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Electric System vulnerabilities: Lessons from recent blackouts and the role of ICT

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Glossary

CIGRE’: International Council on Large Electric Systems

ICT: Information and Communication Technologies

SCADA: Supervisory Control And Data Acquisition

TSO: Transmission System Operator

UCTE: the Union for Coordination of Electricity Transport

Executive Summary

Crucial economic and social functions depend on the security, adequacy, and quality of electricity supply. Although it is possible to prevent the most devastating effects of electrical service interruptions by resorting to local backup power sources in order to ensure continuity and quality of supply, the cost of backup supply systems is significant, so that they are generally limited to ensure essential functionalities of the dependent service infrastructures for a limited amount of time.

Overall the vulnerability of the European electrical infrastructure appears to be growing due to several factors:

- demand is steadily growing, and, although this growth may be forecast, it cannot be easily faced anytime;
- after liberalisation, electricity transactions increase and become more hectic, and operators tend to operate the whole infrastructure closer to capacity limits;
- critical infrastructures, and the electrical system primarily, become highly interconnected with other networked systems and the potential for devastating effects on vital services can create attractive targets for malicious activity, including terrorism.

Why perform this study on blackouts? In the frame of international action plans to enhance the protection of critical infrastructures, energy supply is considered as one albeit important infrastructure for the reasons outlined above. Moreover, recent blackouts have demonstrated that the cause/effect mechanisms can be of cross border nature. The impact of a major failure or a well targeted and successful attack on the electrical system (physical as well as presumed cyber attack) could be a major regional or national blackout possibly with cross-border ramifications. Therefore, in order to better understand vulnerabilities, we start from analysing the mechanisms and causes that have lead to recent blackouts. Based on known facts and publicly available investigation reports, these blackouts were not caused by malicious attacks but nevertheless the current international scene calls for increased vigilance for the malicious risk factor [EC 2004].

In recent years, both Europe and America have experienced a significant number of major blackouts. This report specifically focuses on events that affected Europe and North America during 2003, namely:

August 14, 2003 – North East blackout over the US and Canada;

August 28, 2003 - Southern London distribution;

September 23, 2003 - Danish/Swedish blackout;

September 28, 2003 - Italian electricity transport grid collapse.

and provides a detailed analysis by critical comparison, where available, of diverse and authoritative information sources. The main information sources used include UCTE, Eurelectric, national and international investigation committees like the joint US-Canada investigation committee on the North East blackout, the UCTE Investigation Committee on the 28 September blackout in Italy, the British, Danish, Italian, French, Swedish and Swiss authorities' reports, etc…).

A common pattern that recurs through all the incidents analysed is that a rather trivial initiating event, like a tree contact, was compounded by concurrent factors, like unavailability of other equipment, thus resulting into a chain of events that ultimately led to large and impressive effects – paralysis of wide regions and entire sectors of the economy.

Referring to two of the major events investigated (Italy and American North East), the report pinpoints their common roots and the associated critical issues:

- Current *risk assessment methods* rely on exhaustive application of the so called N-1 criterion to system configuration: the system must be operated in such a way that loss of a single element of the network does not cause unmanageable (and thus escalating) disturbances, because the other elements could replace the lost function. The N-1 criterion implies that after a first incident, measures should be taken as soon as possible to return to normal security situation. Hence load flow analysis is applied exhaustively to single loss states in order to evaluate the resulting grid conditions. It is quite apparent that these methodologies were not entirely appropriate, in that they did not identify security threats in a timely way;
- The electrical system *controls* - intended as the procedures for system management, and the related information and communication infrastructure, comprehensive of monitoring, actuation and protection devices - appear to be no longer adequate to cope with the changing nature of transactions. Transactions that involve different organisations, nations and thus different jurisdictions, current rely on inappropriate procedures and inadequate and/or outdated systems.

The electrical system depends substantially and increasingly from its supporting information and communication infrastructure, because almost all system vital functions are remotely controlled. In this context, the role of Information and Communication Technologies (ICT) becomes apparent in at least two ways:

- Advanced systems for protection, data exchange and situation awareness will be deployed, so as to improve system controls in a way to cope with the European energy market drivers.
- The trend to connect systems to open networks such as the Internet, may increase system vulnerability, due both to accidental faults and malicious cyber attacks..

An increased control systems complexity will in turn require further R&D efforts on advanced ICT security technologies.

1 Introduction

Electricity supply is a key service for modern society. Electric power shows a number of key features:

- it is easy to convert into other energy forms (light; thermal and mechanical power , etc.);
- it is easy and flexible to transport;
- it may be distributed almost everywhere;
- it may be generated rather cheaply from primary sources which cannot be otherwise utilised (water, lignite, low quality coals, etc.).

On the contrary, only a rather limited amount of electric energy can be easily stored: this involves that, in every time instant, energy demand must be balanced from an equal amount of supply, i.e. anytime the exact amount of energy demanded by consumers must be produced. When this equilibrium is not respected, the entire electrical system enters a critical situation.

This key feature has two basic outcomes:

- a transport infrastructure must be built and operated, so as to *dispatch* electricity, i.e. transfer electric power over long distances from generating power plants to end users sites, which are distributed on the entire national territory. Long distance *transport* of electricity takes place via a high voltage grid, operating at several hundred kV (380 kV on the European grid), while regional and local *distribution* relies on a sub-network operating at progressively decreasing voltage levels (132 kV, 20 kV, 380 V on the European grid);
- electricity needs to be dispatched in a safe, reliable and economic way, and this involves a set of rather complex operating activities so as to match power generation capacity with utilisation demand peaks, while ensuring electrical system operating security, reliability of supply, and efficient, low cost power generation and distribution.

Also, it must be pointed out that the electrical system depends substantially and increasingly from the information and communication infrastructure, because almost all system vital functions are remotely controlled, and remote operation and control of distribution and transport grids is based upon an information and communication infrastructure. In turn, the information and communication infrastructure itself depends on electrical supply, which creates an interdependency between the two infrastructures which further compounds their vulnerability.

In the current context, threats against the electrical system are growing – like for other network- based, highly distributed infrastructures – due to several factors:

1. demand is steadily growing, and, although this growth may be forecast, it cannot be anytime easily faced (also because the public often contrasts construction of new power generating plants and transmission lines);

2. power systems have been developed in the past 50 years so as to ensure mutual assistance between national subsystems including common use of reserve capacities and, to some extent, to optimise the use of energy resources by allowing exchanges between these systems. Today's market development with its high level of cross-border exchanges was out of the scope of the original system design. Transactions increase, following electrical system liberalisation, and this involves operating the whole infrastructure closer to security limits;
3. market liberalisation involves that multiple operators exchange critical information so as to jointly operate the system, hence a number of key control systems need drastic reviews in order to fit the operation in a market-driven setting;
4. an increased control systems complexity, required for secure system operation, and their connection to public networks may in turn raise system vulnerability, due both to accidental faults and malicious attacks;
5. critical infrastructures, and the electrical system primarily, are well known to be a privileged target in warfare, as well as terrorist attacks. Current dramatic developments in the international scenario induce not to underestimate the related risk factor.

