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MAINTENANCE OF ACCEPTABLE RELIABILITY IN AN UNCERTAIN ENVIRONMENT

Working Group
C1.2

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cigré

WG C1.2

Maintenance of Acceptable Reliability in an uncertain Environment

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1. Executive Summary

ABSTRACT

This technical brochure considers the issues associated with the occurrence of major system unreliability events in power systems that can be related to planning factors. These issues are examined in the context of the growing complexity of power system operations and electricity trading arrangements. Thirteen major unreliability event incidents spanning the last eight years have been studied. Specific events have been selected which in many cases have led to partial blackouts.

Some of the major events studied have included part or total loss of supply to major cities and it is useful to review network planning standards in the context of events that have occurred. This brochure therefore includes the results of a survey of planning standards in cities. This was deemed appropriate because of the relationship between reliability performance and the coordination of transmission and distribution planning. The survey was conducted among members of CIGRE Study Committee C1 and replies were received from 10 countries.

The analysis of the incidents and survey results identified a number of lead indicators of susceptibility of a particular power system to major unreliability events.

INTRODUCTION

Although major system unreliability events have a low probability of occurrence, their potential impacts on customers have far reaching effects and implications socially, politically and economically. While the causes of these major events are often multifaceted, these events are reviewed in this brochure at a high level before the planning implications are considered in more detail.

In most countries today, power system companies are faced with increasing pressure to provide a low cost and efficient service. While the required infrastructure is usually dictated by technical codes and prescribed planning criteria, there is often pressure to delay investment to the last minute and to revise planning criteria so that more risk is taken on the system. In addition, disaggregation of power system utilities may lead to an elongation in the chain of communication and decreased transparency that may impact adversely on planning for reliability.

In this report, thirteen major unreliability event incidents spanning the last eight years have been studied. Economic, planning, operational and social factors have been identified in relation to each of the case studies. Possible lead indicators of unreliability have been identified to establish the risk of future major unreliability events. These can be broadly classified as economic pressures, impaired communications and system limitations. The report suggests possible solutions to these indicators in order to optimize system development and maintain and improve system reliability.

In regard to the original scope of work for the Working Group, it was decided to group the areas for investigation into three broad areas: investment for general reliability – avoiding major unreliability events; investment for local area reliability; and investment to support the market. These areas are categorized below:

Table 1: Areas For Investigation

Area	Probability of incident	Potential impact on reliability
Avoiding major unreliability events	Very low	Very high
Local area reliability	Low	High
Market operation	Med/high	Med/low

The work described in this brochure focuses on major unreliability events. The remaining areas are recommended for study by future working groups.

There was discussion about the roles and requirements of NERC, NPCC, UCTE and ETSO. It was concluded that direct comparison is not always straightforward or possible because some requirements are presented as interconnection rules for parallel operation, whereas other documents apply only internally to a particular power system, technical jurisdiction or member of an interconnection.

Given the importance of supply to large urban centres, particularly to their central business districts, it was decided to survey planning standards in cities. The results show the use of distribution systems to back up outages in the transmission system. A trade-off is partial utilisation of back-up assets during normal system operation.

CHANGING FUNCTION OF THE TRANSMISSION GRID

Probably one of the main causes of a number of recent major unreliability events lies in the changing function of the transmission grid and delays in adapting to change.

For over 50 years before the deregulation and development of electricity markets, interconnected transmission infrastructure had been built for the purpose of assuring mutual assistance between national subsystems. Typically a single utility controlled generation, transmission and distribution of electrical energy in a given geographical area and such a utility generally maintained sufficient generation capacity to meet the needs of its customers. Interconnections with neighbours and long distance power transfers were generally used for emergencies, for example to provide assistance immediately following an unexpected generator outage.

Such practices contributed to system reliability aided by the laws of physics that govern the flow of electricity. To avoid line overload and tripping, the amount of power flow across each line must be kept below its capacity at all times. The difficulty in controlling individual power flows rises rapidly with the distance and complexity of the network (for example, the number of lines) along the path of an interconnection. Any change in generation or topology of the transmission network will change loads on all other generators and transmission lines in a manner that may not be anticipated or that is difficult to control.

The development of electricity markets over the past decade or two brought a fundamental change to that paradigm. Major transmission infrastructure has become no longer just a tool for mutual assistance, but a platform for shifting ever growing power volumes across the entirety of interconnected networks. Deregulation has resulted in higher cross-border and long distance energy exchanges, which are driven by short-term objectives of individual market participants. Other across-interconnection power flows result from an increasing number of major wind energy generation sources. These flows were usually not anticipated in the original designs of power systems, and difficulties now arise each time they reach and potentially exceed transmission capacity. The likelihood of this is compounded by delays in obtaining new transmission corridors, market-driven load and generation patterns, volatile wind generation infeeds and unusual network topologies.

Due to increased long distance and cross border trading across most national systems, individual Transmission System Operators (TSO) are becoming increasingly interdependent. Interconnected power systems are operated ever closer to their limits for increasingly longer times. Operation under higher stress for longer periods of time will inevitably result in more severe and more frequent incidents.

Impact on TSO Control

The changing functions of the transmission system, higher system stress, volatility of wind generation, and trading volumes changing hourly by thousands of megawatts, make daily operation of power systems much more challenging today.

At the same time as these challenges have been increasing, the range of actions available to system operators has become generally constrained by short term electricity market rules and it was noted [UCTE, "Final Report: System Disturbance on 4 November 2006", 2007] that "The need for a more complex management of interconnected grids is obvious, but has so far not always been supported by regulators and main stakeholders when TSO operators have requested more generation data and intervention rights, particularly in emergency situations."

Impact on Market Participants

Deregulation created the opportunity for greater competition between participants and this weakened the traditional spirit of cooperation that had been the hallmark of the industry for more than 50 years.

Focused mainly on profits and short term objectives, companies started to withhold information of perceived commercial value to their competitors, which was also important for coordination to achieve reliability of supply. This increased uncertainty and the probability of major unreliability events, some of which are documented in this technical brochure. Where possible, regulations mandating the sharing of information for the use of the network operators are being used to overcome confidentiality and conflict of interest issues.

COMPLEXITY

The intrinsic complexity of major unreliability events, the causes of which extend well beyond technical considerations, led to a decision to explore economic, planning, operational and social factors in relation to each of the case studies. The results, based on the available information, can be summarized as follows.

Economic

The reported electricity markets are fully or partially deregulated and unbundled. Two important findings were that deregulation changed the function of the transmission grid and that market rules may interfere with system operation. This leads to a conclusion that the regulatory framework and various incentives should take closer consideration of the impact they create on the grid and infrastructure, and should be directed towards alleviating congestion and stress of the electricity grid.

There is a need to coordinate regulatory regimes for gas and electricity, particularly when they both potentially have a major impact on the power system.

Commercial arrangements for reducing the spinning reserve are quite common. Maintaining the balance of active power in the system includes the use of interruptible loads as a substitute for spinning reserve. These loads can cover a wide range of contracted capacity, ranging from tens of megawatts (industrial customers) to thousands of megawatts (pumped storage). A more recent development is that of contracts with commercial customers for grid peak load reduction, either by disconnection of non-critical loads or by transferring all or part of demand to emergency generators.

Participation in under frequency load shedding protection appears to be mandatory in all jurisdictions. The same applies for under voltage load shedding, although these schemes do not seem to have been so commonly used.

Operational

Two response times are of concern: the time from the trigger event to blackout, and the time for restoration. These times varied substantially in the events reviewed.

It took about 4 hours for the USA/Canadian blackout to develop after the SCADA system became ineffective (about 2 hours after the loss of generation). The UCTE blackout occurred after 32 minutes of insecure operation, those in Italy and Greece occurred after 27 minutes and the one in Sweden/Denmark after 5 minutes. Nearly instantaneous loss of supply occurred in Algeria, Australia, Finland, Great Britain, Iran, Libya and Singapore.

The blackouts typically lasted between 6 minutes and 2 hours. The times for full restoration of loads ranged from 6 minutes (Australia) to between 2 to 18 hours. Extremely long timeframes were recorded in New Zealand, where it took 29 days for a blackout to develop and 3 weeks to restore supply via a temporary 110kV overhead line.

Poor communication between participants contributed to many incidents, particularly poor pre-incident inter-TSO coordination. Poor inter-TSO and TSO/DSO coordination hampered system restoration.

The lack of visibility beyond 'own borders' and lack of effective operational procedures to manage 'system-wide' disturbances were identified as problems in large interconnections. The establishment of an information platform to allow TSOs to observe in real time the actual state of the whole interconnection was recommended following a major incident.

Other reported communication problems included operator failure to record topological changes from ongoing work and TSOs having no on-line information on the total amount of connected distributed generation.

Poor communication of operational planning data and general planning assumptions to operators was also a contributing factor in many incidents. The risk of inadequate communication is high when different parties are involved and when accessing data beyond 'own borders'. For example, in one case a TSO didn't take into consideration lower protection settings on the opposite side of the interconnecting line, owned by another TSO, although this information was critical due to the very high flows on that line. In another case pre-existing line outages were not communicated to the system operator, causing the state estimator to operate incorrectly.

Planning

Planning for low probability events

The reported practices in relation to low probability contingency plans can be summarized in three broad categories:

1. Contingency plans existed and were successfully executed. For example, the action of under frequency load shedding in Australia.
2. Contingency plans existed but not for the severity of events that occurred, for example, there was a contingency plan for the loss of two cables in New Zealand, however four cables failed.
3. There were no contingency plans for the type of disturbance that occurred or developed. For example one independent system operator did not measure system voltages and there were no operational procedures to shed large amounts of load in a matter of minutes (it was later found that the incident could have been avoided by containing the initial disturbance from spreading by under voltage shedding 1,500MW of load). Similarly, circuit breaker failure protection could have prevented another incident. In another case diesel fuel was used as a backup fuel, however there was no contingency plan if the transition failed.

It should also be noted that inappropriate resynchronization procedures delayed restoration in some cases.

All incidents led to the review of planning and operating practices and contingency plans.

Operational management of risks

The lack of an overall picture and poor visibility beyond a particular jurisdiction is an issue for transmission system operators in large interconnected systems.

In some cases heuristic security assessments proved unreliable in identifying N-1 insecure operation and in predicting the immediate effect of planned switching strategies. For these cases, incidents developed after the system was operated in an N-1 insecure state or after a switching operation produced the opposite effect from that desired.

The range of actions available to system operators is generally constrained by the short term electricity market rules. The adequacy and effectiveness of such rules is not always supported by the management of specific conditions, for example those that occurred on 4 November 2006 in Europe. In another case, in Western Australia, a large wind farm, located at the far end of a longitudinal system supplied via two lines, produced unacceptable voltage fluctuations at a nearby city, however the wind farm operator was unavailable. The market rules did not allow the system operator to disconnect the line to which the wind farm was connected, as that would have brought the system into an N-1 insecure operating state. This led to a conclusion that, although the actions of the operators may impact the free operation of the market, operators must be given enough intervention rights, under certain conditions, to quickly bring the system back into the normal operating state.

Relation between design assumptions and operational behaviour

Operators generally run equipment up to assigned ratings. Actual ratings lower than assigned ratings have contributed to several incidents. In one case assumptions to calculate cable ratings were found to be inadequate. In another, inadequate clearances reduced the assigned line emergency rating. In a third case, inaccurate old cable impedance data led to incorrect protection settings. In a fourth case, a lack of spinning reserve assistance available from neighbours was a key cause. In a fifth, there was an explosion of an under-rated circuit breaker located at a key transmission installation. There was no circuit breaker failure protection to contain the disturbance. This indicates flaws in the system design. Similar design shortfalls in relation to the voltage stability contributed to two other incidents. In a few cases, generators were disconnected before the last stage of under frequency load shedding operated. This included mass disconnection of small generators connected to the distribution systems.

Many incidents occurred during a weakened state due to plant maintenance, indicating the need to study these situations in planning and operational planning timeframes. Several incidents occurred because of events well beyond the planning criteria, for which the performance of automatic remedial schemes was crucial.

Use of automatic remedial schemes

Under frequency load shedding protection (UFLS) was not always effective because it either shed less load than expected or because a large amount of generation disconnected before its last stage was activated.

System restoration problems included uncontrolled reconnection of wind generators into an island with a surplus of generation.

Social

The impact of widespread disturbances

Three of the largest incidents in Europe and North America affected between 50 and 60 million people and resulted in disconnection of between 20 and 70 thousand megawatts of load. A regional incident in the south of Sweden and Denmark affected 4 million people and 6,500 MW of load was lost. Outside these large interconnections, incidents in Algeria and Iran respectively affected 98% and 50% (22 million) of population where 5,200 MW and 7,000 MW of load was lost. Two major capital city incidents resulted in the loss of supply to 800,000 people in Helsinki and 410,000 customers in London, however many more people in London were affected due to the loss of supply to the underground railway transport services.

Governing bodies / Control hierarchy. The reported governing bodies and control hierarchy appear to be unique for each technical and legal jurisdiction to the extent that no useful comparison could be made.

PLANNING STANDARDS FOR CITIES

The importance of supply to large urban centres, particularly to central business districts, led to a decision to review planning standards for cities and how they safeguard against major unreliability events. A survey was emailed to members of CIGRE Study Committee C.1 in 2005. Replies were received from 10 countries.

In summary, the survey identified that, despite vastly differing practices and historical constraints, powering of major cities generally requires simultaneous consideration and coordination of the local transmission and distribution network design and operating practices. An important finding for planning for reliability is the desire to target location of generation sources in close proximity to major urban centres.

LEAD INDICATORS

Some of the early warning signs of susceptibility of a power system to major unreliability events include the number, magnitude, frequency, duration or cumulative time of events when the:

- Area Control Error (regulating error or the system frequency error) is outside the permitted dead band
- Voltages at key locations are outside their normal band
- The system is in an insecure state (risk of overload/instability following the next contingency)
- The system is in an ‘unusual’ state
- The number of incidents (near misses) is high
- The number of transmission load relief procedures, as a proxy for ‘near miss’ situations are significant
- Bulk transmission system utilisation change (%) increases over the past few years defined as the ratio between yearly electricity load demand [TWh] and equivalent EHV transmission grid extension [km]
- Percentage of time near critical transfer limits increases
- Maximum loading of key interconnectors (transmission corridors), particularly relative to the load growth, and their load duration curve is approached
- The maximum number of generating and other plant in the system that went on maintenance simultaneously is significant
- Use of equipment for duties beyond their assigned short circuit level occurs
- Percentage of disconnected load increases
- The number of projects delayed, perhaps weighted by the delay time increases, and

- Lack of clear responsibility for power system security occurs.

The analysis of incidents and planning standards in cities identified a list of key possible lead indicators of risk of major unreliability events. These can be broadly classified as economic pressures, impaired communications and system limitations. The more salient indicators are listed below:

Economic Pressures

- It is frequently difficult to obtain permission for new or upgraded infrastructure, which results in undue pressure to run systems harder.
- The development of electricity markets seems to be running ahead of the ability of power systems to support them.
- Liberalisation of network tariffs has resulted in unforseen changes to patterns of generation and line flows
- Inter-regional trading places pressure on interconnectors originally intended only for interchange of mutual support power. Insufficient knowledge of changes to generation and the network in neighbouring systems has exacerbated this problem.
- The ability of TSO's to manage critical events is often constrained by short-term market rules that place market purity ahead of system security.
- The economic incentives/penalties for generators to contribute to reliability may be inadequate.
- Following a large disturbance, the automatic reconnection of unscheduled generation such as wind must be balanced by decreased generation from other plant. This has not always happened and the question arises whether market rules facilitate this.
- There has been insufficient enforcement of technical standards that contribute to reliability.
- Not all markets provide sufficient incentive for reliable generation of reactive power.
- Responsibilities for system adequacy are not always clear.
- The mass proliferation of distributed sources of generation has contributed significantly to the pool of generation but there has been a lack of knowledge of the momentary status of these generators and their performance during power system disturbances, especially their fault ride-through capability.

Impaired Communication Channels

- Between planners and system operators there has been a lack of transparency in communication of accepted emergency procedures, and amongst system operators, information flow has been impaired by structural and hierarchical changes
- Generators have been reluctant to share information such as dynamic models to protect perceived competitive advantages – an issue at the planning stage. In some countries this information is required to be placed in the public domain.

