FINAL REPORT
of the
Investigation Committee
on the
28 September 2003
Blackout in Italy

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Executive Summary

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.

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.

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.

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 3500 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.

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.

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.

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.

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.

Introduction

INVESTIGATION COMMITTEE

The Investigation Committee is composed of:

- Experts of non directly involved UCTE countries:
  E. Grebe (D),
  D. Klaar (NL),
  K. Kleinekorte (D),
  J-M Rodriguez (E) and
  F. Vandenberghe (B), Chairman.

- Representatives of the Transmission System Operators for each of the involved countries:
  Austria : H. Erven,
  France: H. Laffaye,
  Italy: C. Sabelli
  Slovenia: F. Kropec,
  Switzerland: T. Tillwicks

- Supporting expertise:
  France : L. Tassan and S. Callewaert
  Italy : M. Mandozzi
  Switzerland : K. Imhof

- Secretariat:
  N. Janssens
  O. Bronckart

PROFILE OF UCTE

The "Union for the Coordination of Electricity Transmission" (UCTE) is the association of transmission system operators (TSOs) in continental Europe. UCTE members are the companies responsible for synchronous frequency system interconnection in *Austria*, *Belgium*, *Bosnia-Herzegovina*, *Bulgaria, Croatia*, the *Czech Republic,* the *Republic of Serbia and Montenegro*, *France*, the *FYROM*, *Germany*, *Greece*, *Hungary, Italy* , *Luxembourg*, *The Netherlands*, *Poland*, *Portugal*, *Romania,* the *Slovak Republic*, *Slovenia*, *Spain* and *Switzerland.* The system operator of *Denmark* is UCTE associated member.

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 charged with the mission of bringing a transparent and complete explanation of the blackout to the national and European Authorities and to the general community. The Terms of Reference of the Investigation Committee are given in Appendix 1.

The Committee is composed of the following Members, consisting of two groups:

- The group of the "directly involved TSO Committee Members", consisting of 10 representatives: a speaker and an expert for each of the 5 involved countries;

- The Expert Group, consisting of four independent TSO experts from non-directly involved UCTE countries and the Committee Chairman.

The Committee was given the mission to perform an in-depth investigation of the events, to assess the relevant UCTE operational rules in this respect and if necessary, to propose improvements to operational practices and rule setting.

It was agreed that the Committee should operate in full transparency, that all required data should be provided for it by the involved operators and that decision-making concerning the reports of the Committee would be unanimous within the Expert Group in case no consensus in the Committee could be reached.

This report, completing the assignment given to the Investigation Committee by the Terms of Reference, is composed of 6 sections:

1. Factual description of the sequence of events

2. Technical analysis of the events and underlying physical phenomena

3. Root cause analysis with the aim to define management action and further study issues to prevent reoccurrence

4. Analysis of the UCTE system after separation from the Italian grid.

5. Short-term action taken after the blackout in the five directly involved countries

6. Recommendations and conclusions

INSTITUTIONAL FRAMEWORK

For the 5 countries involved it is worth mentioning that the institutional framework in which the grid companies are operating is not fully identical:

- 4 countries (A, F, I and SLO) are EU countries or acceding countries with unbundled TSOs complying with the EU Electricity Directive 96/92;

- Switzerland has, up to now, adopted a different model: ETRANS, a coordination body of 7 grid owners/operators[1], performs system operator tasks vis-à-vis the neighboring TSOs. The 7 grid owners operate, develop and maintain the networks as entities within either the respective vertically integrated companies or companies in different stages of unbundling.

[1] *5 of the 7 Swiss grid owners/operators are UCTE member: ATEL, EGL grid, BKW, EOS and NOK.*

1 Factual Sequence of Events of the Blackout in Italy on Sunday 28 September 2003

1.1 DESCRIPTION OF THE SEQUENCE OF EVENTS LEADING TO THE DISCONNECTION OF ITALY

The sequence of events on Sunday 28 September has been compiled based on the data given by the involved TSOs from Switzerland, Italy, France, Austria and Slovenia that participated in the UCTE Investigation Committee.

1.2 TIME PERIOD BETWEEN 03:00 - 03:30

SITUATION AT 03:00 AROUND ITALY

- Total physical import to Italy was 6 951 MW (including 300 MW through the HVDC link Greece-Italy)
- Total load of Italy was 27 444 MW, this is: 23 957 load (excluding Sardegna) and 3 487 MW pump load
- Total generation of Italy 20 493
- Powerflows at the borders with Italy:
  - Switzerland - Italy: 3610 MW
  - France - Italy: 2212 MW
  - Slovenia - Italy: 638 MW
  - Austria - Italy: 191 MW
  - Greece - Italy: 300 MW
- Scheduled exchange programs:
  - Switzerland - Italy: 3068 MW
  - France - Italy: 2650 MW
  - Slovenia - Italy: 467 MW
  - Austria - Italy: 223 MW
  - Greece - Italy: 285 MW

380 AND 220 KV NETWORK LINES OUT OF OPERATION FOR MAINTENANCE REASONS AND AS PREVENTIVE TOPOLOGY MEASURE

- Switzerland: the following preventive topology measures were taken to have a better distribution on the power flows across the Swiss transmission system and especially the 380 kV lines Lavorgo - Musignano and Soazza - Bulciago: busbar separation in substations Sils 380 kV, Mörel and Innertkirchen (both 220 kV)

- Italy: 220 kV line Soverzene - Scorze, 380 kV lines Suvereto - Montalto2 and Garigliano - Latina, 220 kV line Piazza Dante - San Paolo (all in the middle of Italy), DC-cable Sardegna - Corse , busbar separation in substation Valpelline 220 kV due to high powerflows on the lines Valpelline - Riddes and Baggio - Bovisio

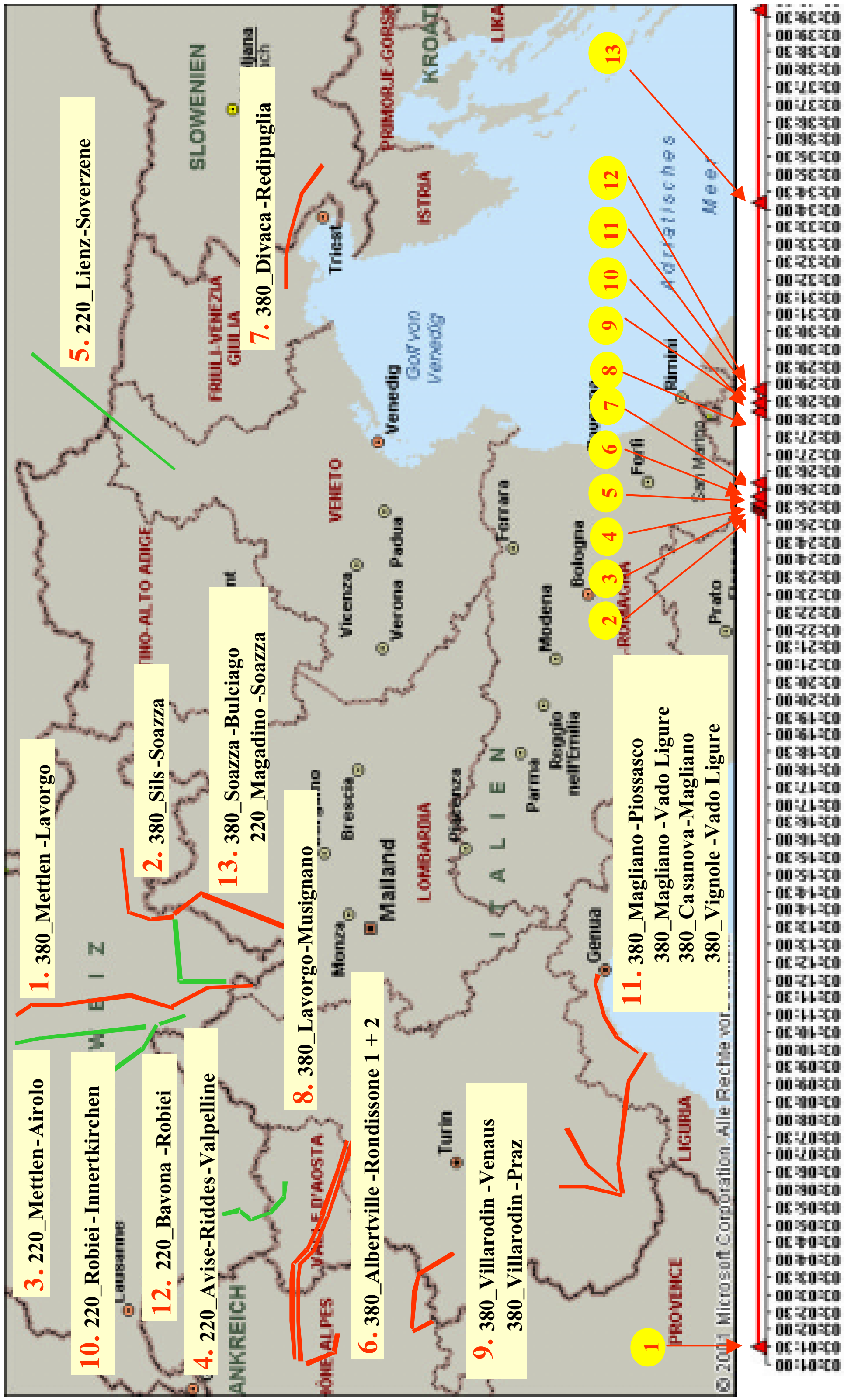
- France: 380 kV lines of Chevalet - Gavrelle, Gaudiere Rueyres, Chesnoy - Tabarderie, Menuel Terrettes 2, Terrettes - Tourbes 2 and La Praz phase shifter

- Slovenia: 220 kV line Podlog - Obersielach to Austria

- Austria: 220 kV line Obersielach – Podlog to Slovenia.

OVERVIEW OF SEQUENCE OF EVENTS

A graphical overview of the sequence of tripping of the most important lines that led to the blackout of Italy is given in the next picture.
In Appendix 2, a tabular overview containing the details of the factual sequence of events for the time period that led to the blackout as well as the restoration process is given.



1. 380_Mettlen-Lavorgo
2. 380_Sils-Soazza
3. 220_Mettlen-Airolo
4. 220_Avise-Riddes-Valpelline
5. 220_Lienz-Soverzene
6. 380_Albertville-Rondissone 1 + 2
7. 380_Divaca-Redipuglia
8. 380_Lavorgo-Musignano
9. 380_Villarodin-Venaus
380_Villarodin-Praz
10. 220_Robiei-Innertkirchen
11. 380_Magliano-Piossasco
380_Magliano-Vado Ligure
380_Casanova-Magliano
380_Vignole-Vado Ligure
12. 220_Bavona-Robiei
13. 380_Soazza-Bulciago
220_Magadino-Soazza
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KROATI
FRIULI-VENEZIA GIULIA
VENETO
LOMBARDIA
ITALIEN
ISTRIA
LIGURIA
PROVENCE
VALLE D'AOSTA
Golf von Venedig
Adriatisches Meer
Triest
Venedig
Padua
Vicenza
Verona
Ferrara
Bologna
Modena
Reggio nell'Emilia
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Rimini
San Marino
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1.3 RESTORATION PROCESS

The next table shows some characteristics regarding the restoration process of the Italian transmission grid.

Relevant transmission grid size	245 substations 112 busbar systems at 380 kV
Time to reenergise the relevant transmission grid	13 hrs. 30 min.
Switching actions in the transmission grid	More than 3 600
Events recorded	More than 80 000
Estimated energy not supplied	177 GWh
Last customer supplied after	18 hrs. 12 min.

2 Technical Analysis of the Events

2.1 INTRODUCTORY COMMENT ON THE RELATION BETWEEN COMMERCIAL TRANSACTIONS AND PHYSICAL FLOWS ON THE NETWORK

It is a basic principle of the operation of electric networks that flows on a network follow the path of least impedance, in accordance with the physical laws of electricity. For example, when generation is increased in France to supply a corresponding load increase in Italy, this will impact the physical flows on all 4 Italian borders and thus Austria, Slovenia and Switzerland will in a natural way provide transit services to this France-Italy transaction. The same applies, of course to the other countries. Transactions from, for example Germany or Poland to Italy will influence cross-border flows on all Italian borders. These influence factors will depend on the characteristics of the grid and of the geographical situation of the corresponding power plants. Also transactions between countries north of Italy, non involving Italy, can cause transit flows through Italy.

As a result, the physical flow on the lines crossing a given border cannot be derived only from transaction information that would be limited to the adjacent countries. An overview of the complete picture is necessary. In other words, it is crucial for network security to have a good prediction of the geographical location of generation, loads and of the topology of the grid.

Therefore, in response to the electricity market development, UCTE TSOs have set up a system of information exchange, called DACF (Day Ahead Congestion Forecast). With this system forecasts are exchanged at regular intervals, on network topology and on the physical configuration of generation and loads in the system. The information gathered via this system, allows each participant TSO to forecast the physical state of his own network, in coherence with the forecast transactions, but without relying explicitly on these transactions. DACF is a new tool, introduced in 2001 and since then is evolving further by increasing the frequency of runs and the number of participating countries.

Due to incidents, short-term changes in transactions, load forecast imprecision, etc, real time flows may significantly differ from the results of the DACF. Therefore, TSOs perform on regular intervals in real-time security assessments of the state of the grid and take corrective measures accordingly. The basic criterion underlying these assessments is that the network must continuously be operated in a state, inasmuch that the loss of each single element (for example the trip of a line) does not jeopardize the security of the interconnection.

These two tools (DACF and real-time security assessment) are the key elements for TSOs to manage the security of the grid. They are based on physical data without explicitly taking into account commercial transactions.

As a consequence, the approach followed in this report will not consider commercial transactions, but only focus on physical data.

2.2 RELEVANT ASPECTS REGARDING THE SYSTEM CONDITION BEFORE THE BLACKOUT

Before the incident the transmission grid in the proximity of the north and northwest border of Italy comprising fifteen 380 kV and 220 kV international tie-lines (especially in Switzerland) was highly loaded. This was caused by the power exchange of Switzerland with the four neighbouring countries, as well as by parallel flows caused by power transactions in the frame of the Italian power import. This power is mainly generated in France, Germany and Poland in terms of the export/import balance of the European interconnected countries. The scheduled amount of Italy's import was around 6 400 MW, which was increased by an Italian control deviation of around 200 - 300 MW.

A general problem with meshed networks, of particular importance for the concerned grid area, is that the loading of the cross-border lines to Italy is mostly not proportional with the capacity of the respective lines. This depends on the overall generation pattern in the surrounding grids in France, Germany, Italy and Switzerland itself, but also in other parts of the UCTE area. In particular, the transmission grid condition resulting from trading activities during the night is frequently characterised by a rather high usage of the internal Swiss transmission grid. The tools for controlling these flows are mentioned in the introductory comment to this chapter.

During the time before the blackout, the Swiss grid was also under pressure and operating close to the security limit given by the commonly agreed UCTE standards (N-1 Security).

2.3 CLASSIFICATION OF STABILITY PROBLEMS IN POWER SYSTEMS

For a systematic understanding of the events it is worthwhile including a brief overview about basic physical problems, which are related to a high loading of transmission systems by transport of electrical energy. Several types of instability phenomena in electrical power systems exist. They are caused by different physical interactions between the various elements of a power system such as adjacent network areas, consumers, control / protection functions and generation units. The main types of instability concern are:

- cascading line tripping by overload[1]
- loss of synchronism due to angle instability
- oscillatory instability causing self exciting interarea-oscillations
- exceeding of the allowed frequency range (over- and underfrequency)
- voltage collapse

As the consequences of instability can be dramatic, its prevention is an all-important aspect in electrical power systems. Though several means exist and are applied to power systems, in order to maintain stability and to master emergency conditions, the nature of electrical power systems includes the risk of uncontrollable chain reactions. This could lead to a complete malfunction of the electricity supply of consumers throughout the grid. During blackout, which large power systems have experienced worldwide, a combination of the above mentioned stability phenomena often occurs.

2.4 CONTRIBUTION OF STABILITY PROBLEMS TO THE BLACKOUT IN ITALY

2.4.1 CASCADING LINE TRIPPING

During the first phase the incident is initiated by cascading line tripping, which can be observed in a similar manner during other blackouts worldwide and can physically be explained. The thermal losses, according to line current, increase the temperature of the conductors and as a result, their lengths and subsequently the line sag is also increased. This leads to less distance between the conductors and ground or trees possibly located under the line. Thus, the risk of a flashover and of a line tripping increases. If a line trips, its loading must be taken up by neighbouring lines which are consequently loaded higher and possibly overloaded, risking the possibility of successive tripping.

First line tripping at 03:01:42 Lavorgo – Mettlen (Switzerland)

The 380 kV line Mettlen – Lavorgo was highly loaded at approximately 86% (100% limit at ambient temperature of 10°C being 2400 A) of its maximum capacity, so that in this case the heating process of the conductors caused a

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[1] Cascading line tripping is not related to stability phenomena according to classical control theory (see: CIGRE Brochure 231: "Definition and Classification of Power System Stability"). However this phenomenon also has an uncontrollable effect on the system and might cause its malfunction to an unpredictable extend. As it is often reported in the sequence of events of other blackouts, it is also mentioned in this paragraph.

decrease of distance to the trees. A flashover occurred as the distance was not sufficient (at a certain point) under the given circumstances. As a consequence there was an increased line sag and possible movement of the conductors by wind, high humidity.

The attempts of single-phase auto-reclosing were not successful and the line was disconnected by its protection device. The attempt by the operators to put this line back into operation failed again because of an overly high phase angle (42^0), which resulted from the continuing high power flow to Italy through the grid; weakened after the line tripping.

The blocking of the line reconnection, in the case of the phase angle difference being too high, has the purpose to protect generators in the proximity against damage or malfunction due to high transient stress during the switching of network elements. The required setting of such blocking devices very much depends on topology and generator location.

Second line tripping at 03:25:21 Sils - Soazza (Switzerland)

After the loss of the first line, the load on the neighbouring lines increased. In particular, the 380 kV line Sils – Soazza, which was operating at around 110 % of its nominal capacity. This overload can be accepted for a limited time interval as the thermal process described above, takes place with a certain time delay according to the thermal time constant of the conductors.

The short-term overload capability of this line was investigated with consideration to:

- the relevant characteristic data of the conductor
- an assumed air temperature of 10 ^{0}C
- an assumed wind speed of 0,6 m/s
- the maximum conductor temperature of 80 ^{0}C
- the initial temperature of the conductor resulting from the loading of this line before the first line tripping
- the recorded loading of the line in the time interval between 03:05 and 03:25

Figure 2.1 shows the maximum admissible operation time in overload condition depending on the line current. In the time interval between 03:05 and 03:25, the maximum current was 2 700 A. With this current the maximum conductor temperature would already be reached after 13 minutes. The average value of the line current was 2 590 A allowing an operation time of up to around 15 minutes.

That means that the time interval in which the grid operator had to decrease the loading of this line to its nominal value was rather limited. From the analysis it must be concluded, that 15 minutes, at the latest, after the first line trip, the line sag of the line Sils - Soazza had exceeded the nominal operational values.

Unfortunately, the different steps taken were insufficient to reduce the overload within the required time interval. After 24 minutes, when this line also tripped after flashover with a tree, its overload was still not completely eliminated.

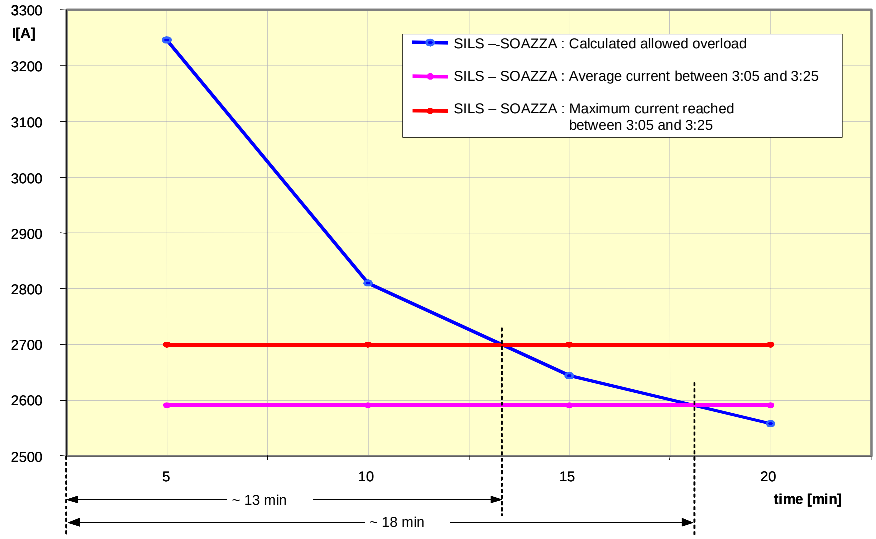


Figure 2.1: Load and Overload Capability of the 380 kV line Sils – Soazza

Third line tripping at 03:25:25 Airolo-Mettlen (Switzerland)

Immediately after the 2nd line tripping an internal 220 kV line in Switzerland took over a significant part of the power flow and was highly overloaded. According to the design of the protection devices the line was disconnected after a delay of around 4 seconds.

Starting of automatic disconnection device at 03:25:26 Lienz (Austria) - Soverzene (Italy)

A special protection scheme is implemented in the Austrian grid, as its' transmission grid requires protection against overload of different internal grid elements, which can be imposed by specific unusual conditions of the surrounding international grid. At different stages, various measures are put in place in order to reduce possible overload conditions. The first step was taken, without significant effect however, as almost simultaneously the Italian grid lost its synchronism with the UCTE main grid. This loss of angle stability can be concluded by the evaluation of extensive recordings collected from the power system, which is described in detail below.

2.4.2 LOSS OF ANGLE STABILITY

Generally the loss of angle stability has dramatic consequences for the power system. This kind of instability is often combined with fast voltage collapse and spreads widely through the power system and is therefore hard to overcome. Due to loss of synchronism of the Italian grid with UCTE, all remaining connecting lines on the cut-set between Italy and UCTE were disconnected by regular function of the protection devices.

The recorded phenomena were decisive in the fact that the emergency situation of the Italian grid after separation from UCTE could not be managed and finally under these conditions the blackout was inevitable.

There are various recordings available, which show all the information regarding the event and give physical explanations. Main conclusions can be drawn from recordings:

- collected from WAMS (Wide Area Measurement System) of UCTE
- of ETRANS and GRTN
- of APG and ELES
- of RTE at the border lines France - Italy

Fig.2.2 a b and c show frequency, voltage and reactive power in Heviz (Hungary) and frequency in Uchtelfangen (Germany) recorded by WAMS. The WAMS' internal clocks recording devices are synchronised by GPS.

Each line tripping in Switzerland produces small frequency steps, which are visible in the recordings in Germany (see Fig 2.2.a). From this, the exact time of the second and third line tripping can be identified (confirmed by small frequency deviations in Italy).