In European electrical systems, most information and communication infrastructures currently in use for remote operation and control are still privately owned and operated. To some extent this may limit the likelihood and impact of cyber attacks for the time being, but in a mid-term perspective the trend towards using open protocols and public information and communication infrastructures for automation support cannot be avoided, due to the widespread availability and flexibility of market standard solutions, and to the feasibility of value-added customer services they provide. Hence, due to economic and political pressures (*liberalisation, European integration, globalisation, standardisation, reduction of operating costs)* adoption of open IC infrastructures for electrical system automation will undoubtedly spread notwithstanding the exposure to cyber attacks threats.

The *dispatching systems* currently in use in most European countries rely on a dedicated infrastructure for communication between the national control centre and the regional ones, and between those latter centers and the remote data acquisition and operation equipment located on power generation facilities and transmission substations. Cyber vulnerabilities may result from the fact that system must be progressively open to a growing number of operators (competitors in the power generation market, control authorities and operating bodies, distribution companies, etc.). In that respect, however, predominant threat factors appear related to the inherent complexity of the electrical infrastructure, which makes review, redesign, and reinstallation of the legacy information and communication infrastructure for monitoring and control also extremely complex, rather than to threats related to hostile intrusion introduced by the opening of the system. Energy trade exchange is unlikely to introduce in the electrical system further vulnerabilities related to information and communication , as the time horizon of open market transactions (market of the day before, adjustment sessions) is such to require access to information which may be sensitive regarding operators commercial strategies, but is unlikely to be critical for the online operation of the electrical infrastructure and the other infrastructures connected.

This landscape may change when looking to more peripheral information and communication infrastructures of the electric system, like the ones used for managing power *distribution* of energy supply to the end-user: for instance, on-line customer management and administration facilities through remote metering systems entirely relies on a public IC infrastructure so as to guarantee openness and interoperability. Although data communication relies on sophisticated cryptographic technology, it is obvious that in an open market context, sooner or later those solutions will have to be shared among distribution companies, so as to make possible remote metering systems interoperability, thus introducing risks related to hostile intrusion by third parties.

However, this report exclusively focuses on progressive establishment of a European energy market, and on the threats this may introduce with respect to the core governing function of the electric system, the infrastructure to monitor and control energy dispatching. To this aim, we first review vulnerabilities arising from increase of cross-border trade *per se*, and then try to draw lessons from by recent blackout events which have pointed out, among other risk factors, the ones related to inadequacies of the IC infrastructure for energy dispatching.

2 Vulnerabilities of the European electricity transport grid

In the context of the creation of an internal European electricity market, the existence of sufficient cross-border transmission capacities and their efficient utilisation gain crucial importance. Historically, transmission system operators (TSOs) have not designed the interconnections between their networks primarily to facilitate bulk power trade, but rather to achieve better reliability and efficiency of supply through co-operation among them. Thus the introduction of open access to transmission networks resulted in a number of bottlenecks in cross-border transmission capacity which may seriously constrain the establishment of a European electricity market. In the year 2001 the European Commission contracted the Institute of Power Systems and Power Economics (IAEW) of the Technical University of Aachen to carry out a comprehensive investigation on electricity transmission capacities between the EU member states plus Norway and Switzerland, with the main objective of identifying bottlenecks in the cross-border transmission systems, and of evaluating ways to increase the level of usable cross-border transmission capacity at the critical locations.

The study [IAEW, 2001] gathered enough data on the frequency and severity of congestion to come to a relatively clear distinction between critical and less critical bottlenecks. Apart from bottlenecks that can only be relieved by adding new DC (direct current) sea cables - a very expensive and long-term measure whose impact capacity can be determined very easily – the study identified the following five interconnections as “critical”:

1. France → Spain,
2. France → Belgium & Belgium/Germany
3. Netherlands (to be analysed in combination), Denmark , Germany
4. France/Switzerland/Austria(/Slovenia) → Italy, and

5. Norway/Sweden

The results of the study were largely confirmed by subsequent events: all the critical regions were hit by congestion crises in the period 2001-2004, although only some of them resulted in significant blackouts. Sweden, Denmark and Italy were the subject of major events in 2003, Denmark in 2002 and Spain in 2001 [Eurelectric, 2004b]. The congestion area at the Belgian border may appear an exception. However, also this area experienced near misses of considerable gravity, since 1998 at least [Electrabel, 1998]. The main problem there is related to potential cascading line trips between Belgium and France (and also between France and Germany) due to thermal overloads. When transactions happen between third parties, e.g. France and the Netherlands or France and Northern Germany the part of the power that will actually flow through the Belgian and Dutch grid strongly depends on the grid topology and on the generation pattern in the affected countries. This makes it difficult for a single TSO to anticipate the problems. More recently it seems that this risk has become even higher, due to the installation of a large amount of wind power in northern Germany. When the wind suddenly stops to blow in northern Germany, part of the deficit is compensated by increased generation in France, Spain, etc., a significant part of which must flow through the Belgian and Dutch system.

The annual report 2003 on system adequacy issued by UCTE, the Union for Coordination of Electricity Transport, confirms that margins for systems security keep eroding. The overall electricity consumption in mainland Europe increased by 3 percent, while generation capacities slightly improved by 1.6%. In particular, power generation from renewable resources went up by 21%. Although the retrospect shows sufficient generation capacities, tight situations appeared in several countries during the summer. The market development led to a sensible increase in international power exchanges of nearly 10% of the overall consumption in Continental Europe. Critical levels of congestion were reached in Italy, Poland, the Czech Republic, Austria and Hungary. Consumption increase (+3.1%, +69TWh) was much higher than in the previous years (0.6% and 2.4% in 2001 and 2002, respectively) [UCTE, 2004b].

Italy is the country featuring one of the highest power price levels within the European electricity market. Since the Italian market is particularly attractive for traders, bottlenecks exist on virtually all of its borders. Concerning power exports from Switzerland to Italy, an allocation procedure has been set up, providing for integrated pro-rata capacity allocations on a yearly basis for both the French and the Swiss borders. Although, according to UCTE, there are no realistic limits relating to interconnection capacities between Switzerland and France, actual bottlenecks exist due to large quantities of power transited from France via Switzerland to Italy. French TSO RTE has thus set up an allocation mechanism on a daily basis for imports from France to Switzerland. Given the current market situation, it is rarely amazing that a number of energy traders intend to boost interconnection capacities into Italy by projecting a number of merchant lines [Eurelectric, 2003a].

The UCTE System Adequacy Forecast 2003 - 2005 report [UCTE, 2004c] confirms that the situation will not improve in the main UCTE block (i.e, the European mainland up to the border with the Commonwealth of Independent States and Baltic states), slightly improve in Iberian countries, and worsen considerably in Italy and Greece[1].

The general industry practice for security assessment has been to use a deterministic approach [IEEE/CIGRE, 2004]. The power system is designed and operated to withstand a set of contingencies referred to as "normal contingencies" selected on the basis that they have a significant likelihood of occurrence. In practice, they are usually defined as the loss of any single element in a power system either spontaneously or preceded by a single-, double-, or three-phase fault. This is usually referred to as the N-1 criterion because it examines the behaviour of an N-component grid following the loss of any one of its major components. In addition, loss of load or cascading outages may not be allowed for multiple-related outages such as loss of a double-circuit line.
In real time, after a contingency, each TSO must return its power system to a N-1 compliant condition as soon as possible, and in case of a possible delay, must immediately inform other TSOs affected [UCTE, 2003]

Power load flow analysis is applied exhaustively to N-1 states in order to evaluate the resulting grid conditions. This way the voltages and currents that different parts of the power system are exposed to are computed, in order to assess the relevant stresses during steady state operation. In most cases, an N-1 state can be sustained for a limited amount of time only (typically 10'-20'), because of the unusual stress on certain components, e.g. power lines due to overload start to stretch and tree contacts cannot be avoided.