- Inter TSO and TSO/DSO coordination is essential in operational timeframes. Limited visibility inhibits the ability to prepare contingency plans for emergency situations.
- A need has been established for limited visibility beyond the boundary of owned assets in order to manage disturbances that spread across the boundaries.
- Effective operator communication is required along the entire path of flow of electricity inclusive of neighbours that can significantly alter the path.

System Limitations

- Difficulty in obtaining approval for new lines has substantially increased the utilisation of some systems with a consequent reduction in redundant capacity.
- System limitations must be identified along the whole path of electricity flow between trading partners eg action in one country may transfer the problem to another. Condensed models of a neighbouring system have not always proven adequate.
- Unpredictability of output of large wind generation installations increases complexity of operational planning, especially security assessment.
- The occurrence of cascade events is very difficult to predict.
- Inadequate protection methods may have system-wide consequences.
- There is a need for defence plans that may include sacrificing parts of the system to save others (when absolutely necessary).

POSSIBLE SOLUTIONS

Some of the possible solutions proposed by this study are:

- Clarify the responsibility for power system security.
- The regulatory framework for electricity and gas and various incentives should take closer consideration of the impact they create on the grid and infrastructure, and should be directed towards alleviating congestion and stress of the electricity grid.
- Promote the placement of new generation in close proximity to load centres thereby eliminating the need for long power transfers.
- Rather than confining to a particular jurisdiction, conduct planning and real-time contingency assessment studies to encompass the entire paths of major normal and emergency power flows.
- Increase co-ordination of system planning and emergency procedures and training of operators to handle emergencies.
- Increase stakeholder awareness of system limitations and economic/reliability trade-offs.
- Devise protection systems to contain the spread of the initial disturbance for low probability events.
- Co-ordinate maintenance across jurisdictions.
- Consider introducing a new planning criterion that addresses the impact of multiple maintenance events during off-peak times.

- Install Wide Area Protection (WAP), Wide Area Measurement System (WAMS) and synchronised high speed data recorders.
- Establish an information platform to allow TSOs to observe in real time the actual state of the whole interconnection.
- Investigate the formulation of maintenance congestion as an indicator of system stress at off-peak times and develop local planning criteria based on this.
- Mandate plant performance characteristics for all generators, including non-synchronous and distributed generation, in the areas of fault ride through capability and the duration and magnitude of the generator fault current contributions that are sufficient for protections to see the fault and provide adequate voltage support.
- In systems with high penetration of distributed generation, TSOs should have on-line access to their status, schedules and changes to the schedules, at least one minute data in the form of aggregate generation data provided by individual DSOs.
- Investigate the practicality of intelligent household appliances (e.g. storage hot water) that would self load-shed during major under-frequency events.

CONCLUSIONS

There is great industry interest in major unreliability events. The gravest concerns are in relation to those that occur in major population centres or are spread over a vast area. Thirteen recent major unreliability events have been documented in this report and planning standards for cities have been surveyed. Economic, planning, operational and social aspects of major unreliability events were identified which led to the development of proposals for lead indicators of susceptibility of power systems to these events.

Economic pressures, impaired communication channels and system limitations were identified as the key lead indicators. Other contributing factors fall under the headings of social, economic, planning and operational complexity. This has led to a conclusion that underlying causes may have originated in rules and regulations governing electricity markets and power system operations but their consequences have been exacerbated by subsequent planning and operational decisions.

2. Introduction

Working Group C1-2 was established to research issues associated with the maintenance of an acceptable level of reliability in an uncertain environment. The scope of the working group is detailed in Appendix A.

Although major system unreliability events have a low probability of occurrence, their potential impacts on customers have far reaching effects and implications socially, politically and economically. While the causes of these major events are often multifaceted, these events are reviewed in this brochure at a high level before the planning implications are considered in more detail.

In most countries today, power system companies are faced with increasing pressure to provide a low cost and efficient service. While the required infrastructure is usually dictated by technical codes and prescribed planning criteria, there is often pressure to delay investment to the last minute and to revise planning criteria so that more risk is taken on the system. In addition, disaggregation of power system utilities may lead to an elongation in the chain of communication and decreased transparency that may impact adversely on planning for reliability.

In this report, thirteen major unreliability event incidents spanning the last eight years have been studied. Economic, planning, operational and social factors have been identified in relation to each of the case studies. Possible lead indicators of unreliability have been identified to establish the risk of future major unreliability events. These can be broadly classified as economic pressures, impaired communications and system limitations. The report suggests possible solutions to these indicators in order to optimize system development and maintain and improve system reliability.

It was recognized that the original scope of work for the Working Group was very expansive and it was therefore decided to group the areas for investigation into three broad areas: investment for general reliability – avoiding major unreliability events; investment for local area reliability; and investment to support the market. These areas are categorized below:

Table 1: Areas For Investigation

Area	Probability of incident	Potential impact on reliability
Avoiding major unreliability events	Very low	Very high
Local area reliability	Low	High
Market operation	Med/high	Med/low

The work described in this brochure focuses on major unreliability events. The remaining areas are recommended for study by future working groups.

The interrelationship between planning criteria and operational performance was found to be important.

There was discussion about the roles and requirements of NERC, NPCC, UCTE and ETSO. It was concluded that direct comparison is not always straightforward or possible because some requirements are presented as interconnection rules for parallel operation, whereas other documents apply only internally to a particular power system, technical jurisdiction or member of an interconnection. However, clear allocation of responsibility for power system security, or lack of it, was found to be important.

Given the importance of supply to large urban centres, particularly to their central business districts, it was decided to survey planning standards in cities. The results show the use of distribution systems to back up outages in the transmission system. A trade-off is partial utilisation of back-up assets during normal system operation.

3. Summary of Recent Major Unreliability Events

A number of major unreliability events have been selected from incidents that have occurred over the last few years. These are summarised here and described in more detail in Appendix B. Information has been collated from reports on websites and in several cases, from information provided by CIGRE members. Maximum effort has been made to ensure accuracy of the information but no guarantee is made in this regard. It may be observed that some of the events do not establish a clear link to lack of transmission capacity. However, these events have been retained as they still raise the issue of the level of redundancy that should be provided to cater for unplanned events, even where a human error may have contributed to the event.

New Zealand, Auckland 20th February 1998:

Central Auckland was supplied by six 110kV cables, two gas filled and two oil filled supplying the CBD area and two oil-filled supplying the non-CBD area. A 172MVA summer peak load coincided with an exceptionally hot and dry period. On 22nd Jan one of the gas filled cables failed near a joint. There was a normal repair team response, as this was not an unusual event. On 9th of Feb, while the first cable was still out of service, the second gas filled cable failed near a joint, and then on the 13th Feb one oil filled cable failed also. The other oil filled cable's load was constrained to 70MVA with significant loss of supply. On 20th Feb the remaining oil filled cable failed and the whole of the Auckland CBD was blacked out for 7 weeks, as the full supply was restored on 27 March 1998.

Algeria, 3rd February 2003:

The trigger event was the loss of two generation units with a total output of 350MW at a time when there was not enough spinning reserve, ie just 84 MW were available. The resulting power deficiency highly stressed the transmission system and there was insufficient spare capacity on interconnectors with neighbours. Transmission lines began to trip: the 300 MW line with neighbour Morocco was disconnected after its loading increased to about 430 MW.

Additional contributing factors included:

- Lack of coordination between overload protection on this line and load shedding in another neighbour - Algeria.
- The under frequency load shedding protection shed less load than expected, and
- Some generators disconnected before the last stage of UFLS operated (poor coordination)

It took just 15 seconds for the major unreliability event to occur.

Iran, 31st March 2003:

A single phase fault appeared on a 230kV line connecting two major substations. An under-rated circuit breaker exploded in one of these substations that had a major role in transferring energy from North to South Iran. The lack of busbar protection and incorrect operation of transformer protection devices spread the fault to the whole substation. Protection devices operated and isolated this substation however, demand and generation could not be balanced in the North and this situation led to 8 hours without supply. In summary:

- Explosion of an under-rated CB tripped the whole key 400/230kV transmission switchyard
- The system separated and the largest island blacked out
- No busbar protection was installed to contain the initial fault

USA, August 14th 2003:

A change in power flows led to a major 345 kV line sagging into a tree and tripping, despite operating within its nominal rating. This event also led to other circuits becoming overloaded and tripping. The voltage dipped temporarily on the Ohio part of the grid, however operators failed to inform controllers in other states as they were unaware of the low voltages and circuit outages due to a failure in their SCADA system. The Mid West ISO (MISO), (which oversees First Energy) did not recognize the urgency of the situation as their state estimation program had flawed information. Two breakers connecting First Energy's grid with American Electric Power were tripped. Many other lines then also tripped in response to sudden changes in flows, blocking any eastward flow of power and creating islands within the Eastern Interconnection. The largest island was substantially under-generated and collapsed despite extensive under-frequency load shedding. A smaller, over-generated island was also formed and survived. This island was used as a starting point to enable restoration.

Investigators eliminated factors such as high power flows to Canada, low voltages earlier in the day or on prior days, the unavailability of specific generators or transmission lines (either individually or in combination with one another), and frequency anomalies as causes on the blackout.

Finland, Helsinki 23rd August 2003:

A circuit breaker was closed at Kruununhaka zone substation end of a cable when a human error caused a three phase short circuit in Suvilahti by closing a 110kV circuit breaker onto earth. A contributing factor was the lack of remote state information to Suvilahti substation from Kruununhaka substation. Relays caused two false trips in lines after which three power plants in Helsinki and Vantaa were tripped off. 400kV and 110kV connections were lost as they were set for the more common faults to earth than rarer three phase faults. Finally, the last connection to the national grid, a 400kV transformer, tripped out. This caused an island and power shortage situation in Helsinki, Vantaa, Sipoo and Kerava with two generators still running. Finally 2.38 seconds after the short circuit fault, the last generator in Vantaa tripped resulting in the loss of supply to 800,000 people.

As a result of the incident, a new operating procedure was implemented for works at zone substations located at the boundary of the cabled area. The procedure requires prior disconnection of all transmission cables from such a substation.

England, London 28th August 2003:

The incident occurred in an underground transmission system. Misoperation of relay protection, superimposed on the system which was weakened due to maintenance, caused the trip of two CBD substations. The incident resulted in the loss of supply to 410,000 customers, however many more people in London were affected due to the loss of supply to underground and railway transport services.

As a result of the incident, over 40,000 protection relays with over 1,000,000 individual settings were checked.

Sweden and East Denmark, 23rd September 2003:

Prior to the fault, two 400 kV lines were out of service due to maintenance work, four nuclear units were out of service due to annual maintenance and three HVDC links from Germany and Poland were out of service. At 12.30, a 1200 MW unit was lost due to internal valve faults. Five minutes later, a disconnector fault caused a double busbar fault leading to the loss of two 900 MW nuclear units and disrupting the South-Western grid. Two minutes later, a voltage collapse developed in the Eastern grid section south of the Stockholm area which isolated Southern Sweden from the Northern and Central grid. Voltage and frequency in Southern Sweden and Eastern Denmark fell to zero within a few seconds due to the inability to feed demand, tripping all remaining generators and lines. The restoration process was started immediately from the intact grid and hydro power in the North. Power was restored to the Swedish Southern provinces within one hour, with the Danish submarine cables being energised after another 10 minutes. Complete restoration was achieved a few hours after the disconnector damage.

In summary:

- The system was weakened due to maintenance of two 400kV lines, three HVDC links and four nuclear units.
- A 1200MW nuclear unit was lost.
- 5 minutes later a disconnector fault occurred (breakdown due to overheating) which caused a double busbar fault, leading to the network separation and further loss of 2x900MW nuclear units.
- Total voltage collapse in the island of Southern Sweden and Eastern Denmark took two minutes to develop.
- This regional incident affected 4 million people and 6,500MW of load was lost.

Italy, 28th September 2003:

The major unreliability event was initially triggered by a tree flashover of the 380kV Mettlen-Lavorgo line. Several attempts to re-close the line automatically were unsuccessful and a manual attempt seven minutes later also failed. The Swiss co-ordination centre of Etrans phoned the Rome control centre of GRTN to help relieve overloads in Switzerland by reducing Italian imports by 300MW. This action was carried out 10min later, however it was insufficient to relieve the loads. The power shift caused the other Swiss 380kV Sils-Soazza line to overload further than its 15min limit and trip. Roughly 12 seconds later, overloads on remaining lines caused other interconnectors towards Italy to trip, causing the Italian system to be isolated from the European network.

This caused a very low system voltage in Northern Italy and the tripping of several Italian power plants. Countermeasures such as disconnection of pumped storage plants, automatic load shedding and load balancing systems were ineffective due to the loss of generation plants (caused by severe transients of voltage and frequency) Two and a half minutes after being disconnected from the rest of Europe, Italy experienced a major unreliability event. This incident demonstrates the need to mandate minimum plant performance characteristics for generators in respect of voltage and frequency transients.

Libya, 8th November 2003:

The trigger event was a short circuit fault on a 220/30 kV transformer. The circuit breaker failed to open and the fault was cleared by Zone 2 distance protection. After the short circuit was cleared, a severe transient arose creating instability between the Western and Eastern regions. The two sections split and islanded, eventually losing generation and leading to partial shut down.

In summary:

- A 220kV CB failed to open on a transformer fault and was cleared by the back up protection, Zone 2 distance protection, which contained the spread of the fault by opening ten 220kV lines
- The system separated, a few generators were lost and UFLS was activated
- Remedy: CB fail protection has been installed on key 220kV substations for faster clearing of such faults

Singapore, 29 June 2004:

The power failure was triggered by equipment failure at a gas terminal. After heavy rain, water leaked into some electrical systems associated with a key pressure safety valve. The loss of gas impacted on generators and 5 of the 6 generating units fed from this terminal did not switch to standby diesel fuel as intended. Three units tripped during the changeover and two other units switched but failed due to blockages in the diesel fuel filters. This led to a falling frequency which tripped the electricity inter-tie to Malaysia and led to several stages of automatic under frequency load shedding. 300,000 customers (about 30% of the total load in Singapore) were interrupted for up to 1 hour 48 minutes.

Greece, 12th July 2004:

On 11th July, one 125MW generator in Peloponnese and one in Northern Greece were out of service. The effect was that about 80MW of power was flowing via Athens to Peloponnese, stressing the Athens grid. On the morning of 12th July, a 300MW rated generating unit was lost in Athens due to auxiliary failure. The failure was repaired however the unit was not synchronised until 12.01pm when the load had peaked to 9160MW.

The switching on of many air conditioners on a particularly hot day of 38 degrees celsius created a surge in demand. However, after 11 min, the generator in Athens again failed due to excess water in the steam drum. This brought the system to an emergency, as it could not keep up with the reactive power demands of the system.

Load shedding was attempted, however it was insufficient to secure the system and another generator unit in Athens tripped. Collapsing voltages caused the system to split by the under-voltage protection of the North-South 400kV lines. Finally all remaining generation in Athens and Peloponnese were disconnected at 12.39pm leading to a total blackout of these areas.

Australia, 13th August 2004:

Significant load shedding was instigated when a 330kV circuit breaker current transformer failed and the subsequent tripping, re-closing and re-opening of the line significantly disturbed voltages and resulted in six nearby generators tripping out of service. 3,100MW (14% of the total supply) were lost which caused the frequency to fall to approximately 48.9Hz.

Automatic under frequency load shedding across Queensland, NSW, Victoria and South Australia, worked as designed and shed 1,500MW (6%) of the demand at that time. A further 340MW of load was shed by the operation of customer equipment in response to temporary over-voltage conditions caused by load shedding in a region far from the initial fault. The system was quickly restored to an acceptable balance after 2 minutes and a major unreliability event was averted.

Europe - UCTE, 4th November 2006:

An incident originating from the North German transmission system led to power supply disruption to more than 15 million households and splitting the UCTE network into three islands. The full resynchronisation was completed 38 minutes after the system split, and, although the TSOs didn't have a complete and clear picture at any moment of the unexpected and exceptional events, a normal situation in all European countries was re-established in less than two hours.

Two root causes were non-fulfilment of the N-1 criterion and inappropriate regional inter-TSO co-ordination during this event. The trigger event was a planned outage of a double circuit 380kV line. The system was weakened by a topology change (bus splitting of a major transmission substation in order to control fault levels). After 32 minutes of insecure operation, the system conditions evolved to cascading line tripping all over the UCTE area. In less than 20 seconds, the UCTE interconnection split into three islands with a large imbalance between load and generation.