At 3:25:28 the 220 kV line Cislago – Sondrio (I) tripped and then the Italian grid lost its synchronism

At this moment a dramatic voltage decrease started in Heviz and simultaneously the reactive power flow to Tumbri (Croatia) increased. This process continued for around 7 seconds and the voltage fell to the minimum value 320 kV, during which time the reactive power flow reached 800 Mvar, see Fig. 2.2.b. During this time interval, also at the substation Albertville, (F) a voltage collapse below 320 kV was indicated by an alarm message from the substation**.** Under consideration of the active and reactive power flow on the border lines it can be concluded that the voltage level in parts of the Italian grid was much below the voltages in Albertville and Heviz during a time interval of around 4 seconds.

The loss of synchronism of the Italian grid is confirmed by the recorded active power flows on the borderlines from France to Italy, as shown on Fig.2.3. By deceleration of the Italian voltage phasor, the angle between the voltages at the substations of the borderlines and the power flow on the lines increased.

In this transient phase line protection devices were triggered and they disconnected the lines according to their regular function. After the tripping of all interconnections to UCTE (apart from the 220 kV line Divaca- Padraciano), within a time interval of around 3 seconds, the voltage in Heviz settled back to near its nominal value and the reactive power approached zero.

At this moment the main interconnection lines between the Italian and UCTE grids were disconnected and the grids were asynchronous, but still rather weakly connected through a 132 kV grid area in the northeast area of Italy. This remaining interconnection showed a relatively high impedance given by the remaining 220 kV line, the 132 kV grid and the respective 220/132 kV transformers. The slipping of the Italian grid against UCTE through this interconnection caused power and voltage swings. The frequency of the power oscillations corresponds to the difference between the frequencies in the Italian grid and in UCTE (e.g. in the time interval from 03:25:50 to 03:25:55)

$f_{UCTE} - f_{Italy} \cong 50{,}2\ Hz - 48{,}4\ Hz = 1{,}8\ Hz$

These power swings disappeared at 03:26:30 when the 220 kV line was disconnected (see Figure 2.2.c).

f,U – Uchtelfangen (D) / Heviz (HU)

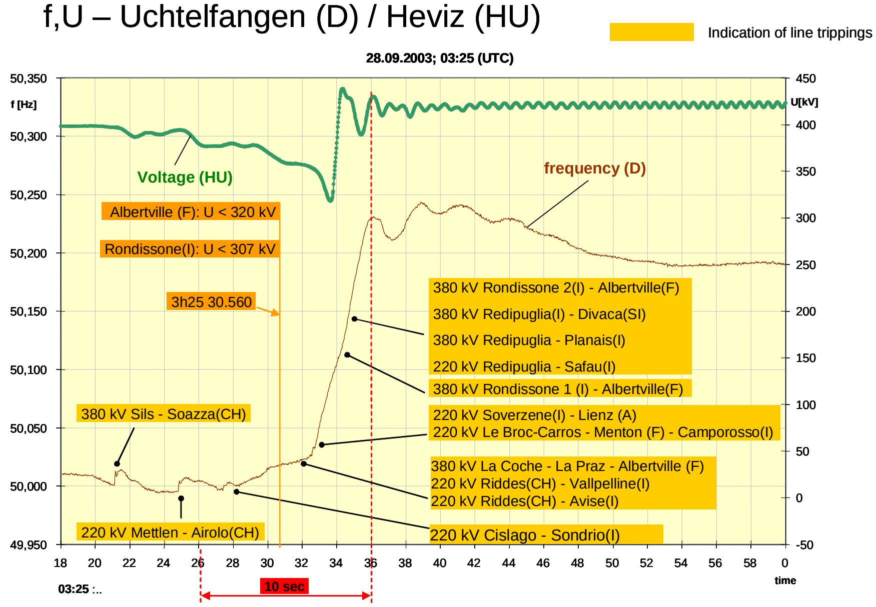


Fig. 2.2.a

f,U – Uchtelfangen (D) –Vigy(F) / Heviz (HU)

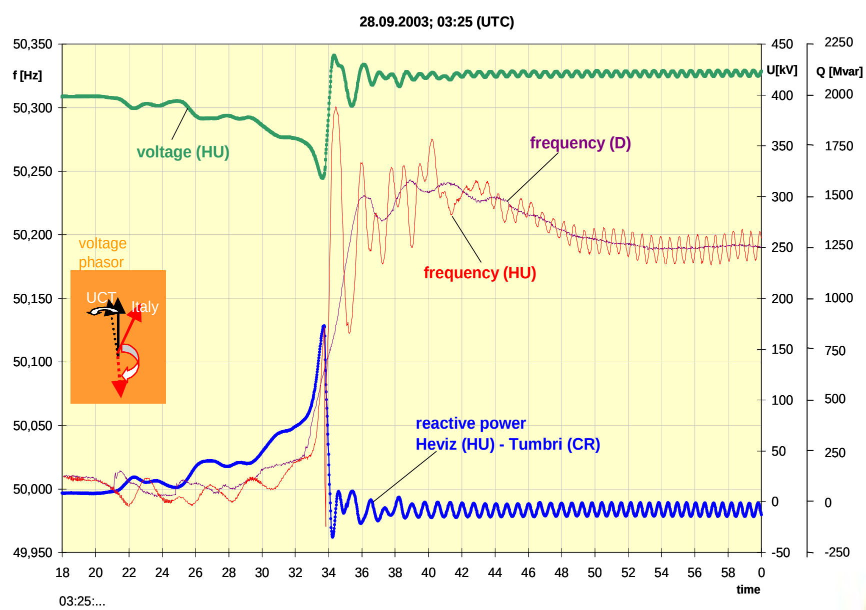


Fig. 2.2.b.

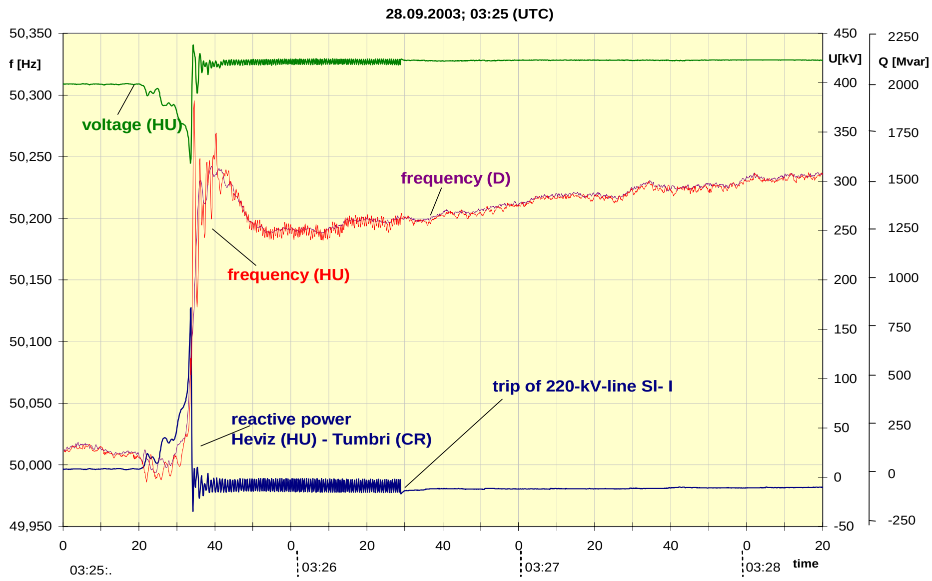


Fig 2.2.c

Figures 2.2.a, b and c: Recording from WAMS in Heviz (Hungary) and Uchtelfangen

Active power - Italy - France

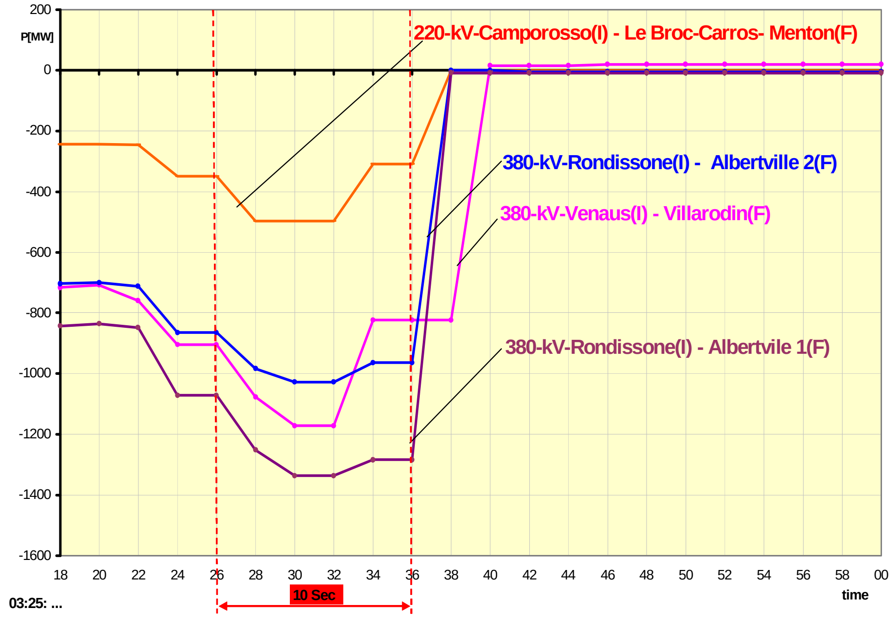


Figure 2.3.a

Active power - Italy - Switzerland

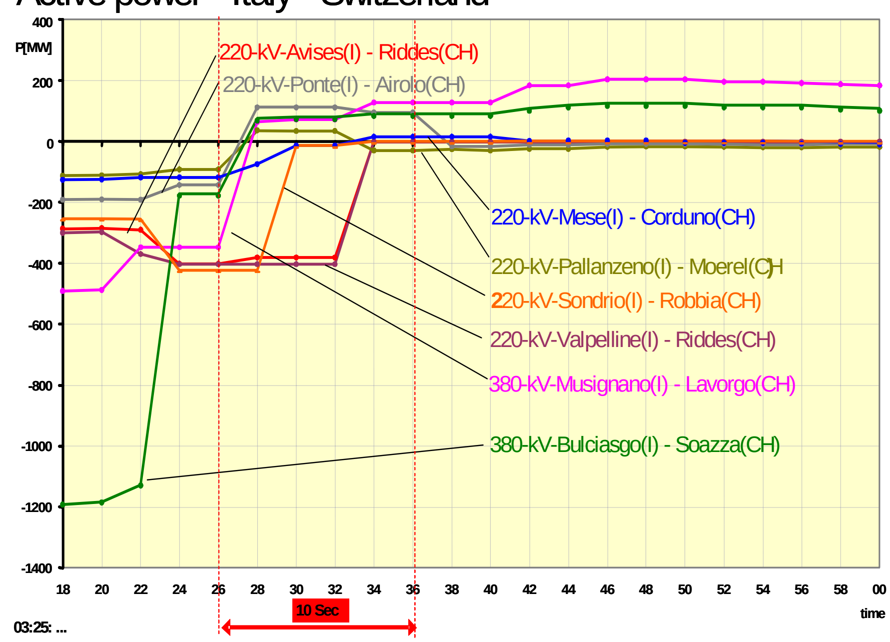


Figure 2.3.b

Figures 2.3.a and 2.3.b: Active power flow on border lines to Italy

2.5 BEHAVIOUR OF THE ITALIAN POWER SYSTEM AFTER SEPARATION FROM UCTE

2.5.1 OVERVIEW OF THE ITALIAN POWER SYSTEM BEFORE THE INCIDENT

On September 28 2003 the Italian power system was operating under N-1 security conditions, prior to the events leading to the incident, as shown by power flows on the 380 kV grid at 03:00 and 03:15, given as records to the UCTE Investigation Committee. Therefore, the power system was capable of correctly dealing with the loss of any individual element of the grid, including any tie-line with neighbouring countries, or the loss of the largest unit in service.

The balance between power input and output on the Italian power system, excluding Sardinia, is displayed in Table 2.1. The Table indicates the expected and actual capacity values (MW) at 03:00 and the actual capacity values at 03:25[2].

	Expected at 03:00	***Actual at 03:00***	***Actual at 03:25***
Demand	23 240	23 930	23 918
Load absorbed by pumping units	3 288	3 487	3 275
Load absorbed by Republic of San Marino + Vatican City	27	27	27
Total LOAD	**26 555**	**27 444**	**27 220**
Thermal generation	18 231	18 748	18 853
Hydro generation	1 051	1 184	1 180
Geothermal generation	580	551	551
Wind generation	10	10	10
Total domestic generation[3]	**19 872**	**20 493**	**20 594**
Imports – northern border	6 408	6 651	6 326
Imports – Greek border	285	300	300
Total UCTE Imports (including import from Greece)	**6 693**	**6 951**	**6 626**
Total Power Input	**26 565**	**27 444**	**27 220**

Table 2.1: Mainland Italy + Sicily capacity balance (MW)

As depicted in Fig. 2.4, neither violation of the transmission capacity limits between the macro areas took place, nor violation of the Total Transfer Capability across borders.

[2] *Capacity balances are computed on an hourly basis; therefore, the capacity values determined at 03:25 are based on the telemeasures of GRTN's SCADA system.*

[3] *The total includes about 3 400 MW of self-generation and of power input on Primary distribution and MV grids.*

Four 380 kV and five 220 kV internal lines were out of service for maintenance, or for other dispatching reasons. Neither of these lines violated N-1 security in the interconnected system nor influenced the usage of border tie-lines.

Fig.2.4 also shows the available operating reserves at 03:25, and their response times.

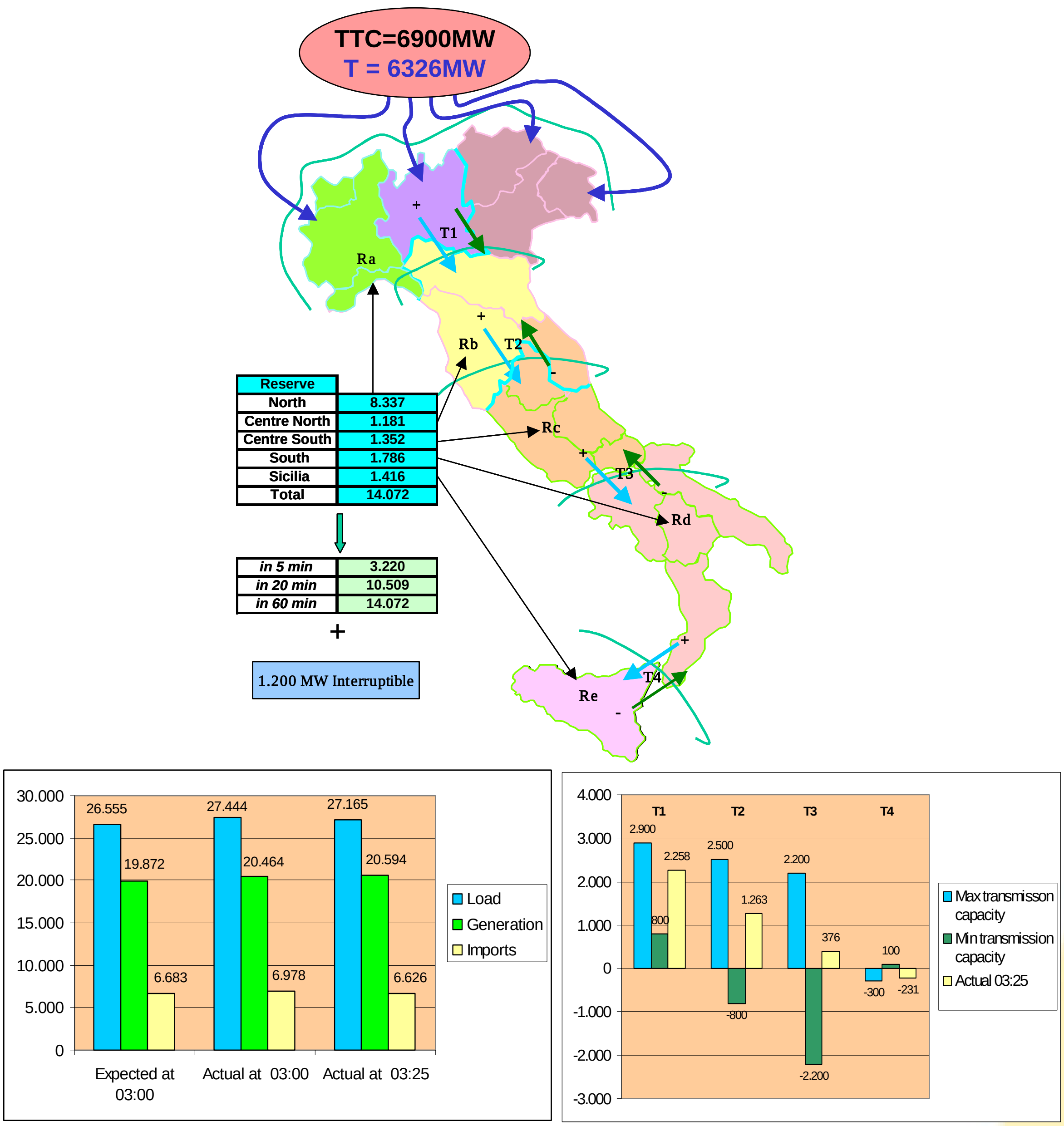


Figure 2.4: Flows and reserves

Hence, the available generating reserve lay well above the 6 400 MW imported from neighbouring countries.

Furthermore, where needed and if adequately alerted, about 1 200 MW of interruptible industrial loads without prior notice might be disconnected within 1-2 minutes manually from the control room of the National Control Centre in Rome.

In other words, the Italian power system was operating under security conditions and utilised the resources to cope with the demand in strict accordance with Decision 67/03 of Autorità per l'Energia Elettrica ed il Gas (the Italian Electricity & Gas Regulator) on the provisional system of electricity sale offers. As common practice in UCTE, GRTN assumed that the remaining interconnected grids close to the Italian border would be monitored under sufficiently secure conditions or in such a way as not to induce a separation from the European system, leading to high, sudden imbalances between power input and output.

The high reserve margins were available both for technical and economic reasons, the former because during off-peak hours the pumping plants accumulate energy and a number of thermal plants could not be shut down for voltage regulation or other technical constraints, the latter because the import was more financially advantageous than domestic production and it is not cost-effective to shut down thermal plants for short periods.

2.5.2 THE SEPARATION AND THE FREQUENCY TRANSIENT

At 03:25:34, the connection between UCTE's system and the Italian system was cut:

- on the French side: along the border and parts of France
- on the Swiss side: inside Switzerland and partly along the border
- on the Austrian side: along the border
- on the Slovenian side: inside Italy.

From this time onwards, the synchronism with the remaining UCTE System was lost (Fig. 2.5)

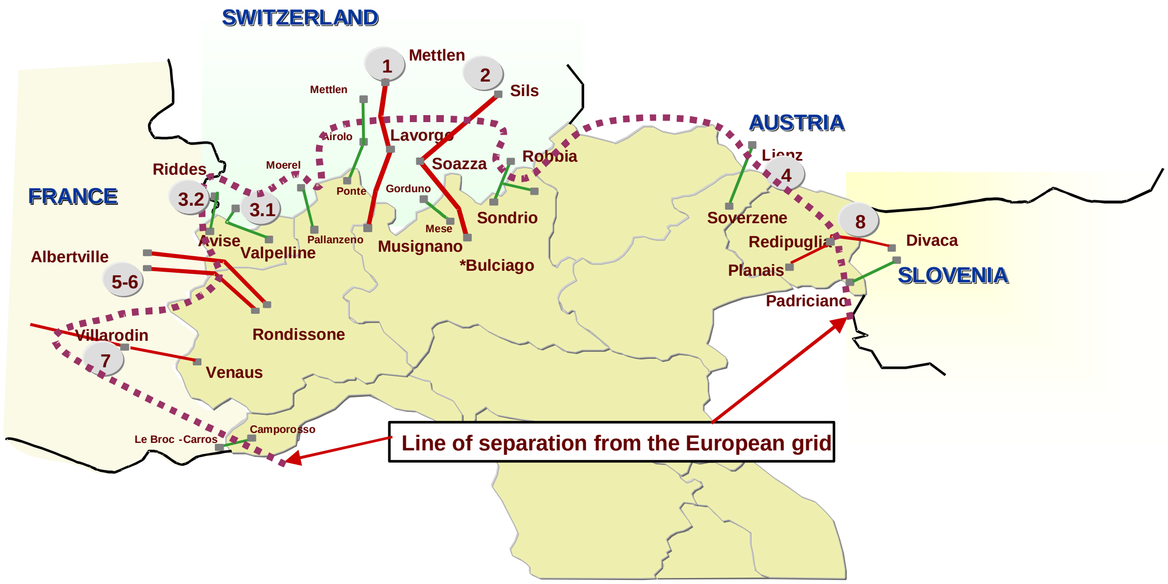
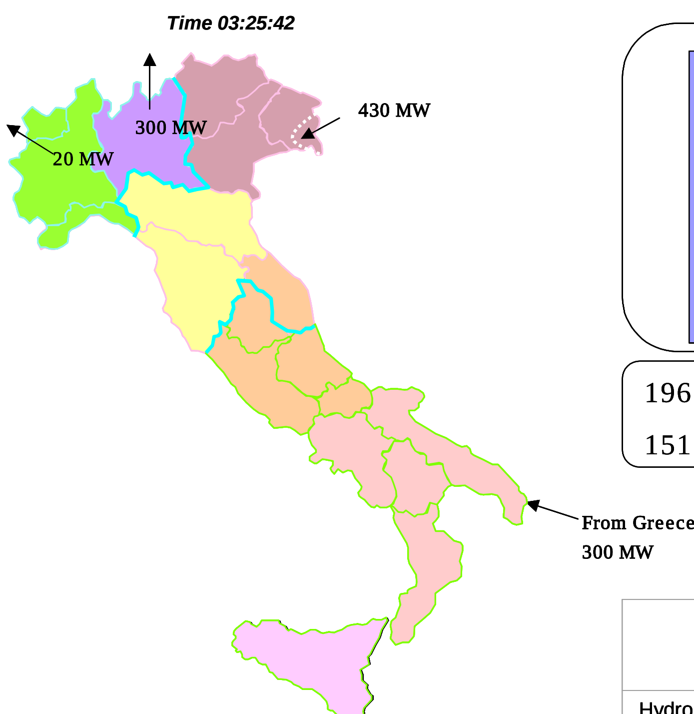
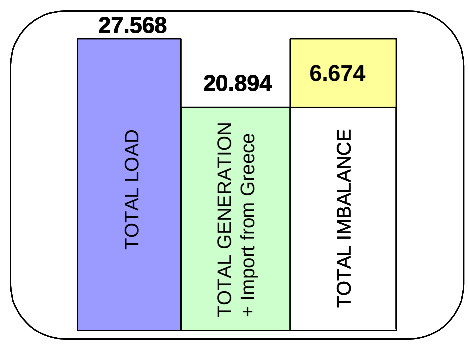


Figure 2.5: Line of separation from UCTE





196 Thermal Units

151 Hydro Units

Power input	***MW***
Hydro generation	1.180
Thermal generation	18.853
Geothermal generation	551
Wind generation	10
Total Generation	**20.594**
Abroad – Greek border	300
Total power input	**20.894**

Figure 2.6: Load imbalance

As shown in Fig.2.6, in the Italian area just after the separation from the European system, a deficit of about 6 646 MW was recorded, of which about 300 MW extra load was in Tessin, supplied through the Lavorgo and Soazza substations, about 20 MW at Villarodin substation in France and the remaining part imports from the northern border.
The deficit caused a frequency transient, which triggered all automatic control measures designed to safeguard the Italian power system.