The deterministic approach has served the industry reasonably well in the past, resulting in high security levels. Its main limitation, however, is that it treats all security-limiting scenarios as having the same risk. It also does not give adequate consideration as to how likely or unlikely various contingencies are. This was acceptable in the traditional monopolistic industry environment. In the new competitive environment, with a diversity of participants with different business interests, the deterministic approach may not be acceptable. There is a need to account for the probabilistic nature of system conditions and events, and to quantify and manage risk [IEEE/CIGRE, 2004].

[1] A major blackout recently affected Attica [CBS News, 2004], whose critical situation had been anticipated quite longtime in advance by several concerned parties [Associated Press, 2004].

3 Summer 2003 electricity supply disruptions

The summer of the year 2003 was characterised by electricity supply disruption events which had wide impact on a number of key economies; these events contributed to direct attention on how crucially modern societies depend from correct operation of the electric infrastructure. They also evidenced the extent all technological infrastructures depend on electricity, although most interdependencies are not usually perceived not only by the public at large, but neither by most infrastructure operators; hence they are not taken into appropriate account into the relevant contingency planning. The blackouts were concentrated within 6 weeks and affected 112 million people in 5 countries [Bialek, 2003]:

1) August 14, 2003 – North East blackout over the US and Canada
2) August 28, 2003 - Southern London distribution
3) September 23, 2003 - Danish/Swedish blackout
4) September 28, 2003 - Italian transport grid collapses.

In the following we give a short summary of the events and of the programmed supply cuts over Italy on June 26, which to some extent were a precursor of the Italian blackout in September. A more detailed analysis of the events is reported in chapter 4.

June 26, 2003 – Programmed supply interruptions over Italy

In view of a shortage of production against extremely high demand (hot temperature and dryness), GRTN, the Italian system operator had to activate its emergency plan to guarantee electrical system security [GRTN, 2003] [AEEG, 2003]. This relies on pre-programmed supply interruptions for prefixed periods to the interruptible customers and, where this was not sufficient, also to customers at large. The activation of this procedure, which involves '*leopard skin'* one hour interruptions all over the national territory, did put into evidence how strongly infrastructures are mutually interdependent with electricity. Although limited in time and extent, problems were recorded to affect automotive transports (green lights were off, galleries lacked lighting, fuel service stations could not deliver); railways; telecommunication, financial and sanitary services, public administration; water and food supply.

August 14, 2003 – American North East

The electric system of Northern Ohio was in a reliable operational state, though being operated near prescribed limits, due to moderately high demand to serve air conditioning. High imports and unavailability of units depleted the critical voltage support. The event was triggered by a contact between a tree and a 345 kV line (these contacts are rather usual and their likelihood increases with power flow due to line sagging). *The event was in a way induced and, above all, inappropriately managed because of some impending problems affecting the monitoring and control equipment.* The *state estimator* used to preview the likely system evolution was out of order for approximately 4 hours and was restarted a few minutes before the black-out (both due to human errors and to technical problems). Another fault to the SCADA server put alarm management out of operation and slowed down the entire SCADA functionality, affecting online data update in particular, to the effect of making control room operators quite totally blind to the event.

Overloading caused a cascade tripping of several remaining lines. 61,800 MW of load were lost at 4 p.m. on August 14; at 8 a.m. the following morning (16 hours later) 48,800 MW were restored. Hence, some 16,000 MW experienced a longer than 16 hour outage [Eurelectric, 2004b].

The restoration varied between the utilities:

- Consolidated Edison fully restored service after 29 hours;
- FirstEnergy restored service to a vast majority of its customers within 36 hours;
- Long Island Power Authority needed 3 days;
- Ontario had full service restored at 8 p.m. on Friday, August 22 (8 full days after the blackout).

The event involved loss of 263 power plants (531 individual units) and left 50 million customers without power in the US and Canada (unsupplied energy: circa 350,000 MWh) [Eurelectric, 2004b].

The blackout caused huge damage, which was initially estimated to amount 6 billions of dollars for the United States only. The impact was amplified by several factors:

- the US energy transport infrastructure is inadequate with respect to demand. In the period 1988-‘98 energy consumption in the United States was increased by 30%, while the transport capacity grew by a 15% only;
- grid management and operation is entrusted to a large number of operators, what hinders the coordination of operations;
- monitoring and control systems and contingency measures against severe disruptions proved to be inadequate.

The event also revealed how damage caused by supply interruption turned out to be far larger than initially estimated, due to growing service dependency from electricity supply. Spencer Abraham, the US Energy Secretary supplied an estimate of direct and indirect damage to the US economy, in the order of 50 billions of dollars, far larger than the initial one.

August 28, 2003 – UK, South London

A combination of events led to an electricity power supply failure in south London that occurred at 18.20 on 28 August. Following an alarm caused by low oil level in a shunt reactor, a transformer was disconnected from the distribution system, as it is the normal practice in these cases. Unexpectedly, automatic protection equipment interpreted the change of power flows, due to the transformer disconnection, as a fault, and disconnected 410,000 customers, including parts of London Underground and Network Rail. Supply was recovered in half an hour (though the restoration of underground operation took longer for safety reasons). *The cause of the incident was the incorrect rating of a protection relay, undiscovered by the extensive quality control and commissioning procedures* [National Grid, 2003] . The event involved the loss of 433 MWh supply [Eurelectric, 2004b].

About 500,000 people were affected by the blackout, including tens of thousands of tube passengers stuck in tunnels as trains broke down. Buildings along the Thames were in darkness, 270 sets of traffic lights failed, and train services stopped from four mainline stations. The impact of the blackout was compounded by the rush hours time which paralysed traffic for several hours after electric power restoration.

September, 23 2003 - Southern Sweden and Eastern Denmark

At 12.36 on Tuesday 23 September 2003 Eastern Denmark and Southern Sweden experienced a comprehensive blackout. The power failure was primarily caused by a fault at a substation in Southern Sweden. During a situation with a number of interconnectors and power lines in maintenance and four nuclear units out of operation, the electric system in Southern Sweden experienced the loss of a large nuclear unit. Approximately 5 minutes after the loss of the large nuclear unit, a double bus-bar fault in a substation on the West coast disconnected four out of five 400 kV transmission lines. Two of the lines provided connection between Central and Southern Sweden, while the two others connected two large nuclear units to the grid. Increasing flows on the remaining lines and low voltage in Southern Sweden made protection relays to trip, and Southern Sweden and Eastern Denmark were completely disconnected from the Central after 90 seconds [Elkraft, 2003] [Eurelectric, 2004b].

The consequences of the fault were so serious that it was not possible to prevent a voltage collapse in Southern Sweden and Eastern Denmark. A total blackout was the result of the voltage collapse, which also caused damage to unit 5 at the largest power station on Zealand, Asnæs Power Station.

Restoration in Denmark was slower than in Sweden, because the black-start facilities in the central power plants on Zeeland failed to operate. The 400 kV grid in Southern Sweden was restored in about an hour. The recovery of the supply took one to six hours in Sweden and Denmark.