The evaluation of the N-1 secure conditions was not based on the results of computer simulations and it was also not based on the possible changes in the system conditions for the following hours. Only an empirical evaluation of the situation was performed.

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

No specific attention was given by the TSO to the fact that the protection devices have different settings on both sides of the Landesbergen-Wehrendorf line although this information was critical due to the very high flow on this line.

The change of time of the planned outage was communicated very late to the other, directly involved, TSO, and even if it was checked for security, the market rules would not have permitted a rescheduled generation exchange to accommodate such a decision, because it was made after 8:00 am the day before. In other words, a limited range of action was available to dispatchers for handling grid congestion (due to the German Energy Law).

The generator related issues included: *a)* significant amount of generation tripped on underfrequency; *b)* lack of control over generating units in an island with surplus generation (quick reduction of schedules and uncontrolled reconnection of wind and combined heat-and-power generation), and; *c)* TSOs had no real time data of distribution connected generation.

Further contributing factors were TSO/DSO co-ordination in the context of defense and restoration plans, and inappropriate co-ordination of resynchronisation procedures during this event.

The Union for the Co-ordination of Transmission of Electricity (UCTE) coordinates the interests of transmission system operators in 23 European countries. Through the networks of the UCTE, 450 million people are supplied with electric energy and annual electricity consumption totals approximately 2500TWh.

4. Economic Pressures, Impaired Communications and System Limitations

From the onset of this research it became clear that the search for causes of susceptibility of a network to major unreliability events should include economic pressures, impaired communications and system limitations. This led to a decision early in the research to break up the overall problem of understanding major reliability events into sub-problems and then address each of them separately. In this respect, this section 3 is aimed at identifying the issues and piece-wise understanding of a number of individual mechanisms involved, before explaining the overall complex phenomena later in this technical brochure.

4.1 Economic Pressures

- Pressure to operate the system closer to its limits – higher risk mode – because of competition and open markets. The need to put in markets seems to be running ahead of our ability to support them.
- The short term electricity market rules generally limit the range of actions available to dispatchers. For example:
  - Unless there is a force majeure event, some market rules do not permit rescheduling of generation after 8:00 am the day before.
  - Some market rules require local dispatchers to exhaust switching actions first before interrupting the generation schedule. One such an action caused the largest blackout in Europe and uncontrolled system separation in less than 20 seconds.

    - These two examples raise the question of the purposefulness of constraining the range of actions available to dispatchers in order to preserve the 'purity' of the electricity market. Whereas each blackout disrupts the market, the disruption of market operation does not interrupt the supply of electricity to customers. The latter also leads to an argument that dispatchers should be left to run the system the best they can, and unconstrained by the fear of legal responsibility for the economic consequences of decisions they make.
- The restoration of the frequency after activation of the defence plans requires sufficient means for rescheduling generation in individual control areas (resources, procedures). However, the automatic restarting of a considerable amount of wind generation in a recent UCTE blackout was not immediately compensated by a corresponding amount of decreased generation in thermal or hydro power plants. In other words, uncontrolled reconnection of generation units was causing further imbalance in the island with a power surplus. This raises a question on whether the market rules have contributed to such behaviour of the generators.
- Electricity market rules need to be refined to include mechanisms that foster optimal system restoration and reward/penalise behaviour which helps/aggravates the situation.
- In the long term, the pressure to run the system harder is compounded by difficulties to get the necessary permits for new infrastructure or for upgrading existing infrastructure.
- Under pressure to make more transmission capacity available to the market TSOs are tempted to take more risks and perhaps go too far.
- As the overall reliability of transmission systems is generally very high, in power systems that have not experienced major blackouts recently, the perception of the actual risks is low. Then the temptation to overlook a certain seldom contingency can become great. Similar considerations apply when taking risks with short circuit current levels.
- Pressure on electricity industries for affordable solutions to low probability failure events
    - Market stresses and accountability to stakeholders
        - Customers may not want to pay increased prices to cover extra generation for use during a few hours of the year, in peak loads
    - Risk Analyses
        - Issues of costs and benefits

- Limited economic incentive or inappropriate penalty regime for generators to contribute to a reliable network
    - Long term fuel sources
        - Windfarms introduce power quality issues and unpredictable cross system power flows.
        - Fossil fuel plants situated closer to the source of fuels rather than loads. The situation is worse for renewable sources of generation.
    - Pricing trends

        - Dependency on fuel source (eg gas supply)
        - Ancillary services eg secondary reserve, black start etc
    - Interconnected networks are now more dependent on other sections
        - Originally connected as a contingency plan for increased reliability however, increased power flows along these lines are creating stresses
            - Interconnectors were not originally designed to handle these increased power flows
        - If correct backup of lines is not undertaken, one line outage can cause stress on other lines and threaten the whole network:
            - Italy
            - USA
            - Europe – UCTE
        - Dependency from other systems not always available due to confidentiality
        - New generation size and locations not known between regions
        - Market uncertainty – too little and/or too late information.
    - Deregulation
        - The impact of new rules not well assessed/anticipated.
            - For example, in the USA, the removal of the “stacking” tariffs and their replacement with the “postage stamp” tariff for transmission of electricity facilitated placement of new generation away from main load centres. This increased the loading on the transmission system.
            - Need for greater coordination and coherence of planning issues and reliability (eg UCTE rules too general, Regulators have little technical expertise) NERC standards becoming mandatory.
            - In North America, cross country rules are in place and violators of rules will be placed on web site affects funding capability
            - Regulators beginning to increase their protection expertise.
            - In Asia platform is ASEAN – issue in early stage
            - System operators should be enabled by legislation to focus on the events they manage, unconstrained by the threat of legal action or other distractions.
        - Little central enforcement of planning issues and reliability in large interconnections
        - Economic incentives for private generators compete with economic reliability planning done by the utility
            - Less incentive for new generators to produce reactive power as opposed to active power, however reactive power is needed to maintain and stabilise the voltage in the networks
                - USA
                - Iran
                    - Restoration impeded as power plants did not cooperate in maintaining the required VArs

        - Assumptions made about generator capability to generate reactive power. Authority either with ISO or with TNSP
        - Ontario Power Authority monitors long term generator capacity and reactive availability and develops an integrated plan
        - UK Seven Year Statement – Regulator as last resort?
        - Australia Statement of Opportunity
        - Slovenia 10 year plan
        - Belgium indicative 10 year plan
            - In Belgium, the ISO is responsible to verify the long term adequacy of reactive generation
        - Italian market rules do not provide for reactive power remuneration
        - Israel – eight year plan mandatory – from 2006 disaggregation – expect changes
        - Malaysia – 10 year plan includes reactive – generator reactive requirements included in grid code
- Due to liberalisation, in many countries it is not always clear who is responsible for the adequacy of the system: long term equilibrium between generation and consumption
    - Lack of accountability and responsibility
        - Need for impartial governing body
    - Belgium indicative 10 year plan: this plan is not mandatory and it is assumed that the market will fulfil it.
    - possibly the same in other countries
    - New generation units placed in more economically advantageous areas, governed by lower costs of labour and fuel, regulations and taxes
        - Impairs ability to forecast and prepare long term plans
        - Spain – incentive arrangements to encourage generator to locate in areas of most benefit – depends on fuel source
        - Slovenia – easy to build combined cycle plant but network more difficult. New generation located in existing generator locations – drivers to increase transmission voltages – long lead times
        - Other costs tend to dominate location rather than network costs
        - Malaysia – location dominated by site and fuel
- Increased power flows cause an increased stress if not sufficiently planned for.

- Impact of mass proliferation of new generation sources and their fault ride through characteristics. For example, massive proliferation of relatively inflexible early combined cycle plant (CCP) caused numerous operating problems in the UK. Similarly, the Malaysian incident in 1996 was caused by GT flame out, and control systems have improved since.
- UK CCP's initially designed to sit on system with no frequency changes – need to be returned to match dynamics of system through new technical requirements for plant performance characteristics.
- Impact of distributed generation.
- Traditionally the distribution companies did not permit islanded operation of embedded generation. Mass proliferation of distributed generation requires review of that policy, which would require cooperation between the ISO and the DSO's to coordinate the rules of connection and also to share information about the installed power of distributed generation
- Impact of non-scheduled generation (windfarms). For example, over frequency problems on grid portions therefore weakly interconnected, changing power flows/sudden lack of power when wind stops or there is lack of fault ride through performance during system disturbances.
- The need to temporarily curtail wind generation due to system security and possible remuneration of interrupted wind power.
- The massive development of wind farms in the European grid poses the problem of stability of the system at an incident where all these wind farms could disconnect and increase the extension of the incident. Quick changes in wind generation induce flows through the European grid which can stress some parts of the grid in certain circumstances.

4.2 Impaired Communication Channels

- Internal
  - Planners vs Operators
    - Lack of transparency in accepted emergency procedures

- External
  - Amongst system operators
    - Structural/hierarchical changes impairing information flows.
    - Agreed procedures may not have been in place.

    - Due to the increase of international flows, there is also a greater need for data exchange between system operators in operational planning and in real time to be better aware of the state of the electrical system and to have the opportunity to develop measures in case of unacceptable system stresses.
- Amongst Generators
    - Limited information (location, size voltage level but not dynamic model) sharing for perceived competitive advantage – an issue at the planning stage
    - UK/Ireland/Belgium: the basic planning information becomes public after the generator connection is approved
- Generators and Networks
    - Information flows may be governed by regulations/grid codes.
- Inter TSO and TSO/DSO coordination
    - Is essential in operational time-frames
    - No specific attention was given by the TSO that the protection devices on the other end of the interconnecting line with a neighbouring TSO have different settings.
    - The need for limited visibility beyond the boundary of own assets. This applies to neighbouring TSOs and downstream DSOs and implies partial overlap of computer models. These may include physically or electrically close lines and transformers, flows along key transmission routes and remote generation sources (wind farms) the variability of which can considerably impact local power flows and conditions.
    - The need for an information platform that would enable TSOs to observe in real time the actual state of the whole interconnection in order to quickly react during large disturbances.
    - Mass proliferation of distributed generation, combined with their untimely disconnection during frequency excursions, can make under frequency load shedding defence plans ineffective.
    - Most TSOs do not have real time data of the generating units connected to the distribution system.
    - Mass proliferation of relatively small generating units connected to the distribution system for which remote visibility is not required makes it harder for the local DSOs to assess their real time data and whether they remained connected or not. This increases the need for regular testing to ensure

correct operation of under and over frequency protection of generating units connected to the distribution system.

- Limited transparency
  - Limits ability to plan
  - Limits ability to prepare contingency plans for emergency situations
- Effective communication is required between entities along the whole path of the flow of electricity, inclusive of neighbours which can considerably alter that path.
- Few problems in UK, for example protection, maintenance, distribution/transmission.

4.3 System Limitations

- Must be identified along the whole path of the electricity flow between trading partners eg action in one country may transfer problem to another.
- They could be intrinsic in the system design, but always exacerbated by planned or unplanned outages.
- At the local level, similar considerations apply to powering large urban centres, such as CBDs of major cities and regional centres. Refer to Section 5 which is dedicated to planning standards in cities.
- Unpredictability of wind conditions and increasing popularity and number of large wind generation projects introduce a new dimension of complexity in power system planning and operation.
- Security assessment should include possible changes in the system conditions for the following hours (for example, favourable/unfavourable wind conditions) and possibility (short term market rules permitting) of rescheduling exchanges to accommodate the particular wind conditions.
- Planning and communication
  - Model adequacy
  - Approx models for other countries (UCTE condensed model) not always adequate
- Cascade Events not correlated – very difficult to predict
  - Italy
    - Stricter controls on generation behaviour in presence of frequency and voltage degradation, probably through revised technical requirements for plant performance characteristics. However it is very difficult to test these performance characteristics and to ensure that they are maintained.
  - Need for defence plans which sacrifice bits to save others but only when absolutely necessary. (can commercial arrangements help provide a solution)

- Use backup generators in larger buildings for reducing system peak loads of short duration
  - Bumpless transfers of load to backup generators which are not synchronised to the supply network, or
  - Temporary disconnection of, for that purpose contracted, load upon a request from the power system or network control.

- Contingencies – security standards specific contingencies for CBD vs other areas
- Weather Extremes
  - Italy, Greece
- Changing generation and load patterns
  - Increasing peak loads
    - Italy
      - From 1995 up to day the transmission grid utilisation rate increased by 25% due to load growth and difficulties in authorising and building new lines
  - Air conditioners
    - Greece
    - Australia
    - Malaysia
    - Japan work on changing load characteristics
    - Voltage issue – paper from Saudi Arabia 2002 Cigre
- Understanding of original specifications
  - Correct specifications
    - Iran – Under-rated CB
  - Updating specifications of new plant and equipment
    - New Zealand
- Ongoing monitoring
- Long term degradation
  - New Zealand
- Limited visibility of other grids and connections which may affect own reliability
  - Italy
  - USA
- Proper protection methods
  - Australia
  - Iran
    - No under-voltage protection
    - No busbar protection
    - Mis-operation of transformer protection at substation
- Vegetation Management – modelling of tree growth
  - Italy
  - USA/Canada

5. Complexity

The intrinsic complexity of major unreliability events described in sections 2 and 3, the causes of which extend well beyond technical considerations, led to a decision to explore economic, operational, planning and social factors in relation to each of the case studies. The results, based on the available information, are presented in Appendix C and can be summarized as follows.

5.1 Economic

The reported electricity markets are fully or partially deregulated and unbundled. Two important findings were that deregulation changed the function of the transmission grid and that market rules may interfere with system operation. This leads to a conclusion that the regulatory framework and various incentives should take closer consideration of the impact they create on the grid and infrastructure, and should be directed towards alleviating congestion and stress of the electricity grid.

There is a need to coordinate regulatory regimes for gas and electricity, particularly when they both potentially have a major impact on the power system.

Commercial arrangements for reducing the spinning reserve are quite common. Maintaining the balance of active power in the system includes the use of interruptible loads as a substitute for spinning reserve. These loads can cover a wide range of contracted capacity, ranging from tens of megawatts (industrial customers) to thousands of megawatts (pumped storage). A more recent development is that of contracts with commercial customers for grid peak load reduction, either by disconnection of non-critical loads or by transferring all or part of demand to emergency generators.

Participation in under frequency load shedding protection appears to be mandatory in all jurisdictions. The same applies for under voltage load shedding, although these schemes do not seem to have been so commonly used.

5.2 Operational

Two response times are of concern: the time from the trigger event to blackout, and the time for restoration. These times varied substantially in the events reviewed.

It took about 4 hours for the USA/Canadian blackout to develop after the SCADA system became ineffective (about 2 hours after the loss of generation). The UCTE blackout occurred after 32 minutes of insecure operation, those in Italy and Greece occurred after 27 minutes and the one in Sweden/Denmark after 5 minutes. Nearly instantaneous loss of supply occurred in Algeria, Australia, Finland, Great Britain, Iran, Libya and Singapore.

The blackouts typically lasted between 6 minutes and 2 hours. The times for full restoration of loads ranged from 6 minutes (Australia) to between 2 to 18 hours. Extremely long timeframes were recorded in New Zealand, where it took 29 days for a blackout to develop and 3 weeks to restore supply via a temporary 110kV overhead line.

Poor communication between participants contributed to many incidents, particularly poor pre-incident inter-TSO coordination. Poor inter-TSO and TSO/DSO coordination hampered system restoration.

The lack of visibility beyond ‘own borders’ and lack of effective operational procedures to manage ‘system-wide’ disturbances were identified as problems in large interconnections. The establishment of an information platform to allow TSOs to observe in real time the actual state of the whole interconnection was recommended following a major incident.

Other reported communication problems included operator failure to record topological changes from ongoing work and TSOs having no on-line information on the total amount of connected distributed generation.

Poor communication of operational planning data and general planning assumptions to operators was also a contributing factor in many incidents. The risk of inadequate communication is high when different parties are involved and when accessing data beyond ‘own borders’. For example, in one case a TSO didn’t take into consideration lower protection settings on the opposite side of the interconnecting line, owned by another TSO, although this information was critical due to the very high flows on that line. In another case pre-existing line outages were not communicated to the system operator, causing the state estimator to operate incorrectly.