A reconstruction based on currently available data infers that a weak connection of the Italian power system with the Slovenian grid was kept, through a 132 kV line still connected via a 132/220 kV transformer at the Padriciano substation, until the Italian network was disconnected by protection. As a result, an asynchronous operation occurred through this weak link.
The power input on the grid was the total amount of Italian generation and the electricity imported via the cable link with Greece.

- In particular, at the point of separation from the UCTE network, in Italy there were in operation:
- 196 units thermal generation (56 units were in the distribution[4] network at voltage level lower than 132 kV)
- 151 units hydro generation (133 units were in the distribution network at voltage level lower than 132 kV)

2.5.3 THE TRANSIENT STATE UNTIL THE BLACKOUT

The negative imbalance between power injection to the system and system load, which occurred as described above, was equal to 6 646 MW and caused an abrupt frequency drop, followed by primary control operation of the generating units, the disconnection of the in-service pumping units and the load shedding in the high voltage and medium voltage grids.
Before reaching the state of blackout, the Italian system recorded a frequency transient of approximately 2,5 minutes, starting with its separation from the European system (Fig. 2.7). The trend of the transient behaviour was affected by the reaction of defence systems, regulating systems and by the tripping of various generating units. The speed control effect and primary control of in-service generating units reached their highest value of about 1 465 MW a few seconds after the event. Nevertheless in this time interval, frequency fell by 1,5 Hz.
The voltages recorded after the tripping of the interconnected lines on the French side returned closely to their initial values. On the north-eastern side, in contrast, there was a voltage drop lasting all the time the Italian system was connected with Slovenia[5].

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[4] The Distribution network includes around 2000 substations 132/MV connected to the primary system, and the related lines ranging from 132 kV to 220 V. In particular at 132 kV level Distributors control all their switching devices, even if part of the 132 kV lines belong to the National Transmission Network.

[5] The frequency was recorded in the centre of Italy. The imbalance curve was evaluated on the basis of available information. Some approximations are possible.

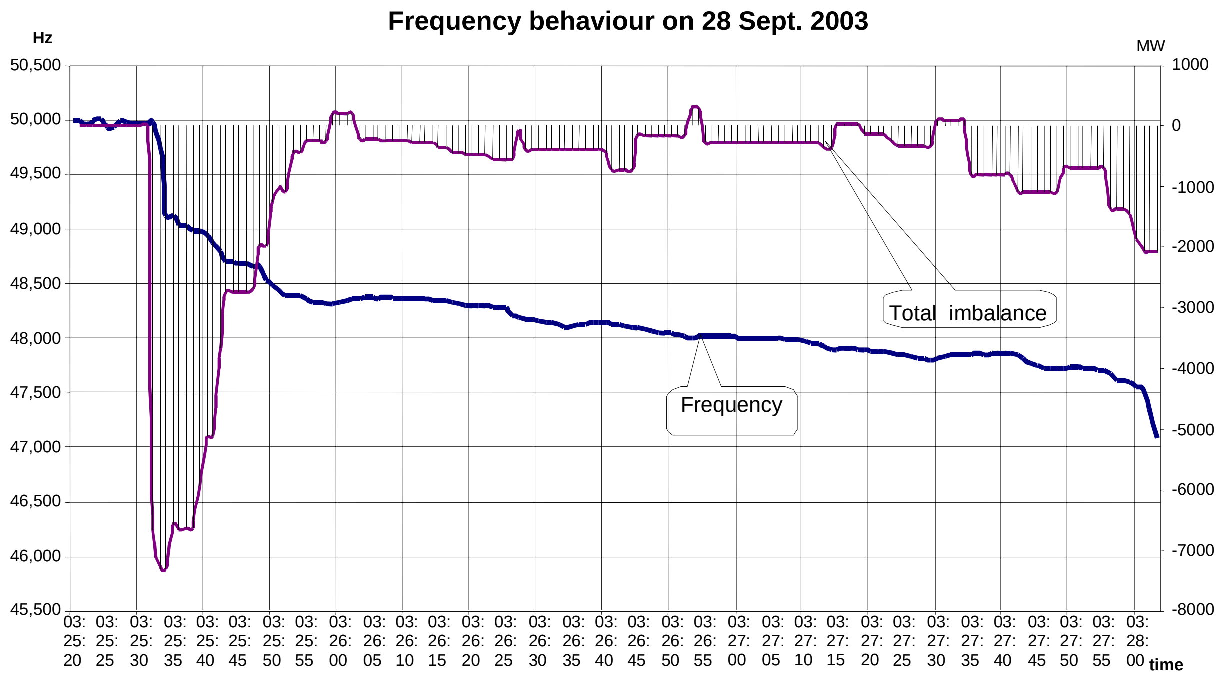

Figure 2.7: Frequency vs. Imbalances

All the pumping units in service were automatically disconnected between 49,720 and
48,985 Hz, shedding about 3 220 MW.

In addition, starting from 49,70 Hz, about 1 017 MW were relieved by automatically disconnecting industrial customer loads at transmission and sub-transmission levels 132 kV and 6 693 MW were shed automatically at MV level, about 85% of 1 300 frequency relays functioned normally[6].

The decline of the frequency was drastically reduced but it persisted due to 4 132 MW generation loss after the tripping of the largest units (> 50 MW) and around 3 400 MW of power injections into the 150-132 kV and distribution grids, totalling 7 532 MW.

31 thermal units initiated the sequence for switching on their "house-load". Only eight of them successfully completed the sequence and remained in isolated operation on house-load. These units could improve subsequent restoration phase.

Some underfrequency relays activated the programmed automatic sequences to island two well-defined portions of the network and the related load in southern Italy. Each of these two isolated portions of network should have been fed by a

[6] *The 380 kV and 220 kV network is considered "Transmission". The 150 kV and 132 kV network is considered 50 % "Transmission" and 50 % "Distribution" according to the different assigned functional attributes. Lower levels of voltage are considered as Distribution.*

thermal unit, but only one was regularly configured and successfully completed the islanding sequence.

The opening of the 380 kV AC link in the extreme southwestern region of Calabria separated the grid of Sicily from the rest of the country to allow the islanding around a power plant to work on house-load.

In short, at the end of the 2,5 min transient, following the separation from UCTE's grid, the residual imbalance was estimated to be at least 1 900 MW. This was due to loss of the power input on the grid that amounted to approximately 14 200 MW. The disconnected load was equal to around 10 900 MW and the primary regulation was in total, approximately

1 400 MW as a combined contribution from load (300 MW) and governors (1 100 MW).

Therefore, owing to the imbalance between generation and loads, frequency fell below 47,5 Hz, resulting in the tripping of the generating units that were still in operation but with the consequent unavoidable loss of load. Only the aforementioned load island was supplied by one thermal power plant in southern Italy.

The following table 2.2 summarises the main causes of trip by the relevant thermal units as reported by their owners before and after reaching 47,5 Hz.

	Tripping before reaching 47,5 Hz		Tripping after reaching 47,5 Hz		TOTAL	
Main causes of unit trip	[MW]	[Units]	[MW]	[Units]	[MW]	[Units]
Boiler failure	0	-	899	3	899	3
High Temperature of Exhaust Gases	306	2	0	-	306	2
Loss of Excitation	119	1	635	1	754	2
Loss of Synchronism	163	1	0	-	163	1
Turbine Tripping	714	6	580	7	1 294	13
Underfrequency Relay Operation	621	5	4 760	26	5 390	31
Underimpedance Relay Operation	90	1	382	2	472	3
Undervoltage Relay Operation	405	1	0	-	405	1
Other causes	782	4	459	2	1 241	6
TOTAL	3 200	21	7 724	41	10 924	62

Table 2.2: Unit trips

The main causes of generation loss on the Italian grid are listed and briefly described below.

a) Boiler failure

Operation of boilers in steam plants requires some auxiliary equipment, e.g. feed pumps. The power to these auxiliary services is often supplied by the grid. The extended fault in the grid during the transient period, before and after the disconnection from UCTE, therefore caused boilers to block for lack of auxiliary equipment. The voltage collapse at the moment of disconnection is suspected to have been at the root of the boiler's failure.

b) High temperature of exhaust gases

Following a frequency drop, turbines participating in the primary frequency control, under the influence of the speed governor, increased power output in order to offset the frequency drop. In gas turbines, this effect is combined with reduced air mass flow in the compressor, thus causing exhaust gas temperature to rise too high, and the turbine to shut down.

c) Loss of excitation

In many generators, the excitation winding is supplied by the HV, via a step-down transformer and a rectifier ("excitation system"). For the excitation system to work effectively, the supply (grid) voltage needs to remain within a certain range.
As a result of the grid fault, local voltage fluctuations rose, causing the tripping of excitation systems. The consequence being: the protection against the loss of excitation, tripped the generators.

d) Loss of synchronism

After the separation of the Italian system from UCTE, power swings and oscillations occurred on the Italian grid. As a result, some generators lost synchronism, and were therefore tripped by protections.

e) Underfrequency relay operation

Imbalances caused generators to slow down. In order to prevent the subsequent improper working of generators and auxiliary equipment (e.g. gas turbine compressors), underfrequency protections tripped the generators when frequency crossed a low threshold. The threshold setting, in two cases was too conservative so that five generators (overall power: 620 MW) were tripped before frequency reached 47,5 Hz. Three of the aforementioned thermal groups were Gas Turbine units, totaling 485 MW.

f) Underimpedance relay operation

Generators are usually equipped with an underimpedance protection against faults on the output terminals or on the HV side of the step-up transformer. On the lines still in operation, the disturbance in the Italian grid (tripping of the interconnecting tie-lines) caused a current increase and, at the same time, a voltage decrease. This would have appeared as an external impedance decrease due to a fault. As a result, the underimpedance protection tripped some generators.

g) Undervoltage relay operation

If the generator output voltage decreases (e.g. due to a decrease of grid voltage), the auxiliary service supply voltage may no longer be sufficient, and the operation of the whole unit may be jeopardized. Therefore, a low-voltage protection trips the generator when the output voltage drops below a given threshold.

h) Turbine Tripping

Mainly due to gas turbines protection.

i) Other causes

In this category several causes are included: low pressure of inlet gas from the metallurgical pipeline, low pressure of bearing oil, tripping to the house-load, logic disabled owing to faulty seal of throttle valves, sudden load disconnection in islanded electrical areas.

2.5.4 SHORT DESCRIPTION OF THE AUTOMATIC LOAD SHEDDING IN ITALY

The purpose of the load shedding plan is to arrest the frequency before the value of 47,7 Hz, to avoid the intervention of the minimum frequency protection of the generators that intervene at 47,5 Hz.

The automatic load shedding plan in Italy is based on relays that:

- in the range of 49,7 Hz up to 49,1 Hz, firstly shed the pumps if they are running. Within this range there are typically 5 steps that are set to act on a "minimum value of frequency" or on a certain value of the "rate of change of frequency (df/dt)"[7]. The relays operate according to the setting that is firstly overcome. The total pumping load that could be shed is about 6 000 MW (1 200 MW for each step).

- in the range from 48,8 Hz up to 47,7 Hz there are typically about 14 steps of 0,1 Hz each (the interval and the number of the steps could vary from one area to another depending on the typical shape of the load and the network characteristics). The first five steps are set to operate on a "minimum value of frequency" or on a certain value of the "rate of change of frequency (df/dt)"[8]. Also in this case relays intervene according to the setting that is firstly overcome.
  Each step of the load-shedding plan sheds a decreasing percentage (from 5% down to 3 %) of the related areas' load.

The total load under automatic load shedding is about 50% - 60 % of the national demand.
The plan is implemented at HV level on large industrial plants and pumping plants and at MV level, by selecting the feeders where no preferential loads are connected. The plan is "hard wired" and tuned at peak load periods and it is therefore impossible to hourly adapt the load to guarantee the same percentage ready to be shed at any given time.

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[7] *These steps (Df/dt) are typically set as follows: -0,10 Hz/sec, - 0,20 Hz/sec, - 0,30 Hz/sec, - 0,40 Hz/sec, - 0,50 Hz/sec.*

[8] *These steps (Df/dt) are typically set as follows: -0,60 Hz/sec, - 0,70 Hz/sec, - 0,80 Hz/sec, - 0,90 Hz/sec, - 1,00 Hz/sec.*

The load shedding plan has worked properly, even though as a matter of fact the load available, at the moment of the separation, turned out to be less than 10 000 to 11 000 MW (excluding pumps). This is due to the residential load, that at night is mainly composed of preferential loads that are not included in the defence plans due to binding contractual and legal conditions.

Further investigations are needed to assess whether sheddable load would be compatible with upper voltage limits of the network.

2.5.5 SERVICE RESTORATION

2.5.5.1 The restoration plan of the Italian System

The *Restoration Plan* is a set of coded guidelines that are used by the personnel in charge of the operation of the Italian power system to restore supply after a large area incident or blackout.

This plan is based on several restoration paths designed to work in parallel: to restore the auxiliary services of shut down plants, to reconnect the thermal power plants that succeeded islanding or tripping to the house-load and to stabilise the load of such plants. The first stages of the restoration process can be performed autonomously by the Telecontrol crews or by people in the substations, even without communication. The load is progressively added to the islands that emerge from each path and afterwards the islands are re-meshed into each other, under the dispatching coordination.

The restoration "paths" designed and used for restoring the network after the blackout have been:

- 13 in northern Italy
- 9 in central-south Italy
- 4 in Sicily

The restoration paths are initialised by 24 hydro or gas turbine units with black-start capability. The same function can be assigned to the UCTE grid if healthy and promptly re- energised.

During extreme circumstances like the ones in question, the teams in charge are trained to restore the electricity supply service in a fast and efficient manner, after preliminarily disconnecting all the switching devices.

Even if no specific performance index exists, the overall success of the plan depends on the following features:

- the number of available thermal units, operating on their house-load after separation from the grid and the duration of their capability to sustain this situation;

- the readiness of hydro and gas-turbine units to perform black-start, activate restoration paths and to enable all required paths to work in conjunction;

- the reliability of telecontrol and their telecommunication systems to operate, within a given timeframe, the switching devices in the electrical substations of transmission grids and gradually ballast the thermal units adding load at the distribution level;

- the availability of hydro, conventional thermal and gas-turbine units, for delivering the voltage along the restoration paths and adequately regulating frequency and voltages in the areas where supply is to be restored.

In addition:

- the restoration procedure cannot be started before a clear picture regarding the origin of the outage has been established and has to be managed with enough caution to avoid repeated incidences of the disconnections

- consideration needs to be made for machinery that has been stressed both mechanically and thermally by the previous incident

- alternative paths have to be available to cope with the probable unavailability of switching devices as multiple operations need to be performed

- System Operators act as intermediaries with the responsibility for coordination, while Producers, Transmission operators and Distributors have to guarantee performance

The process for a large outage like the one in question implies a complex set of communications amongst all the operators. To summarise, the description of supply restoration on the Italian power system made hereafter focuses on the 380 kV grid.

Most of the restoration processes were performed satisfactorily in comparison to the severity of a total outage. However, for the purposes of sharing experience in the present report, the paragraph stresses the difficulties encountered in managing the incident and the time required for restoring the power system to normal working order.

2.5.5.2 The restoration report

From the statistical point of view the following figures summarise the restoration:

The Relevant Transmission Grid size	- *245 Substations* - *112 busbar systems at 380 kV* - *4500 bays*
Time to re energise the Relevant Transmission Grid	*13h. 30 min*
Switching operation in the Transmission Grid	*More than 3 600*
Events recorded in Transmission control + remote operation centres	*More than 80 000*
Energy not supplied (estimated)	*177 GWh*
Total time to restore 98%of the expected energy	*13 hrs. 30 min*
after 6 hrs. 30 min load [MW] re-supplied	50 %
after 10 hrs. load [MW]re-supplied	70 %
after 15 hrs. load [MW] re-supplied	99 %
Last customer supplied after	*18 hrs. 12 min*

The process of restoration summarised in 4 stages:

Stage 1	from 03:28 to 08:00	*From the diagnosis to the Northern Area resupply*
Stage 2	from 08:00 to 12:00	*Intermediate steps*
Stage 3	from 12:00 to 17:00	*The complete resupply of Mainland*
Stage 4	from 17:00 to 21:40	*The final stage and the re-supply of Sicily*

2.5.5.3 RESTORATION STAGE 1 [03:28 to 08:00]

Since the very beginning the implementation of the Restoration Plan appeared affected by:

- a relatively small number of plants on house-load
- lack of immediate information on the root causes of the outage

Based on the first communications exchanged with ETRANS and RTE, the hypothesis of a blackout on a European scale was ruled out, but the root causes of the incident remained unknown. Aware of the national extent of the blackout, the plan for the restoration paths was immediately implemented.

GRTN's control room operators coordinated the preparation of this plan after performing the first recognition; it has to be considered that the opening of some lines occurred beyond the Italian border and the information unavailable.

According to the Restoration Plan, general targets were re-connecting the thermal units, awaiting house-load and making the network available to feed the auxiliaries of the blocked thermal units and then restoring the electricity supply to users within the shortest possible time (especially in metropolitan areas).

Approximately 3 hours after the blackout (06:30):

- Northwestern Italy had been almost completely energised and reconnected to the French grid. Hydro resources were available to progressively re-supply the area loads.

- Eastern Milan area (Lombardy region) had two backbone lines not yet connected to each other but synchronous with the European system via the connection with Switzerland.

- All buses for the areas' thermal plants were live and thermal units with an overall nominal capacity of about 750 MW had been synchronised (although still operating at their technical minimum).

- Eastern Venice area (Veneto region) was fed by Slovenia as far as the 380 kV substation of Camin, whilst the northern Venice area; (Friuli region) was supplied as far as the Udine substation.

- Part of the northern Florence area (Emilia region) had been connected to Lombardy via the 380 kV S. Rocco substation.

Around 08:00 at the end of the first stage:

- The northeastern grid was not yet meshed with the rest of the Northern System but it was synchronous with it via the UCTE System. However, the substations connecting most of the thermal plants in that area were live and stable enough to start to feed the auxiliary services.

- In the central-southern area, no significant progress had been made. Consequently, it was still impossible to re-supply the Florence area (Tuscany region) via the Tyrrhenian backbone and then continue towards the geographically close generation cluster of the Rome area.

- In the southern area, despite the remote control problems of the substations affected by the incident, an alternative restoration path was attempted towards the generation cluster in the extreme southern-east area (Puglia region) and around the Brindisi thermal plant, but most of the main thermal plants were still out of service and the unavailability of telecommunications systems had yet not been solved.

During the first stage expected failures occurred, i.e.:

- Failure or operational difficulties in starting black-start units;
- Voice and data communication problems and subsequent difficulties in switching from some Transmission Telecontrol Centres and lack of information from the field
- Problems emanating from the Tele control centres
- Failure to operate of few disconnectors

In general these difficulties were overcome by finding alternative routes for restoration and instructing - by telephone - the on-call teams, which had progressively reached HV substations and the HV/MV substations of the distribution grid.

Owing to the unavailability of a telecom company and telecommunications network (which carried the telecontrol signals exchanged between GRTN's control rooms), the SCADA system of the National Control Center in Rome lost complete visibility of the data recorded in the Florence area and northern Rome area from 06:31 to 13:17. However, this did not impact too much on the service restoration time.

These problems were clarified in the central, southern areas and in Sicily and two strategies were consequently adopted. They were as follows:

1) creating as many islands as possible in the southern areas,

2) proceeding step by step from North to South relying on interconnection with UCTE and on the hydraulic resources.

The re-synchronisation with the UCTE Network began by connecting the lines listed below:

At:	03:46:02	220 kV	Pallanzeno	Morel	Line
	04:03:09	220 kV	Camporosso	Broc Carros	Line
	04:08:18	380 kV	Venaus	Villarodin	Line
	04:13:50	380 kV	Redipuglia	Planais	Line
	04:32:23	380 kV	Redipuglia	Udine - Safau	Line
	04:37:09	380 kV	Bulciago	Soazza	Line
	04:41:10	380 kV	Rondissone	Albertville 1	Line
	05:16:01	380 kV	Musignano	Lavorgo	Line
	05:38:06	220 kV	Ponte	Airolo	Line
	06:26:04	220 kV	Mese	Gorduno	Line
	06:46:46	220 kV	Sondrio	Robbia	Line
	07:46:31	220 kV	Pallanzeno	Morel	Line

The operational difficulties mentioned in the previous paragraph persisted in southern Italy, especially at the Transmission Telecontrol Station and at the Distribution Centres.
In particular, on-call personnel were sent to attend several of the most crucial substations and locally carry out the operations ordered by GRTN.
Consequently, GRTN's control room operators continued their coordination of

switching operations so as to implement restoration paths within the shortest possible time and create alternatives in case of a negative outcome.

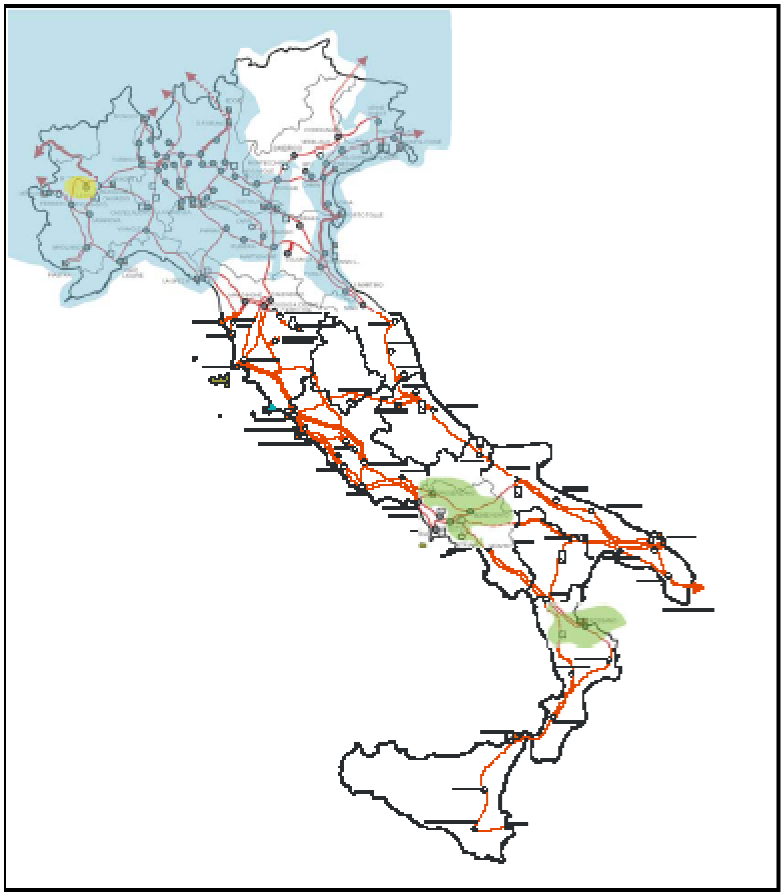

Figure 2.8: End of Stage 1

2.5.5.4 RESTORATION STAGE 2 [08:00 –12:00]

The restoration of the power system continued at a lower pace than desired because of switching difficulties, mainly due to telecontrols and to minor problems of disconnectors in some key substations[9]. Such problems had been encountered in particular by the Telecontrol Centre and of the Operational Centres of southern Italy, which telecontrols a wide network from Central to the Sicilian Areas.