The root cause of the incident was the combination of the initial loss of the large nuclear unit with the double bus-bar fault in the substation on the West coast, which drove the system beyond its security criteria (N-3 situation) [Elkraft, 2003].

The lost supply was about 10,000 MWh in Sweden and 8,000 MWh in Eastern Denmark [Eurelectric, 2004b].

September 28, 2003 - Italy

Starting at 3:01 on the night of September 28, an event originated in Switzerland resulted into a blackout which affected the whole of Italy except Sardinia. Italy was importing about a quarter of the domestic consumption (including big pumped storage plants) through fifteen transmission lines from France, Switzerland, Slovenia and Austria, when a line tripped due to a tree flashover. *After re-connection failed, the Swiss grid operator called for a 300 MW decrease in import (in order to return to the actually scheduled import), failing to recognise the overloading of the remaining lines.* In twentyfour minutes, a second line tripped, initiating a cascade tripping of all transmission lines along the Italian border. In two and a half minutes, Italy went into a total blackout.

The event took place on Saturday night, when nearly all productive activities were at rest, thus resulting into limited impact on the population and the economy. Nevertheless energy restoration required from 3 to 19 hours, 3-4 hours for the northern of Italy up to 19 hours for Sicily.,. However, as the blackout took place on a Saturday night, in addition to limiting direct damage, also made event management simpler by guaranteeing high mobility of event management and rescue teams. On both respects, a blackout during a working day might result into a completely different scenario. Nevertheless, it was the largest blackout in Europe since ever, at least in peace times, comparable in size with the American North East event (about 170,000 versus 350,000 MWh estimated energy not supplied; 50 million people involved).

4 Analysis of the Summer 2003 blackouts

4.1 American North East

The final report of the joint *ad-hoc* US-Canada investigation committee on the blackout [US-Canada 2004] evidenced the following groups of causes for the event:

Causes of the Blackout's Initiation

The Ohio phase of the August 14, 2003, blackout was caused by deficiencies in specific practices, equipment, and human decisions by various organizations that affected conditions and outcomes that afternoon—for example, insufficient reactive power was an issue in the blackout, but it was not a cause in itself. Rather, deficiencies in corporate policies, lack of adherence to industry policies, and inadequate management of reactive power and voltage caused the blackout, rather than the lack of reactive power. There are four groups of causes for the blackout:

Group 1: *FirstEnergy and ECAR failed to assess and understand the inadequacies of FE's system,* particularly with respect to voltage instability and the vulnerability of the Cleveland-Akron area, and FE did not operate its system with appropriate voltage criteria. (Note: This cause was not identified in the Task Force's Interim Report. It is based on analysis completed by the investigative team after the publication of the Interim Report.)

A) FE failed to conduct rigorous long-term planning studies of its system, and neglected to

conduct appropriate multiple contingency or extreme condition assessments.

B) FE did not conduct sufficient voltage analyses for its Ohio control area and used operational voltage criteria that did not reflect actual voltage stability conditions and needs.

C) ECAR (FE's reliability council) did not conduct an independent review or analysis of FE's voltage criteria and operating needs, thereby allowing FE to use inadequate practices without correction.

D)Some of NERC's planning and operational requirements and standards were sufficiently ambiguous that FE could interpret them to include practices that were inadequate for reliable system operation.

Group 2: *Inadequate situational awareness at FirstEnergy. FE did not recognize or understand the deteriorating condition of its system.*

A) FE failed to ensure the security of its transmission system after significant unforeseen contingencies because it did not use an effective contingency analysis capability on a routine basis.

B) FE lacked procedures to ensure that its operators were continually aware of the functional state of their critical monitoring tools.

C) FE control center computer support staff and operations staff did not have effective internal communications procedures.

D) FE lacked procedures to test effectively the functional state of its monitoring tools after repairs were made.

E) FE did not have additional or back-up monitoring tools to understand or visualize the status of their transmission system to facilitate its operators' understanding of transmission system conditions after the failure of their primary monitoring/alarming systems.

Group 3: *FE failed to manage adequately tree growth in its transmission rights-of-way.*

This failure was the common cause of the outage of three FE 345-kV transmission lines and one 138-kV line.

Group 4: *Failure of the interconnected grid's reliability organizations to provide effective real-time diagnostic support.*

A) MISO did not have real-time data from Dayton Power and Light's Stuart-Atlanta 345-kV line incorporated into its state estimator (a system monitoring tool). This precluded MISO from becoming aware of FE's system problems earlier and providing diagnostic assistance or direction to FE.

B) MISO's reliability coordinators were using non-real-time data to support real-time "flowgate" monitoring. This prevented MISO from detecting an N-1 security violation in FE's system and from assisting FE in necessaryì relief actions.

C) MISO lacked an effective way to identify the location and significance of transmission line breaker operations reported by their Energy Management System (EMS). Such information would have enabled MISO operators to become aware earlier of important line outages.

D) PJM and MISO lacked joint procedures or guidelines on when and how to coordinate a security limit violation observed by one of them in the other's area due to a contingency near their common boundary.

Source: US-Canada [2004]

In summary, the numerous causes and contributing factors can be grouped into four categories:

1. inadequate management of tree growth in transmission rights-of-way
2. inadequate situational awareness
3. inadequate diagnostic support
4. inadequate system understanding

Apart from the triggering event, due to 1., the whole deployment of the crisis is almost entirely due to concurrent unreported failures both of FE's supervisory system and of the diagnostic equipment (the state estimator) available at MISO, the regional TSO. In turn, this was the main cause for the inadequate situational awareness at First Energy and MISO. Failure to provide backup to this equipment can hardly be understood in the context of such a complex and hazardous supervisory task – when compared with security standards applied in the energy sector in Europe and to other safety critical processes almost everywhere.

4.2 United Kingdom

In the following we report an excerpt of the National Grid company Investigation Report into the incident [National Grid, 2003]:

Introduction

A combination of events led to an electricity power supply failure in south London that occurred at 18.20 on 28 August. Restoration began at 18.26 and power supplies from National Grid were fully restored at 18.57. This report describes the circumstances leading to the loss of supply, the steps taken to restore supplies and the measures in hand to minimise the risk of a recurrence.

Transmission System in South London

The transmission system in south London consists of four substations at Littlebrook, Hurst, New Cross and Wimbledon. Normal demands of around 1,100MW are drawn by EDF Energy to supply domestic customers and London Underground, together with supplies for other large users including NetworkRail. Following the incident supplies were lost from Hurst, New Cross and part of Wimbledon.

Maintenance Activity in the Area

On 28 August 2003, scheduled maintenance was underway on one circuit from Wimbledon to New Cross and one from Littlebrook to Hurst. This level of maintenance is usual during the summer months, when demand for electricity is generally lower. In line with normal practice, the arrangement of the transmission system to accommodate the maintenance had been agreed with the operator of the distribution system for the London region, EDF Energy, well in advance, during July 2002. Routine weekly communication between EDF Energy and National Grid resulted in the planned outage at Wimbledon proceeding on 1 July 2003. EDF Energy confirmed that it could arrange its distribution system to accommodate this outage securely for the maintenance period.

The First Fault

The sequence of events started at 18:11. Engineers at the Electricity National Control Centre (National Control) received an alarm indicating that a transformer, or its associated shunt reactor, at Hurst substation was in distress and could fail, potentially with significant safety and environmental impacts. This "Buchholz alarm", told National Control that gas had accumulated within the oil inside the equipment, which can lead to a major failure. National Grid has approximately 1,000 transformers with associated equipment connected to its transmission system and on average only 13 Buchholz alarms are received each year.