5.3 Planning

Planning for low probability events

The reported practices in relation to low probability contingency plans can be summarized in three broad categories:

4. Contingency plans existed and were successfully executed. For example, the action of under frequency load shedding in Australia.
5. Contingency plans existed but not for the severity of events that occurred, for example, there was a contingency plan for the loss of two cables in New Zealand, however four cables failed.
6. There were no contingency plans for the type of disturbance that occurred or developed. For example one independent system operator did not measure system voltages and there were no operational procedures to shed large amounts of load in a matter of minutes (it was later found that the incident could have been avoided by containing the initial disturbance from spreading by under voltage shedding 1,500MW of load). Similarly, circuit breaker failure protection could have prevented another incident. In another case diesel fuel was used as a backup fuel, however there was no contingency plan if the transition failed.

It should also be noted that inappropriate resynchronization procedures delayed restoration in some cases.

All incidents led to the review of planning and operating practices and contingency plans.

Operational management of risks

The lack of an overall picture and poor visibility beyond a particular jurisdiction is an issue for transmission system operators in large interconnected systems.

In some cases heuristic security assessments proved unreliable in identifying N-1 insecure operation and in predicting the immediate effect of planned switching strategies. For these cases, incidents developed after the system was operated in an N-1 insecure state or after a switching operation produced the opposite effect from that desired.

The range of actions available to system operators is generally constrained by the short term electricity market rules. The adequacy and effectiveness of such rules is not always supported by the management of specific conditions, for example those that occurred on 4 November 2006 in Europe. In another case, in Western Australia, a large wind farm, located at the far end of a longitudinal system supplied via two lines, produced unacceptable voltage fluctuations at a nearby city, however the wind farm operator was unavailable. The market rules did not allow the system operator to disconnect the line to which the wind farm was connected, as that would have brought the system into an N-1 insecure operating state. This led to a conclusion that, although the actions of the operators may impact the free operation of the market, operators must be given enough intervention rights, under certain conditions, to quickly bring the system back into the normal operating state.

Relation between design assumptions and operational behaviour

Operators generally run equipment up to assigned ratings. Actual ratings lower than assigned ratings have contributed to several incidents. In one case assumptions to calculate cable ratings were found to be inadequate. In another, inadequate clearances reduced the assigned line emergency rating. In a third case, inaccurate old cable impedance data led to incorrect protection settings. In a fourth case, a lack of spinning reserve assistance available from neighbours was a key cause. In a fifth, there was an explosion of an under-rated circuit breaker located at a key transmission installation. There was no circuit breaker failure protection to contain the disturbance. This indicates flaws in the system design. Similar design shortfalls in relation to the voltage stability contributed to two other incidents. In a few cases, generators were disconnected before the last stage of under frequency load shedding operated. This included mass disconnection of small generators connected to the distribution systems.

Many incidents occurred during a weakened state due to plant maintenance, indicating the need to study these situations in planning and operational planning timeframes.

Several incidents occurred because of events well beyond the planning criteria, for which the performance of automatic remedial schemes was crucial.

Use of automatic remedial schemes

Under frequency load shedding protection (UFLS) was not always effective because it either shed less load than expected or because a large amount of generation disconnected before its last stage was activated.

System restoration problems included uncontrolled reconnection of wind generators in an island with surplus generation.

5.4 Social

The impact of widespread disturbances

Three of the largest incidents in Europe and North America affected between 50 and 60 million people and resulted in disconnection of between 20 and 70 thousand megawatts of load. A regional incident in the south of Sweden and Denmark affected 4 million people and 6,500 MW of load was lost. Outside these large interconnections, incidents in Algeria and Iran respectively affected 98% and 50% (22 million) of population where 5,200 MW and 7,000 MW of load were lost. Two major capital city incidents resulted in the loss of supply to 800,000 people in Helsinki and 410,000 customers in London, however many more people in London were affected due to the loss of supply to underground and railway transport services.

Governing bodies / Control hierarchy. The reported governing bodies and control hierarchy appear to be unique for each technical and legal jurisdiction to the extent that no useful comparison could be made. However, clear allocation of responsibility for power system security, or lack of it, was found to be important.

6. Planning Standards for Cities

The importance of supply to large urban centres, particularly to central business districts, led to a decision to review planning standards for cities and how they safeguard against major unreliability events. A survey was emailed to members of CIGRE Study Committee C.1 in 2005. Replies were received from 10 countries.

The survey comprised the following four questions:

- **Question A.** Are the security standards and planning processes used in developing the transmission system supplying the capital city higher than for the rest of the transmission system? What are the security standards and planning process used in developing the transmission system supplying the capital city?
- **Question B.** Are the security standards used for the transmission network supplying the capital city co-ordinated with the security standards used for the distribution network within the capital city i.e. simultaneous outage of a

transmission circuit (overhead or cable) and any distribution circuit? If so, what contingencies are considered i.e. what combinations of transmission and distribution outages are considered as simultaneous?

- **Question C**. Do you use special protection schemes to intertrip load or generation to protect transmission or distribution circuits as a normal part of planning or only for infrequent maintenance conditions?
- **Question D.** Is the security standard applied in planning the transmission network supplying the capital city the same as that used for the distribution network within the capital city?

In addition to the four questions, the recipients of the questionnaire were asked to provide comments or any additional information considered appropriate.

In summary, the survey, presented in Appendix D, identified that, despite vastly differing practices and historical constraints, powering of major cities generally requires simultaneous consideration and coordination of the local transmission and distribution network design and operating practices. An important finding for planning for reliability is the desire to target location of generation sources in close proximity to major urban centres.

7. Major Changes Over the Past Two Decades

While changes over the past two decades did not necessarily cause major unreliability events, they may have contributed, driven by economic, technological and social changes.

Three major changes experienced over the past two decades include changes in fuel for power generation, increased uncertainty due to deregulation of the industry and the changed role of the transmission system. These will be described here and briefly discussed in terms of their impact on power system security and reliability.

7.1 Fuel

7.1.1 Traditional fuels

The first power stations utilised hydro energy potential for the generation of electricity. For over half of the 20th century, coal and hydro electric plants were the dominant source of electric energy. The use of nuclear power for commercial electricity generation began in the sixties and was given a boost in the aftermath of the oil crisis in the seventies. The enthusiasm for nuclear power was shaken after a few incidents and unresolved concerns for safe long-term storage of the nuclear waste. A number of European countries renounced nuclear power and devised a program to accelerate phasing out their existing nuclear power plants.

The use of natural gas for electricity generation is largely constrained by the availability of gas and open cycle gas turbines have been traditionally used for peaking plant. Use of gas became extremely popular around the world in the nineties with the mass proliferation of gas turbines operating in the combined cycle mode as base load units. Today combined cycle plant is the dominant type of new generation in Europe and North America, and probably in most of the world where gas is available.

Common for all these traditional types of power plant (hydro, coal, nuclear and gas) is that they use synchronous generators to generate electricity and connect to the grid. Together, they have dominated the industry for over a century. Synchronous generators are robust, reliable and extremely suitable devices to ride through disturbances and provide continuity of supply to customers.

7.1.2 Wind power

The unchallenged dominance of the traditional power generation plant started to change in the past decade. Initiatives in various countries to reduce dependence on imported fuels, and perhaps climate change, have led to a global wind power boom. An unprecedented market growth of 32% was recorded in 2006 [Modern Power Systems, March 2007, p-3, “Global wind power boom”], when about 16,000MW of new wind capacity was installed, bringing the total installed wind energy capacity worldwide to about 75,000MW.

Countries with the highest total installed capacity are Germany with 20,900MW, Spain with 11,600MW, the USA with 11,600MW, India with 6,300MW and Denmark with 3,100MW.

Europe is still leading the trend with 49,000MW of installed capacity at the end of 2006, representing 65% of the global total. European wind generation produced about 100TWh of electricity in 2006, or about 3.3% of total EU electricity consumption. The wind power was second only to gas-fired capacity in terms of new installations in the EU and the USA.

Newer players gaining ground are China with 1,347MW and France with 810MW. The installed capacity of wind turbines in Australia reached 870MW in 2006 with a further 150MW under construction. In New Zealand, the current figure of 170MW will nearly double to 321MW after completion of projects under construction.

There is a world-wide trend toward an increasing proportion of the aggregate generation coming from wind power. Two characteristics of wind power plant have important consequences for security: the output of wind turbines can only be scheduled to the extent wind conditions can be predicted, and; wind turbines are not connected to the grid via synchronous machines. Both these characteristics adversely impact power system security and may require remedial measures.

Wind generation has been shown to integrate better with hydro or some other flexible source of generation, for example in Brazil, Europe, Australia and New Zealand.

7.1.3 Link between fuel and generation

Deregulation in the USA has established a regulatory link between fuel and generation. Of concern are transport prices for gas and electricity and their impact on the location of generation and stress of the transmission system.

In the early years of deregulation there was pancaking of electricity tariffs and postage stamp prices for gas transport. Pancaking of electricity tariffs meant that each utility along the trading path was entitled to charge a fee for transporting electricity across their own power lines, so the overall charge was the sum of individual charges. Postage stamp prices for gas transport was a fixed price structure which did not take consideration of the distance over which the gas was transported. This price structure for transport of electricity and gas discouraged long distance electricity trading and ensured that new generators were located in the close proximity of major load centres, which was beneficial for power system security.

Deregulation reversed the situation. Pancake electricity tariffs were replaced by postage stamp tariffs, while, at about the same time, postage stamp gas transport prices were replaced by those based on the distance from the source. The new electricity and gas tariffs effectively shifted new generators away from load centres towards gas sources. Local and regional government initiatives accelerated this trend by offering various incentives to attract developers of new generation in areas that were typically located far away from major load centres.

No new transmission lines were built to accommodate such long distance trading, and it did not take long before it was not possible to transport electricity to major load centres due to the congestion of the transmission grid. This example demonstrates the need to coordinate the regulatory regimes, particularly when they potentially have a major impact on the power systems.

7.2 Uncertainty

The deregulation and creation of electricity markets over the past decade or two has led to disaggregation of utilities and decentralised decision making. Different and sometimes conflicting short-term commercial interests have often precluded information sharing, and even, in some cases, led to information manipulation through gaming. The net effect has been increased overall uncertainty in the industry, which also adversely impacts security.

For example, it is difficult to plan network expansion when the location, size and timing of new generation sources are not known. The broad-brush approach of investigating all possible combinations of options is not possible because their number grows exponentially with system size.

While many countries are trying to develop competition in electricity, they are still exercising some level of overall control of pricing, planning and operations, and countries such as Spain and Portugal have adopted a new proactive approach for extending their transmission networks towards selected geographical regions abundant in wind energy to attract and speed up new developments in the area. The traditional approach has been to wait for wind applications and then construct lines.

7.2.1 Government interventions

Recent concerns with energy dependency and climate change are also making it more difficult to predict future developments, because of uncertainty over potential interventions of the governments in various countries.

For example, in 2004, a major stimulus for the development of renewable energy was triggered, by setting a target to achieve a 15% contribution from renewables to Great Britain's electricity needs by 2015, on a path to achieving a 20% overall contribution by 2020 [http://www.number-10.gov.uk/output/page6333.asp]. Wind energy, expected to be increasingly offshore, was expected to be the primary source of renewable power.

In 2005, a target was set to supply 10 percent of electricity from renewable sources by 2010 in Great Britain. [http://www.nao.org.uk/pn/04-05/0405210.htm].

In March 2007, the 27 EU countries agreed to a target of a 20% overall boost in renewable fuel use by 2020, and will each decide how to contribute to meeting that target. However, they recognised the contribution of nuclear energy in "meeting the growing concerns about safety of energy supply and carbon dioxide emission reductions".

Regardless of the actual outcome in each EU country, any aggressive focus on a target to supply a certain percentage of electricity from renewable sources is likely to lead to a concentrated effort to improve renewable generation technology – embedded and distributed generation, supply and demand management and energy control are likely to evolve rapidly.

Mass proliferation of renewable and other generation connected to the distribution system, if it eventuates, may also provide a limited relief for the transmission system. Historically, this has not been feasible because economies of scale made generation plant of higher ratings more economical. Time will show whether the perceived benefits of such generation, aided by electricity pricing, government initiatives and improved technology, will influence, and by how much, the established economic framework in favour of mass proliferation of distributed generation and various load management solutions.

7.2.2 Wind uncertainty

Unpredictability of wind as the primary source of energy, compounded by that of a relatively high ratio of installed wind power capacity and the capacity of the local transmission system in the vicinity of newly installed wind turbines, creates numerous operating problems, ranging from local power quality problems to those that may impact the whole power system.

For example, the amount of generation reserve in the system, that would be sufficient otherwise, may not be sufficient if the wind penetration exceeds a certain threshold. In the isolated system of Western Australia, with respective minimum and maximum loads of 2,400MW and 4,500MW, that threshold was found to be about 15% of the total load connected at the time. Ireland has similar limitations.

A recent German study [Modern Power Systems, March 2007, p-25-28, 'Living with wind power in Germany'] reports that 36GW of installed wind turbine capacity in Germany in 2015 would provide the firm capacity of only 5-6 percent of that value. Clearly, the impact of unpredictability of such a large magnitude on transmission capacity and its utilisation, power flows across the system, unit commitment and system operation is very significant.

7.3 Changing function of the transmission grid

Probably one of the main causes of a number of recent major unreliability events lies in the changing function of the transmission grid and delays in adapting to change.

For over 50 years before the deregulation and development of electricity markets, interconnected transmission infrastructure had been built for the purpose of assuring mutual assistance between national subsystems. Typically a single utility controlled generation, transmission and distribution of electrical energy in a given geographical area and such a utility generally maintained sufficient generation capacity to meet the needs of its customers. Interconnections with neighbours and long distance power transfers were generally used for emergencies, for example to provide assistance immediately following an unexpected generator outage.

Such practices contributed to system reliability aided by the laws of physics that govern the flow of electricity. To avoid line overload and tripping, the amount of power flow across each line must be kept below its capacity at all times. The difficulty in controlling individual power flows rises rapidly with the distance and complexity of the network (for example, the number of lines) along the path of an interconnection. Any change in generation or topology of the transmission network will change loads on all other generators and transmission lines in a manner that may not be anticipated or that is difficult to control.

The development of electricity markets over the past decade or two brought a fundamental change to that paradigm. Major transmission infrastructure has become no longer just a tool for mutual assistance, but a platform for shifting ever growing power volumes across the entirety of interconnected networks. Deregulation has resulted in higher cross-border and long distance energy exchanges, which are driven by short-term objectives of individual market participants. Other across-interconnection power flows result from an increasing number of major wind energy generation sources. These flows were usually not anticipated in the original designs of power systems, and difficulties now arise each time they reach and potentially exceed transmission capacity. The likelihood of this is compounded by delays in obtaining new transmission corridors, market-driven load and generation patterns, volatile wind generation infeeds and unusual network topologies.

Due to increased long distance and cross border trading across most national systems, individual Transmission System Operators (TSO) are becoming increasingly interdependent. Interconnected power systems are operated ever closer to their limits for increasingly longer times. Operation under higher stress for longer periods of time will inevitably result in more severe and more frequent incidents.

7.3.1 Impact on TSO Control

The changing functions of the transmission system, higher system stress, volatility of wind generation, and trading volumes changing hourly by thousands of megawatts, make daily operation of power systems much more challenging today.

At the same time as these challenges have been increasing, the range of actions available to system operators has become generally constrained by short term electricity market rules and it was noted [UCTE, "Final Report: System Disturbance on 4 November 2006", 2007] that "The need for a more complex management of interconnected grids is obvious, but has so far not always been supported by regulators and main stakeholders when TSO operators have requested more generation data and intervention rights, particularly in emergency situations."

7.3.2 Impact on Market Participants

Deregulation created the opportunity for greater competition between participants and this weakened the traditional spirit of cooperation that had been the hallmark of the industry for more than 50 years.

Focused mainly on profits and short term objectives, companies started to withhold information of perceived commercial value to their competitors, which was also important for coordination to achieve reliability of supply. This increased uncertainty and the probability of major unreliability events, some of which are documented in this technical brochure. Where possible, regulations mandating the sharing of information for the use of the network operators are being used to overcome confidentiality and conflict of interest issues.