During stage 2:

- four hours and a half had elapsed since the beginning of the blackout. Thus, local thermal units were unlikely to go back into service within a short time;

[9] *In the standard local control systems, the automation of sequences does not allow manual opening of the circuit breaker; it does however, operate the disconnectors. This adds time to the restoration process, due to doubling the number of operations to be executed.*

- additionally, as the accident happened before the pumping plants had completed the filling of their upstream basins, in stage 3 of restoration, scarcity of the energy availability of such plants also started to rise.

- the outage of telecommunications network also extended to Naples and Palermo. As a result, from 08:50 to 12:03 and 13:17, respectively, the SCADA system lost complete visibility of such areas. This further complicated the coordination of activities for re-supplying the central-southern part of the country.

- owing to the limited energy availability of pumping units, imports from other countries were increased to the extent allowed by the availability of the primary grid.

Furthermore, considering the progressive exhaustion of the hydro generating resources which were in service on the grid, GRTN asked Distributors to implement the load interruption of industrial loads and the 1st level of load shedding (rotating load shedding plan) from 11:00 to 18:00 in the northern and central-northern regions that were electrically restored, but the response was not effective.

From north–east, other 4 substations and the busses of another large thermal plant in Emilia region were re-energised, but the presence of a weak link with the rest of the northern network and the status of the underlying grid prevented the Adriatic backbone from being energised, which would have induced excessive voltages
Also Tuscany was re-supplied via the Apennine backbone. Voltage was thus delivered to the Bargi substation (at 08:26) where one pumping unit was re-synchronised.

The connection between the Southern Turin area (Liguria region) and Lombardy was consolidated.

In the Rome area, at 09:28 after a few attempts to deliver voltage from a hydro black-start unit which had failed owing to voltage instability, another 310 MVA unit, was started up from the east in order to better control the same restoration path. At 09:45 voltage was delivered to the 380 kV busses of the thermal plant in the area, via several substations in the 220 kV grid.
From Tuscany, the auxiliaries of a large Power Plant in the area of northern Rome (Lazio region) were energised and from 10:06 the re-supply of the metropolitan area of Rome began.

In southern Italy at 10:15, the 380 kV Montecorvino-S. Sofia line allowed the synchronisation between the load island sustained by Rossano thermal plant and the one sustained by Presenzano pumping storage plant.

At Valmontone substation, the closure of the 380 kV lines to Tuscany (at 10:40) increased the meshing between the grids of the Rome area and of central-northern Italy. The subsequent delivery of voltage to the 380 kV busses of Presenzano substation from Valmontone failed owing to voltage phase angles at the two nodes.

From 11:25 to 11:52 at the Adriatic backbone, it was possible to energise some 380 kV substations along the Adriatic coast allowing the re-supply of some important regions located in central Italy (Umbria region) and along the Adriatic coast (Marche region).

The following lines contributed to restoring the interconnection with UCTE's grid:

At:	08:09:17	220 kV	Avise	Riddes	line
	08:21:53	220kV	Soverzene	Lienz	line

At the end of stage 2, load in the Northern area was practically restored. Although the 380 kV grid was re-energised up to Rome and the Adriatic backbone was energised up to Marche region, the re-supplied load was still low. In the Southern area two electric islands in the southern area of Rome and in the extreme southwest region of Calabria were remeshed and expanded.

The main target was to perform the re-supply of Central-Southern Italy and Sicily within the shortest possible time. Furthermore, it was essential to deliver voltage to the generation cluster of Brindisi thermal plants in order to allow its generating units to go back into service.

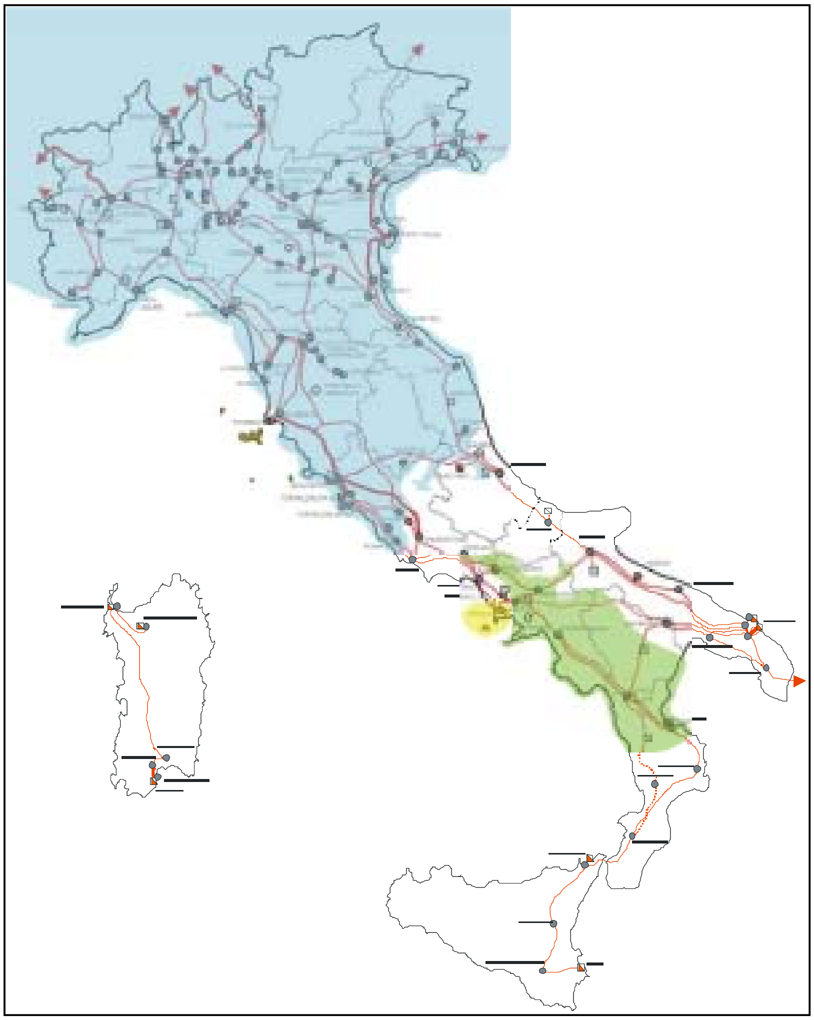

Figure 2.9: End of Stage 2

2.5.5.5 RESTORATION STAGE 3 [12:00 to 17:00]

The only thermal power plant that was still not re-energised was Brindisi Sud. The import energy from the Greek grid resulted in being the most important because it enabled the power flows between northern-southern macro areas, to be relieved of restoring security conditions.
The status of the grid and the lack of generation in Central-Southern Italy induced high power flows from North to South, creating a risk situation. This phenomenon would become worse during the evening peak period. Therefore, it became crucial to restore also the link with Greece and thus allow the import up to 500 MW.
High voltages in the Brindisi area, a faulty bus disconnector on the Sorgente line in the 380 kV Rizziconi substation and problems at Galatina substation when closing the breakers of the cable link with Greece affected system recovery time in the southern area and namely in Sicily.

The restoration of supply in the metropolitan area of Rome was completed at 13:17.

Owing to high voltage and phase angle difference in the restoration of southern area, it took more time than expected to energise busses at the Brindisi production sites. Similarly, restoring Brindisi along the Tyrrenian coast was not possible and it was therefore necessary to proceed along to the Adriatic restoration path to complete the restoration of the whole mainland southern area.

The need for re-supplying Sicily, where the restoration paths incorporated at that time were critical, required the amortisation of the submarine cable between Calabria and Sicily to the mainland from Calabria region between 15:05 and 16:38.

The interconnection with UCTE's grid completed closure at Rondissone substation and Galatina substation:

At:	12:44:04	380 kV	Rondissone	Albertville 2	line
	16:50:00	380 kV	Galatina	Arachtos	dc link

Figure2.10: End of Stage 3

2.5.5.6 RESIDUAL STAGE 4 (from 17:00 up to 21:40)

All the previously described difficulties, which were experienced upon service restoration, were amplified on the Sicilian grid.
After several unsuccessful attempts to restore the service independently, without interconnection with the Mainland, it was decided to supply the island from Calabria.
This was done at 16:38hr but the exchange could not exceed 200 MW.
Therefore, the re-supply time of the island from mainland was affected by the need to accommodate the load ramp in Italy expected at 20:00.
In effect, out of two possible paths for service restoration in mainland Italy from north to south, only the first one turned out to be practical. Hence, service restoration followed a geographic sequence; postponing the return of southern Italy's power system to normal operating conditions.
With the restoration of the Sicilian grid, the Italian power system was again under control and the cessation of the emergency conditions was officially announced at 21:40, 18 hrs 12 min. after the blackout.

2.6 COMPARISON WITH THE INCIDENT ON 20 MAY 1993

On 20 May 1993 the main part of the Italian grid was separated after cascading line tripping. Only the area of Piedmont remained in parallel operation with the UCTE main grid. The export to Italy was reduced from around 5 400 MW to 1 300 MW. The resulting deficit of 4 100 MW, which occurred in the islanded part of the Italian grid, was managed by the emergency plan with automatic disconnection of pumps and load shedding. The frequency of the disturbed area was stabilised at around 48,8 Hz and the islanded system reached a stable condition (according to the concept of emergency control) for such an event.

The main difference with the recent event is that besides cascading line tripping, no other stability problems arose. Therefore the transition from interconnected to island operation happened without severe interactions between the Italian grid and the UCTE main grid. So the influence on the remaining UCTE grid and on the islanded grid of Italy was limited and manageable.

2.7 EFFECT OF SYSTEM LOADING ON STABILITY MARGIN

The transmission distance of considerable power transfer from the generation located in Central Europe to the consumers in Italy led to a relatively high phase angle difference in the stationary parallel operation between the UCTE main grid and the Italian grid. This played a crucial role in the dramatic consequences of the incident. This can be concluded from the following two facts:

- The immediate reconnection of the line, which tripped first, was not possible because of a steady state phase angle difference higher than expected.

- The cascading line tripping evolved into a severe angle stability problem, because the initial phase angle difference between UCTE main grid and the Italian grid was rather high.

Following the strong market request for higher transmission capacities the concerned TSOs have removed some internal congestion in recent years, by strengthening their grid. Further improvements are planned over the next few years. The security standards based on the results of classical stationary load flow analysis will be kept or even improved. However, it is inevitable, that the resulting phase angle difference between UCTE main grid and the Italian grid will be increased should higher levels of power be imported. Due to this, the overall stability margin of the interconnected power system will be reduced and its consequences should be observed very carefully.

After the 28 September 2003, it has to be realised that also in Europe, where the network is highly meshed and stability problems never appeared to be so critical. Power system stability must be thoroughly analysed - even in the case of N-2 contingencies. This will require more thorough stability analyses, in order to identify possible conditions that could lead to stability problems and the necessity to define suitable countermeasures if required.

3 Analysis of Root Causes

The Committee has examined the sequence of events to identify the root causes leading to the blackout, from the point of view of management intervention necessary to avoid its reoccurrence. The analysis therefore, is not exhaustive with regard to the detailed technical analysis but draws attention to the elements that are relevant from a managerial standpoint.

The event happened at the time of the week when the load drew close to its minimum. Contrary to its outward appearance, this did not mean that the stress on the transmission system was lower than at peak hours. Indeed, as the bulk of cross border exchanges finds its origin in structural price differences, it is not the national consumptions that define the level of exchanges, but rather the transmission capacity of the system itself. Irrespective of the consumption level, market parties continuously use all available sourcing outside Italy as far as is allowed by the transmission grid.

3.1 THE N-1 SECURITY RULE

A general and long-standing operation principle in UCTE is the N-1 security rule. It basically sets the requirement that a single incident should not jeopardize the secure operation of the interconnected network. Such incidents are, for example, the tripping of a generating unit, a transmission line or a transformer. In particular, the N-1 principle aims at avoiding cascade effects. This principle is used worldwide, though its practical details may vary widely, depending on local circumstances and UCTE reliability requirements. On the highest voltage levels, it implies that the grid must be meshed and the necessary spare capacity in generation and transmission be foreseen.

When considering the first event that triggered the sequence (loss of Mettlen-Lavorgo, called the Lukmanier line), the N-1 rule implies two steps:

- First, by applying corrective measures following the loss of the line, it must be ensured that such a loss does not jeopardize the stable operation of the interconnected network.
- 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.

The scheduling procedure is a deciding factor for the state of the network before the occurrence of the first line flashover at 03:01. After exchange schedules have been agreed and matched for their consistency via UCTE (which happened on Saturday evening 27/9 at 18:30) each TSO executes an N-1 security analysis for its network, either by applying the agreed schedules on the state of

expected network or by checking the agreed schedules on a comparable previous network state. This leaves the possibility for bi-or multilateral modifications before real-time setting of the load-frequency controllers.
In the case of ETRANS, which is a coordination body between the seven Swiss grid operators and not a TSO itself, ETRANS relies for its data and corrective procedures on these grid operators. Formal assurance has been given to the Committee that the ETRANS operators possess the necessary power and adequate information for this purpose.

The main question examined in the Committee's discussions during the three weeks following the event was:

> "Was the system, before the first event (i.e. the trip of the Lukmanier line), in a state compliant with the N-1 security criterion?"

In other words: had corrective measures preventively been identified and prepared so that, after the loss of the line and in accordance with the principles of good business practice, the continued secure operation of the interconnected network would be ensured?

The Committee's response to this question was positive, as explained below under the next heading.

3.2 N-1 CRITERION WITH REGARD TO LOSS OF "METTLEN-LAVORGO"

Immediately after the loss of the line at 03:01, the flow was automatically and instantaneously redirected over several parallel lines, due to the meshing of the network. This created several overloads on these parallel lines, the Sils-Soazza ("San Bernardino") line being one of them. This line carried, due to its relatively close position, the highest overload, at a level that the Committee estimated sustainable for a time period of about 15 minutes. Indeed, if the overload was to continue for more than 15 minutes, the conductor temperature would exceed the maximum allowable temperature of 80°C. This would, in turn, cause the line to sag beyond its leeway design dimensions and thus increase the risk of flashover in an unacceptable way.

This overload on the San Bernardino line after the loss of the Lukmanier line had been correctly estimated by the ETRANS N-1 security assessment and therefore, corrective measures to reduce the overload on the San Bernardino line had been identified and prepared. The adoption of these measures was expected to be in line with the principles of good operational practice.

However, it became clearly apparent that, regarding the corrective measures necessary to deal with the event, all available margins had to be exhausted. If the corrective measures once applied, failed to succeed returning the system back to secure operation, it would no longer be a viable option. Here malfunctioning occurred on a variety of levels and it is these components that formed one of the root causes of the event.

In this specific case ETRANS needs as corrective measures which are necessary to comply with the N-1 rule, also action to be undertaken in the Italian system.

Analysis of the system's state at 02:45 and 03:00 has brought the experts to the conclusion that shutting down the pumps of the pumping storage plants in Italy was, from a technical point of view, the appropriate way of fulfilling the N-1 rule and restoring N-1 safety after loss of the line.

This was confirmed by the check list available to the ETRANS operators, which explicitly mentions that, in case of loss of Mettlen-Lavorgo, the operator should call GRTN, inform GRTN about the loss of the line, request for the pumping to be shut down, generation to be increased in Italy. This clause is mentioned in Italian on the ETRANS checklist for this incident[1].

There is no official procedure or special agreement established between ETRANS and GRTN, apart from the operational practice (which was demonstrated in previous cases) to shut down the pumps in mutual support, when requested under emergency conditions by ETRANS.
As the Italian system was pumping about 3 500 MW and the GRTN operators effectively had the authority to order the shutting down of the pumps within approximately 5 minutes, the Committee concluded that these measures would have been sufficient to return the system to a secure N-1 system state.

As a consequence, the Committee concluded that, for this moment of time, the system state preceding the first trip was in a condition compliant with the N-1 criterion.

ROOT CAUSE 1: UNSUCCESSFUL RECLOSING OF THE LUKMANIER LINE BECAUSE OF A PHASE ANGLE DIFFERENCE THAT WAS TOO HIGH

After a tree flashover on a line, it is in the majority of cases possible to manually reconnect the line. Indeed, after carbonisation of the affected tree, the line is in most cases in a state allowing safe re-closure as seen from an electrical point of view. An attempt to re-close the line was the first action undertaken by ATEL operators in close cooperation with ETRANS.

However, the operators did not succeed in reconnecting the line because an automatic device refused to switch the breakers, based on the criterion that the phase angle difference over the line exceeded 30°.
The ETRANS operator needed 10 minutes to coordinate ATEL's unsuccessful attempts to re-close the Lukmanier line and the possible countermeasures of EGL. This time period was crucial, according to the findings above, that the overload on the San Bernardino line was only sustainable for approximately 15 minutes.

ROOT CAUSE 2: LACKING A SENSE OF URGENCY REGARDING THE SAN BERNARDINO LINE OVERLOAD AND CALL FOR INADEQUATE COUNTERMEASURES IN ITALY

After unsuccessful re-closure of the line, it was necessary to activate the foreseen countermeasures for this N-1 case, not only to return to a sustainable value for the created overload on the San Bernardino line, but also to return the system as soon as possible to a new N-1 secure state.

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[1] *"Kommunikation per Telefon: ….. GRTN: Scatto della linea 380 kV Lavorgo-Mettlen. Fermare pompe, aumentare produzione !"*

The overload recorded on the San Bernardino line immediately after the first trip was, as explained above, only sustainable for a short period of 15 minutes. Such overload is temporarily acceptable according to business practice in the given N-1 context, namely because countermeasures were available within a corresponding time window, as explained in the previous section.

At 03:11[2], the ETRANS operators requested GRTN to decrease the control deviation by 300 MW[3]. The Italian control deviation[4] was fluctuating in the range of 200 – 300 MW (import surplus). The reduction of the Italian import from about 6700 MW to about 6400 MW was in effect 10 minutes after the beginning of the phone call.

The ETRANS checklist[5] also mentions that this communication shall be confirmed by fax[6].

The load flow analysis showed that this reduction could keep the San Bernadino line in an admissible operative condition; under the prerequisite however, that the following favorable boundary conditions could be met:

- air temperature of 10 °C and wind speed of 0,6 m/s
- the overload of the conductors is eliminated at the latest within 15 minutes
- minimum distances of conductors to trees are respected along the whole right-of-way
- the assumption regarding the location of additional and reduced generation (300 MW) in Italy and UCTE main grid respectively

However, this measure (and other ones, which had only small effect) did not leave a security margin to manage uncertainties. A violation of one of the above-mentioned prerequisites led to the risk of the line tripping; the case in point.

Clearly, this measure was insufficient to return the system to a new N-1 secure state.

From the measures taken it must be concluded that the operators were unaware of the urgent situation.

COMMENTS ON COMMUNICATION AND DATA EXCHANGE

Some comments on communication and data exchange between ETRANS and GRTN, which will be subject to further investigation, are to be mentioned in the context of this root cause.

The Committee did not find fault with the actual effect of the communication between ETRANS and GRTN. It was mentioned on the Swiss documents that ETRANS requested from GRTN, for the control deviation to be reduced by

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[2] Registered by ETRANS at 03:10:47.
[3] See section on communication.
[4] The control deviation is (approximately) the difference between the scheduled import and the actual physical import.
[5] According to the trilateral emergency procedure between ETRANS, GRTN and RTE dispatchings.
[6] The ETRANS fax journal indicates faxes to the GRTN dispatching at 04:34 – 06:05 - 06:36 – 08:53 – 09:14 - 09:29 – 09:41. According to GRTN, the first fax was received at 09:41.

300 MW and it was recorded that this reduction occurred, in effect, 10 minutes later.

However, some issues in the context of this phone communication need further investigation. ETRANS and GRTN, although agreeing on the request for 300 MW, disagree on the further content of the conversation, for which no voice registration was made available to the Committee by either party.

According to ETRANS, *"GRTN was informed by ETRANS on the trip of the 380 kV line Mettlen-Lavorgo and the resulting overload of the 380 kV line Sils-Soazza and asked for the control deviation to be reduced by 300 MW[7]".*

According to GRTN*, "ETRANS did not mention the line Mettlen-Lavorgo and the resulting overload on the 380 kV line Sils-Soazza, but only asked to reduce the control deviation by 300 MW".*

In this respect, it must be mentioned that GRTN receives from ETRANS on-line flow data about the most important Swiss transmission lines. This data set does not have the same level of completeness as the data on their own internal system that TSOs normally handle.
The experts found that the existence of such data set exchange does not imply that GRTN should assume responsibility for undertaking spontaneous action, as the affected lines are outside the perimeter of GRTN responsibility and the incident is not part of the GRTN N-1 contingency analysis.

This matter will be dealt with in more depth in future investigation, especially regarding the expected clarification of the dissent on the content of the phone call and regarding an examination of the on-line data exchange between ETRANS and GRTN.

3.3 UNSUCCESSFUL ISLAND OPERATION[8] OF ITALY AFTER DISCONNECTION

ROOT CAUSE 3: ANGLE INSTABILITY AND VOLTAGE COLLAPSE IN ITALY

The analysis of the sequence of events showed that angle and voltage instability occurred just before the complete disconnection of the Italian system.

This resulted in extremely low voltages in the northern Italian system at the moment of disconnection from the UCTE system.

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[7] *Information in the data file handed over by ETRANS: "03:10:47 – Kommunikation – Dispatching ETRANS informiert GRTN über Ausfall Lukmanier und Überlast der San Bernardino – verlangt 300 MW Korrektur".*

[8] *Island operation is the operation of a part of the network (i.c. Italy) separately from the UCTE system.*

This begs the question as to why the Italian network did not succeed islanding after disconnection, relying on:

- stopping the pumps (which indeed happened automatically after disconnection),
- shedding part of the load (corresponding with the balance of lost imports), for which automatic load shedding relaying was reported to exist on medium voltage levels in Italy,
- keeping in service all running generation capacity.