National Control contacted EDF Energy to discuss the Buchholz alarm and asked EDF Energy to disconnect the distribution system from the transformer. Then, as is normal practice in this situation, National Control initiated a switching sequence to disconnect the transformer from the transmission system. This switching sequence temporarily left supplies dependent on a single transmission circuit from Wimbledon that feeds New Cross and Hurst substations. Under National Grid operating procedures a Buchholz alarm is sufficiently serious to warrant the isolation of equipment and reduced security is acceptable for “switching time”. This is a period of time, normally around five to ten minutes, during which the transmission system is rearranged, by connecting and disconnecting circuits, so that the affected equipment can be taken out of service.

The switching sequence to remove the transformer began at 18:20, disconnecting Hurst substation from Littlebrook substation. This enabled a safe shutdown of the transformer which had suffered the alarm, but left Hurst supplied only from Wimbledon via New Cross.

The Second Fault

Unexpectedly, a few seconds after the switching, the automatic protection equipment on the number two circuit from Wimbledon to New Cross operated, interpreting the change of power flows, due to the switching, as a fault.

The transmission system is extensively fitted with many levels of automatic protection equipment, aimed at isolating faults and preventing damage to equipment or even a complete shutdown of the transmission system. They measure system characteristics, such as voltage and current and, in the event of a fault, will automatically disconnect affected equipment. On the National Grid transmission system there are approximately 43,000 such pieces of equipment, each with its individual settings to meet local requirements.

The automatic protection relay disconnected the circuit from Wimbledon to New Cross. This disconnected New Cross, Hurst and part of Wimbledon from the rest of the transmission system, causing the loss of supply. 724MW of supplies were lost, amounting to around 20% of total London supplies at that time. This affected around 410,000 of EDF Energy’s customers, with supplies being lost to parts of London Underground and NetworkRail.

Restoration

Restoration actions began at 18:26, re-energising the Hurst substation from Littlebrook and then isolating the Wimbledon to New Cross circuit, that had automatically disconnected itself, to prevent a recurrence.

At 18:38 National Control offered to restore supplies to Wimbledon for EDF Energy. EDF Energy requested restoration of that supply at 18:48 and restoration was completed at 18:51. From this point onwards, London Underground could restore electricity to the underground network, when they considered it was safe to do so.

At 18:41 EDF Energy restored supplies via National Grid’s Hurst substation to approximately one third of the consumers.

Some 30 switching actions enabled National Grid to restore overall supplies to all substations concluding with New Cross at 18:57 which restored the remaining supplies for NetworkRail. The substations remained connected to the rest of the transmission system via a single circuit until 23:00, the time at which the automatic protection equipment that had operated at Wimbledon was successfully isolated. The number two circuit from Wimbledon to New Cross was then safely returned to service and normal levels of security were restored. A rapid check was made to similar automatic protection equipment.

Source: National Grid [2003]

Although this event cannot really compare with the others because it concerned the distribution network rather than the transmission grid, and involved a single operator, it shows a common pattern in two respects to the others:

- the crisis was due to a double fault (N-2). The loss of the transformer required a change in power flows which was incorrectly interpreted by an automatic protection as a short circuit. This pattern recurs in all the incidents analysed in this report;
- the major effect of the crisis was the blocking of the London tube, with subsequent paralysis of the traffic in the whole Greater London, a patent instance of critical infrastructures interdependency. Again, this is a common pattern which recurs throughout all the incidents analysed.

4.3 Sweden/Denmark

The key remarks of the Danish operator, Elkraft are reported in their press release of November 11 [Elkraft, 2003]:

The whole power system must be evaluated both to reduce the risk of extensive blackouts in the future and to ensure that voltage is restored sooner after a power cut. Those are some of the conclusions in the report that Elkraft System publishes today after the power failure on 23 September. Svenska Kraftnät also publishes a report on the cause of events today.
The power failure was primarily caused by a fault at a substation in Southern Sweden. The consequences of the fault were so serious that it was not possible to prevent a voltage collapse in Southern Sweden and Eastern Denmark. A total blackout was the result of the voltage collapse, which also caused damage to unit 5 at the largest power station on Zealand, Asnæs Power Station.

The last time we experienced a power failure that caused a total blackout on Zealand was in 1981, so fortunately, this type of incident is rare, but since such a serious power failure has grave consequences for society, we will initiate a number of activities to reduce the risk of it happening again and to ensure quicker restoration of the power supply than was the case on 23 September - should it happen again in spite of everything.

The activities include an evaluation of the East Danish transmission grid to strengthen any weak points and an analysis of how the primary power stations in Eastern Denmark cope with violent disturbances in the transmission grid. Re-energising the East Danish transmission grid from one of the power stations on Zealand after an extensive power cut must also be quicker.
The system operators in the Nordic countries will go through the set of rules governing the operation and planning of the Nordic power system to see whether the rules need modernisation.
Finally, the experience gained from the power failure on 23 September will be part of the analysis of security of supply initiated by the Danish Energy Authority together with the two system operators in Denmark, Elkraft System and Eltra."

Source: Elkraft, [2003]

On the technical causes of the blackout, the Swedish operator [Svenska Kraftnät, 2003] further points out that:

> The cause of the major black-out was that a very severe grid fault occurred only a few minutes after a more ordinary but still most significant fault. The probability of such a coincidence is extremely low as the interrelation between the faults in the two separate locations was either zero or very weak. The initial fault (loss of a 1250 MW generation unit) can be classified to be on the N-1 level according to generally applied grid security standards. Any subsequent single N-1 level fault should be managed without any external consequences to the supply, provided that 15 minutes are available for activation of stand-by reserves if necessary. The fact that the double busbar fault, shutting down two major nuclear units and severely reducing the transmission capacity, occurred only 5 minutes after the initial loss of generation gives that the entire disturbance complex can be classified to be on at least a N-3 level. This is far beyond the severity degree that the Nordic Power System is designed and operated to cope with. Dynamic simulations have been made during the analysis process, showing that the system should have managed any arbitrary combinations of faults on a N-2 level of severity.
>
> **Source: Svenska Kraftnät [2003]**

In summary, the Swedish/Danish event is the most 'technical' of the events reported, and appears truly due to an exceptional chain of events. Neither the operators, nor third parties explicitly blamed lack of preparedness and co-ordination among the parties involved, or insufficient exchange of information.

4.4 Italy

Causes of the blackout

On the night of 28-29 September 2003 Italy imported about 6900 MW to cope with a total demand of 27500 (2200 from France, 3600 from Switzerland, 190 from Austria, 630 from Slovenia. There were no significant deviations from what the regulators had planned. Swiss import was mostly through Canton Ticino: 2360 MW of the total 3600 were delivered mostly by two 380 kV lines, San Bernardino and Lucomagno (Lukmanier), and a 220 kV one, San Gottardo. The event chain that caused the blackout is acknowledged by the major sources on the event [UCTE, 2004a] [SFOE, 2004] and [CRE AEEG, 2004] :

1) Lucomagno line trips due to a tree flashover

2) 1300 MW are re-routed mostly through the San Bernardino line (110% overload). 550 MW about are re-routed through France and Slovenia

3) The Italian operator alerted 10' later reduces import by 300 MW. No overload was occurring on the Italian lines.