8. Major Contributing Factors

The analysis of incidents, planning standards in major cities and recent changes in the industry, described in sections 2 to 6 here, identified key issues associated with the incidents. These can be broadly classified as economic pressures, impaired communication channels and system limitations. The more salient factors are summarised below:

8.1 Economic Pressures

- It is frequently difficult to obtain permission for new or upgraded infrastructure, which results in undue pressure to run systems harder.
- The development of electricity markets seems to be running ahead of the ability of power systems to support them.
- Deregulation of network tariffs has resulted in unforseen changes to patterns of generation and line flows
- Inter-regional trading places pressure on interconnectors originally intended only for interchange of mutual support power. Insufficient knowledge of changes to generation and the network in neighbouring systems has exacerbated this problem.
- The ability of TSO's to manage critical events is often constrained by short-term market rules that place market purity ahead of system security.
- The economic incentives/penalties for generators to contribute to reliability may be inadequate.
- Following a large disturbance, the automatic reconnection of unscheduled generation such as wind must be balanced by decreased generation from other plant. This has not always happened and the question arises whether market rules facilitate this.
- There has been insufficient enforcement of technical standards that contribute to reliability.
- Not all markets provide sufficient incentive for reliable generation of reactive power.
- The mass proliferation of distributed sources of generation has contributed significantly to the pool of generation but there has been a lack of knowledge of the momentary status of these generators and their performance during power system disturbances, especially their fault ride-through capability.
- Responsibilities for system adequacy are not always clear.

8.2 Impaired Communication Channels

- Between planners and system operators there has been a lack of transparency in communication of accepted emergency procedures, and amongst system operators information flow has been impaired by structural and hierarchical changes
- Generators have been reluctant to share information such as dynamic models to protect perceived competitive advantages – an issue at the planning stage. In some countries this information is required to be placed in the public domain.
- Inter TSO and TSO/DSO coordination is essential in operational timeframes. Limited visibility inhibits the ability to prepare contingency plans for emergency situations.
- A need has been established for limited visibility beyond the boundary of owned assets in order to manage disturbances that spread across the boundaries.
- Effective operator communication is required along the entire path of flow of electricity inclusive of neighbours that can significantly alter the path.

8.3 System Limitations

- Difficulty in obtaining approval for new lines has substantially increased the utilisation of some systems with a consequent reduction in redundant capacity.

- System limitations must be identified along the whole path of electricity flow between trading partners eg action in one country may transfer the problem to another. Condensed models of a neighbouring system have not always proven adequate.
- Unpredictability of output of large wind generation installations increases complexity of operational planning, especially security assessment.
- The occurrence of cascade events is very difficult to predict.
- Inadequate protection methods may have system-wide consequences.
- There is a need for defence plans that may include sacrificing parts of the system to save others (when absolutely necessary).

9. Lead Indicators of Major Unreliability Events

Some of the early warning signs of susceptibility of a power system to major unreliability events include the number, magnitude, frequency, duration or cumulative time of events when the:

- Area Control Error (regulating error or the system frequency error) is outside the permitted dead band
- Voltages at key locations are outside their normal band
- The system is in an insecure state (risk of overload/instability following the next contingency)
- The system is in an ‘unusual’ state
- The number of incidents (near misses) is high
- The number of transmission load relief procedures, as a proxy for ‘near miss’ situations are significant
- Bulk transmission system utilisation change (%) increases over the past few years defined as the ratio between yearly electricity load demand [TWh] and equivalent EHV transmission grid extension [km]
- Percentage of time near critical transfer limits increases
- Maximum loading of key interconnectors (transmission corridors), particularly relative to the load growth, and their load duration curve is approached
- The maximum number of generating and other plant in the system that went on maintenance simultaneously is significant
- Use of equipment for duties beyond their assigned short circuit level occurs
- Percentage of disconnected load increases
- The number of projects delayed, perhaps weighted by the delay time increases,
- Limited transparency between parts of power system, limited information sharing and limited contingency plans occur, and
- Lack of clear responsibility for power system security occurs.

Additional trend information can be obtained by monitoring how these indicators change over time.

10. Avoiding Major Unreliability Events

The analysis of recent major reliability events shows that they are usually caused by a complex sequence of cascading events that were not effectively managed in the required operational time-frames.

Underlying causes, in many occasions, originated in rules and regulations governing electricity markets and power system operations and in delays in adapting to the changes in the generation mix and to industry deregulation.

10.1 In Operational Timeframes

Central to avoiding blackouts in operational time frames is to operate power systems securely, which means within the security limits defined by the list of credible contingencies for which the system was designed. That may be a problem in very large interconnections where there is no 'overall picture' due to poor visibility beyond own borders. In many cases, power systems were operated beyond their security limits when the incident occurred and this contributed significantly to system unreliability.

A practical question for avoiding blackouts is therefore how to identify states of non-secure operation of the power system. This is important as they usually precede blackouts, and, in many cases, system operators were not aware of them because 'nothing had happened'.

The National Electricity Market (NEM) in Australia sets a good example on how to effectively operate a large interconnected system with long distance trading. Two key success factors, in our opinion, are computerised dynamic on-line power system security assessment, that covers the whole interconnection and is based on the constantly evolving power system specific constraint equations, and the IT platform which provides the overall picture of the state of the interconnection to all participants and system operators. Europe and the USA, who recently experienced major incidents, have not yet achieved this milestone. To a significant degree they have been handicapped by the significantly greater size of their power systems and the relative autonomy within each country or state.

High quality real-time assessment of the state of the interconnection with respect to the security limits, together with the power of the operators to expand the list of credible contingencies, in response to adverse weather and bushfire conditions, enables reliable, adaptive and effective management of the NEM interconnection.

For disturbances more severe than those a system has been designed to withstand, the correct operation of protection and robustness of generators to remain connected is essential to contain the spread of the disturbance and minimally interrupt the supply to customers.

A number of incidents were caused by protection problems that were present but only triggered when a particular set of circumstances occurred (London, Helsinki). It is important to have commissioning and testing procedures that minimize the risk of such "booby traps".

An alternative approach to enhance power system security is to design the system to a higher standard by expanding the list of credible contingencies. This was done in Iran in 2003, after a widespread blackout, by including in planning criteria circuit breaker fail faults on critical transmission installations and subsequently retrofitting the additional protection.

10.2 Regulatory Response

The regulatory challenges concerning operational factors include finding the right balance between ‘purity’ of the electricity market and power system security.

Namely, the creation of electricity markets has increased complexity of system operation, while the ability of TSO’s to manage critical events has become, constrained by short-term market rules. This was recognised as one of the root causes of the largest blackout in history in Europe, which occurred on 3 November 2006, and similar considerations apply to two other major blackouts in 2003 in the USA and Italy.

In response to that finding, the working group that investigated the 2006 incident recommended EU countries adapt the regulatory or legal framework that would give system operators more control over the generator output to manage grid congestions. Coincidently, an operational power quality problem in Western Australia, caused by wind generation, identified the need for a similar change.

In addition, technical issues concerning plant performance requirements have emerged as regulatory issues.

10.2.1 Plant Performance Requirements – Non-synchronous Generation

It was reported in [Modern Power Systems, March 2007, p-25-28, ‘Living with wind power in Germany’] that characteristics of the current technology of non-synchronous generators in Germany, through which wind generators are connected to the grid, introduce additional problems for maintaining the existing level of security of electricity supply. These problems include generator fault-ride through capability and the duration and magnitude of the generator fault current contributions that are insufficient for protections to see the fault and provide adequate voltage support.

Similar shortcomings were associated with early designs of combined cycle plant, resulting in improved design, which now permits them to meet their share of the control duty requirements imposed on the aggregate generation for the operation of the power system. This required mandating certain plant performance requirements as a condition for connection to the network. These typically include voltage and frequency fault ride through capability, reactive power capability and control duties.

Wind technology is no different and, for example, one wind farm in Western Australia improved the original design by installing discharge resistors and can now ride through zero volts for one second.

Non-synchronous generation is acknowledged now in many countries. The approaches taken vary. For example, while many have the same requirements for all types of generation, non-synchronous generators are given concessional treatment in Western Australia in terms of technology and specific plant performance requirements for reactive power. The rationale was a decision to help to facilitate the initial proliferation of renewable generation in Western Australia.

10.2.2 Plant Performance Requirements – Distributed Generation

The generators connected to the distribution system in the EU are now required to have the same fault ride through capability as large generators connected to the transmission system. The recommendation retrospectively applies to units already in service. This was deemed necessary because, in a few incidents, the large amount of distribution connected generation (up to 3,400MW) disconnected at about 49Hz, which made the under frequency load shedding ineffective.

Another technical recommendation for the EU, concerning generators connected to the distribution system, is the requirement for TSOs to have on-line access to their status, schedules and changes to the schedules, at least as one-minute data. This will probably take the form of aggregate generation data provided by individual DSOs.

11. Possible Solutions

The following potential solutions are proposed for limiting the impact of future major unreliability events:

Regulatory:

- The regulatory framework for electricity and gas and various incentives should take closer consideration of the impact they create on the grid and infrastructure, and should be directed towards alleviating congestion and stress of the electricity grid.
- Promote the placement of new generation in close proximity to load centres thereby eliminating the need for long power transfers.
- Rather than confining to a particular jurisdiction, conduct planning and real-time contingency assessment studies to encompass the entire paths of major normal and emergency power flows. This should include:
    - Definition of the relevant part and specific conditions in the adjacent systems which have to be taken into consideration in TSO’s security analyses.
    - Simulation of contingencies at critical locations outside the TSO’s own boundaries.

- Expand transmission capacity to physically accommodate new market demands (may not work effectively in highly meshed networks, as transmission paths could vary significantly).
- Increase stakeholder awareness of system limitations and economic/reliability trade-offs.
- Clarify the responsibility for power system security.
    - There may be a need for a co-ordinated official regulatory body governing reliability standards.

System operation:

- System operators should have the control over generation output (changes of schedules, ability to start/stop the units).
- System operators should be empowered to expand the list of credible contingencies in response to adverse weather conditions, for example storms and bushfires.
- Reduce the chain of communication.
- Reduce time to carry out necessary actions.
- Establish an information platform to allow TSOs to observe in real time the actual state of the whole interconnection.
- Mandate computerised online contingency security analysis (for example, N-1 simulations), connected to the alarm processing system, to include:
    - Schedules, and, where wind penetration is significant, possible changes of schedules, for the following few hours.
    - Preparation and regular check of the efficiency of remedial actions through computer simulations.

TSOs:

- Increase transparency to assist in planning. This equally applies to generators.
- Design above N-1 rating for certain parts of the system (for example, for bulk transmission, key transfer paths and corridors and major load centres)
- Mandate duplicated or back-up protection on key transmission plant so that a circuit breaker failure cannot blacken the whole system.
- Operational contingency plans to include events beyond those for which the system is planned.
- Install Wide Area Protection (WAP), Wide Area Measurement System (WAMS) and synchronised high speed data recorders.
- Devise protection systems to contain the spread of the initial disturbance for low probability events and protect other parts of the system that can be saved.
- Install synchronisation equipment on major lines and substations, and
- Increase TSO/DSO co-ordination of system planning and emergency procedures and training of operators to handle emergencies. This should include:

- The restoration and re-energization process has to be explicitely coordinated by the TSO regarding DSOs actions and the related responsibilities and duties of involved parties must be clarified within a national framework.
- In systems with high penetration of distributed generation, TSOs should have on-line access to their status, schedules and changes to the schedules, at least one-minute data in the form of aggregate generation data provided by individual DSOs.

Interconnections:

- Define a "Master Plan" defining principles of operation and TSOs' responsibilities to manage interconnection-wide or regional disturbances.
- Increase inter-TSO co-ordination of system planning and emergency procedures and training of operators to handle emergencies. This would require to:
  - Develop capability and procedures for rapid decentralised restoration and resynchronisation.

Maintenance:

- Co-ordinate maintenance within the system and across jurisdictions, as many blackouts developed from situations where more than one item of plant was on maintenance.
- The need to specify credible pre-contingency operating states (for example, N-1-1 starting from the intact system, etc), not just credible contingencies.
- Investigate the formulation of maintenance congestion as an indicator of system stress at off-peak times.
- Limit the maximum number of plants that can simultaneously be on maintenance.
- Consider introducing a new planning criterion that addresses the impact of multiple maintenance events during off-peak times.
- Consider introducing a new N-x-1 planning criterion to account for the maintenance practice, where x is the maximum number of components permitted to go out of service during an off-peak time, defined as the specified percentage of the system peak load. The rationale is to translate the maintenance practice into the planning criteria to be studied in the planning time-horizons. Any violations should result in changes to the intended planned maintenance. System reinforcements may be required only if the planned maintenance could not be re-scheduled. An example is the N-1-1 criterion at 80% of peak load, starting from the intact system, that applies to the bulk transmission system and major load and generation centres.

Plant performance:

- Mandate plant performance characteristics for all generators, including non-synchronous and distributed generation, in the areas of fault ride through capability (for voltage and frequency excursions) and the duration and magnitude of the generator fault current contributions that are sufficient for protections to see the fault and provide adequate voltage support.

- Generators connected to the distribution system must have the same fault ride through capabilities as those connected to the transmission system.
- All generators must remain connected after the action of the last stage of the under frequency load shedding protection is completed. This requirement should retrospectively apply to units already connected to the transmission and distribution system.
- In systems with high penetration of distributed generation, TSOs should have on-line access to their status, schedules and changes to the schedules, at least one minute data in the form of aggregate generation data provided by individual DSOs.

Household appliances:

- Investigate the practicality of intelligent household appliances (e.g. storage hot water) that would self load-shed during major under-frequency events. Namely, automatic disconnection of individual household appliances has great potential to provide system relief during major under frequency events and may be quite feasible in the near future to supplement the conventional centralised under frequency load shedding. The additional cost would include local control logic.

12. Conclusion

There is great industry interest in major unreliability events. Of the gravest concern are those that occur in major population centers or spread over a vast geographical area, as they can adversely affect millions of people. Thirteen recent major unreliability events have been documented in this report. The importance of supply to large urban centers, particularly to their central business districts, led to a decision to review planning standards in cities. Analysis of the above and comparison with real events identified critical contributing factors and a number of lead indicators of susceptibility of a particular power system to major unreliability events.

Economic pressures, impaired communication channels and system limitations were identified as the most common contributing factors. Others include social, economic, planning and operational, leading to a conclusion that underlying causes may originate in the governing macro-economic rules and regulations, which could be compounded by subsequent planning decisions and operational events. These include:

- Long-distance power transfers which were not anticipated when systems were designed.
- The importance of understanding the system's limitations and the risks associated with increased loading.
- The need to pay more attention to the importance of identifying and respecting system security limits.

- The importance of operating the system securely within technical limits in the face of demands for increased capacity.
- The importance of defence plans to prevent widespread blackouts and facilitate rapid restoration; the importance of maintaining the defence plans and ensuring the integrity of the defensive measures (for example, in a number of cases automatic load-shedding did not perform as expected).
- TSOs had no control over generation output (changes of schedules, ability to start/stop the units) and, in some cases, the behaviour of generators was aggravated the situation.
- Generators connected to the distribution system did not have the same fault ride through capabilities as those connected to the transmission system and they disconnected before the last stage of the under frequency load shedding protection was initiated.
- A number of incidents were caused by protection problems that were present but only triggered when a particular set of circumstances occurred (London, Helsinki). It is important to have commissioning and testing procedures that minimize the risk of such "booby traps".
- One incident was caused by inadequate cable specification for the local soil.

The report concludes with a list of possible planning recommendations and approaches to avoid or mitigate future major unreliability events.

13. Future Work

As noted earlier, the original scope of work was very broad and in order to produce a manageable and timely report the scope of work was constrained to major unreliability events. Study by future working groups could cover local area reliability issues and market operation impacts as identified in Table 1.

Appendix A **Terms of Reference**

CIGRE Study Committee N° C1

PROPOSAL FOR CREATION OF A NEW WORKING GROUP

***WG* N°** C1-2 **Name of Convenor :** Phil Southwell (Australia)

Title of the Group : Maintenance of Acceptable Reliability in an Uncertain Environment by the Timely Provision of Network Capacity and Management of Constraints

Scope, deliverables and proposed time schedule of the Group :

Background :
Earlier work, most recently WG 37-30, has considered the problems facing the network planner as electricity markets lead to uncertainty in the sizing and location of dispatchable and non-dispatchable generation. This is further complicated by the increasing use of interconnections by adjacent electricity businesses to supplement their local power requirements. In particular, WG 37-30 analysed the development of medium and long term planning methods. The issues raised by this earlier work are in the forefront of concerns that face network planners. There is therefore a need to explore some of the key issues further. Areas of particular interest are the question of what is an acceptable level of reliability, how was this level determined and how is this reliability measured and assessed. The issue is further complicated by pressure to increase the utilisation of network assets and, at the same time, tailor the performance of the system to satisfy changing customer needs.
This project will review previously completed work, survey changes that have occurred in more recent years and analyse specific findings to determine particular trends and practises.