A necessary condition for keeping the generation in service and thus for successful island operation of the Italian system was that the voltage and frequency conditions at the moment of disconnection were close to nominal. This condition was not fulfilled: 21 out of 50 large thermal units were lost before the 47,5 Hz threshold was reached, mainly due to transient voltage collapse, which was caused by dynamic interactions between the UCTE main grid and the Italian grid during the disconnection phase. Thus the Italian system did not have the possibility of successful island operation after disconnection.

As a consequence, the observed instability phenomenon was a root cause for the fact that the Italian system was not successful in executing its island operation after disconnection.

The Committee makes clear that these phenomena and its severe consequences could not be foreseen according to the state of the art and the operational experience in UCTE. Though it is too early to reach a final assessment, the Committee would like to point out that the blackout risk is often caused by these stability phenomena, whenever the systems are highly loaded by long distance transmission of electrical energy, as in the power systems of USA and the IPS/UPS.

3.4 RIGHT-OF-WAY MAINTENANCE PRACTICE

ROOT CAUSE 4: POSSIBLE INSUFFICIENT RIGHT-OF-WAY MAINTENANCE PRACTICES

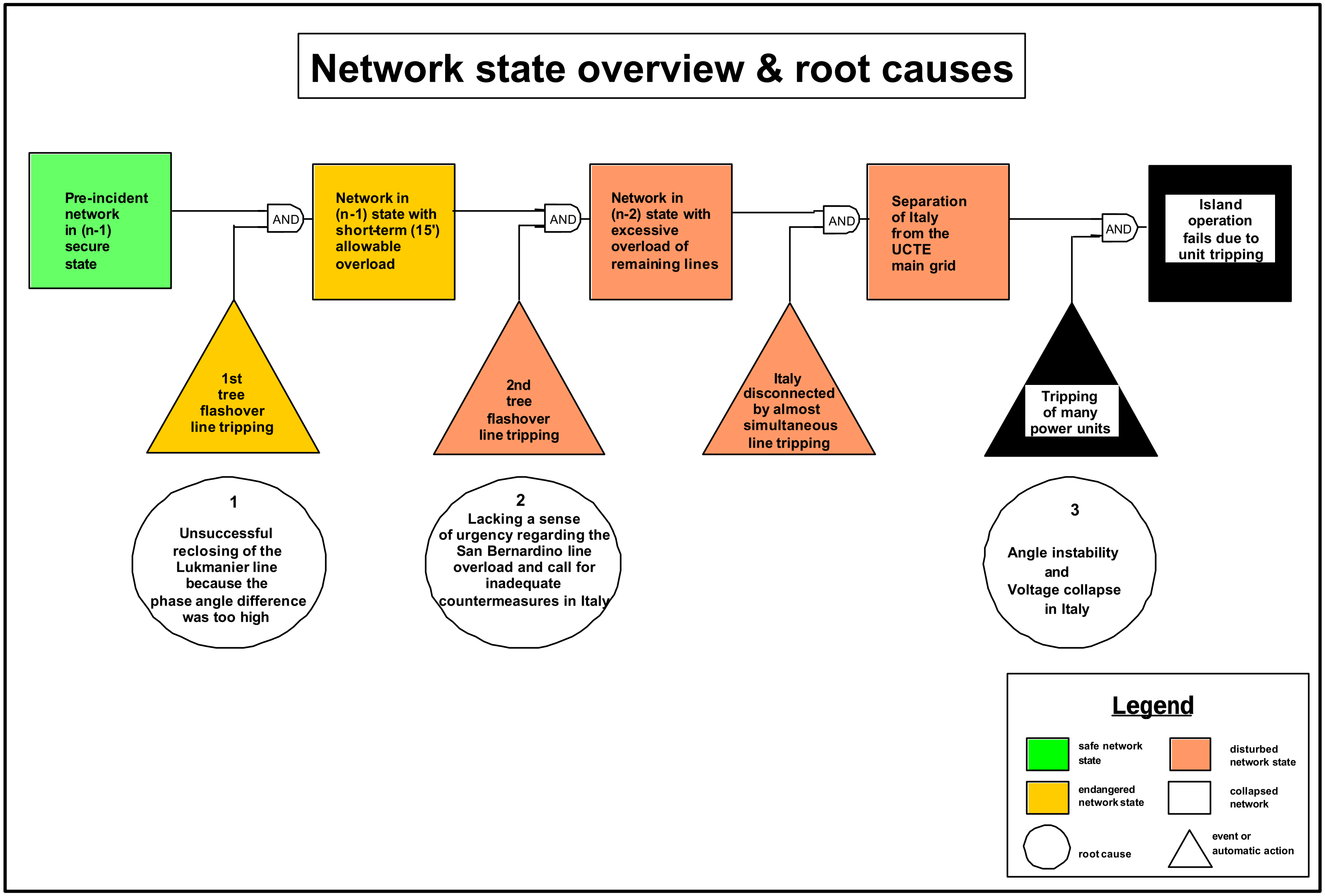
Line flashover, apart from the excessive (temporary) overload margins, may have been caused by insufficient right-of-way maintenance. Overload and right-of-way maintenance are interrelated: in case of insufficient leeway, the overload at which flashover occurs will decrease.

Concerning right-of-way maintenance, best management practices are defined and regulated on a country-by-country basis, taking into account geographic conditions, vegetation, climate, line and tower design, etc.
Therefore, the Committee did not perform a technical audit of these practices. In the meantime, the Swiss Authorities conducted an investigation on the line maintenance practices before the incident. Their findings are that the line inspections and line maintenance measures 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.

Table 3.1. Summary of root causes

These root causes should be seen in the context that the interconnected network was developed with a view to assure mutual assistance between national subsystems and, to some extent, to optimise the use of energy resources by allowing exchanges between these systems, but not in view of the present high level of cross-border exchanges. The development of the market has led to operators using parts of the network continuously, to its limits as far as is allowed by the security criteria. The blackout must be seen in this context.

	Identified root cause	Impact on events	Origin of root cause	Action
1	Unsuccessful re-closing of the Lukmanier line because the phase angle difference was too high.	Decisive	Large phase angle due to power flows and network topology	Study settings of concerned protection devices. Reassess possible consequences for NTC to Italy. Coordination of emergency procedures.
2	Lacking a sense of urgency regarding the San Bernardino line overload and call for inadequate countermeasures in Italy	Decisive	Human factor	Operator training for emergency procedures. Reassess acceptable overload margins. Study real-time monitoring of transmission line capacities
3	Angle instability and voltage collapse in Italy	Not the cause of the origin of the events but was the reason that successful island operation of Italy after its discon-nection did not succeed.	General tendency towards grid use close to its limits	Further studies necessary on how to integrate stability issues in UCTE security & reliability policy.
4	Right-of-way maintenance practices	Possible	Operational practices	Perform technical audit if necessary, improve tree cutting practices


Network state overview & root causes
Pre-incident network in (n-1) secure state
AND
1st tree flashover line tripping
1
Unsuccessful reclosing of the Lukmanier line because the phase angle difference was too high
Network in (n-1) state with short-term (15') allowable overload
AND
2nd tree flashover line tripping
2
Lacking a sense of urgency regarding the San Bernardino line overload and call for inadequate countermeasures in Italy
Network in (n-2) state with excessive overload of remaining lines
AND
Italy disconnected by almost simultaneous line tripping
Separation of Italy from the UCTE main grid
AND
Tripping of many power units
3
Angle instability and Voltage collapse in Italy
Island operation fails due to unit tripping
Legend
safe network state
disturbed network state
endangered network state
collapsed network
root cause
event or automatic action

4 Analysis of the UCTE system after separation from the Italian grid

4.1 INTRODUCTION

After the disconnection of Italy, the UCTE main grid had to manage a sudden power surplus equal to the amount previously exported. Subsequently, even the UCTE system was strongly affected and the dynamic response of different physical quantities caused an unusual and endangered system condition during the transient phase immediately after the disconnection of the Italian grid. In most of the grid operation centres, a great number of alarm messages were received and were managed by the grid operators. The messages concerned mainly:

- Overfrequency
- Overvoltage
- Deviation of power exchange from the scheduled value
- Tripping of grid elements, generation and pump units

The following analysis of the UCTE system behaviour is focused on:

- how the power balance of UCTE was kept by automatic and manual actions
- how the frequency was settled back to the normal operating range
- the control behaviour of the individual control blocks.
- why a number of loads, generation/pump units and lines tripped

Given that the UCTE 2nd synchronous zone is connected to the Italian grid through a DC link to Greece, it was also affected by the Italian blackout, when the DC link tripped after the collapse of the Italian grid.

It should be acknowledged that a detailed analysis of the UCTE system is out of the original scope of the investigation committee. Nevertheless, observations of the systems' overall behaviour should be clarified by technical explanations. In addition, it must be identified, which conclusions can be drawn for further recommendations and requirements in order to improve the system stability in case of such events. Fig. 4.1 shows the geographical area of the synchronous zones of UCTE.

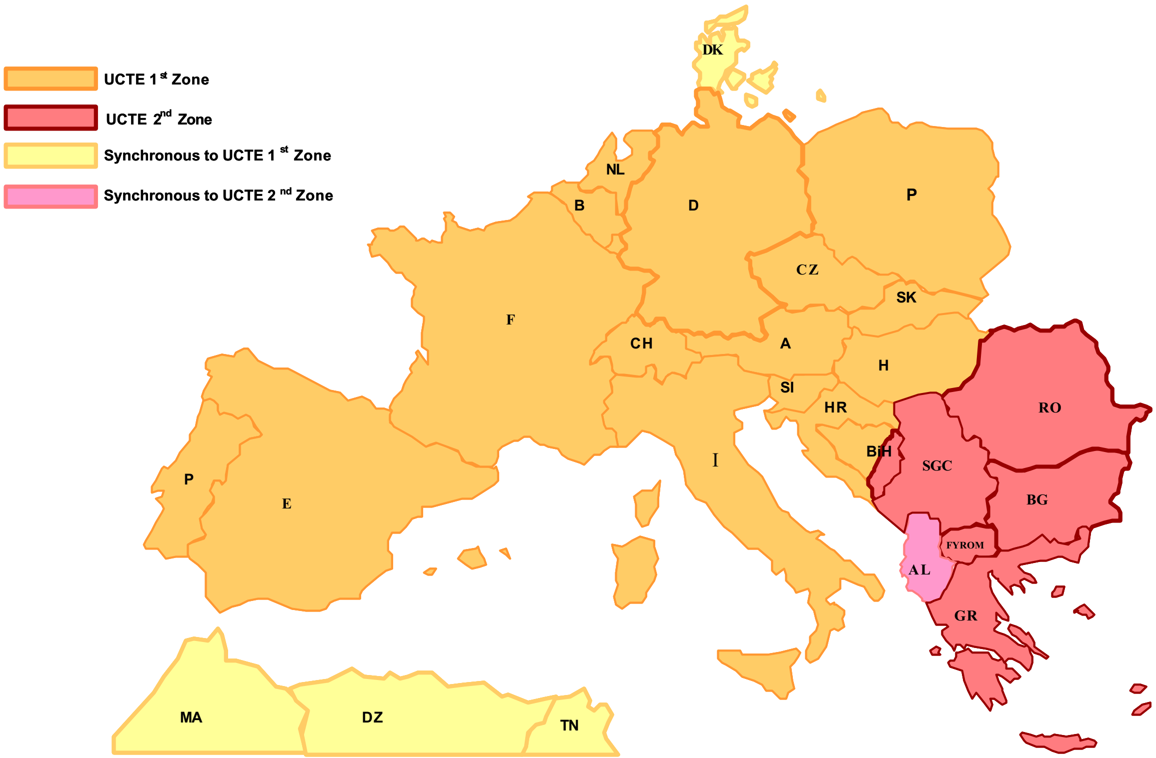


Fig 4.1: First and second synchronous zones of UCTE

4.2 PRIMARY AND SECONDARY CONTROL OF THE FREQUENCY AND THE ACTIVE POWER IN 1ST SYNCHRONOUS ZONE

The frequency recording in the time interval of 3,5 minutes after the separation of Italy is shown in Fig 4.2. The high power surplus led to an acceleration of all generators connected to the grid, which is visible by the rapid increase of the frequency. The frequency deviation reached the maximum value of around 240 mHz after 4 s and was stabilised at around 190 mHz within 1 minute by the primary control. This overfrequency corresponds to the stationary behaviour of the primary control and is kept constant until the secondary control is activated. The network characteristic number of the UCTE system resulting from the primary control and the load dependence on the frequency is given by

$$\lambda_{primary} = \Delta P / \Delta f \cong 6\,400 \text{ MW} / 0{,}19 \text{ Hz} = 33\,700 \text{ MW/Hz}$$

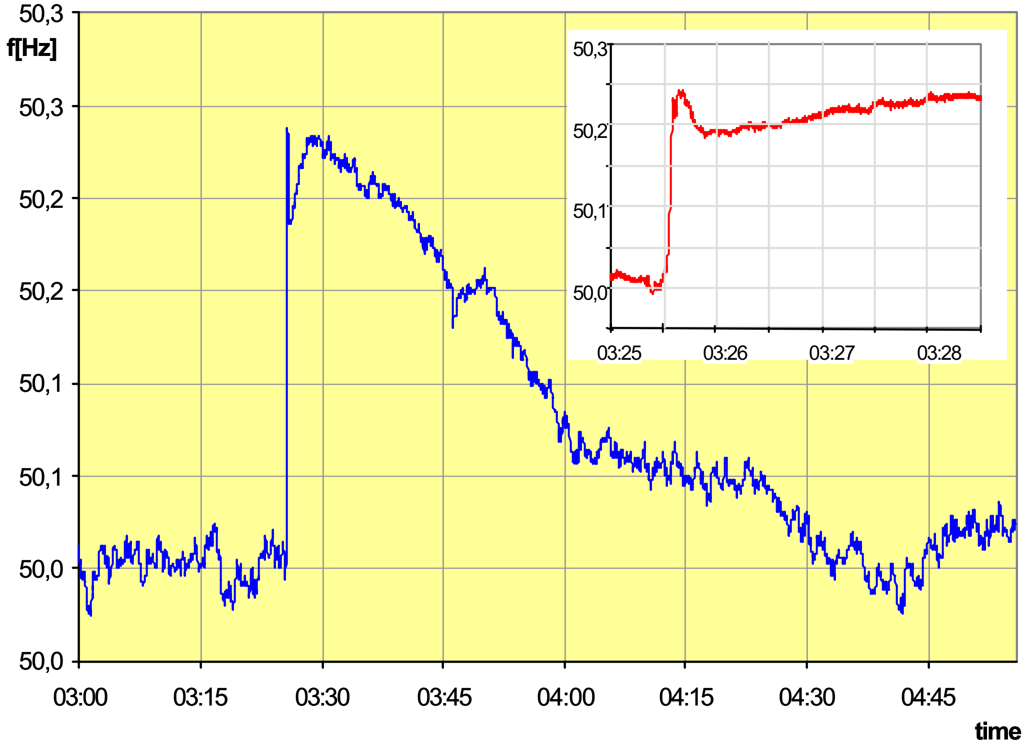


Fig 4.2 Frequency recording of the UCTE 1st zone (2 hours and zoom of 3,5 minutes)

To fully comprehend the frequency behaviour and the assessment of the manual action undertaken in the time period up to one hour after the separation, it is necessary to consider the effect of the secondary control in this unusual case. The control signal of the secondary control of each control zone is given by:

$$u_i = \frac{1}{Ti} \int (\Delta P_i + k_i \Delta f)\, dt \,, \qquad \text{(i: control area of UCTE)}$$

ΔP_i : actual exchange power minus scheduled values in control area i
k_i : network characteristic number assigned to the control area I
T_i : time constant of the secondary controller

The Area Control Error of each control zone i is given by

$$ACE_i = \Delta P_i + k_i \Delta f$$

According to the law of secondary control, each control zone i will reach a stationary state when its ACE is zero, that means

$$\Delta P_i = - k_i \Delta f$$

The whole power system reaches a stationary point, given by the secondary control, when

$\Delta P_{UCTE} = \Sigma \Delta P_i$ and $\Delta f = \Delta P_{UCTE} / \lambda_{UCTE}$ is reached,

with $\lambda_{UCTE} = \Sigma k_i = 19\ 800$ MW/Hz

Thus the secondary control ensures that each control zone matches its own power balance and thereby the total power mismatch in the system ΔP_{UCTE} is kept very small during normal operating conditions. According to the network characteristic number $\lambda_{UCTE,}$ the resulting frequency deviation Δf is kept within a very narrow operating range. Moreover, in case of disturbances with resulting power mismatch in a certain control zone, the respective secondary controller will compensate the power mismatch by activating positive or negative regulating power. The frequency deviation according to the primary control will appear, only during a transient phase, until the secondary control of the disturbed control zone becomes effective.

After separation of the Italian grid, the situation was unusual, because the power mismatch within UCTE

$\Delta P_{UCTE} \cong 6\ 400$ MW (equal to the loss of exported power to Italy)

was rather high and, according to the logic of the secondary control, was assumed to find its origin outside the remaining control zones of the system. Consequently, the frequency deviation determined by the secondary control as a stationary operating point is:

$$\Delta f = \Delta P_{UCTE} / (\lambda_{UCTE} - \lambda_{Italy}) \cong 370 \text{ mHz}$$

This stationary frequency deviation is independent from possible further power-mismatches within the control zones inside UCTE area. Therefore, the possibly positive effect on the frequency due to the tripping of some units or reduction of generation due to unsuitable control design might be compensated (at least partly) by the regular function of the secondary control of the respective control zone.

In Fig. 4.2 the effect of the secondary control is visible: the frequency deviation increases again reaching nearly 240 mHz after a few minutes. The theoretical stationary point with a frequency deviation of about 370 mHz was not reached, because the manual actions of grid operators were already taken after a few minutes.

In order to reduce the stationary overfrequency, there exists in principle two options:

- adaptation of the scheduled exchange power (reduction by the export to Italy), or
- blocking of the secondary control and directing generation units to reduce their production and/or to start pump units

After separation of the Italian grid, manual actions were executed by the grid operators in the control blocks B (Belgium), CENTREL (Poland, Czech republic, Slovaquia, Hungary), CH (Switzerland), D (Germany) and FEP (France, Spain, Portugal). Fig. 4.2 shows that within the following time period, the frequency was reduced continuously and reached the nominal value after around one hour.

Change of secondary control mode in Spain

Due to an overfrequency setting in the Spanish secondary controller, the control mode automatically switched to pure frequency control. This led to a continuous increase of import power from France to Spain. When a preset load limitation for the cross-border transmission lines was reached, the overload limiter of the secondary controller was activated and confined the power import to Spain within admissible limits.

4.3 LOSS OF UNITS AND LOADS DUE TO FAST VOLTAGE COLLAPSE

The loss of angle stability between the UCTE system and the Italian grid caused a fast voltage collapse not only in the Italian grid but also in the surrounding border areas. As the reactive power of small generators is rather limited, these units are unable to withstand the fast voltage collapse; even if the excitation control might have reached the ceiling voltage. Some small hydraulic units in Austria with a total generation of 70 MW and several units in pumping mode with a total consumption of 180 MW lost synchronism and tripped.

For large generation units, connected near the Italian border, a strong response from the generator excitation control was reported. Due to the size of these units and their robustness mainly due to the performance of their control, they were able to remain in a stable working condition.

In Slovenia some sensitive loads (100 MW) tripped due to the insufficient voltage quality.

As the secondary control was not blocked in Austria, there is no resulting effect on the power balance in the system by tripping of units. The effect of the load-tripping in Slovenia is considered as negligible.

4.4 LOSS OF GENERATION AND TRIPPING OF PUMPS

Many units tripped or reduced their generation in an uncoordinated manner due to the over frequency. This was in general not caused or justified by technical reasons, but were a consequence of the control strategy applied to the units. The frequency of UCTE is considered to be very stable and always within a very narrow operating region. Under this assumption, a frequency deviation greater than a certain threshold is often used to identify the disconnection of the unit from the grid or an island operation of a grid area after its separation from the interconnected system. This approach is problematic, as the control actions triggered by such criteria are contrary to system requirements.

As the complete positive or negative primary control power is activated at +/-200 mHz according to UCTE rules, the under- and over frequency thresholds are often adjusted at 48,8 Hz and 50,2 Hz respectively. This overfrequency threshold was reached in the whole UCTE grid after separation of Italy. The consequences were:

- tripping of dispersed generation in Spain (about 380 MW)
- tripping of coal fired units in Czech Republic due to control problems caused by the change of the turbine control from power to speed control mode (430 MW)
- tripping of several pumps units in Germany (460 MW)
- un-coordinated reduction of generation of coal fired units in Czech Republic after change of the turbine control from power to speed control mode (340 MW)
- reduction of generation of nuclear power station in Switzerland (115 MW)
- reduction of generation of coal fired and nuclear units in Germany (770 MW)

After activation of negative primary control power, the generation of a gas-fired unit in Hungary decreased below the minimum value and the unit tripped (50 MW). A gas turbine (CCGT) was turned off by protection system of the burning system, because the increase of frequency was too fast (80 MW).

In addition, a CCGT unit in Spain (210 MW) and a coal-fired unit in Romania (250 MW, 2nd zone) tripped due to unknown reasons.

Due to unit tripping and unsuitable control design, the total generation loss was almost 2 400 MW in the 1st zone (250 MW in the 2nd zone).

A resulting effect on the power balance within UCTE could only be possible, if the secondary control was blocked during the entire period of overfrequency (1 hour). As the secondary control in CENTREL was only blocked for a few minutes, there was no permanent positive effect of the generation outage in the CENTREL control block on the UCTE power balance. This is confirmed by the ACE recordings' of this control block.

The trip of units in Germany, Switzerland and Spain caused in total a loss of 1 475 MW generation and 460 MW pump load, which was effective for the UCTE power balance in a long term, as the secondary controller of the respective control blocks were blocked.

4.5 OVERALL POWER BALANCE IN UCTE

At about 04:30, the UCTE frequency had recovered its nominal value. At this moment, the restoration of the Italian system had started and Italy imported about 300 MW. Starting from an initial imbalance of approximately 6 400 MW at the moment of the disconnection of Italy, this means that the UCTE system had absorbed an imbalance of approximately 6 400 – 300 = 6 100 MW. At 04:30, the two main blocks contributing to this effect were the French (including Spain and Portugal) and the German control blocks. The methods adopted were different, as shown on the figures in section 4.6.

The French block decreased exports by about 2 500 MW by resetting the program schedules at about 03:45 and then de-blocking the secondary control. The German control block contributed by about 3 500 MW by keeping the secondary control blocked, redirecting generation and starting of pumps.

4.6 BEHAVIOUR OF THE INDIVIDUAL CONTROL BLOCKS

Fig 4.3 shows the Area Control Errors (ACE) and the unintended deviations of power exchange ΔP of the six control blocks in the 1st synchronous zone.

