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SYSTEM SECURITY IN THE LIGHT OF SYSTEM FAILURES IN 2003

Final Report of the Investigation Committee on the 28 September 2003 blackout in Italy

In the immediate aftermath of the 28 September 2003 blackout in Italy, Transmission System Operators' (TSO) executives of the five involved countries (Austria, France, Italy, Slovenia and Switzerland) met within the framework of UCTE 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.

It was agreed that all required data would be provided by the operators of the five countries to the Committee and that they should operate in full transparency. The Committee, with the full cooperation of these operators, comprised, apart from representatives of the involved countries, experts from Belgium, Germany, the Netherlands and Spain.

After giving the factual description of the sequence of events (chapter 1), the report brings the technical analysis of the main phases in the blackout: the disconnection of Italy, the dynamics of the isolated Italian system during the two and a half minutes of its island operation before the blackout, the restoration of the Italian system and the behavior of the UCTE system after the sudden split of the synchronous area, causing the loss of its exports to the Italian control area (chapters 2 and 4). The Committee's findings on the root causes of the incident are listed and discussed in chapter 3. Chapter 5 deals with the short-term measures taken after the blackout and the report concludes with chapter 6, which lists and comments recommendations and conclusions. <<<

1) Context

It must be emphasised that the original function of the interconnected systems is to form a backbone for the security of supply. To this aim the system has been developed in the past 50 years with a view to assure mutual assistance between national subsystems. This includes common use of reserve capacities and, to some extent, optimising 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. It has led the TSOs to operate the system closer and closer to its limits as allowed by the security criteria, which in essence have remained unchanged over this period of time.

Nevertheless, in the last few years, the transmission system operators have steadily improved the capability of the existing infrastructure. Cross border exchanges have been increased by employing several measures, i. e. computerised control and data acquisition, phase-shifting transformers, coordination mechanisms and electronic data exchange between operators.

The blackout must be seen in this general context. <<<

2) Sequence of events and analysis

The sequence of events was triggered by a trip of the Swiss 380 kV line Mettlen – Lavorgo (also called the »Lukmanier« line) at 03:01 caused by tree flashover. Several attempts to automatically re-close the line were unsuccessful. A manual attempt at 03:08 also failed.

Meanwhile, other lines had taken over the load of the tripped line, as is always the case in similar situations. Due to its proximity, the other Swiss 380 kV line Sils – Soazza (also called the »San Bernardino« line) was overloaded. This overload was acceptable in such emergency circumstances, according to operational standards, only for a short period. The allowable time period for this overload was approximately 15 minutes, according to calculations by the experts.

At 03:11, a phone conversation took place between the Swiss coordination centre of ETRANS in Laufenburg and the GRTN control centre in Rome; the Italian transmission system operator. The purpose of the call was to request from GRTN countermeasures within the Italian system, in order to help relieve the overloads in Switzerland and return the system to a secure state. In essence, the request was to reduce Italian imports by 300 MW, because Italy imported at this time up to 300 MW more than the agreed schedule, which amounted to 6,400 MW on the northern border.

The reduction of the Italian import by about 300 MW was, in effect 10 minutes after the phone call at 03:21 and returned Italy close to the agreed schedule.

This import reduction, together with some internal countermeasures taken within the Swiss system, was insufficient to relieve the overloads. At 03:25, the line Sils – Soazza also tripped after a tree flashover. This flashover was probably caused by the sag in the line, due to overheating of the conductors.

Having lost two important lines, the then created overloads on the remaining lines in the area became intolerable. By an almost simultaneous and automatic trip of the remaining interconnectors towards Italy, the Italian system was isolated from the European network about 12 seconds after the loss of the line Sils – Soazza. During these 12 seconds of very high overloads, instability phenomena had started in the affected area of the system. The result was an unsatisfactory low voltage level in northern Italy and consequently, the trip of several generation plants in Italy.

After separation from the European network, the fast frequency drop in Italy was temporarily stopped at approximately 49 Hz, by the primary frequency control and the automatic shedding of the pumped storage power plants and part of the load. Subsequently, additional generating units tripped for various reasons: turbine tripping, underfrequency relay operation, high temperature of exhaust gases, loss of excitation, etc. Despite additional load shedding, the frequency continued to decrease and the system collapsed 2 minutes and 30 seconds after the separation of the country, when the frequency reached the threshold of 47.5 Hz.

The analysis of the UCTE system outside Italy after the splitting of the network shows that the primary frequency control performed well, limiting the positive frequency deviation. The early trip of some generation units by overfrequency has been observed. These units were either large centralised plants or smaller decentralised units embedded in the distribution system. Some generation units switched their control mode from load frequency or load control to frequency control. Generally speaking for the UCTE area, there were differences between the control areas in the way the frequency/power control reacted. The event was also observed in the second UCTE synchronous zone, due to the tripping of the HVDC link Greece – Italy.