Scope :
In particular the project will address the issues listed below:
1. Review the network reliability standards used and how they are changing
2. Assess the use of probabilistic vs deterministic planning methods
3. Review whether new methods and tools are required to assess reliability and future risks
4. Assess the use of signals to participants to optimise system development and, at the same time, maintain and if necessary improve system reliability
5. Assess the methods used in communication of the key issues with stakeholders
6. Assess how to maintain reliability in a system where new lines are delayed or cannot be built but the
market is demanding more transmission capacity
Deliverables : Report to be published in Electra or technical brochure with summary in Electra

Time Schedule : start : November 2002 **Final report** : 2005

Comments from Chairmen of SCs concerned :

Approval by Technical Committee Chairman : **Date** :

* or Joint Working Group (JWG), of Task Force (TF), of Joint Task Force (JTF)

Appendix B

Summary of Recent Major Unreliability Events

	Country	Date	MW Load Lost	% Load Lost	Duration [hours] & Unserved energy	People affected	Causes
	New Zealand	20/2/98					•
1	Algeria Nearly whole country other than Southern island	3/2/03	5200	95% (est)	5	98% (est)	• Loss of 350MW unit (trigger event) • Not enough spinning reserve (only 84MW) • Highly stressed transmission system, ie insufficient spare capacity on interconnectors with neighbours • UFLS shed less load than expected • Some generators disconnected before the last stage of UFLS operated (poor coordination) • Blackout in 15 seconds
2	Iran Northern part islanded and blackened	31/3/03	7063	50%	8	22M	• Explosion of under-rated CB tripped the whole key 400/230kV transmission switchyard • System separated and the largest island blacked out • No busbar protection to contain the initial fault
3	Lybia	8/11/03	120	5%	Not reported		• 220kV CB failure to open a transformer fault cleared by the back up protection, distance Zone 2, which contained the spread of the fault by opening ten 220kV lines • System separated, a few generators lost and UFLS activated • Remedy: CB fail protection installed on key 220kV substations for faster clearing of such faults
4	Jordan	11/03	< 1500		Not		• 400kV line protection coordination error separated 400kV

					reported		network • the 132kV network tripped on overload due to additional power transfers • Nearly whole system collapsed, other than part next to Egypt
5	Singapore	29/6/04	Not reported	30%	Up to 1 hour and 48 min	300K	• Equipment failure at a gas terminal due to heavy rain • Loss of gas fuel for gas turbines • Automatic changeover to standby disel fuel failed on three units • Two units switched but then failed due to blockage in the diesel fuel filters • Falling frequency tripped the interconnector to Malaysia • The action of under frequency load shedding protection arrested the frequency decline
6	Greece	12/7/04	Not reported	100%	Not reported		• The Athens system was stressed by two generators out of service, transferring 80MW to Peloponnese • 300MW generator in Athens tripped in the morning hours of a very hot day • The load surged due to switching of many air conditioners • The generator resynchronised but tripped again shortly after • Load shedding was insufficient to secure the system, so • Another generator in Athens tripped Collapsing voltages caused the system to split and the regions of Athens and Peloponnese experienced a total blackout
7	UK - London	28/8/03	Not reported		Not reported		• Underground transmission. • Misoperation of relay protection, superimposed on the weakened system due to maintenance caused the trip of two CBD substations. • Remedy. Over 40,000 protection relays checked, with over 1,000,000 individual settings

8	Italy	28/9/03	more than 20,000	about 95%	about 18h EENS 177GWh	56M	• Line flashover and unsuccessful auto and manual reclosing (40deg angle > 30 deg) overloaded adjacent line. • Slow overload relief and trip of the overloaded line initiated cascading outages of 16 lines leading to the separation of Italy and blackout in 3 minutes. • 1900MW deficit after UFLS action • 3,400MW of distributed generation tripped at around 49Hz. •
9	Finland - Helsinki	23/8/03	614	100% capital	32' average per customer EENS 198MWh	800K	• Human error, closing a 110kV CB onto earth, blacked out the capital Helsinki in less than 2.4 seconds. Short cable runs. • Contributing factors included: no status monitoring of switching apparatus, no distance protection on the cable and inaccurate data on the old oil cable impedance. • In addition, 400/110kV infeeds lost due to poor coordination for long lasting 3-phase faults, which was set for more often faults to earth. • New operating procedure for boundary substations in the cabled area (CBD): switch first from the boundary sub end with parallel cables off.
10	Sweden & East Denmark	23/9/03	6650	100% region South Sweden & East Denmark	EENS 10GWh	4M	• System weakened due to maintenance of two 400kV lines, three HVDC links and four nuclear units. • Loss of a 1200MW nuclear unit 5 minutes later followed by • A disonnector fault (breakdown due to overheating) which caused double busbar fault, leading to the network separation and further loss of 2x900MW nuclear units. • Total voltage collapse in the island of Southern Sweden and Eastern Denmark took two minutes to develop.
11	USA & CAN	14/8/03	>70,000	Not report	Not reported	50M	• Loss of a 345kV line triggered chain of events that led to the blackout affecting over 50M of people in NE USA & Canada.

				ed			• Iranian Remark: In fact 4 lines were lost because of bad vegetation management. Bad system operation did the rest. This is not a good example for the report and does not show any signals of lack of transmission capacity. • Contributing factors included: • Inadequate system understanding • Inadequate situational awareness • Inadequate reliability coordinator diagnostic support • Non-compliance to standards • Vegetation management • Zone 3 relays • Remedial measures included recom. for institutional changes
12	Australia	13/8/04	1840	9%			• Explosive CT failure resulted in tripping of six nearby generators • 3000MW of generation lost or 14% of total supply • 1500MW load shed by the UFLS • Additional 340MW of load shed by the operation of customer equipment
13	Europe – UCTE	4/11/06	Not reported	Not reported	38’ to resynchronise, less than 2 hours to normal	15M households	• Non fulfilment of the N-1 criterion and inappropriate regional inter-TSO coordination. • The sequence was triggered by the planned outage of a double circuit 380kV line and after 32 minutes of insecure operation, the system conditions evolved to cascading line tripping all over the UCTE area. • In less than 20 seconds, UCTE interconnection split into three islands with large imbalance between load and generation. • Further contributing factors included: ➢ Tripping of generators on under-frequency before the last stage of under frequency load shedding protection, and

							uncontrolled reconnection of generators in the island with surplus generation. ➢ Limited range of action available to some dispatchers (due to market rules). ➢ TSO/DSO co-ordination ➢ Inappropriate co-ordination of resynchronisation.
							•

Sources:

Algeria: http://www.cigre-c2.org/workshop/large_disturbances_2004/Algeria%20presentationincident03fev03v3.pdf
Iran: http://www.cigre-c2.org/workshop/large_disturbances_2004/Iran%20-%20cigre2004.
Lybia: http://www.cigre-c2.org/workshop/large_disturbances_2004/LibyaCIGRE-2004-2.pdf
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Sweden: http://www.cigre-c2.org/workshop/large_disturbances_2004/Black-out%20in%20Sweden%20and%20Denmark%202003%2023.pdf
Italy: http://www.cigre-c2.org/workshop/large_disturbances_2004/Swiss%20WS_Large_Disturbances_Load_Flow_Swiss_Grid_CigreParis_V5.pdf
http://www.cigre-c2.org/workshop/large_disturbances_2004/itallyPresentazione%20CIGRE_9_8_04-LES.pdf
N.America http://www.cigre-c2.org/workshop/large_disturbances_2004/ParisMtgUSABlackoutPresentation.pdf
Australia: http://www.nemmco.com.au/marketandsystemevents/232-0020.pdf

Europe: http://www.ucte.org

Appendix C Analysis Of Each Major Unreliability Event in Terms of Economic, Operational, Planning & Social Factors

ECONOMIC

	Structure of Market **Is the market liberalised/unbundled, level of deregulation and are the Generator Companies and Networks privatised?** **Are there any other market related contributing factors?**	***Commercial arrangements*** **Are there any contingency arrangements in the event of a major unreliability event?** **Are these commercial or prescribed?** **Issues – load demand shedding – generation capacity reserve – spinning reserve, interruptible load, under frequency load shedding, generation shedding, transmission constraints**
New Zealand	• Deregulated • Partly privatised	• No commercial arrangements
Algeria		• Less load shed by Automatic Under Frequency Load Shedding than expected
Iran	• Deregulated	
USA and Canada	• De-regulated • Privatised networks • To be reviewed	• Transmission load relief procedures • Interruptible loads • Automatic under frequency load shedding (UFLS) operated as planned • The UFLS was inadequate for the system that separated into islands.
Finland	• Part of Nordpool market, fully liberalised and unbundled	
Great Britain	• Fully liberalised and unbundled	
Sweden and Denmark	• Part of Nordpool market, fully liberalised and unbundled	• Not reported if the under voltage load shedding protection was installed or operated during this voltage collapse.

Italy	• Fully liberalised and unbundled • On the demand side: At present every non-domestic customer is eligible for access to the market. By July 2007, all customers will be eligible. • High dependence on power import due to the electricity price differentials. At time of incident, import was approx 22% of night demand (approx 6300MW)	• Interruptible pump storage of 3.6 GWAuto under-frequency load shedding operated quite correctly but the load shed was insufficient to avoid the blackout, considering loss of the generators at the same time • Automatic interruptible load and interruptible pump storage were in place to balance power on critical sections. They were ineffective, however, because the scheme was set to prevent cross-border overloads only, and, after the Swiss line tripped, it could not relieve internal Swiss overloads. (system now improved – operational action)
Libya	•	•
Singapore	•	• UFLS
Greece	• Partly liberalised • Independent ISO •	• 380MW of under frequency load shedding
Australia	• Partly liberalised • Fully unbundled in east	• 1,500MW shed by Automatic Under Frequency Load Shedding, which is roughly 6% of the NEM (National Electricity Market) load. • Clause 4.3.5 of the National Electricity Code requires Market Customers with load of more than 10 MW to make at least 60% of their load available for automatic under-frequency load shedding at frequencies within the range 47 to 49 Hz as nominated by NEMMCO.

Europe – UCTE	• Largely liberalised and unbundled with large cross-border trading to equalize generation prices, although there is no single legal jurisdiction in this interconnection of 23 countries. • The late announcement by the shipyard to bring forward the outage made it impossible to reduce the exchange program between Germany and the Netherlands for the planned outage of Conneforde-Diele line in the same way as prepared for the 5 November. • Namely, according to one TSO (Tenne T), no exchange program reduction is possible after 8:00 am for the day ahead, due to agreed auction rules (capacity considered as firm, except in the case of 'force majeure'). • The dispatcher actions constrained by market rules in some jurisdictions.	• UCTE has technical rules for pool operation. • Uncontrolled islanding created three islands with large imbalance between load and generation. • The amount of load shed not released at the time of writing this report. • The impact on market rules on real time operation of the power system •

OPERATIONAL

	Response Times **What were the critical time frames involved from the trigger event to total system restoration?**	*Communication Strategies* **What was the communication between all involved parties?** **Was there any breakdown in communication?**	*Communication of operational planning and General Planning Assumptions to Operators* **How are the planning assumptions communicated to operators and in what depth and capacity?**
New Zealand	• 29 days from loss of first cable to full blackout • 3 weeks from the blackout to restore full supply via temporary 110kV overhead line • Limited supply restored within hours by switching; and additional capacity from 40 MW of portable generation brought in over several days	• No breakdown in communication • Extensive communication with affected customers, media, politicians, and other stakeholders after the event. • Appeals to customers to reduce load after the 1st oil cable failed.	• Planning was based on N-2 security criteria for CBD. • Cable ratings were calculated on basis of typical UK data for ambient soil temperature and soil thermal resistivity. These were inappropriate for Auckland's volcanic soils. • Operators aware of cable ratings (alarms set in SCADA) and security criteria.
Algeria	• Blackout 15 secs after trigger event • 5 hours of blackout until restoration		• Some generators were disconnected before the last stage of under frequency load shedding was operated
Iran	• 8 hours of blackout until restoration	• Communication patterns and protocol elongated system restoration time	

USA and Canada	• 2 hours and 10 min after generating plant shuts down, major blackout is caused in USA • 3 hours, 50 minutes and 57 seconds after the MISO system became ineffective from missing information, the 345 kV line tripped by sagging into a tree and the system slid into an uncontrollable cascade	• First Energy controllers fail to inform other controllers in nearby states of the two major line outages due to SCADA failure • Operators at Mid West ISO did not recognise urgency of situation as their state estimation system had flawed information • Poor communications between MISO and PJM reliability co-ordinators	• Two previous line outages were not communicated to the MISO state estimator and its missing status caused a large mismatch error that stopped the MISO state estimator from operating correctly
Finland	• Major unreliability events occurred 2.4 secs after CB was closed onto earth		• Inaccurate data on the old oil cable impedance led to incorrect protection settings
Great Britain	• Restoration began 6 minutes after the major unreliability event • Power supplies were fully restored 37 minutes after blackout • Impact on rail network lasted considerably longer	• Communication issues between trans and dist operators and rail network	• Incorrect operation of relay protection • This incident was beyond the scope of the planning criteria
Sweden and Denmark	• 5 min after loss of nuclear unit, disconnector fault leads to a double busbar fault. • Leads to the loss of two 900 MW nuclear units and disrupts south western grid		• System was weakened due to maintenance on two 400kV lines, three HVDC links and four nuclear units.

Sweden & Denmark continued…	• 2 minutes after disconnector fault, there is voltage collapse in the eastern grid section south of the Stockholm area. • Blackout lasted about 2 hours, full restoration after 8 hours		
Italy	• Swiss operator phoned to the Italian operator about 10 minutes after the trigger event (Mettlen – Lavorgo 380 kV Swiss Line trip), asking for a load reduction of 300 MW • The Italian import reduced by about 300 MW 10 minutes later • The load reduction was quite insufficient to relieve the line overloads • Sils-Soazza line tripped due to overheating 24 minutes after the trigger event; 12 secs after Italy was disconnected from European system • 27 Minutes after the trigger event, Italy experienced a major unreliability event • Swiss operators tried several times to automatically recluse the line, including a manual	• There were no operational procedures about pump load reduction in case of the Swiss line tripping • No cohesive communication between GTRN and ETRANS • Communication problems in Italy (between TSO and transmission owners) during the restoration process	• In operational planning no overload is allowed. In real time operation 'Sils-Soazza' Swiss line could only handle an overload of 20% for 20 min max. During the event the overload was higher. • Request of 300 MW load reduction was insufficient to relieve overloads

Italy continued……	attempt 7 minutes after first line trip • Restoration process attempted immediately • Restoration to North of Italy after 2 hours • Full restoration about 18 hours after the trigger event.		
Libya			
Singapore	•		•
Greece	• Generator lost 11 minutes after peak load at 12.01 • 13 min later, load shedding was attempted • 38 min after initial peak load, major unreliability event occurred		• Generator unit lost due to excess water in steam drum
Australia	• 15 sec after fault protection gear goes into operation • 6 min later frequency is stable	• Communication strategies did not contribute to incident. • Existing strategies were adequate.	• Communication of planning assumptions to operators did not contribute to incident. • Existing strategies were adequate.
Europe - UCTE	• The N-1 security criterion breached by advancement of the planned outage of a double circuit 380kV line and after 32 minutes of insecure operation, the system conditions evolved to cascading line tripping all	• Change of time of the planned outage communicated very late to other directly involved TSOs, and was not checked for security. • Computer security assessment carried out by the neighbouring TSOs showed that their own systems were stressed but secure.	• No specific attention was given by E.ON Netz to the fact that the protection devices have different settings on both sides of the Landesbergen-Wehrendorf line although this information was critical due to the very high flow on this line.

	over the UCTE area. • no exchange program reduction was possible to accommodate that last minute decision to bring forward the outage due to the market rules. (8:00 am for the day ahead is the latest) • Dispatcher actions were also constrained by the market rules. • Empirical security assessment failed and the switching manoeuvre aggravated the critical situation rather than alleviating it. This indicates the need for computer security assessment. • The switching manoeuvre caused cascading tripping of lines all over the UCTE system and, in less than 20 seconds, the system was separated into three islands.		