4) The Swiss operator tries to reclose the Lucomagno line: impossible because the phase angle difference was too high

5) All subsequent countermeasures by the Swiss operator are not enough to avoid collapse of a second line: San Bernardino trips 24’ after the first one due to overload. About 10’’ after San Bernardino line tripping, all Swiss connections are opened by distance protections.

Immediately after the blackout, transmission system operators’ executives of the five involved countries (Austria, France, Italy, Slovenia and Switzerland) met within the framework of UCTE (Union for the Co-ordination of Transmission of Electricity), whose statutory aim is to provide a reliable market base by efficient and secure electric "power highways", and decided to set up an independent UCTE Investigation Committee that was given the mission to bring a transparent and complete explanation of the blackout to the national and European Authorities and to the general community. The Committee conclusions [UCTE, 2004a], are summarised below:

The operation of the European interconnected electricity system is subject to security and reliability standards set within the framework of the UCTE cooperation. A main principle underlying these standards is that the system must be operated in such a way, that any single incident, for example the loss of a line, should not jeopardize the security of the interconnected operation. This is called the N-1 rule. This rule also states that in case of loss of N-1 security the system must not only withstand the situation, but it is supposed to return to the N-1 secure state as soon as possible to resist a possible new event. It implies that countermeasures must be identified and prepared at each moment and for each single incident, enabling the system to be brought back to a safe state when an incident occurs. Regarding the Italian September blackout, The UCTE Committee’s finding in this respect is that the system was complying with the N-1 rule at the time, ETRANS taking into account countermeasures available outside Switzerland.

foreseen:

1. Unsuccessful re-closing of a first line in Switzerland (Lukmanier) because of a too high phase angle difference

Due to the high loads on the remaining lines, an automatic device, aiming at protecting the equipment, blocked according to its design settings the possibility of restoring the line back into service.

2. Lacking a sense of urgency regarding the overload of a second line connecting the Swiss system to Italy (San Bernardino) and call for inadequate countermeasures in Italy

The operators were unaware of the fact that the overload was only allowable for about 15 minutes. A single phone call by ETRANS took place 10 minutes after the trip of the first line. ETRANS asked for the imports to be decreased by 300 MW. This measure was completed by GRTN within 10 more minutes. Even together with the Swiss internal countermeasures, it was insufficient to relieve the overloads.

3. Angle instability and voltage collapse in Italy

This was the reason why the Italian system collapsed after its separation from the UCTE system. It was not the cause of the origin of the event.

4. Right-of-way maintenance practice

Tree cutting, to maintain safe distances regarding flashover, is subject to national regulation" *(NdA: this is to remark that responsibility over the primary cause of the event is stipulated by national regulations which look to be inadequate and/or not properly enforced,).*

Source: UCTE [2004a]

The regulating Authorities of the countries mostly involved, the Italian Authority for Energy and Gas, the French Energy Regulation, and the Swiss Federal Commission on Energy initially set up a joint investigation on the Italian event. The investigation initially involved also SFOE, the Swiss Federal Office for Energy, which subsequently failed, according to [CRE AEEG, 2004], to deliver any information, and proposed to adopt the UCTE report. Also, SFOE proposed to involve the French and Italian TSO and the integrated Swiss electricity companies to take part into the investigation. AEEG and CRE did not agree with that procedure. Subsequently, SFOE unilaterally issued a report on the event [SFOE, 2003], while the Italian and French regulatory authorities came to a joint conclusion, reported in [CRE AEEG, 2004].

The Swiss Federal Office report stresses the following points:

It would appear that the main causes of the blackout in Italy were a line to ground fault on the Lukmanier line, the inability to restore this line, a phone call between ETRANS and GRTN that did not take adequate account of the severity of the situation, possible instabilities in the GRTN network, and perhaps insufficient distances between conductor cables and trees.

But these are merely factors that triggered the blackout. The underlying causes of the incident that occurred on 28 September 2003 are the unresolved conflicts between the trading interests of the involved countries and operators and the technical requirements of the existing transnational electricity system. Present-day standards and legal instruments are lagging well behind economic realities.

(…)

The blackout indicates the urgency for developing and implementing international electricity trading regulations, and for co-ordination among network operators so that security and reliability can be assured at all times. All network operators must adapt their IT infrastructure and network technology to the latest status of science and technology with the aid of corresponding analysis and optimisation programs.

The binding implementation of recognised principles – such as those laid down by the EU in its ordinance on conditions of network access for international electricity trading, which was approved on 26 June 2003 – is of equal importance"

(…)

The Swiss Federal Office of Energy recommends proprietors of Swiss transmission lines to create a Swiss network operator as an independent operator of the transmission network as soon as possible and – without waiting for the introduction of legal provisions governing the electricity industry – on a voluntary basis.

Switzerland urgently needs a comprehensive federal law governing the electricity industry. A consultation process concerning the regulation of the electricity industry should take place by the second half of 2004 at the latest – if necessary in the form of a conference.

Switzerland urgently needs a strong regulator who is able to regulate and control the market as an equal partner together with regulators of neighbouring countries and the EU Commission. This institution is a high priority in view of the urgent need for regulation in the areas of crisis prevention and handling.

Source: SFOE [2003]

The key results of the Italian and French regulators inquiry are the following [CRE AEEG, 2004]:

1. The operators of the Swiss transmission grids, in day ahead planning of the system for the 28th of September and in the operations of the night between September 27-28th, 2003, did not foresee sufficient prevention and preparation measures to guarantee the security of grid operation and supply across other power systems in Europe;

2. The integrated Swiss electricity companies did not comply with the content of UCTE rules during the night of September 28th.

3. During the night of September 27-28th, following the accidental loss of the Mettlen-Lavorgo 380 kV line (Lukmanier line) the operators of the Swiss transmission grids took inappropriate measures and underestimated the actions that should have been requested to other TSOs. These operational mistakes led to the consequent loss of the Sils-Soazza 380 kV line (San Bernardino line), and thus to a condition of the interconnected grids out of control.

As a consequence they reached the following conclusions:

1. Future UCTE rules should take into account, as improvement, the return of experience of these events. Compliance with new rules shall be made legally binding and monitored. Independent assessment and control shall be enforced also through the function of national regulators.

2. Co-ordination among TSOs shall be reinforced for operational planning and real time operation of the interconnected grids.

3. A legal and regulatory framework coherent with European legislation is necessary in Switzerland to ensure the security of grid operation and supply in Europe.

Source: CRE AEEG [2004

As mentioned, although advocating a role in the definition of this framework, the SFOE report substantially agrees with the tree points above.