In Italy, the restoration process started immediately after the blackout. Nearly all of the northern part of Italy was energised before 08:00, the central part around 12:00 and the remaining parts of mainland Italy at 17:00. Sicily was fully energised at 21:40. Although some difficulties were encountered, the restoration process was successfully performed. <<<

3) Security and reliability standards – security of the system

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, implying two steps:

– First, by applying corrective measures following an incident, it must be ensured that the stable operation of the interconnected network is not jeopardized;

– Second, as soon as possible after ensuring stable operation, complementary measures must be taken if necessary to return the system to the N-1 security state;

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 secure state when an incident occurs.

The Committee examined the state of the system just before the occurrence of the first event and the countermeasures that had been identified and prepared to tackle the loss of the Mettlen–Lavorgo line. The Committee's finding in this respect is that the system was complying with the N-1 rule at this time, ETRANS taking into account countermeasures available outside Switzerland.

In this specific case, the appropriate countermeasure for the loss of the line was the shutting down of the pumps in the pump storage plants located close to the connection points of the Swiss tie-lines to Italy and therefore have a high influence on their loading. The pumping load in Italy amounted to about 3,500 MW.

Shutting down the pumps in mutual support, when requested under emergency conditions by ETRANS, is operational practice, although there is no official procedure or special agreement between ETRANS and GRTN on this course of action.

After a double incident that occurred with the same two Swiss lines in September 2000, a trilateral procedure was established between France, Switzerland and Italy. This procedure involved the mutual transmission of information by fax in case of an emergency on the critical lines between the 3 countries. However, the ETRANS operator did not execute it before the blackout happened, since no fax was sent and no phone call was made to RTE within this time window.

Concerning the security state of the Italian system, it was assessed that the countermeasures were available for facing the loss of the interconnections on the Northern borders, by combined measures such as primary reserve, load shedding and stopping of pumping storage plants. <<<

4) Main reasons for the blackout

1. *Unsuccessful re-closing of the Lukmanier (Mettlen – Lavorgo) line because of a phase angle difference that was too high*

   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 San Bernardino (Sils – Soazza) line overload and call for inadequate countermeasures in Italy*

   The operators were unaware of the fact that the overload on Sils–Soazza 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. Despite the joint effort with the Swiss internal countermeasures, it was insufficient to relieve the overloads.

3. *Angle instability and voltage collapse in Italy*

   As explained in the sequence of events, this was one of the main reasons why the Italian system collapsed after its separation from the UCTE system. It was not the original cause of the event.

4. *Right-of-way maintenance practices*

   Tree cutting, to maintain safe clearances regarding flashover, is subject to national regulation. Therefore, the Committee did not examine these practices.

   The Swiss Federal Inspectorate for Heavy Current Installations conducted an investigation into the line maintenance practices before the incident. Their findings are that the line inspections and line maintenance practices of the two affected transmission system operators ATEL Netz AG and EGL Grid AG were both in full compliance with the Swiss regulation in this area.

   Nevertheless, this Swiss Authority decided to review the procedures for maintenance practices and documentation of the conducted inspections. With regard to the increased load flow on specific lines, the assumptions for sag calculation are also subject to evaluation by the authorities. <<<

5) Short-term measures taken after the blackout

In the aftermath of the incident, measures were taken in all the involved countries.

The Net Transfer Capacity (NTC) towards Italy has been significantly reduced during off-peak hours and slightly during day hours. This was based on more conservative assumptions and taking into account a larger set of contingencies.

A Memorandum of Understanding was signed between ETRANS and GRTN to improve the management of the interconnection. The work between ETRANS and GRTN started immediately and major parts of it are already completed. Similar action has been agreed with the other neighbouring countries.

At ETRANS, one operator was on shift during the blackout. The Swiss representative declared ETRANS being in the process of recruiting additional operators in order to have two operators in shift by mid-2004.

The phase angle calculation has been incorporated in the ETRANS contingency analysis. Additional real-time exchange of information between ETRANS and GRTN is being implemented. This real-time exchange covers the areas with mutual influence between Switzerland and Italy and is part of the respective state estimator perimeters. More particularly, the representation of the status of the Sils – Soazza and the Mettlen – Lavorgo lines will be improved.

Cross-training of Swiss and Italian dispatchers has been organised.

Some measurement and protection equipment has been adapted or upgraded: special protection schemes to initiate load shedding and installation of Phase Measurement Units (PMU).

The Investigation Committee welcomes these measures and encourages ETRANS and GRTN to expedite their further implementation. <<<

6) Recommendations and Conclusions

Features of the blackout

In view of the recommendations for further work, the following features of the blackout are mentioned:

– Up until the time of the first incident (the loss of the Lukmanier line), the system was in a state compliant with the security criteria: the total level of import towards Italy did not exceed the level that was jointly accepted and its control deviation was within the Transmission Reliability Margin (TRM).

– The blackout was not caused by some extraordinary »out of criteria« event such as a severe storm, a cyber-attack, simultaneous lightning strikes on several lines, etc…

– The blackout was triggered by causes in Switzerland. The initial stages in the sequence of events were out of reach for action by the Italian operators.

– After the first contingency, although the foreseen countermeasures for returning the system to a secure state were available from a purely technical point of view, human, technical and organisational factors prevented the system from returning to a secure state. These factors are related to known principles and available tools of the TSO business. They do not reveal fundamental deficiencies in the existing rule setting of the UCTE system.