PLANNING

	Low probability Contingency Plans **Were there any low probability contingency plans in place for the failure?** **How were they used in the failure?**	***Operational management of risks*** **How was the risk and failure handled by operators and management?** **Are operators empowered to act when required?**	***Relation between design assumptions and operational behaviour*** **How were the design assumptions considered by the operators?**	***Use of Automatic remedial actions*** **Were there any automatic remedial actions?** **How effective were they? If not effective, why?**
New Zealand	• Contingency plans based on loss of two cables. Loss of all four cables had not been considered in contingency planning.	• No particular concern about loss of both gas cables. • Operators responded to loss of 3rd cable by switching load away. Mgmt response was to request customers to reduce load. • Spare cable joints kept in the UK, despite routine failures of aged cables. • Response to failure of	• Operators ran cables to their assigned ratings. • Assumptions used in calculating cable ratings subsequently found to be inadequate. Namely, the original cable specification, based on conditions in London, was	• No automatic remedial actions were in place

New Zealand cont…..		4th cable was to bring in temporary generation from around NZ and overseas, and to construct a 10 km 110 kV overhead line into the CBD in three weeks to restore full supply. New 110 kV cable laid in 9 months. • Problems identified in previous major unreliability events such as deficiencies in vegetation management, operator training and system condition visualisation were not addressed and repeated in this instance	inappropriate for the Auckland's volcanic soil that has low humidity and thermal conductivity	
Algeria		• Not enough spinning reserve Insufficient spare capacity on interconnectors with neighbours	• Less load was shed than expected	• UFLS was not fully utilised

Iran	• No under-voltage protection in 4 provinces	• Power plants did not co-operate fully to maintain the required VArs	• Under-rated CB • No busbar protection to contain initial fault	• Load shed relays in the North were not operated properly
USA and Canada	• No operational procedures in place to shed large amounts of load from Cleavland area in a matter of minutes • MISO did not measure system voltages • First Energy operators did not access any contingency plans or the contingency analysis model • FE did not have an effective contingency analysis capability cycling periodically on-line and did not have a practice of running contingency analysis manually as an effective alternative for identifying contingency limit violations. • There are no commonly	• Inadequate vegetation management • Reactive power reserves from generators located in the Cleveland-Akron area were consistently lower than those from generators in both neighboring systems and unable to fully supply the reactive power demand • MISO was using non-real-time information to monitor real-time operations in its area of responsibility. • MISO operators had no effective means to shed an adequate amount of load quickly and First Energy operators did not have the capability to	• First Energy was operating in an insecure state prior to the loss of the generating station	• Two breakers connecting First Energy grid with American Electric Power grid are tripped • UFLS is initiated on the under-generated island however, system still collapsed

USA continued……	accepted criteria that specifically address safe clearances of vegetation from energized conductors • There are special protection schemes in Canada for loss of large number of lines in a particular corridor – driven by NERC standards	manually or automatically shed that amount of load in the Cleveland area in a matter of minutes		
Finland	• New operating procedure for boundary substations in the cabled area	• No status monitoring of switching apparatus • No distance protection on cable		
Sweden and Denmark		•	• System was enabled to handle N-1 contingencies, however combination of faults degraded system to N-3 level. • System simulations showed that the system should have handled random	

Sweden & Denmark continued…..			combinations of faults on a level of N-2	
Italy	• Revised defence plans put in place – after major unreliability event to cater for problems on Swiss grid and power plants and for accelerating restoration process	• N-1 rule for Swiss Mettlen Lavorgo line only secure once the shutting down of pumps is undertaken • Inadequate vegetation management on Swiss lines • When restoration attempted, was delayed as the amount of available power capacity were not fully suitable for restoration as soon as expected	• Line could only handle overload of 20% for 20 ~~15~~ min max, however was overloaded over 20% for 25 min before tripping. • Italy importing 300MW more than scheduled	• Approx 10GW of load shed automatically by under-frequency protection devices • Interruptible pump storage was not used in time • Automatic devices able to control power flows on Italys critical sections but couldn't act after Swiss line trip because they were only set to cover cross-border line overloads and not internal Swiss overloads. (system now improved)
Libya	• Back-up protection • UFLS	• Some generators lost		• UFLS activated
Singapore	• Diesel fuel used as a back-up however, no contingency plan if this fails	•	•	• UFLS
Greece	• No study on the role of reactive power and how to avoid shortages	• Many of the planned new upgrades were not integrated into the	• Topological changes from ongoing works	

Greece continued….		system until after the summer peak	were not reflected in the database • Capacitor banks that were supposedly connected for the System Estimator solution were not connected in reality. This and other errors led to a mismatch in the order of 50MW	
Australia	• Automatic under-frequency load shedding used to control frequency following generation loss.	• Operational systems responded adequately	• NEMMCO has recommended changes to the Code to clarify the requirement on generators to ride through disturbances caused by credible contingencies including not just the initial fault but also reclosing onto a sustained fault.	• Protection cleared fault correctly. • UFLS responded adequately to restore frequency, however the sharing of the load shedding between regions could be improved. • NEMMCO is reviewing UFLS arrangements.
Europe - UCTE	• N-1 not fulfilled	• Market rules do not permit to reschedule	• Dispatchers gave no specific	• Some generators tripped on under frequency before the

		generation exchange to accommodate decisions for changes made after 8:00 am the day before. • Dispatcher actions also constrained by market rules. One such a permitted/mandated action triggered the cascading.	attention to the fact that the protection devices have different settings on the other side of the interconnecting line with the neighbouring TSO, although this information was critical due to the very high flow on this line.	last stage of the under frequency load shedding protection. • Uncontrolled re-connection of generation in an island with surplus generation. • Uncontrolled re-connection of DSO loads in the island with shortage of generation. • Inappropriate resynchronisation procedures. • Final report unavailable at the time of writing this report.

SOCIAL

	Governing bodies/ Control hierarchy **Who are the Governing/Controlling bodies?** **What are their functions?** **What is the extent of their controlling powers on reliability?**	*Impact of widespread disturbance* **How many customers were affected?** **What area was affected?** **MW / % of the system load lost?** **Energy unsupplied, MWh?**
New Zealand		• Auckland CBD affected only. Initially approx 80,000 customers affected, subsequently approx 30,000 affected by daily short-term blackouts for three weeks.
Algeria		• 98% of population affected • 5200MW load lost, est. 98% of total load
Iran		• 22M people affected • 7063 MW load lost, 50% of total load
USA and Canada	• North American Electric Reliability Council (NERC) East Central Area Reliability Coordination Agreement (ECAR) is one of the 10 regional NERC reliability councils. It is responsible for monitoring compliance with NERC operating policies and planning standards. ECAR is also responsible for coordinating system studies conducted to assess the adequacy and reliability of its member systems.	• 50M people affected • > 70,000 MW of load lost
Finland		• Helsinki, 800,000
England		• South London, 410,000 customers including the loss of supplies to underground and railway transport services

Sweden and Denmark	• National Regulator	• 4M people affected (1.6m in Sweden, 2.4m in Denmark) • 6550 MW load lost (4700 MW in Sweden, 1850 MW in Denmark), 100% of the south region of Sweden and Denmark lost
Italy	• Regulator (AEEG) • Ministry of Industry (MAP)	• Nationwide – 56M people affected • More than 20,000 MW load lost, 95% of total load
Libya		• 120 MW load lost, 5% of total load
Singapore		• 30,000 customers were affected • 1,390MW interrupted, 30% of total Singapore load
Greece		• Athens
Australia	• ACCC – transmission regulator and authorises the Code • NEMMCO – market and system operator –responsible for maintaining system security and reliability. • NEMMCO is provided with powers to direct as a last resort to maintain reliability.	• 1500MW of load was shed which represented 6.6% of load supplied at the time of the incident.
Europe - UCTE	• Interconnection of 23 countries • UCTE has technical rules for pool operation • Not a single legal jurisdiction • The actions of dispatchers are also constrained by local market rules. • Different TSOs in some countries. • Final report and recommendations unavailable at the time of writing this report.	• 15 million European households lost electricity. • Resynchronisation completed after 38 minutes • Situation normalised after less than 2 hours in all affected regions. • The demand and energy not supplied data unavailable at the time of writing this report.

Appendix D

Table – Summary of the survey on planning standards in cities

QA: Are transmission standards for CBD higher than those for the rest of the system?

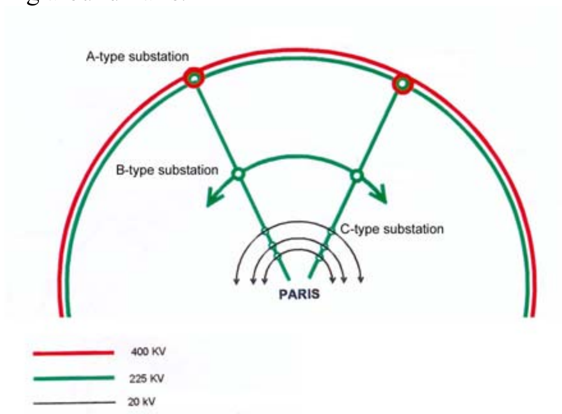
QB: Are transmission standards for CBD coordinated with those for CDB distribution?

QC: Do you use special protection schemes as a part of normal system planning?

QD: Are transmission standards for CBD the same as those for CDB distribution?

	QA	QB	QC	QD	Comments
Russia	No	Yes	Yes	N/a	Moscow is a large megapolis with population of about 14 mln. citizens concentrated on the territory with radius of 20-25 km. Electricity supply for Moscow and Moscow Region (radius of 100 km) provides Joint Stock Company Mos-Energo, which is a daughter company of RAO “EES Rossii”. As for 01.01.04 installed capacity in Mos-Energo amounts to more than 15GWt, a number of power stations – more than 20, for the most part of they are thermal co-generating stations, i.e. generating both electricity and heat, the main fuel – natural gas, a reserve fuel – black oil. Electricity production in 2003 accounted for more than 75 TWh. QA: There are no special standards for an electricity supply scheme’s construction for Moscow and other large towns. The Industry standards exist, in particular those that are being contained in the Regulation for Electricity Equipment Arrangement, in the Regulations for technology of high voltage transmission lines&substations designing, in the Guidelines on methodology of power system designing, and also in a large number of national standards for different kinds of power equipment, in addition longstanding experience of designing and operation should be taken into account. All that as a whole founded a good thought-out system on securing electricity supply.

	QA	QB	QC	QD	Comments	
					QB	1. The present practice has formed the following approach that resulted in a high secured electricity supply scheme in the <u>Moscow Region:</u> 1.1. Moscow and Moscow region are self-balanced both by electricity and power. In other words power stations of Mos-Energo covers the full electricity demand of Moscow and Moscow Region with necessary power reserve – more than 15%. 1.2. A strong distributing electricity network of Moscow based on 220 – 110 kV and lower, includes a number of serious technical decisions that provide security of its operation, among them: - availability of deep high voltage lead-in lines, - a high degree of inner reservation of power output by means of creation of ring structure of 110 kV networks. 1.3. A high degree of reservation of external electricity network by means of creation of a circle of TLs and substations of 220 kV, as well as a circle of TLs and substations of 500 kV around Moscow. Substations in that circles have strong electrical links with both an inner distributing network of Moscow and the Unified power System. 1.4. After putting into operation in the nearest years new capacities at some of nuclear power stations in the Central European Region of Russia a more powerful circular network structure of 750 kV around Moscow and Moscow Region will be completed. 1.5. High requirements on the Power system Vitality as well as to auxiliaries. These requirements are being stipulated at the planning stage and observed at operation stage in the first place – through load or/and generation shedding fulfilled automatically or according to operator's instruction under emergency conditions.
					QC	1.6. A strong and reserved system of relay protection, aimed at fast localization of outage consequences as well as at short-circuit current equipment protection. 1.7. A strong and reserved system of automatic emergency control aimed at: - preservation of power stations parallel work, preventing escalation of stability violation - elimination of electricity network & substations overload, as well as of inadmissible voltage levels, including using disconnection of generation and/or customers as a controlling factor (that is being stipulated at the planning stage).

	QA	QB	QC	QD	Comments
					QD: - A hard system of a centralized dispatch' control both inside Mos-Energo and in the UPS as a whole that should exist irrespective of Holding RAO "EES Rossii" restructuring as well as of introduction of competition in the Power Industry of Russia.
France	Yes	Yes	No	N/a	*The structure of the transmission system supplying Paris* Moving outwards from the center of Paris, the 225 kV/20 kV substations supplying the city are located on three successive rings. These substations are referred to as the 'C-type substations'. On each of these three rings, there is no 225 kV network between the C-type substations. The distribution network, though, is quite well developed between them and provides security of supply for any substation from the nearest one. The C-type substations are supplied by radial 225 kV underground cables. These radial cables are issued from 225 kV substations (referred to as B-type substations). These B-type substations play an interconnection role and are located on a 225 kV ring, just on the outskirts of Paris. Finally, the radial 225 kV lines stretch out from each B-type substation to 400 kV/225 kV (A-type) substations, which are located on an even farther ring around Paris. 

	QA	QB	QC	QD	Comments	
					QA	*The security standards used for Paris* The security standards which have been taken into account in the planning process are : • N-1 225 kV radial line supplying any B-type substation from its A-type substation The network is able to sustain this kind of incident thanks to the B-type substations being interconnected. • N-2 neighbour C-type substations on the same ring In case of a loss of supply affecting any C-type substation while the nearest one on the same ring is under maintenance, the whole load of both substations can be supplied by the surrounding C-type substations, thanks to the distribution network. In order to minimize the risk of N-2 neighbour C-type substations on the same ring, the radial 225 kV cables supplying these neighbouring C-type substations are issued from two distinct B-type substations (or, at least, from two distinct busbar sections). This N-2 security standard is quite specific to Paris.
					QB	The security standards that have been taken into account in the planning process don't include contingencies such as the simultaneous outage of one transmission circuit and one distribution circuit. Nonetheless, as explained in the previous section, the transmission network directly relies on the distribution network in case of the outage of one or two C-type substations from the same ring. This has been made possible only thanks to the adequate sizing of the distribution network between the C-type substations. In fact this network scheme results from a strong coordination over years between transmission and distribution divisions in the framework of EDF working as an integrated utility.
					QC	As far as Paris is concerned, this kind of protection schemes are not used as a normal part of planning. The radial structure of the network supplying Paris minimizes the risk of an outage of a circuit (or a substation) resulting in a constraint on another circuit. There is no 225 kV network between the C-type substations located on a same ring, and the distribution network between them is unmeshed.

	QA	QB	QC	QD	Comments	
					QD	As explained in the 'Question a)' section, the key principles regarding the planning of the transmission network supplying Paris have been : - Radial 225 kV circuits with very little dependency one from another - Matching the N-2 C-type substations security standard thanks to the distribution network. These principles are not the same as the ones used for the distribution system inside Paris. For the largest French city, specific security standards are applied in addition to the classical N-1. The types of incidents which are considered are : - N-1 supplying substation, - N-2 lines For such incidents the requirements are that 40% of the lost load must be supplied again 30 minutes after the incident.
Portugal	Yes	Yes	No	No	Capital Lisbon	
					QA	In terms of planning process for the TS (Transmission System)which includes in Portugal the 400, 220 and 150kV voltage levels)we use different security standards in reference with the rest of the TS. Actually, we consider a n-2 security criteria for two lines in the same tower no matter the line's length, meanwhile for the rest of the country this n-2 criteria is only used for "long" lines, over 35km. Also we seek an instantaneous n-1 security standard for transformer outage, while for other region we admit some instantaneous loss of load facing a transformer failure ,that can be replaced after some time via distribution network.
					QB	Basically concerning Lisbon city there are two voltage distribution levels which can constitute alternative supply to TS failure - the 60kV and the 10kV, though they have, as it is natural, different amount capacity as well different restoration time. Taking this in account and facing a TS outage we consider the 60kV distribution system is all OK. If finally any additional problem can occur in this level, there will be the 10kV system which, anyway, can restore the loads, though with much more delay.
					QC	As a rule, we do not use any special automatic protection schemes to intertrip load, though manual and centralised orders can be issued to intertrip load via dispatch centres.
					QD	Actually the distribution structure in Lisbon in based on 60kV feeders supply, not meshed. So, the failure of one 60kV feeder (line or transformer) leads to an instantaneous loss of load and the service should be restarted through the 10kV level, while the TS has at least an instantaneous n-1 criteria of any TS element.

