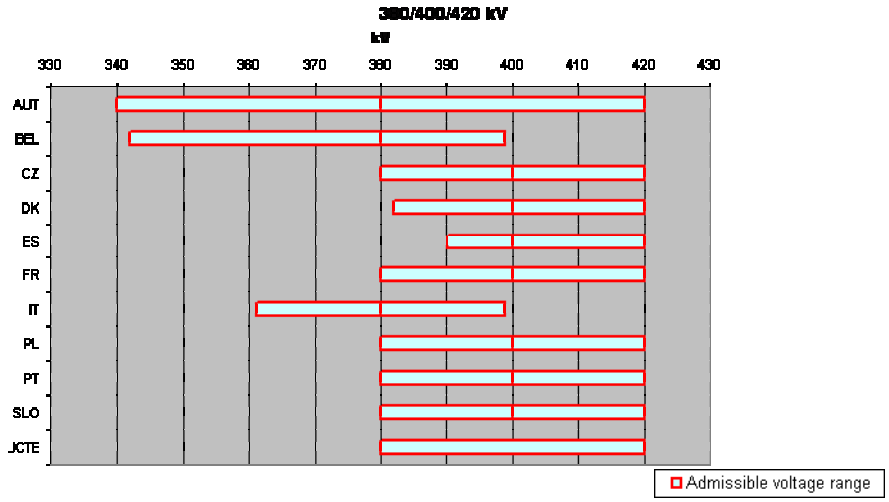
Table A2-2: Network elements taken into account in the N-1 security analysis (UCTE countries marked yellow)

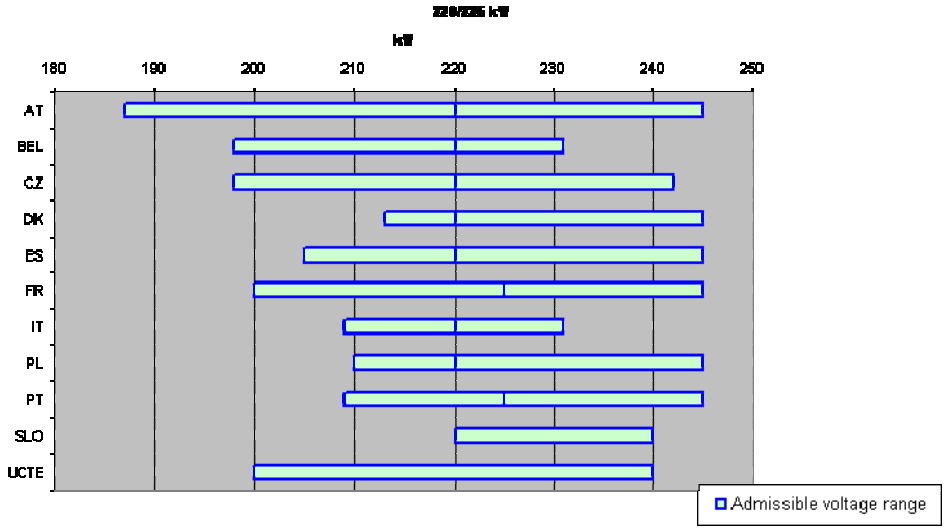
Country	AUT	BEL	CZ	DK	ES	EST	FIN	FR	IT	LUX	NL	NOR	PL	PT	SK	SLO
Line	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Transformer	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●
Production unit		●	●	●	●	●	●	●	●	●	●	●		●		●
Other		●	●	●	●						●					
N-k																
Bus-bar		●				●	●	●		●	○	●	●		○	
Double circuit line		○			○		●	○	●	○			○	○	○	●
Other		●	●		●	○	○	○	○	○	○				○	
● : taken into account									○ : taken into account under conditions							

Table A2-3: Contingency analysis time period

Country	AUT	BEL	CZE	ESP	FIN	FRA	ITA	NL	PL	PT
Frequency of contingency analysis	every 2 min	every 15 min	when necess.	Every 10 min	every 10 to 20 min	every 15 or 5 min	every 15 min	every 10 min	every 15 min	every 5 min

Table A2-4: Acceptable range for the two main voltage levels of 380/400 kV and 220/225 kV used in the European transmission grids[35].





Whereas ERGEG does not consider the above examples being an exhaustive list, neither attempts to propose here actual detailed and technical common solutions, it is important to emphasize once again the urgent need for addressing appropriately all the relevant issues for system security and providing the adequate, common solutions as soon as possible.

[35] Whereas voltage/reactive power related issues are indeed of local character, different tolerances / acceptable voltages in the interconnected power systems are a possible cause of problems for e.g. protection settings and N-1 security analysis.