Reasons for the Italian system collapse and its protracted restoration

A separate issue from investigation on the reasons why the triggering event chain of the blackout was inadequately dealt with, is why the Italian system collapsed, once isolated from the UCTE grid, and why restoration was so cumbersome. In its final report on the event [AEEG, 2004], the Italian authority for Electricity and Gas performs an analysis for what regards the reasons for the Italian system collapse and its long restoration:

E4. La mancata adozione delle previste contromisure ha comportato l'inefficacia delle

logiche di controllo delle sezioni critiche poste a difesa dell'integrità della rete di

interconnessione con l'estero. (Missing adoption of the foreseen (i.e., UCTE) countermeasures has resulted in the inefficiency of the control logic of the critical sections to defend the integrity of the net in front of cross-border interconnections)

(…)

Il 28 settembre 2003, la mancata adozione delle previste contromisure ha determinato lo stabilirsi di eventi verso i quali, le logiche di controllo automatiche della sezione critica Rondissone-Albertville e della sezione critica Estero, poste a difesa dell'integrità della rete di interconnessione con l'estero, si sono rivelate inefficaci. (On September 28, 2003, missing adoption of the foreseen countermeasures has determined a chain of events which made ineffective the automatic control of the critical section Rondissone-Albertville and of the foreign critical section)

(…)

E5. La separazione del sistema elettrico nazionale dalla rete UCTE è stata caratterizzata da fenomeni di instabilità transitoria del sistema elettrico italiano rispetto alla rete UCTE. (The separation of the national electrical system from the UCTE grid has been characterised by phenomena of transient instability of the Italian electrical system with respect to the UCTE grid).

(…)

La diffusione dell'interruzione in Italia (the spread of interruptions in Italy)

E6. In seguito alla separazione del sistema elettrico nazionale dalla rete UCTE, la diffusione dell'interruzione del servizio elettrico nel territorio nazionale è stata causata da una serie di eventi concomitanti tra i quali rilevano, primariamente, il distacco anticipato di unità di produzione rispetto ai termini prescritti e, in seconda battuta, una non efficace reazione del sistema di alleggerimento automatico del carico.

(As a result of the separation of the national electrical system from the UCTE grid, the spread of service interruptions in the national territory has been caused from a series of concurrent events: primarily, the anticipated separation of power generation units with respect to the prescribed terms and, second, an ineffective reaction of the load separation system)

In particolare (More specifically:)

E7. Durante la fase di diffusione dell'interruzione del servizio il comportamento di 21

gruppi di produzione è stato apparentemente difforme da quanto stabilito nelle Regole

tecniche di connessione alla rete di trasmissione nazionale. (During the service interruption spread phase the behaviour of 21 power generating groups was patently different from what established in the technical Rules of connection to the national transmission grid.)

E8. L'azione complessiva di alleggerimento automatico del carico non ha raggiunto i livelli

previsti nelle Regole tecniche di connessione. Inoltre, è stato riscontrato che un certo

numero di imprese distributrici connesse alla rete di trasmissione nazionale non è

dotate di dispositivi di alleggerimento automatico del carico. (The whole automatic load relief action did not comply with the levels established by the technical connection Rules. Moreover, several distributors connected with the national transmission grid were not equipped with automatic load relief devices)

(…)

E9. Il tasso di insuccesso della attuazione delle azioni di rifiuto di carico 12 dei gruppi di

produzione è stato molto elevato. Ciò ha compromesso gravemente il ripristino del

servizio elettrico. (The rate of failure of the load rejection actions by power generating groups was very high . This seriously compromised service restoration)

(…)

E10. Nella maggior parte dei casi non si è verificato l'avvio autonomo delle unità di prima riaccensione. Il GRTN ha gestito il ripristino del servizio mediante le sole direttici di rialimentazione a partire dal Nord. Ciò ha causato il notevole ritardo del ripristino del servizio elettrico nelle regioni del Centro e del Sud. (In most cases the independent start of the first blackstart units did not take place. The GRTN managed the service restoration only through the lines connecting the North to the rest of Italy. This caused the remarkable delay of service restoration in the Center and South regions)

(…)

E11. Durante le fasi di ripristino del servizio elettrico, i sistemi di telecomunicazione per il controllo in remoto degli organi di manovra degli elementi della rete di trasmissione nazionale hanno subito fenomeni di instabilità e saturazione. Inoltre, il sistema di alimentazione in emergenza di detti sistemi di telecomunicazione si è rivelato inadeguato. (During the service restoration phases, the telecommunication systems for remote control of manoeuvre of components of the national transmission elements grid endured phenomena of instability and saturation. Moreover, the emergency supply system of the above telecommunication systems resulted inadequate.)

(…)

Dalle ore 08:00 alle ore 14:40, non è stato possibile utilizzare il predetto sistema di controllo automatico a causa di mancanza di alimentazione (dovuto a non adeguatezza dei sistemi di alimentazione di emergenza) dei sistemi di telecomunicazione utilizzati a tale fine. Ciò ha comportato la necessità di utilizzo del sistema di telecomunicazione satellitare e di attuazione in manuale delle manovre necessarie a ripristinare la rete di trasmissione nazionale, inficiando il pronto ripristino del servizio. (From hours 08:00 to hours 14:40, it was impossible to use the foretold automatic control system because of lack of supply, due to inadequacy of the emergency supply systems of the relevant telecommunication systems. This required the use of a backup satellite telecommunication system and to manually operate the restoration, thus compromising ready restoration of service).

Source: AEEG [2004

5 Conclusions

The major incidents summarised, the American NE blackout and the Italian one, show a common pattern. The systems have been developed in the past 50 years with a view to assure mutual assistance between national subsystems including common use of reserve capacities and, to some extent, to optimise the use of energy resources by allowing exchanges between them. Today's market development with its high level of cross-border exchanges was out of the scope of the original system design. This has led the TSOs to operate the system close to its limits reducing the security margins. Both blackouts must be seen in this general context. Other similar circumstances include:

- In both situations, neither electrical system management nor operating procedures, nor system automation were revised so as to adequately cope with the new scenario. In both cases, a rather frequent event (a short circuit between a line and a tree) was not timely reported to operators, therefore it was not adequately managed and turned out into a disastrous cascade of failures. This pinpoints the inadequacy of the risk assessment methods currently available to operators. Fast, on-line security assessment and dynamic security assessment are required.
- Regarding the Italian case, the UCTE report points out as an accident originated in Switzerland did require the timely intervention by the Italian operator to be adequately dealt with. However the Italian operator does not have direct visibility of events that happen in other countries, and therefore had to be warned on the phone from the Swiss operator.
- The American system alike lacks a governing body who may effectively coordinate operators activities. Although NERC, the North American electric reliability council, did advance a proposal to that effect, this met the opposition of several regional operators. Moreover the malfunction of a critical equipment (the *state estimator*), which was supposed to act as a common reference for the operators involved in a triggering event, was a key factor in the failure of the system, in that it drew in deceit operators on the likely progression of events.
- In the Italian case, restoration was further compounded by *critical infrastructure interdependency*. After two hours, the emergency supply to several vital information and communication equipment ceased to work, hence this equipment could no longer operate. This required to resort to a backup satellite facility for communication, and to manually operate all the remotely controlled equipment, thus making restoration far longer and more cumbersome.
- In the American case restoration was even longer and more cumbersome, due to the inherent complexity and the extension of the crisis, the plethora of actors involved, and inadequacies of automation and support equipment.

A significant feature of the Italian case is that it clearly outlines how the two basic attributes of power service reliability, i.e. adequacy and security, are somewhat contrasting. During the summer crisis of June 26, due to exceptional weather conditions, the Italian operator was unable to meet demand requirements (failure to provide an *adequate* service), while the September blackout scenario is one where the Italian system, crucially dependant from power imports, failed when this import was suddenly cut off due to a fault, thus showing a lack of overall *security*. The system operator was driven to crucially rely on imports for several reasons, among them the pressure from public opinion after the summer crisis, thus operating the system closer to its security limits. Also, the deployment of the Italian crisis is largely due to the premature tripping of protection relays, made to protect specific assets, like power plants, transformers, and lines: in that case, *security* in asset protection prevailed over *adequacy,* i.e. caused a total failure to meet demand.