<table>
<tr><th></th><th>QA</th><th>QB</th><th>QC</th><th>QD</th><th colspan="2">Comments</th></tr>
<tr><td rowspan="5">South Africa</td><td rowspan="5">No</td><td rowspan="5">No</td><td rowspan="5">Yes</td><td rowspan="5">No</td><td colspan="2">Capital Pretoria</td></tr>
<tr><td>QA</td><td>Not necessarily. We consider the cost of unserved energy when dealing with these issues as well as the willingness of the customer to pay for premium quality. We have an overall Transmission System Planning Guide and a Grid Code which provides the standards and planning process. This could result in the ley areas being the towns with major industrial loads and commercial loads.</td></tr>
<tr><td>QB</td><td>This is not done in a rigorous manner. The ideal situation is to have a reliability planning tool that can simulate multiple probabilities. The co-ordination is done through engineering forums and appraisals of plans. When we develop emergency preparedness plans we also identify risks that were not considered and then revisit the plans</td></tr>
<tr><td>QC</td><td>We do this in the Systems Operations environment and have developed several inter-tripping schemes.</td></tr>
<tr><td>QD</td><td>We do not co-ordinate this at this stage.</td></tr>
<tr><td>USA</td><td>Yes</td><td>Yes</td><td>Yes</td><td>No</td><td colspan="2">All NPCC members comply with all NERC planning standards, see Planning Templates, and operating policies as well as the Council's more stringent Regionally specific criteria In addition, NPCC has more specific Regional requirements which explicitly defines the multiple element single contingencies which NPCC considers critical in assuring the reliability of the system. Historic review and studies of the performance of the NPCC system indicate that the system instability, cascading, and voltage collapse could result following these credible normal contingencies if the system operating limits did not recognize the reliability impact of the following contingencies;</td></tr>
</table>

	QA	QB	QC	QD	Comments	
					QA	**Single Line to Ground (SLG) Fault with Normal Fault Clearing;** - Due to the system topology of the Northeast and the number of Ring Bus configurations on the system, NPCC feels this is critical when determining Operating Limits. **Double Circuit Tower (DCT), with Normal Fault Clearing;** - NPCC has a great number of double circuit towers within its Region. - Topology and Geography create an increased likelihood for lightning strikes of the DCT resulting in loss of both circuits. - Historical data indicates a sufficiently high probability for DCT loss to warrant its consideration when developing Operating Limits. **Bipolar Loss of a DC Circuit, without AC fault;** - Historical data of the Phase II DC connection to Quebec indicates a sufficiently high probability of loss of the both poles of a DC line to warrant inclusion. **SLG fault with Delayed Clearing (stuck breaker or protection system failure)**; - Due to the limited application of Independent Pole Tripping (IPT) breakers on the Northeast bulk power system. - No remote indication of the ability of a breaker to operate and trip as intended during a fault condition. (there may be energized breakers on the system that, due to loss of air, oil etc., are incapable of tripping). **Special Protection Systems (SPS) failure;** - NPCC has a large number of SPS installed on its system which must be considered when determining Operating Limits. - SPS in some cases have been installed rather than building new transmission due to a number of reasons and the interactions and effects of mis-operation and failure to operate are critical issues that need to be considered when determining Operating Limits. Most of these multiple element contingencies have been utilized to establish system design requirements and system operating limits since the formation of the NPCC. They are routinely considered to ensure the reliability the system. NPCC design criteria states that “the probability of disconnecting non-interruptible customers due to resource deficiencies, on the average, will be no more than once in ten years.” The probability of disconnecting non-interruptible customers would increase if the system operating limits did not recognize these multiple element single contingencies and insufficient resources were scheduled to be in service. The above are applied on a “region-wide” basis. In addition there are even more stringent reliability rules, such as higher reserve criteria and loss of load criteria, for the Cities that are imposed by the New York State Reliability Council and local utilities.

	QA	QB	QC	QD	Comments	
					QB	NERC and NPCC Regional Criteria apply only to the “Bulk Systems” which are generally considered to be of specific voltage levels and in NPCC’s case performance based. NPCC’s Criteria only apply to the interconnected electrical systems within northeastern North America comprising generation and transmission facilities on which faults or disturbances can have a significant adverse impact outside of the local area. In this context, local areas are determined by the Council members. As such no regional assessments of security involve “simultaneous” simulations of transmission and distribution circuit outages.
					QC	NPCC presently allows a special protection system (SPS) to be used judiciously in system design, and when employed, shall be installed, consistent with good system design and operating policy. A SPS may be used to provide protection for infrequent contingencies, or for temporary conditions that may exist such as project delays, unusual combinations of system demand and equipment outages or availability, or specific equipment maintenance outages. An SPS may also be applied to preserve system integrity in the event of severe facility outages and extreme contingencies. The decision to employ an SPS shall take into account the complexity of the scheme and the consequences of correct or incorrect operation as well as its benefits.
					QD	NPCC Regional Criteria only apply to the Bulk System. More stringent local standards apply to city distribution systems. For example, an N-2 criteria is used for the underground cable network in New York City.
Northern Ireland	No	Yes	Yes	Yes		
					QA	Are the security standards and planning process used in developing the transmission system supplying the capital city higher than for the rest of the transmission system. Answer: No What are the security standards and planning process used in developing the transmission system supplying the capital city. Answer: (n-1) in winter, and (n-m-1) in autumn and summer, where “m” is the number of components out-of-service due to maintenance. Note: Winter system peak load is implied.
					QB	Are the security standards used for the transmission network supplying the capital city co-ordinated with the security standards used for the distribution network within the capital city i.e. simultaneous outage of a transmission circuit (overhead or cable) and any distribution circuit. If so what contingencies are considered i.e. what combinations of transmission and distribution outages are considered as simultaneous. Answer: Distribution Control Centre & Tx control co-ordinate outages. Major activity has a risk management panel.
					QC	Do you use special protection schemes to intertrip load or generation to protect transmission or distribution circuits as a normal part of planning or only for infrequent maintenance conditions. Answer: Regular.

	QA	QB	QC	QD	Comments	
					QD	Is the security standard applied in planning the transmission system supplying the capital city the same as used in distribution system within the capital city. Answer: P2/5 is used for both but the Group Demand is different.
Belgium	No	-	No	No		
					QA	We use the same planning standards for the big cities as for the rest of the country. Classically we use the (N-1) criterium for all net elements and generation units and (N-2) criterium for one net element and one generation unit or two generation units, and this at peak load. Besides on the 380kV-grid, we also use plan the grid to withstand a busbar default.
					QB	In combination with the distribution network, we do not take into account an incident on the transmission grid at the same moment as an incident on the distribution network.
					QC	We do not use special protection schemes in the normal part of planning. We accept that load can be shifted from one network to another or from supply point to another, to relieve a limited overload (10%).
					QD	The security standards are the same for the transmission grid as for the distribution network excepted as mentioned the busbar default. This is not taken into account in distribution networks.
Canada	No	Yes		No		

	QA	QB	QC	QD	Comments	
			Yes		QA	For supply planning to the Capital City of the Country and the Province, the security standards are the same as for other large urban areas in the Province on a per delivery point basis. However, within the planning processes special studies such as low probability / high impact studies are conducted to determine if low probability events (such as the simultaneous losses of 2 or 3 major elements), warrant special consideration for supplying multiple delivery points, given the possible consequences. We have done this in the past by quantifying the Expected Value of Lost Load (based on, Probability of the Event X Associated Load Loss X Value of Lost Load to customers) and comparing it to the cost of the mitigating measures. If the annual carrying cost of the mitigating measures is equal to or less than the Expected Value of Lost Load, on an annual basis, consideration is then given to implementing the mitigating measures. This approach is was in place when the utility was involved in centralized planing and was self regulated. The security standards become more complicated when dealing with a Regulator and the challenges of the new market environment. Standards such as these will be set in conjunction with the Regulator and are currently based on historical levels of performance and ensuring that these do not degrade. Other challenges of the new market environment include cost sharing with beneficiaries for facilities, which are above standard and / or do not cover average carrying costs over the long-term.
					QB	In Ontario the transmission Company typically owns the step-down Transformation facilities and the contingencies considered would include single (and in special circumstances double) contingency combinations of Lines and Transformers. On a planning basis we do not usually investigate combinations down to the feeder level because the impacts at the feeder level are typically reduced ten fold. However, we do investigate the possibility of large-scale load transfers from one transformer station to another, facilitated by transfer capability within the distribution system, as a mitigating action for loss of supply from a transformer station.
					QC	In the past, we typically only used Special Protection Schemes (SPS's) where it is not economic reinforce the system because the magnitude of load exposed to the contingency is small and / or the probability of the contingency occurring is very low. SPS's have also been used when there have been approval delays in building new facilities, such as a major new transmission line. There are challenges in utilizing this approach in the new Market, as the Regulator does not yet understand these concepts.

	QA	QB	QC	QD	Comments	
					QD	The distribution system is planned by independent entities in Ontario but joint studies are typically conducted to ensure good planning co-ordination. Since the distribution system in Ontario consists of strictly the low voltage facilities (< 50 kV) this system imposes much lower consequences and it is my understanding that the planning standards are significantly lower when planning at the distribution level. In the past many of the larger distribution utilities also used the Value of Lost Load concept to decide on incorporating redundancy or back-up facilities within their systems.
Japan	Yes	Yes	Yes	N/a	As a reference of a population of big cities in KANSAI area, OSAKA has a population of 2.63 million, and KYOTO has one of 1.47 million in 2004. Incidentally, TOKYO has a population of 12.37 million. Now, we define transmission system and distribution system in this paper as follows. - "Transmission system" is composed of 500kV, 275kV, 154kV and 77kV transmission lines, and transmission substations where have 77kV and more bus-bars in the secondary sides of transformers. - "Distribution system" is composed of 22 kV and 6kV distribution lines and distribution substations where have 22kV and/or 6kV bus-bars in the secondary sides of transformers.	

	QA	QB	QC	QD	Comments	
					QA	KEPCO has the following **philosophies** on system planning. Basically, we have not admitted an interruption on the N-1 condition and we have not applied generation and load shedding to our system planning. Because an incident on transmission system has big impact to customers, social and economy, and many hours need to resume power supply. However, in the case of our bulk power system, we have applied generation and load constraint to our system planning in order to prevent power system collapse on the N-2 condition. Moreover, even if the power system is suffered unexpected large generation and/or load dropping, we separate our power system into health system and fault system in order to prevent power system collapse. In the same way, we have taken into consideration N-2 condition on system planning for big cities, in order to prevent a large interruption in big cities, but with temporary interruption, and we try to resume disconnecting power system as soon as possible. The other side, distribution lines are consisted one-circuit and they are operated radically, because they are installed widely and it may be easy to repair them comparing with transmission lines. Therefore, temporary interruption occurs when there is a fault in distribution lines, but we try to resume disconnecting power system as soon as possible. And also, on the view points of control of short-circuit current, circuit breakers installed between secondary sides bus-bars of transformers in distribution substations are disconnected in normal operation condition. Therefore, temporary interruption occurs when there is a fault at transformers, but we try to resume disconnecting power system as soon as possible. In addition, we have equipped the two kinds of protection devices for each main equipment, which are main protection and backup protection relays in order to clear completely any faults in transmission lines, distribution lines and transformers. Because costs of protection devices are lower than main equipment, such as circuit breakers, transformers. That is to say, actually, we have applied N-2 condition to protection scheme. Morevor, we try to improve equipment reliability Moreover, we try to improve equipment reliability with the followings: - Prevent incidents caused by external factors through adoption of in-house, GIS and /or underground cable - Avoid going into N-2 condition caused by un-behaviour of circuit breakers (That is to say, circuit breaker isn't able to open a circuit.) and protection devices through high quality requirements and strong maintenance for equipment.

	QA	QB	QC	QD	Comments	
					QA	As **security standards**, we set allowable interruption time (or restoration time) as target in the event of interruption, according to demand density and demand importance. An allowable interruption time in central part of big cities with high demand density is set within 30 minutes, only one of fault section is set within 2 hours. Except central part of big cities, it is set within 2.5 hours. As a reference, actual achievement of interruption time per household was 4 minutes in 2000. Our **planning processes** to carry out the above allowable interruption time are as follows. Roughly summarized, in order to maintain customer satisfaction, we set allowable interruption time as one of indexes, and we have completed it with not only power system configuration (system planning), but also equipment performance and maintenance. For example, we have installed only one circuit breaker per line, but we have required high performance to equipment and have maintained them.
					QB	**1. Concrete example for application of N-1 standards** **1-1** Transmission substations supplying to big cities have double bus-bars in the primary and secondary side, not only out-door type but also in-door type. **1-2** Transmission lines to big cities have two lines for bus-bar receiving substations or three circuits for unit receiving substations, and over-load capacity is limited in 150% per circuit, therefore normal capacities are 75% and 100% per circuit respectively. **1-3** Transmission substations to big cities and distribution substations in big cities have two or three transformers, and over-load capacity is limited in 150% per transformer, therefore normal capacities are 75% and 100% per transformer respectively. **1-4** Normally, 22kV distribution lines for customers have two lines but one is used as reserve circuit, therefore temporary interruption occurs when there is a fault in this line. However, 22kV distribution lines for large customers such as buildings and shopping malls in big cities have 3 circuits and use them together.

	QA	QB	QC	QD	Comments	
					QC	**2. Prevention large interruption and rapid resumption** **2-1** Transmission lines to the big cities have plural routs in order to prevent a large interruption, and moreover it is easy of rapid resumption to switch 77kV and 6kV power system. **2-2** In order to prevent loss of function of distribution substations in big cities, underground transmission lines which have 2 lines are installed in separate routes individually to never be cut off both lines at the same time. **2-3** Since Distribution substations have single bus-bars due to narrow floor space, circuit-breakers are installed in their primary bus-bars in order to disconnect from accident sections, save time for searching them, and shorten resumption time. **2-4** Distances between distribution substations in big cities are short, because it is necessary to install a lot of distribution substations in high density area. Therefore, it is easy to make interconnection between distribution substations by 6kV distribution lines, and form two-way circuits. But disconnecting switches at the interconnecting points are normally opened. Moreover, some switching devices are equipped on distribution lines, and in the event of accidents, they separate accident sections and supply electricity except accidents sections from both distribution substations automatically for rapid resumption on our developed system, which is called “Automatic Operation System for Distribution” (hereinafter AOSD). **2-5** In the event of accidents in transmission lines and distribution lines, including simultaneous accidents, it is possible to be rapid resumption by a combination of AOSD and AOST. Herein AOST means automatic operation system for transmission. For an example, in the event of accident at transformer in a distribution substation, these systems automatically calculate supply reserves and shortage of relative distribution system, they decide provision methods, and carry out the best way, such as supplying from another distribution transformer and/or another distribution substation.
					QD	**3. Reduction of accident rate** **3-1** In order to achieve high equipment reliabilities on distribution substations in big cities, In-housing and/or GIS are applied to them to reduce accident rate caused by external reasons. **3-2** Good performance protection devices and circuit breakers are installed, and regular maintenance is given them for keeping these good performances.

	QA	QB	QC	QD	Comments	
Hungary	No	Yes	No	-		
					QA	In Hungary there is no difference between the security standards and planning process of capital city and other region. 120 kV and above there is a harmonized, common planning standards among distribution companies, the transmission company and the independent system operator. Standards are fully compatible with the UCTE recommendations.
					QB	Generally the n-1 criteria is the standard, but calculations are made for double contingency cases to check the system security (n-1-1 = one network element + one generator unit).
					QC	Only for emergency situations.
					QD	See our reply to QA above.
Switzerland	No	No	No	No	As a preremark to my answers for Switzerland I have to mention the fact that for the planning process each network operator has its own security guidelines (we have no standards). Coordination of security aspects is therefore very limited. Especially we have a certain coordination between the 7 TSO's.	
					QA	Security guidelines in Switzerland make no reference to the politcal importance of a city or a region containing the capital city. There are only economical criteria for the planning process.
					QB	The distribution network within the capital city or any other city may be built according a higher security level for the supply of special important districts as the government complex or headquarters of banks. But this is not coordinated with the transmission network around the city.
					QC	We do not use special protection schemes to intertrip load or generation as a normal part of planning. We may have special protection schemes for emergency or special maintenance conditions.
					QD	No, see also our answer to question QB.

Appendix E

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