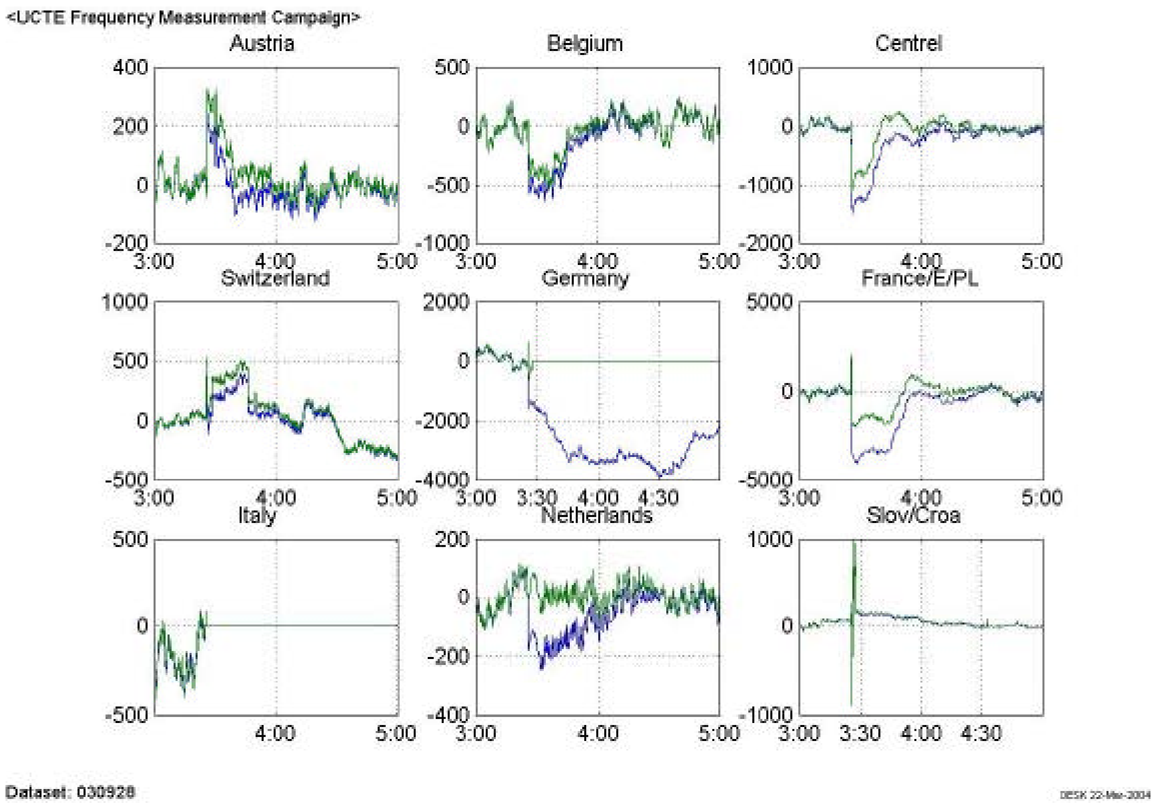


Fig 4.3: Area Control Error (green line) and unintended power exchange (blue line)

The behaviour of the individual control blocks is described hereafter:

Austria
For a few minutes the ACE increases up to +220 MW, which corresponds approximately to the loss of the pumping units in this control block. Due to the negative primary control power the ΔP - signal of the control block lies slightly below the ACE. After around 20 minutes both control signals settle back close to zero.

Belgium
In Belgium the scheduled stop of pumps was cancelled in order to support the reduction of power surplus, this led to a negative ACE of about -450 MW. Due to

the primary control the power exchange was even more reduced by around 350 MW. After about half an hour both control signals settled back close to zero.

CENTREL

The ACE spontaneously reached nearly -800 MW, which corresponds to the generation loss in Czech Republic. In addition the power exchange was reduced by the primary control reaching in total up to 1 200 MW. Although the secondary controller was blocked, albeit for only a few minutes, positive secondary control power was activated and the ACE reached almost zero after a slight overshoot. The power exchange remained slightly reduced in proportion to the frequency deviation due to the primary control.

Switzerland

In Switzerland the ACE increased up to 500 MW during a time interval of about 20 minutes, because the area of Tessin with a consumption of 200 MW was separated from UCTE and remained connected to the Italian grid. An added factor being the reduced losses of the Swiss grid by about 100 MW, when the power transit to Italy was interrupted. Due to the rise in the control signals the secondary control was blocked automatically. In addition some generation units were started in the south of Switzerland, in order to reconnect the network of Tessin with the Swiss transmission grid and to support the restoration process in Italy. At 03:46 the canton Tessin was reconnected with the Swiss grid and the ACE was reduced to about 60 MW. In the time period after 04:30 the ACE and ΔP were negative at about -250 MW.

In proportion to the frequency deviation, the power exchange ΔP is slightly below the ACE, due to the primary control.

It should be noted that the Swiss grid operator was fully concentrated on the process of system restoration. The supervision of the ACE had a lower priority during these 20 minutes after the blackout.

Germany

In this control block the secondary controller was blocked immediately after the separation of the Italian grid, its behaviour became insignificant. The power exchange was reduced by about 1 800 MW immediately after the separation of the Italian grid due to the primary control and the loss of generation in this control block. Furthermore, regarding the aforementioned manual operations; these led in total, to an increase of the power import by more than 3 700 MW.

France, Spain, Portugal

This control block absorbed a significant part of the power surplus immediately after separation of the Italian grid. This was caused by the spontaneous generation loss in Spain (590 MW) and the primary control of this control block, which was much more effective than requested, according to the network characteristic number. In total the power exchange was temporarily reduced by about 3 800 MW, which led to a negative ACE of about -2 400 MW.

About 20 minutes after the separation of the Italian grid, the scheduled power export was reduced by about 2 000 MW and the ACE settled back close to zero, while the export power remained reduced at the new scheduled value.

This is illustrated on figure 4.4

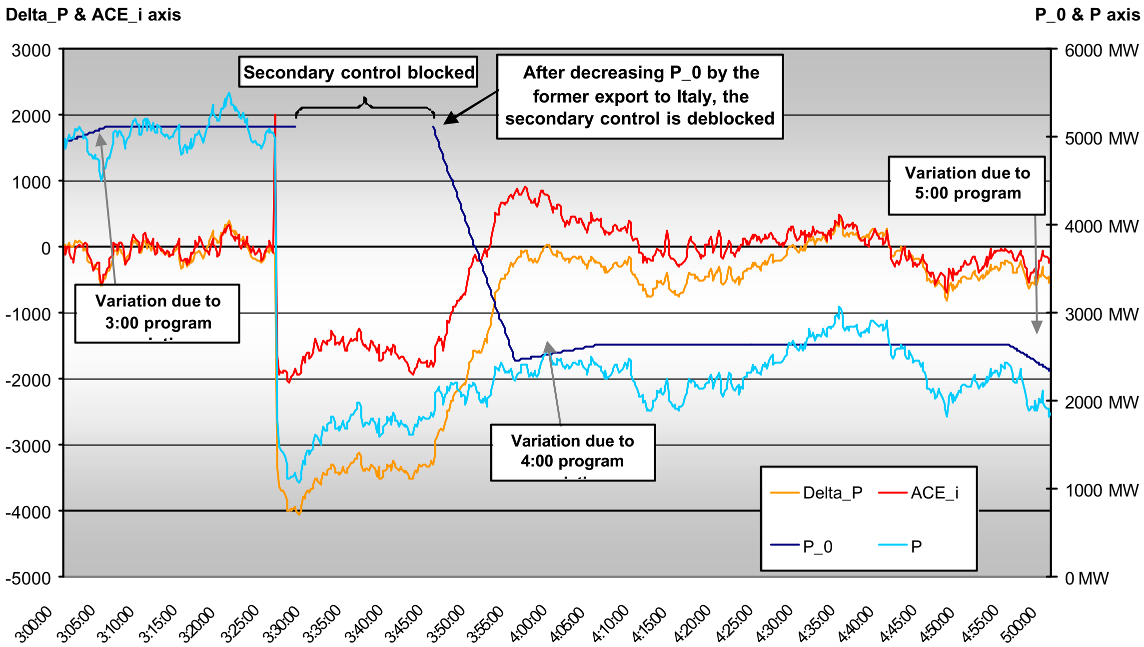


Figure 4.4

Italy

The recording of the ACE for the Italian control block, after its separation, is not shown here. The power exchange shows the interruption of the import after the separation of the Italian grid. After starting the restoration of the Italian grid its power import was around 200 MW at 03:45 and 300 MW at 04:30.

Netherlands

This control block shows quite ideal behaviour of its power frequency control. The disturbance is outside of this control block so the ACE remains close to zero, while the control block absorbs negative primary control power up to 200 MW according to the network characteristic number and in proportion to the frequency deviation.

Slovenia, Croatia, Bosnia and Herzegovina

This control block is relatively small and has no significant influence on the overall system. From this point of view, apart from the transients, there were no important observations during the separation phase.

4.7 OVERVOLTAGES IN THE TRANSMISSION GRID

The loss of the export power to Italy caused a sudden change of the overall load flow pattern in the UCTE transmission grid. As the reactive power balance and the voltage of each transmission line depend on its loading, the voltage profile in the grid was strongly affected in areas where the highest changes of the power flow occurred, mainly in:

- the border areas to Italy: Austria, south/east of France, Slovenia, Switzerland and
- Belgium, the north/east of France, south/west of Germany and Hungary,

From more than 50 substations, overvoltage alarm messages were received; some voltages reached up to 450 kV.

A voltage above the admissible maximum value of 420 kV causes the risk of damage to the grid elements; mainly power transformers, voltage and current transducers. Furthermore, the probability of a flashover is increased.

Most of the overvoltages disappeared within a few minutes thanks to automatic switching of shunt reactive power and the automatic excitation control of generators. Many generators connected in the grid areas with high voltage profiles were operating at the limit of their admissible operating range with minimum excitation and maximum absorption of reactive power.

4.8 TRIPPING OF GRID ELEMENTS

Within the grid of Slovenia, the protection device of the 220 kV line Divaca - Klece was triggered by transient behaviour of the voltage and the current during the separation phase of the Italian grid. Additionally, the synchronous compensator in Divaca tripped due to voltage oscillations during the asynchronous operation.

4.9 FREQUENCY BEHAVIOUR IN THE 2ND SYNCHRONOUS ZONE

Fig 4.5 shows the frequency recording of the 2nd synchronous zone. Before the separation of the Italian grid, the consumption within the 2nd zone was around 200 MW below the load forecast, while the frequency was slightly above 50 Hz. At 03:28, the Italian system collapsed and consequently the DC link to Greece tripped and caused a power surplus of 300 MW, which is equal to the previous export power to Italy. The maximum value of the frequency was 50,28 Hz, slightly higher than in the 1st synchronous zone. In order to reduce the frequency the grid operators in Greece started a 115 MW pump unit at 03:35 and requested the reduction of generation by 150 MW at coal fired units.

After the tripping of a 250 MW unit in Romania at 04:17, the frequency decreased and reached the usual operating range, with higher frequency deviations than in the 1st zone, which is usual for a smaller system like the 2nd zone. However the frequency increased again, obviously due to the effect of the secondary control in Romania.

Further on in the considered time interval, the frequency had the tendency to increase as the load demand was continuously decreasing.

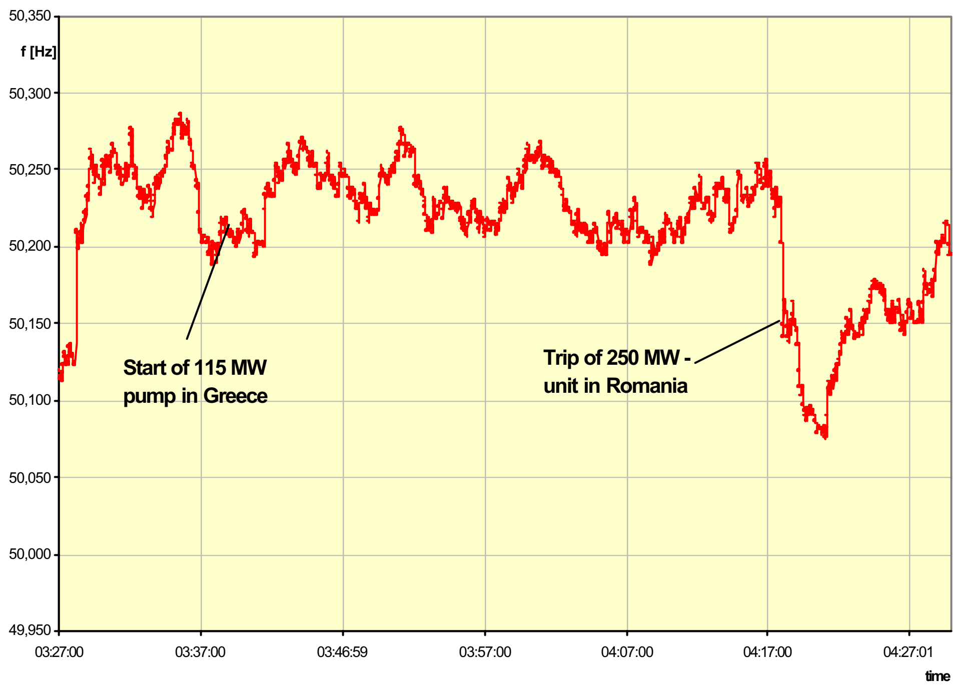


Fig 4.5 Frequency recording of the UCTE 2nd zone (1 hour)

4.10 CONCLUSIONS

Apart from minor exceptions, no interruption of the electricity supply occurred in the UCTE grid. The automatic functions of the system worked correctly during the critical phase immediately after the disconnection of the Italian grid. In particular the transient phenomena were damped well (e.g. interarea oscillations) and the high power surplus was absorbed by the primary control, by means of which the frequency could be stabilised within a few seconds.

Nevertheless it must be emphasised, that the UCTE system also was in an endangered condition after the separation from the Italian grid. The situation could be managed, as the grid operators immediately took various emergency precautions. This was achieved mainly by directing generation and pump units to new schedules and rescheduling exchange programs, which were necessary to return the transmission system back to a safe condition.

The risk regarding the system security was increased by unsuitable control design of generation and pump units, which caused an uncoordinated change of generation and consumption respectively. Consequently, the loading of different transmission lines were changed in an uncoordinated manner; not only by the loss of the export power to Italy but in addition, by the change of the generation/load pattern within UCTE. This effect is a consequence of the highly meshed and wide area synchronously interconnected system. More especially, the loading of lines from France to Germany and Belgium increased significantly.

In particular, the observations indicate that the generation and pump units are too sensitive regarding frequency deviations. It is well known from smaller power systems, like the 2nd synchronous zone of UCTE, that the units are technically able to withstand certain deviations of voltage and frequency. However, in normal operational conditions of a large system like UCTE, the frequency is kept within a very narrow range, that often is wrongly used as basic precondition for the design of the units and their control functions. Consequently, the units might not be able to support the stability of the grid in the requested manner, when the normal operation range of voltage or frequency is exceeded after a disturbance in the grid. In particular, the split of an interconnected power system might cause unusual frequency deviations in the islanded or separated parts.

A problem raised in Europe during last few years is the fact that the physical influence of modern generation units, especially dispersed generation, on the overall system behaviour is completely different from conventional generation units. This effect is no longer negligible and will probably have an increasing importance in the near future. Moreover, their physical limits are different from conventional generation units, which cause their tripping in case of certain voltage or frequency variations, as was observed at some CCGT and wind farms in UCTE after separation of the Italian grid.

All these aspects must be considered in the frame of the definition of grid requirements for generation units.

Further on, the incident shows that there is a need for better co-ordination of the power frequency control in the interconnected power system in unusual or emergency conditions.

5 Short-Term Actions taken after the Blackout

Immediately after the blackout, all the countries directly involved, Italy and its neighbours, took a set of short-term measures in order to avoid the repetition of these events and, more in general, to improve the overall security. In particular, GRTN considered urgent to initiate measures with ETRANS, but the final goal is to share the same improvements with the five neighbouring TSOs, including Greece. Only the most important elements are reported in this chapter. The tracks for longer-term action to be taken at UCTE level are described in chapter 6.

5.1 OPERATIONAL MEASURES

Net Transfer Capacity

Immediately after the outage, the Net Transfer Capacity (NTC) towards Italy was reduced on GRTN initiative as a precautionary measure during peak hours and during off-peak hours. The contingency analysis used for the reassessment of the NTC includes the loss of both lines Mettlen-Lavorgo and Sils-Soazza, as happened on September 28^{th}. The need of a reduction is based on recordings showing evidence that the two Swiss lines that tripped on 28 September 2003 were loaded on average with 300 MW more during off-peak hours than during peak hours. Due to the different generation patterns in Europe the physical flows transiting through Switzerland are often higher during the night than during peak hours.

The reassessment of the total NTC from neighbouring northern countries to Italy lead to a total NTC value for the winter 2003-2004 of 6 050 MW during day hours and 4 570 MW during night hours. Taking into consideration the technical elements mentioned in the previous paragraph and as a temporary precautionary measure, the maximum nominations from the Swiss control area towards Italy were set at 2 800 MW during day hours and at 1 600 MW during night hours.

Table 5.1 compares the new values of the NTC for the winter period to the previous ones.

Total NTC		NTC splitting			
Year		France	Switzerland	Austria	Slovenia
	MW	MW	MW	MW	MW
2003 Day and night	6 300 (TRM : 500 MW)	2 650	3 050	220	380
2004 *Day*	6 050 (TRM : 500 MW)	2 650	2 800	220	380
2004 *Night*	4 570 (TRM: 500 MW)	2 450	1 600	180	340

Table 5.1 : Winter NTC

Operation
Austrian Power Grid has taken several short-term actions:

- Modified grid topology (operation with separated busbars in certain substations) in order to reduce the power flow on critical 220 kV lines. This new topology is not applied permanently but for relatively long periods if necessary. A drawback is that, should a busbar fault occur, security for regional utility could not under all circumstances be guaranteed.
- Intensified use of phase-shifting transformers. However, the effect is limited by minimum and maximum voltage levels as power flows and voltage levels will always be influenced simultaneously.

At ETRANS[1], 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. For operational planning purposes, a third shift engineer will be added in the late afternoon, mainly for the security assessment for the next day.

Contingency analysis
In identifying the causes of the blackout in Italy, large phase angle difference between the extremities of a tripped line has been identified as being a possibly important aspect. In Switzerland, it has been included in the contingency analysis.

In Italy, a forecast based on more complete information (using the TSO Electronic Highway) has been set up as a preventive security assessment. Additional data has been requested by GRTN and will be provided by ETRANS in order to gain a broad overview of the Swiss grid and to receive an early warning

[1] *We refer to the Introduction "Institutional Framework" for the mission of ETRANS.*

in addition to the agreed communication procedure. The data set is defined to enable the state estimator to provide reliable results. GRTN is promoting the extension of this concept to its other neighbouring TSOs.

In Austria, the following measures are taken if (N-1) security is endangered:

- shut down of storage pumps
- change of generation schedules (re-dispatch)
- revise energy exchange with Federal Railway System

5.2 COMMUNICATION AND PROCEDURES

The blackout was initiated by the flashover of lines with trees. The Swiss Federal Inspectorate for Heavy Current Installations is reviewing 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 calculations are also being evaluated by the authorities.

Shortly after the blackout, ETRANS, together with the Swiss grid operators, and GRTN started an intensive co-operation to improve the communication on a technical and operational level and to identify measures to improve the network security of the Swiss-Italy interconnection. GRTN and ETRANS signed a Memorandum of Understanding (MoU) in December 2003, defining common measures to be executed and tested in the short term.

This MoU focuses on the following aspects

- Organisation framework: single interface in Switzerland for operation
- Improvement of all operational procedures for the management of the Swiss-Italy interconnection
- Each TSO is responsible for guaranteed security conditions relying on its own countermeasures
- Common countermeasures have to be agreed in advance and clearly stated; the decisions must be based on reliable measures and signals

Discussions also took place between RTE and GRTN on protections settings and on the harmonization of operational procedures.

Besides the Electronic Highway that enables the exchange of online measurement and indication information, ETRANS has started to put key network security information about the Swiss grid on the ETRANS Web. In its first phase this new type of no “mission critical” information exchange is being tested between GRTN and ETRANS.

ELES (Slovenia) initiated action as follows:

- Internal procedures for communication between neighbouring TSOs and Block Coordination Centre (ETRANS) in case of possible outage that might jeopardize neighbouring electric power systems have been revised : if a contingency does not satisfy the N-1 security criterion, the neighbouring TSOs are informed by facsimile.

- Implementation of Real-time data exchange with neighbouring TSOs has been expedited.

5.3 ADDITIONAL DISPATCHER TRAINING

GRTN and ETRANS have developed a one-week cross-programme aiming at exchanging knowledge and experience between dispatchers. Training commenced in January 2004 and is planned to be repeated on a yearly basis. The goal is to share operational experience and improve on-the-job mutual trust among operator teams.
The development of reference languages and dictionaries (standardised expressions) to improve understanding is included in the goal.

5.4 EQUIPMENT

GRTN decided to upgrade the performance of a special protection scheme that elaborates a signal to shed load in an area close to the French-Swiss border. The purpose of the system is to relieve the overload on the five 380 kV tie-lines also in case of incidents and high power flowing from France and/or Switzerland. For upgrading the system some supplementary information from the Mettlen-Lavorgo and Soazza-Sils lines are needed. For this reason GRTN and ETRANS agreed to provide direct and fast reliable signals on the state of these two Swiss lines.

In Slovenia, the relay protection system has been thoroughly revised and unification of different protection systems among respective substations is under consideration.

ETRANS and the Swiss grid operators have installed four phase measurement units (PMU) sending online information to Laufenburg. In Italy, GRTN is ready to install seven PMUs already available. These devices provide additional information about a critical network state and assist in acquiring additional know-how for use in network security calculation.

On a general UCTE level, the implementation of WAMS (Wide Area Measurement System) is under consideration. Digital WAMS units are data loggers synchronized by satellite, capable of obtaining better power system data at higher sampling rates than existing devices, and provide longer integrated recordings of multiple parameters. These devices will be integrated into a wide-area control network.

As a temporary measure, GRTN and ETRANS have installed direct phone lines independent from any other carrier. GRTN has extended the same initiative to RTE (France), APG (Austria) , ELES (Slovenia) and HTSO (Greece).
Voice recorders have been installed and are presently in use at ETRANS and GRTN dispatching centres.

In order to provide fast and reliable early warning signals to neighbouring dispatching centres, ETRANS has proposed to implement a so-called "Alarm box". This alarm box would aim at establishing a fast and reliable mechanism to give a first warning signal about transmission or production problems to neighbouring control centres by pressing a single button that leads to an immediate warning signal in the other centre. In a first introductory phase, a test installation will be put in place between GRTN and ETRANS.