In conclusion, the main issues involved in the events overviewed in this report, and namely, in the two key events affecting Italy and the American North East, appear to be three:

1. Is reliability of electrical supply diminishing? If so, what are the ***socio-economic*** long term causes, or driving forces of this process? And specifically, can liberalisation be blamed? In that respect, the authoritative Eurelectric report on Power Outages in 2003 [Eurelectric, 2004b] claims that its main finding <u>is that liberalisation did not in itself lead to the recent blackouts</u>, although recognising that *"market liberalisation and the creation of a single European market have indeed changed the environment in which a secure electricity supply must continue to be ensured. The traditional integrated planning of power generation and transmission has disappeared; the European networks, originally designed for mutual assistance, are now hosting transit of commercial flows over long distances, driving system operators to become more and more inter-dependent, while at the same time substantial commercial interests have appeared and the number of market actors has significantly increased. These new challenges must be duly evaluated, the necessary technical, organisational and functional adjustments need to be defined, and appropriate measures must be taken*". Also, this report acknowledges that *"major power outages are viewed by consumers as a failure of the whole electricity industry, irrespective of the actual reasons and contributing factors. (…) The society will hardly tolerate interruptions in the extent of those have occurred since the summer of 2003. The power outage events may increase scepticism to liberalisation in citizens, and have already done so in some officials both at national and European levels." "Most of the existing cross-border lines connecting in Europe were designed in the past to realise a large network improving global safety, socialising reserves and providing mutual assistance in case of emergency (generation or grid faults). Today, as the single European electricity market is developing, the transmission networks are more frequently used for commercial exchange of electricity and thus operated closer to their technical limits, whilst their security margins are reduced. This trend is encouraged by regulators, who aim at stimulating competition among Member States."*

2. Related to the first issue, but worth of a specific focus on its own, there is a ***methodological*** issue: do we have adequate risk assessment methodologies in the electrical sector? The question appears fourfold:

   - Risk assessment methods rely on exhaustive application of the N-1 criterion to system configuration. Load flow analysis is then applied to evaluate the resulting grid conditions (this is the measure which was likely unattended by the Swiss operator, while it was probably irrelevant in the US case, where the operators were unaware of the contingency). Moreover, load flow analysis is a steady-state analysis, which fails to take into account the impact of sudden disturbances, and although there exist innovative dynamic assessment techniques available, these are not yet applied in the standard operators practice. "*The N-1 security level proved irrelevant as defence in Sweden and Denmark, where the combination of contingencies appeared to be at a N-3 level (the actual security level prior to the events has been estimated from simulations to be at N-2 level). Inappropriate application of the N-1 principle (i.e. recovering of the normal operation within a certain period of time) clearly contributed to the events in the US/Canada and Italy. Although the deepening of defence beyond N-1 level (N-2, N-3, etc.) could enhance system security, its cost effectiveness is questionable. Already ongoing investigations on a more flexible probability-based approach, in addition to the N-1 principle, should continue; where the duration, profile and consequences of a blackout can be taken into account in defining the necessary level of defence.*" [Eurelectric, 2004b].

- Many incidents arise from a pattern where the initial fault of a power system is compounded by incorrect tripping of protection devices. Although there exist risk assessment methodologies for power systems, like load flow analysis, and testing/compliance control procedures for automation and protection equipment, there is no methodology for evaluating risks arising from power system failures and automation systems altogether. On the contrary, even reliability related terminologies are divergent in the two domains.

- We do not have adequate ways to forecast and assess the socio-economic impact of long electricity crises. Different studies, mainly based on customers' own evaluations, provide widely ranging estimates for the cost of an unsupplied kWh. Shorter outages for industrial customers are valued the highest levels (e.g. 1,000 €/kWh), while long outages (over 24 hours) are put by residential customers around 5€/kWh, and in cases below 1€/kWh. But these estimations are to a great extent uncertain; partly due to a lack of objective approximation of actually incurred costs, and partly due to the difficulties of drawing an appropriate balance between including and excluding directly and indirectly associated damages (e.g. a longer outage of the London Underground due to safety considerations was a consequence of the otherwise short UK event) [Eurelectric, 2004b].
- Finally, data about frequency, duration and gravity of blackouts are hard to compare in Europe, while the US situation had been the subject of comprehensive studies by NERC, fully reported for instance in [US-Canada, 2004], which shows beyond any doubt that the US situation kept worsening in the last 10-15 years.

3. The issue of the electrical system ***controls*** (intended as the procedures for system management and control, and the related information and communication infrastructure, comprehensive of monitoring, actuation and protection devices) which appears to be no longer adequate because:

- alarms are not displayed on the screen of the operators that would have to manage them, due to either jurisdictional issues (Switzerland/Italy);
- critical equipment is not duplicated so as to remove the effects of their malfunction (North America);
- in both cases the defense plan of the systems failed. Automatic protection devices were not able to avoid system collapse. Furthermore, in the Italian case, restoration was made long and cumbersome due to inadequacies of the supporting information and communication infrastructure, as far as emergency supply systems are concerned.

This third issue is intertwined (as an effect) to the first two issues - as shown by the role of risk assessment methodologies, both off-line (*a-priori*) and on-line, in that context - but worth again of a specific focus on its own. There is a growing consensus about the inadequacy of the European system cybernetics: "*The lack or inadequacy of communication, co-ordination and/or data exchange between system operators seems to have played a major role in the escalation of some of the examined events. In some cases, there was a lack of sense of urgency, so that the designed procedures were not applied. Binding rules for coordination among system operators both in normal operation and in other situations are desirable. These rules must take account of the new challenges imposed by the liberalisation and integration of the European markets (larger cross-border flows, appearance of commercial interests, etc.). Tools and means to intensify collection and availability of real-time data should be examined and established*" [Eurelectric, 2004b]. TSOs in the UCTE area are still applying non-binding recommendations, which were developed before liberalisation (since 1999, a binding System Operation Agreement is in force between the NORDEL TSOs; requiring inter alia the currently valid security criteria to be observed in daily operations) *[ibidem]*.

UCTE proposed an Operation Handbook as a coordinated and updated draft of a set of various rules and recommendations set up between the system operators of the UCTE countries since the founding of UCPTE in 1951. The Operation Handbook will be underpinned by a Multilateral Agreement between the UCTE system operators, which is under preparation in parallel with the further drafting of the Operation Handbook. This will include adequate data exchange (e.g. the appropriate communication channels, data exchange protocols, cryptographic scheme, etc.);

However, once such an agreement is stipulated, a number of issues will require further investigation:

a) enhancement and innovation of <u>protection systems</u> so as to coordinate protection intervention over wide areas; the potential role in that respect of novel data acquisition and communication equipment, like wide-area phasor measurement systems;
b) systematic approaches to situation awareness so as to allow TSOs to timely analyse the huge amount of data generated in anomalous situations and appropriately react (all continental Europe is interconnected, hence any event, even far away, may have impact on your own system). Proper training and decisions support systems will be needed in order to:
   - assess the current situation and timely pinpoint emerging dangers;
   - analyse contingencies and forecast their likely outcomes;

- suggest immediate countermeasures and appropriate recovery actions.

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