– The behaviour of the UCTE system outside Italy after disconnection did not reveal critical malfunctions on a global level.

– The restoration process of the Italian system was performed successfully. However, its duration might have been reduced should more units have successfully switched to house load operation or have performed black-start capability. >>>

>>> *Ongoing action within UCTE*

The UCTE Working Group on Operations & Security and its subgroups are elaborating an Operation Handbook that collates and updates the recommendations and rules set up since the creation of UC(P)TE in 1951. The Investigation Committee proposes a set of recommendations arising from the analysis of the events. They do not involve a fundamental change of direction in this ongoing work, but rather draw special attention to some aspects of particular interest as highlighted by the investigation of the blackout.

The recommendations in this respect are:

R1: For interconnections between UCTE control blocks, confirm, set up or update where necessary the emergency procedures between the involved TSOs. They should be made mandatory and integrated in the joint operator training programs. Their performance should be evaluated at regular intervals.

R2: UCTE is reviewing its rules and introducing the Operation Handbook: the policies 3 and 5 on security assessment should specifically take care of the following issues:

- harmonise criteria for compliance with the N-1 principle;
- determine criteria for the time delay to return the system to N-1 secure state after a contingency;
- include issues such as phase angle and voltage stability into the standard short term contingency analysis;
- define clear guidelines for sharing of tasks to be performed, taking into account the perimeter of each control centre.

R3: Intensify the ongoing work on Day-Ahead Congestion Forecast (DACF) in UCTE, regarding the following aspects: increase the frequency of DACF calculations, increase the number of areas involved and provide quality indicators for the involved data and computation results in order to assess the performance of the tool.

R4: Extend the existing real time data exchange among neighbouring TSOs. Data should be consistent to run the state estimators in a reliable way on a wider topology basis.

R5: To determine on a UCTE level a set of minimum requirements for generation equipment, defence plans and restoration plans, as a basis for harmonization to be implemented throughout the respective national grid codes and regulations.

R6: Further work on a UCTE level is needed to agree the implementation of appropriate load-frequency control strategies should an accidental split of the synchronous area occur.

R7: As a support tool for dynamic analysis and monitoring of the UCTE system, accelerate the ongoing Wide Area Measurement System (WAMS) installation program.

Recommendations on a national level

In the unbundled business framework, special attention must be paid to national regulations or grid codes governing the technical and operational requirements of the generation-transmission-distribution supply chain. The UCTE Operation Handbook (OH) and the underlying Multilateral Agreement (MLA) between TSOs under preparation, provide basic harmonisation criteria for these regulations.

R8: National Grid Codes (or equivalent regulation) should enforce a set of minimum requirements, to be harmonised on UCTE level, with respect to the specification of generation units regarding their robustness in case of frequency and voltage disturbances.

R9: National regulations should, insofar as they are not yet implemented, provide for:

- binding defence plans with frequency coordination between load shedding, if any, and generator trip settings;
- binding restoration plans with units sufficient capable of switching to house-load operation and black-start capability. Due consideration should be given to joint simulation, training and evaluation of these plans with all involved parties.

R10: Tree trimming practices should be evaluated and the operational results should be audited with respect to the line sag in maximum rated overload condition.

R11: The blocking of On Load Tap Changers (OLTC) of transformers in case of severe voltage drop should be accepted practice.I

Interface with the regulatory framework

Since the first electricity Directive of 1996, the countries of the European Union have been forerunners of a transmission system model with independent TSOs. The new Directive of 2003 has added, among others, legal unbundling and the necessity of effective TSO decision-making rights with respect to the network assets, their operation, maintenance and development.

The blackout and subsequent investigation has cast no doubt on this model in principle. On the contrary, the lack of a grid operator's empowerment and independence could be identified as a potential security risk.

A basic recommendation to be made in this respect is the fact that in a liberalised market, the interconnected countries, as far as it is not yet the case, should adopt this TSO model in order to prevent incompatibilities with possible consequences on the system operation and network security.

Concerning this broadly accepted principle of TSO empowerment to control the flows on the system, it involves several tasks for which the TSOs must be in charge in a transparent and non-discriminatory way, on the one hand vis-à-vis market participants and on the other hand vis-à-vis neighbouring TSOs. These tasks include the assessment of transmission capacity, the redispatch of generation or the activation of reserves when security is at stake, as last resort measure the management of defence plans, etc.

A clearly identified risk regarding system security is the possible lack of adequacy between generation and load, either on a general or a regional level. Although it is out of UCTE scope to give further recommendations on the actual type of market rules and incentives regarding adequacy, the necessity was clearly identified. On a general level, adequacy implies also the harmonisation on several issues such as taxation, building permission and environmental constraints. Distortions regarding these elements lead to non-balanced developments, putting strains on the system and thus generating security risks.

Finally, maintaining the same level of reliability, in a system with steadily increasing loads and dramatic changes in the location and structure of the generation mix, needs significant investments in transmission. The regulated structure of the TSO business in most of the UCTE countries gives an appropriate framework for these investments, provided that it yields a fair and stable return on investment. <<<