6 Recommendations and Conclusions

6.1 GENERAL CONTEXT

Starting from the root causes leading to the blackout, given in Chapter 3 and the findings from the subsequent chapters, this chapter will provide recommendations for further work in UCTE, for technical and organisational issues to be implemented on a national level and concerning the regulatory framework.

In this respect, it is worthwhile to recall some main features of the blackout:

- 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.

Table 6.1. illustrates the link between the root causes mentioned in this report and the recommendations given in this final chapter. Apart from the four root

causes listed in chapter 3, the underlying reason (the high level of import of Italy) is mentioned in table 6.1. as well as some of the main findings since the release of the Interim Report: the active power imbalance in the Italian system after disconnection, the restoration process of the Italian system and UCTE system behaviour after disconnection.

Identified cause or issue	Recommendation
Use of the system for purposes other than it was originally intended for	1, 2, 3, 4, 7 sections 6.2. and 6.5.
Root cause 1: too high phase angle difference	2
Root cause 2: lacking a sense of urgency …	1, 4
Root cause 2: … call for inadequate countermeasures	1, 2, 4
Root cause 3: angle instability ….	7
Root cause 3: … voltage collapse	5, 7, 8, 9, 11
Root cause 4: tree trimming	10
Active power imbalance in Italy after disconnection	5, 8, 9
Duration of system restoration	9
UCTE system behaviour	5, 6

Table 6.1. Main causes and recommendations

6.2 THE UNDERLYING FRAMEWORK FOR RELIABILITY RULE SETTING

6.2.1 UCTE LEVEL

The technical rules on reliability and security of the interconnected system are being grouped together in the UCTE Operation Handbook (OH), of which draft chapters of Policies 1 and 3 are currently available for consultation on the UCTE website[1]. The Operation Handbook is 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. Major aspects of the system planning and system operation phase are described by former UCTE recommendations and rules, which are still valid and in place but under review by the ongoing OH transformation process. The aim is to deliver a complete set of operation standards before the end of 2004.

The Operation Handbook will be underpinned by a Multilateral Agreement (MLA) between the UCTE system operators, which is under preparation in parallel with the further drafting of the Operation Handbook.

6.2.2 THE ELECTRICITY SUPPLY CHAIN ON NATIONAL LEVEL

In most UCTE countries, rights and obligations of generators, Transmission & Distribution grid operators and grid users have been defined by various documents with different legal or contractual bases, such as Grid Codes. These

[1] www.ucte.org

may combine access, connection requirements, operation or planning codes, contracts for delivery of ancillaries, defence and restoration plans.

For secure functioning of the interconnected system, these documents must be binding; compliance to these documents for systems and equipment must be assessed with a minimum of harmonisation necessary on the UCTE level.

The UCTE Operation Handbook provides minimum requirements for several issues such as primary and secondary control, N-1 security, etc.
For other issues, such as generator unit protection settings, parties will rely much more on national practices, complemented with UCTE or other international rules and standards.

It is strongly recommended that vertical unbundling of the Generation-Transmission-Distribution (G-T-D) chain should not generate a lack of attention for the technical interaction between the G, T and D components of the system, especially regarding robustness in cases of disturbance or emergency.

6.3 RECOMMENDATIONS FOR ACTION BY THE UCTE BODIES

The recommendations in this section are part of the ongoing work in the UCTE Working Group on Operations & Security and its subgroups. They do not involve a fundamental change of direction in this work but rather draw special attention to some aspects of particular interest as highlighted by the blackout investigation.

6.3.1 OPERATIONAL PROCEDURES

It has been mentioned in Chapter 5 that the Memorandum of Understanding (MOU) agreed between GRTN and ETRANS in December 2003 focuses, amongst others, on the improvement of the operational procedures for the management of the Switzerland-Italy interconnection.

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. In this respect, the single phone call to GRTN has been treated in chapter 3.
These examples demonstrate the importance of correctly applying the emergency procedures between TSOs, once they have been agreed.

Recommendation 1
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.

6.3.2 N-1 CRITERION WITH RESPECT TO BULK POWER TRANSMISSION

It has already been mentioned that the transmission system is used today for purposes other than what it was originally intended for. In the past, the power flows between areas were more easily predictable. Due to more volatile exchange patterns, operators need to perform security analysis much more frequently.

Already before the incident the UCTE Working Group Operations & Security launched an initiative to review some implementation aspects of the N-1 criterion. A list of items to be analysed was summed up and the status review was already performed during summer 2003.In addition, some aspects will be investigated by UCTE experts with high priority, taking into account the lessons learnt from the root causes analysis:

- The compliance with the N-1 criterion cannot be assessed purely on a national or control area basis. Due to the increase of transits the interference between regions is growing. A methodology has to be worked out to guarantee an improved observability among TSOs to highlight the impact of possible N-1 violations from adjacent areas.

- Due to bulk transmission large phase angles may occur across major transmission lines in case of an outage and this may hinder re-closing the line. Therefore, where necessary, the N-1 procedures should be enhanced to take into account the phase angle. The maximum admissible phase angle before reconnection of a tripped line very much depends on network topology and the location of generators. UCTE will define basic criteria on this issue. The same yields for the effects of line sag, which depends on individual line design, ambient conditions and of course, on line loading. It will also be checked how indicators for extreme line sag can be implemented as an early warning signal.

- UCTE will also tackle the question as to which action within which time delay is to be undertaken each time a contingency has occurred, causing the need to return the system to N-1 security.

Recommendation 2

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.

6.3.3 DAY-AHEAD CONGESTION FORECAST (DACF)– FORECAST OF TIE-LINE LOADING AND ASSESSMENT OF INTERCONNECTION CAPACITY

This issue is covered by policy 4 of the UCTE Operation Handbook.

Since optimal dispatch of power plants is not part of the TSO business, there is the need to predict the flow pattern.. As the contract path doesn't match the physical path, TSOs need to establish a methodology to forecast the load flow in advance based on generation pattern, network topology and exchange balances. This is part of the operation-planning phase and may result in the detection of congestions. The DACF, nowadays in operation in UCTE through the Electronic Highway, enables the preparation of scenarios for off-line system analysis. DACF constitutes a chapter of the UCTE Operation Handbook (Policy 4). A brief description of DACF is given in appendix 3.

Having determined by means of the DACF tool the tie-line loads that a given system state can support in full respect of security criteria, the relationship can be established between given commercial interarea transactions and the physical flows resulting thereof. In other words, the values for the Available Transfer Capacity (ATC) and the Net Transfer Capacity (NTC) values can be determined.

Recommendation 3
Intensify the ongoing work on 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.

6.3.4 REAL TIME DATA EXCHANGE

Due to incidents, short-term changes in transactions, load forecast imprecision, etc., real time flows may significantly differ from the DACFs' results. Therefore, TSOs perform on regular intervals in real time security assessments of the state of the grid and take corrective measures accordingly. The basic criterion underlying these assessments is that the network must continuously be operated in N-1 security.

For such real time security assessment to be fully effective, TSOs need a sufficient level of observability of the system data in the neighbourhood of their control area in real time.

In principle, the extent and quality of real time data exchanged between TSOs should be sufficient to run the state estimators in a reliable way and perform the contingency analysis. Such data exchange already exists on several interfaces in the UCTE area. However, the blackout and its context of increasing cross border flows have demonstrated the need to enhance the exchange of real time data between TSOs, in order to enlarge the area of reliable state estimation.

Recommendation 4

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.

6.3.5 TECHNICAL SPECIFICATION OF GENERATION UNITS

An inquiry has been conducted within UCTE globally, to examine the equipment behaviour during the events of 28 September 2003. The main findings are described in the chapters 1, 2 and 4 of this report.

The early tripping of some generators by under- or overfrequency has been observed. These generators were of the centralised or the decentralised type. Some trips occurred in accordance with the settings of protections, others not. Some generators changed their control. The frequency / power control was handled differently in the various control areas.

The various settings and algorithms implemented were based on the (usually very stable) character of the frequency in the UCTE system observed in the past. The events recorded on 28 September 2003 show that, due to the high power flows resulting from the opening of the electricity market, a system-wide disruption may transpire.

The new operation conditions demand further questioning in regard to the technical requirements. For instance, due to its significant penetration level, the effect of the distributed generation may no longer be neglected and appropriate technical requirements need to be defined. The findings of the above-mentioned inquiry, stress the need for reinforcement and harmonisation of the requirement and operation rules for the equipment. The operation rules in emergency conditions are generally part of defence or restoration plans on a national level. The relevant topics will be discussed within the UCTE working group: "TSO forum".

In section 6.4, the main issues regarding the robustness of generation units in case of disturbances will be addressed. To a certain extent, requirements will have to be defined for connections to the medium and low voltage grid.

Recommendation 5

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.

6.3.6 CONTROL ACTION AND COORDINATION OF THE LFC IN CASE OF EMERGENCY

Load-frequency control (LFC) of the UCTE system is based on a decentralised approach, which is often described as frequency-bias-tie-line control. The settings of the secondary load-frequency control systems take into account the scheduled exchanges between control areas. When a split of the synchronous area has occurred, these settings become irrelevant, because the sum over all exchange schedules is no longer equal to zero.

The blackout showed that the suddenly occurring imbalance when losing a whole control area might reach the order of several thousand MW. This endangers the remaining system. This risk is rather small if control areas are more or less balanced, but in case of a bulk import or export this effect has to be taken into account for the emergency procedures.

As already mentioned in chapter 4, a coordinated LFC contr ol strategy is required in such cases. As soon as an incident has occurred and once the operators have assessed the systems' state, the schedules must be adapted appropriately. Before this initiative comes into effect, several control strategies may be adopted, for example: the temporary blocking of the secondary control.

Recommendation 6
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.

6.3.7 DYNAMIC STUDIES AND IMPROVEMENT OF THE EXISTING WIDE AREA MEASUREMENT SYSTEM (WAMS)

Performing UCTE-wide stability analysis is part of a long-term coordinated research effort by the UCTE members.

As a basic support tool for stability analysis, UCTE members have operated, since 1998, a "Wide Area Measurement System" (WAMS) which consists of logging devices at certain places in the grid that are time synchronised by GPS. Recordings are triggered by e.g. underfrequency, overfrequency, frequency transients or undervoltage. A wide range of trigger options can be chosen. The results can be accessed by remote reading and deliver precisely timed synchronised recordings. In this way frequency variations can be traced not only versus the time axis but also according to the place in the system too. The set of logging devices is used to monitor interarea oscillations, to learn about the dynamic behaviour of the system and to improve the UCTE power system model, which is used for off-line stability analysis.

The analysis given in this report was very much supported by the WAMS recordings. Therefore UCTE started an ad hoc team to analyse further improvements of the monitoring system. In the context of system extension, like the interconnection with CENTREL in 1995 or the re-synchronisation with the southeastern part of UCTE, the WAMS plays an important role. The new modes of interarea oscillations, which arise after the system extension, are monitored including their damping by specific control devices (e.g. PSS).

Additional sites are under inspection to install extra data loggers. Due to the changed system use, e.g. more bulk transmission, the dynamic security aspects of the existing UCTE system calls for reassessment. The currently installed data loggers are shown on figure 6.1.

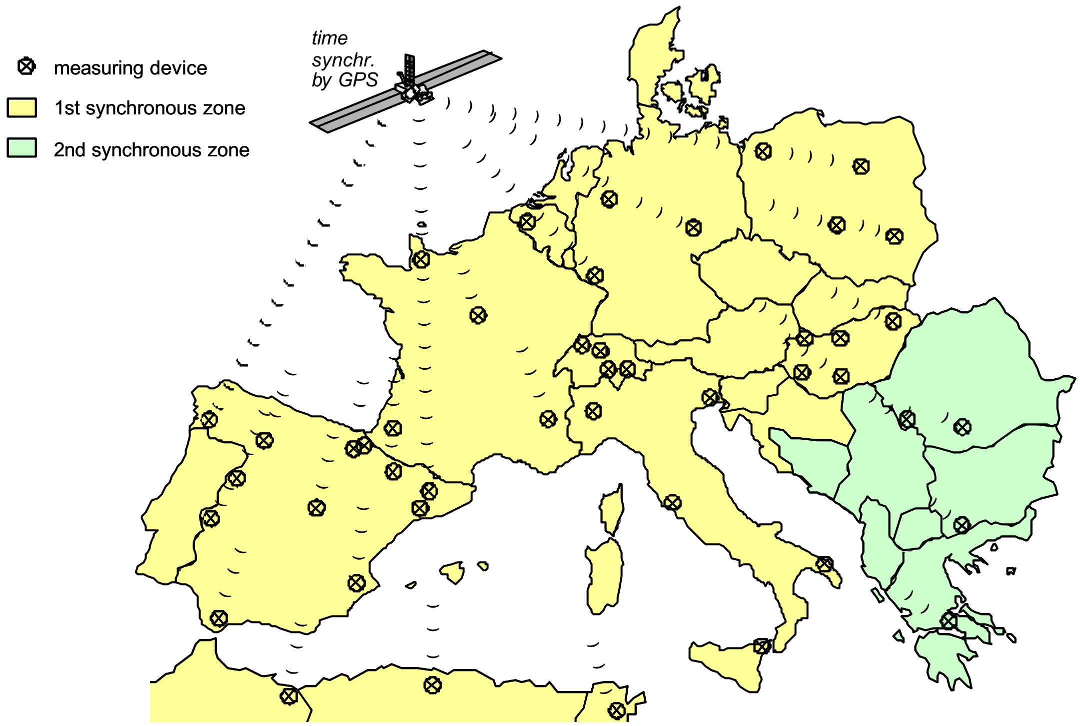


Figure 6.1: UCTE WAMS

> **Recommendation 7**
> As a support tool for dynamic analysis and monitoring of the UCTE system, accelerate the ongoing WAMS installation program.

6.4 RECOMMENDATIONS REGARDING THE SUPPLY CHAIN ON A NATIONAL LEVEL

6.4.1 GENERATION UNIT TECHNICAL SPECIFICATIONS

Although UCTE may provide basic harmonisation criteria, the requirements of generation units are enforced by national regulations and grid codes.

A distinction may be made between centralised and distributed generation (DG).

Centralised generation
The generating units must remain connected to the power system for as long as possible, in order to help overcome disturbances and avoid cascading effects. Therefore, limiters must be incorporated into the generating units control in order to ensure operation under severe conditions; possibly with reduced capabilities and to avoid a trip triggered by the protection devices. Over- and under-excitation limiters are well known examples of such devices.

However, an automatic disconnection of the generating units outside a given frequency and voltage interval is motivated by the safety of the equipment and the possibility to switch, in time, into a stable isolated operation on house-load, thereby shortening the start-up process in case of blackout. The underfrequency threshold for the centralised generation was set to 47,5 Hz in the past. However, the introduction of heavy-duty gas turbines in open cycle or combined cycle brought about, to some extent, the releasing of the disconnection threshold. Exceptions from the 47,5 Hz underfrequency level should be limited as much as possible and duly justified for technical reasons.
A similar argument applies to the overfrequency disconnection threshold.

Attention must be paid to other requirements such as reactive power capability, robustness against voltage disturbances, design of excitation system, dynamic behaviour, etc. However, not all topics need integration on a system level, since the regional grid features allow or recommend variants for the generating units' behaviour.

Distributed generation (DG) and cogeneration
First of all, the distinction between centralised and decentralised (or distributed) generation is not uniform among the TSOs. In any case, the effect of the increasing amount of new types of generation units, in particularly renewables like wind farms, on the overall system's behaviour has to be observed carefully. This is primarily due to specific physical characteristics, which are completely different from conventional generation units. The harmonisation of technical requirements on a system level requires a harmonisation of the equipment definition to which these requirements apply.

In many countries, there is a legal obligation prescribing automatic disconnection of the distributed generation (DG) from the MV and LV public distribution networks, in case of trip out of the circuit breaker supplying the line, to which DG is connected or when the public network undergoes faults or abnormal operations. Indeed, power supply from islanded DG onto MV or LV lines disconnected from the network, should be avoided in view of the potential damage to customers due to large deviations of voltage and frequency from rated values. During repairs of a faulty MV or LV line, the relevant DG must be disconnected for the safety of utility personnel.

To avoid the use of costly tele-transmission equipment, a local criterion is often used to detect feeder disconnection, based on the frequency. Thus, in case of system frequency drop, DG is tripped, aggravating the generation-load imbalance.
The connection code (technical requirements on equipment) should impose sufficiently large frequency and voltage operation intervals for DG.
In case of significant penetration degree of DG, voltage support, and possibly frequency support, should be encouraged.

While the Operation Handbook under development handles the TSO to TSO relations and therefore describes a horizontal technical framework, there is also the aspect of grid access, which is handled by national electricity acts, grid codes or even bilateral contracts. This framework must be compatible with system requirements harmonised on UCTE level (cf. Recommendation 7).

Recommendation 8
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.

6.4.2 DEFENCE AND RESTORATION PLANS

Frequency driven load shedding on a local level is an essential part of defence plans to avoid system-wide disruptions in case of multiple or severe contingencies.

Defence plans should take into account the tendency towards higher levels of underfrequency settings on the generation side (for technical reasons of gas fired plant, for security reasons on generation units embedded in distribution networks).

If the amount of generation units with underfrequency thresholds above 47,5 Hz is significant in a given area, this has to be compensated by a corresponding review of the load shedding plans. In this case, the robustness of the load shedding plan may be endangered in case of heavy frequency transients.

Voltage and stability driven load shedding are issues to be examined taking into account the local network and system characteristics.

The rapidity of the restoration of a system after blackout heavily depends on two factors: the capability of generation units to remain in operation on the house-load after disconnection of the grid and the availability of some geographically spread black-start units in the system.
Simulation and testing exercises on defence and restoration plans is a joint task for generators, TSOs and distributors.

The Committee asserted that each defence plan is a strictly last resort option. Its success is dependent on a complex set of interactions between generators, system grid operators and customers, starting from a quite often already disturbed system state. Therefore, TSOs endeavour to succeed but have to deny liability for the performance of a defence plan.

Recommendation 9
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 in-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.

6.4.3 TREE TRIMMING PRACTICES

Given the observed strong correlation between the reliability of overhead lines and the right of way maintenance and leeway specifications, special attention should be given to tree trimming practices.

> **Recommendation 10**
> Tree trimming practices should be evaluated and the operational results should be audited with respect to the line sag in maximum rated overload condition.

6.4.4 MEASURES AT DISTRIBUTION NETWORK LEVEL

Experiences from earlier disturbances have shown that some important measures should be taken to improve the system's resistance against phenomena such as voltage collapse and frequency distortions. Apart from setting appropriate technical requirements on distributed generation (recommendation 8) and participating in frequency-driven (and possibly voltage-driven) load shedding (recommendation 9), the following specific measure should be part of the defence plans.

> **Recommendation 11**
> The blocking of On Load Tap Changers (OLTC) of transformers in case of severe voltage drop should be accepted practice.

6.5 RECOMMENDATIONS REGARDING THE INTERFACE WITH THE REGULATORY FRAMEWORK

6.5.1 EMPOWERMENT AND INDEPENDENCE OF TSOS

All of the credible models for creating new competitive electricity markets, recognize that there must be a single network operator responsible for controlling the physical operation of a control area, coordinating generating schedules, balancing loads and resources in real time, acquiring ancillary network support services required to maintain reliability, and coordinating with neighbouring control areas – performing Systems Operations (SO) activities[2].

The above statement from an academic may be found in many variants in the literature on electricity sector reform. The countries in the European Union have been forerunners of this model since the first electricity Directive of 1996. The new 2003 Directive 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.

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[2] *Paul L. Joskow in "Electricity sector restructuring and competition: a transaction-cost perspective", Cambridge University Press 2002 (Edited by Eric Brousseau and Jean-Michel Glachant)*

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:

- The assessment of transmission capacity (ATC and NTC – cf. section 6.2) available to market players.

- In order to be able to handle contingencies, TSOs must have the authority to re-dispatch generation or to activate reserve or balance generation capacity when security is at stake. The mechanisms employed to cover the costs involved must be, as far as possible, transparent and with the appropriate incentives to maintain the right balance between security and economic criteria. Where re-dispatching, reserve or balancing power is not available by competitive offer, regulatory control of such power purchase is necessary.

- After full exploitation of the measures described above, TSOs must be empowered to take last resort measures such as, transaction curtailment and load shedding for keeping the system secure.

- As indicated in section 6.3, TSOs must be empowered to participate in enforceable standard setting and demonstrate their compliance in assessment regarding the technical requirements of generation capacity, emergency and restoration plans.

6.5.2 SYSTEM ADEQUACY

In recent years, UCTE has increased its activities as watchdog for system adequacy, by publishing regular power balance forecasts, taking into account the main transmission constraints. These activities are being further developed.

Although it is not strictly a UCTE competence, clearly, market rules and incentives tending towards better adequacy are essential:

- On a market level: where structural congestion occurs, signals should be given to market players to promote a more geographically adequate development of generation and to the system as a whole. It is out of UCTE's scope to give further recommendations on the type of potential initiatives and interests (local tariffs with clear allocation signals, market based congestion mechanisms, market coupling, etc.)

- On a general level: the need for harmonisation on several issues: taxation, building permission, environmental constraints and all other elements leading to non-balanced developments, put strains on the system and lead to security risks.

6.5.3 INVESTMENTS IN TRANSMISSION SYSTEM

When considering system adequacy, it must be kept in mind that TSOs experience huge difficulties with gaining the permission for new interconnection capacity and for reinforcement of the internal grids. This element must be taken into account when considering the location of new generation capacity.

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 investment 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.

Appendices

APPENDIX 1 – TERMS OF REFERENCE

UCTE

Italian 28/9/03 black-out Investigation Committee

TERMS OF REFERENCE

Introduction

The following UCTE Members involved in the 28/9/03 blackout on the Italian peninsula:

- Swiss UCTE members, represented by H. Niklaus and T. Tillwicks, ATEL (Switzerland),;
- Austrian Power Grid (Austria), represented by H. Kaupa and E. Pokorny;
- ELES (Slovenia), represented by U. Salobir and F. Hocevar;
- ETRANS (Switzerland), represented by K. Imhof;
- GRTN (Italy), represented by C. Sabelli and G. Manduzio;
- RTE (France), represented by P. Bornard and H. Laffaye;

and UCTE representatives:

- M. Fuchs, President
- F. Vandenberghe, Chairman of the Steering Committee
- M. Bial, secretary general,
- K. Kleinekorte, Convenor of the Working Group Operations & Security
- F. Cahyna, Advisor,

have met on 2 October 2003 in Brussels and agreed to set up an independent UCTE Investigation Committee (the "Committee") according to the Terms of Reference as set forth below.

Parties to the Terms of Reference

The present Terms of Reference are agreed between 10 UCTE members involved in the Italian blackout ("Directly involved UCTE Members"): APG (Austria), ELES (Slovenia), GRTN (Italy), RTE (France) and Swiss UCTE members ATEL, BKW UTN, EGL Grid, EOS, ETRANS and NOK.

Purpose of the Committee

The Purpose of the Committee is to bring a transparent and complete explanation to national an European Authorities and to the general community and to assess and possibly improve UCTE Reliability rules by :

- investigating, on the level of the 5 involved countries, events and causes relative to the 28/9/03 Italian black-out,
- evaluating them with respect to UCTE reliability rules and possible bi-or multilateral agreements relevant to system security and reliability,
- examining compliance with rules,
- assessing adequacy of present practices and rule-setting
- possibly proposing improvements to practices and rule-setting.

The Committee shall produce reports (Reports) according to a procedure and time schedule as set out in the present Terms of Reference (TOR).

Composition of the Committee

The Committee is composed of the following Members (Committee Members), belonging to two different groups :

- Group of "Directly involved Committee Members": Two representatives – one designated speaker and one supporting expert – for each of the 5 involved countries: Austria, France, Italy, Slovenia, Switzerland. For each representative, an alternate member may be appointed, who may replace the representative in case the latter is unable to attend.

- Group of experts ("Experts Group"):

  - three independent TSO experts from non directly involved UCTE countries. The Convenor of the UCTE Working Group Operations and Security shall be a member of the Experts Group and is designated as Data Manager for the tasks of the Committee.
  - the Committee Chairman, assisted by a secretary. The Chairman of the Steering Committee has been designated for this task.

The name list of the Committee Members as of 6/10/03 is attached to these Terms of Reference.

Tasks of the Committee

1. Collect all relevant data for the purpose of the Committee, according to a list and specification decided by the Committee on proposal by the Data Manager.

2. Based on collected data, establish a factual sequence of events concerning all relevant data such as, among others:
   - pre-incident conditions of the network, a.o. interchange schedules and load flows;
   - Loss of interconnection lines;
   - Coordination and communication between control centres;
   - Response of power plants, especially with respect to control actions;
   - Load shedding (if any),
   - Transient phenomena;
   - Etc..

3. Investigate the sequences of events from a “good practices” point of view and compare them with other situations and events with similar or comparable grid state.

4. Perform a “root cause” analysis of events.

5. Investigate compliance with UCTE rules and, if applicable, bi-or multilateral agreements and/or practices established and applied between TSOs relevant to system security and reliability.

6. Assess adequacy of existing rules and agreements and possibly, propose improvements.

Data collection and exchange

- All Directly involved Committee Members shall provide data in good faith, as decided by the Committee, as soon as possible and in any case not later than the deadline set by the Committee.

- During the activities of the Committee, all data provided within the scope of the Committee shall be stored in a secure and strictly confidential way by the Data Manager in a dedicated “Data Warehouse”.

- All data in the Data Warehouse shall be made accessible exclusively to each Member of the Committee.

Data confidentiality

The Committee Members and the Secretary shall not use any information obtained by the activities of the Committee (especially all data contained in the Data Warehouse) for any purpose other as required by its legally or regulatory imposed obligations as Transmission System Operator, nor disclose any such information to any third party other than the Committee Member's TSO personnel who have a strict need to access such information for the proper performance of their professional Transmission System Operator activities and who are correspondingly bound by the same strict obligations of confidentiality.

This excludes information which is already in the public domain for reason other than by breach of this clause or already lawfully in the possession of the concerned party.

Publicity of Data by the Committee's reporting

The Directly involved Committee Members agree that all data that are to be included in the Reports by the Committee, on which the Committee shall decide according to the procedure below, shall not be subject to the above-mentioned confidentiality clause from the moment of delivery of the Reports by the Committee.

Reporting and time schedules

A first intermediate Report by the Committee shall be made available to the UCTE President on 20 October 2003 at 16h00. This report shall contain at least full and transparent information concerning the points 1, 2, 3, 4 and 5 above-mentioned under the heading "Tasks of the Committee".

From this moment on, all information contained in this Report shall be considered as in the public domain.

After delivery of the first intermediate Report, the Committee shall continue its activities on point 6 mentioned under the heading 'Tasks of the Committee". Procedures and deadlines for the next step(s) shall be determined in due time.

Committee decision making

With regard to the Purpose of the Committee, the Committee Members shall aim at consensus on all decision-making relative to the scope of work.

Following procedures are agreed in the case that no consensus can be reached:

- Directly involved Committee Members shall provide to the Data Manager, in due time and as far as available all data which are considered unanimously by the Experts Group as being essential for fulfilling the Purpose of the Committee;

- Information obtained in the course of the Committee's activities and which is considered unanimously by the Experts Group as being necessarily included in the Report of the Committee, shall be included in the Report.

- Statements and conclusions to be included into the Report have to be unanimously agreed by the Experts Group.

With regard to the urgency of the Scope of work, all decision making by the Committee can be made by E-mail.

Duration

Present Terms of Reference are valid until 31 March 2004.

APPENDIX 2

FACTUAL SEQUENCE OF EVENTS OF THE BLACKOUT IN ITALY ON SUNDAY 28 SEPTEMBER 2003

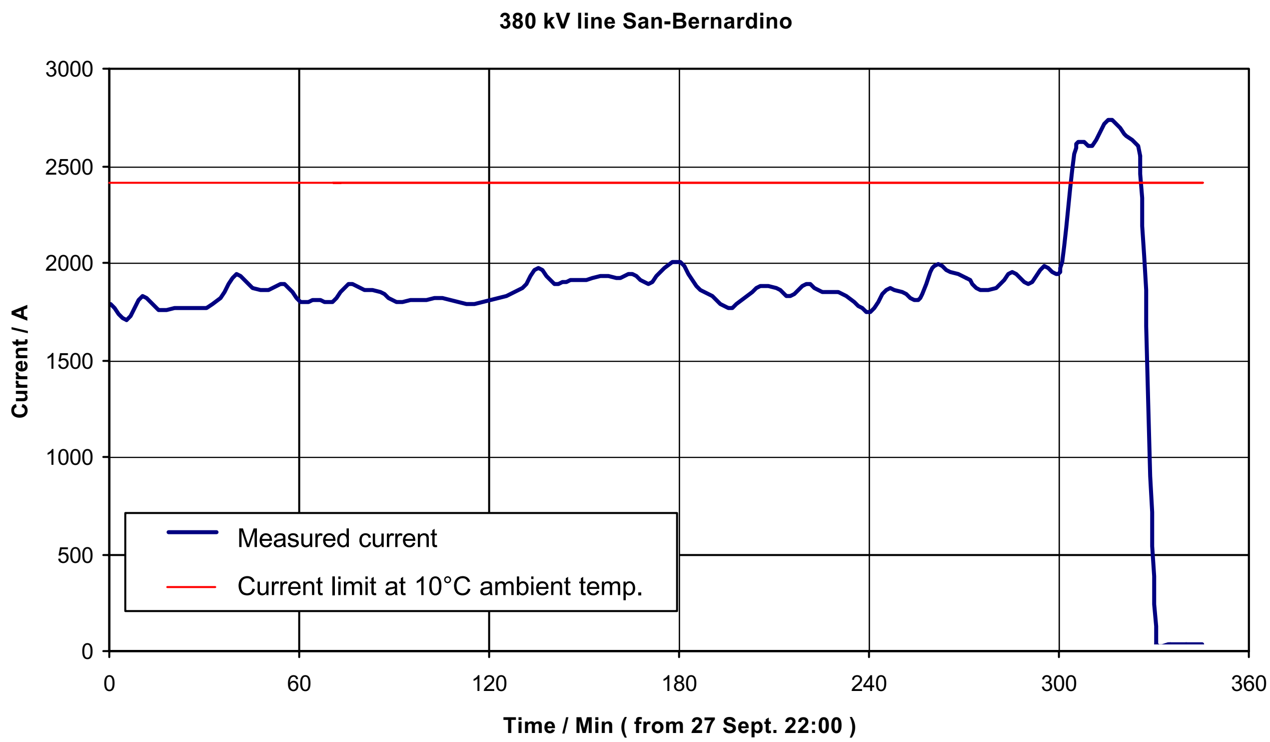
The following table shows with several time stamps the events that took place including some notable details.
The transferred power flow before the outage from each tripped line is shown between brackets in most cases.
The time indicated for each event might be inaccurate since there is no time synchronisation between all protection devices.
The sequence of events has been set up according to the best available information.

Time	Events	Coun-try	Details
03:01:21	• Single phase to ground fault at 380 kV line Mettlen-Lavorgo • 380 kV line Mettlen - Lavorgo: starting of zero sequence protection	CH CH	
03:01:42	• 380 kV line Mettlen-Lavorgo definitely switched off at Lavorgo; after two unsuccessful automatic attempts to reconnect the line, line at Mettlen still connected and under voltage	CH	• 2 100 A (limit: 2 400 A) • A proposal was made by EGL to ETRANS (by phone) to disconnect the 380 kV line Pradella-Filisur, in order to reduce the incoming 380 kV power flow from Austria. This proposal was rejected by ETRANS because it would strongly weaken the interconnection with Austria. • EGL, ATEL and ETRANS started the coordination to take Swiss internal countermeasures.
03:05:53	• Load alarm at Lavorgo 220 kV transformer 1	CH	• 871 A (limit: 866 A)
03:06:12	• Heavy load on the 220 kV line Mettlen-Airolo was spotted	CH	• 1 970 A (limit: 2 400 A); this current earlier was 1 200 A
03:08:23	• Attempt at Lavorgo to get 380 kV line Mettlen-Lavorgo into operation again	CH	• Due to an overly high phase angle difference of 42° this attempt failed
03:10:47	• Communication (phone call) between ETRANS and GRTN	CH	▪ ETRANS asked GRTN to reduce the import of Italy by 300 MW. The reaction of GRTN came into effect 10 minutes after the beginning of the call.
03:18	• EGL decided to switch off one 380/220 kV transformer in Soazza after the coordination with ETRANS and ATEL	CH	• This was an additional measure from ETRANS in order to reduce the load of the 380 kV line Sils - Soazza below 100%
03:22:02	• Tap change of 220 kV transformer 1 at Lavorgo	CH	• ATEL has changed the transformer tap in Lavorgo, which slightly reduced the load of the transformers in Soazza • 840 A
03:25:21	• Trip of 380 kV line Sils - Soazza line [1 783 MW] after single phase to ground fault • Protection of 220 kV line Mettlen - Airolo triggered at Airolo	CH	▪ Line was first disconnected at Sils, then at Soazza. (2 700 A ; limit: 2 400 A)
03:25:25	• Trip of 220 kV line Mettlen - Airolo at Airolo [740 MW]; at Mettlen the line stays connected and under voltage	CH	• A, F: undervoltage alarm • UCTE 1st zone, overvoltage alarm in A, B, F, D, HU, SLO • At a great number of substations, voltage > 420 kV, lasting until 03:32 Reduction of overvoltage is realised in ○ HU: by 350 Mvar shunts switched on ○ A: by 200 Mvar shunt reactor switched on ○ A, B, D, HU, SL: by many generation units that operated at underexcitation limit • All circuits from Airolo were tripped, i.e. to the direction of Mörel, Ponte, Lavorgo and Mettlen: 3 070 A (limit: 2 400 A). The canton Tessin remains connected to Italy but is disconnected from the Swiss transmission system and the UCTE system.
03:25:26	• Start of automatic disconnecting device at Lienz	A	▪ I > 900 A on 220 kV line Lienz - Soverzene (limit: 750 A)
03:25:28	• Trip of busbar coupler at Lienz • Trip 220 kV line Cislago - Sondrio	A I	• I still > 900 A on 220 kV line Lienz - Soverzene

Time	Events	Coun-try	Details
03:25:30	• Undervoltage alarm	F	• At Albertville: Unom < 80 %
03:25:32	• Trip of 380 kV line Albertville - La Coche • Trip 220 kV line Riddes - Avise [281 MW] • Trip 220 kV line Riddes - Valpelline [299 MW] • Trip of storage pump at Malta (145 MW) by voltage drop, tripping of storage pump within 110kV network (35 MW) by voltage drop, tripping of several small generators (within 20 kV networks)	F CH - I CH - I A	
03:25:33	Trip of 220 kV line Lienz - Soverzene at Lienz [209 MW i.e. >548 A] • Trip of 220 kV line Le Broc-Carros - Menton - Camporosso [248 MW] • Frequency alarm in all control centres of the first UCTE zone • Area control area alarm, 1st UCTE zone: CZ, CH, E, D, HU, PL, F	A - I F - I	• I > 1 200 A • Due to the tripped 220 kV line Lienz - Soverzene: voltage increased in southern Austria until 03:27, i.e. approx. 250 kV at Lienz (maximum permissible voltage 245 kV) and approx. 431 kV at Lienz (maximum permissible voltage 420 kV). • Frequency: > 50,20 Hz • This area control alarm lasted until 05:45
03:25:34	• Trip of 380 kV line Albertville - Rondissone 1 at both substations [841 MW] • Trip of 380 kV line Albertville - Rondissone 2; disconnected only at Rondissone [682 MW]	F - I F - I	• Single phase fault + automatic reclosure + finally three phase trip
03:25:35	• Trip of 380 kV line Divaca - Redipuglia [646 MW] • Trip of 380 kV line from Redipuglia to Planais • Trip of 220 kV line from Redipuglia to Safau	SL - I I I	
03:25:42	• Trip of 220 kV line Divaca - Klece including 220 kV synchronous compensator in Divaca • 100 MW of sensitive loads tripped • Change from power frequency control to frequency control mode • Trip of pump load o 180 MW (loss of synchronism) o 250 MW (due to overfrequency) • Trip of generation units due to loss of synchronism in: o 35 MW near Italian border (hydro) • Trip of generation units due to overfrequency o 430 MW (coal, after change to speed control mode) o 380 MW (renewables) o 215 MW (coal) o 95 MW (gas) o 130 MW gas/CCGT • Trip of generation: 210 MW Castellon (CCGT), reason unknown • Nuclear generator's control mode change due to overfrequency: 115 MW generation reduction	SL SL E A D A CZ E HU HU HU E CH	• Increase of voltage on 380 kV and 220 kV level in the rest of the Slovenian network • 460 MW of pumps voluntarily maintained in service in B, contrarily to schedule • From 03:25 until 03:50 some 1 740 MW of pumps were started in D; 180 MW of pumps were started in A at 03:35 as well as 115 MW in GR; at 04:29 in BG 50 MW of pumps were started
03:26	• All circuits at 220 kV Fiesch disconnected • Generation units malfunctioning due to overfrequency : o 340 MW (coal, after change to speed control mode) o 770 MW (coal)	CH CZ D	• Fiesch without voltage • From 03:26 until 04:30 some 1 570 MW generation decrease in D and 4 000 MW in F

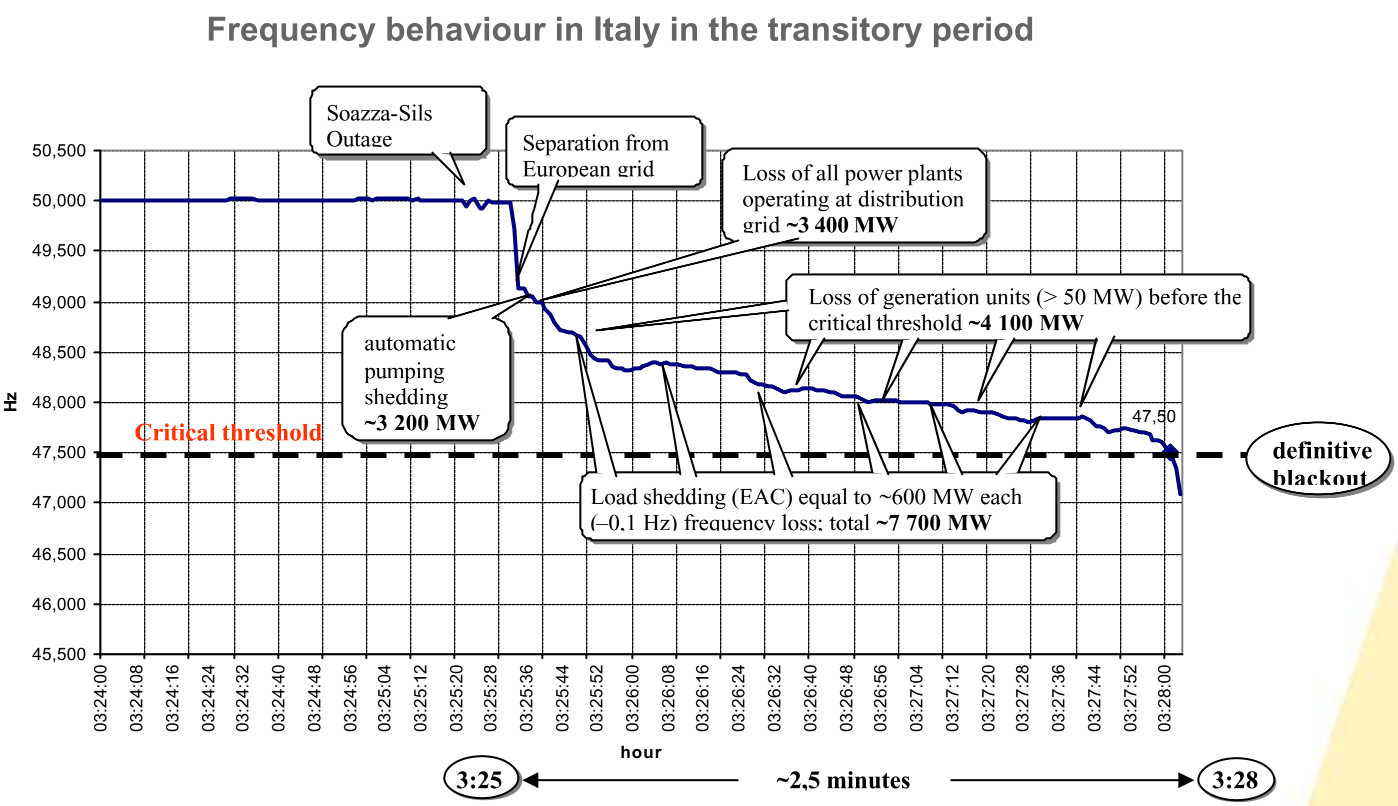
Time	Events	Coun-try	Details
03:26:30	• Final disconnection of the Italian system at I-SL border		• About 55 sec after the trip of the 380 kV line Redipuglia-Planais (I) a weak 132 kV link connecting Italy to Slovenia (transformer 220/132 kV at Padriciano substation and transformer 380/132 at Redipuglia connected to Padriciano through a 380/220 kV transformer) was open. The asynchronous operation was consequently interrupted.
03:27	▪ Activation of overload limiter in LFC related to 400 kV line Hernani (E) - Argia (F) • Manual blocking of secondary control in 1st zone: CH, CZ, B, D, F, G, SI, PL	E	• Setting of the overload limiter: 900 MW; line capacity autumn : 1 520 MVA
03:28:08	• All connections at 380 kV Lavorgo without voltage, including Lavorgo - Musignano [503 MW] • 220 kV line Gorduno - Mese [125 MW] without voltage • 220 kV line Airolo - Ponte [191 MW] without voltage • Trip of 220 kV line Robbia - Sondrio [253 MW] • Trip of 220 kV line Pallanzeno - Serra [110 MW] • Trip of 220 kV line Padriciano - Divacia; disconnected at Padriciano [199 MW]	CH - I CH - I CH - I CH - I CH - I SL - I	• Area of Tessin (South of Switzerland) without voltage
03:28:10	• Trip of 380 kV lines Villarodin - Praz and Villarodin - Venaus [712 MW]	F F - I	• 20 MW load was lost in the Maurienne valley
03:28:14	• Trip of 220 kV line Innertkirchen - Robiei	CH	
03:28:28	• Trip of 380 kV lines Casanova - Magliano, Magliano - Vado Ligure, Vignole - Vado Ligure and Magliano-Piossasco	I	
03:28:29	• Trip of 220 kV line Robiei - Bavona	CH	
03:29	• Area control area alarm, 2nd UCTE zone: BG, GR		
03:34:11	• Trip of 380 kV line Soazza - Bulciago; disconnected at Soazza [1 205 MW] • Trip of 220 kV line Magadino - Soazza	CH - I CH	
03:35	• Frequency alarm in all control centres of the second UCTE zone		• Frequency: > 50,28 Hz
04:18	• Trip of generation unit: 250 MW (coal, 2nd zone), reason: vibrations	RO	

The next graph shows the current on the 380 kV line Soazza - Sils (San Bernardino) with a maximum peak of about 2 700 A.
The tripping of this line was the second outage in Switzerland and was prominent in playing a decisive role in the blackout of Italy.



GENERAL OVERVIEW OF THE SYSTEM COLLAPSE IN ITALY AFTER DISCONNECTION

The following picture shows an overview of what happened with the frequency in Italy during the transition period which started with the disconnection of Italy from the UCTE grid at 03:25:34. Some 10 900 MW of load was shed in Italy (including Sicily) before the definitive blackout situation occurred at 03:28. So this blackout became a reality after about 2,5 minutes after the disconnection of Italy from the UCTE grid. Sardinia and a limited number of load islands were not involved in the blackout in Italy mentioned.
A summary of the events within this short time interval after the disconnection: pumps were automatically shed and load shedding took place because of underfrequency; generators got tripped within both the distribution grid and the high voltage grid.



GENERAL OVERVIEW OF THE RESTORATION OF THE ITALIAN SYSTEM

The events of the restoration process are summarised in the next table.

Time	Events	Country	Details
03:28 - 08:00	**STAGE 1:** **DIAGNOSIS AND RESUPPLY OF NORTHERN ITALY**	I	
03:28	• Analysis of situation by GRTN • Restoration plan of GRTN activated	I	• The restoration plan is based on several parallel working restoration "paths" to restore the auxiliary services of shut down power plants, to reconnect thermal power plants that succeeded in load rejection and to stabilise load of such plants. The restoration paths are initialised by 24 hydro and gas turbine units with black-start capability or with help of the UCTE grid. • The restoration plan covers the following areas: o Northern Italy supplied via 13 restoration paths o Central-south Italy area supplied via 9 restoration paths o Sicily supplied via 4 restoration paths.
03:42	• Reconnection of the 380 kV line Soazza - Sils	CH	
03:46	• Start of successive reconnection of interconnectors to Italy • Reconnection of the 220 kV line Pallanzeno - Morel	I - CH	
04:03	• Reconnection of the 220 kV line Camporosso -Menton - Le Broc-Carros	I - F	
04:08	• Reconnection of the 380 kV line Venaus - Villarodin	I - F	
04:13	• Reconnection of the 380 kV line Redipuglia - Planais	I	
04:32	• Reconnection of the 380 kV line Redipuglia - Udine/Safau	I	
04:37	• Reconnection of the 380 kV line Bulciago - Soazza	I - CH	
04:41	• Reconnection of the 380 kV line Rondissone 1 Albertville	I - F	
04:52	• Reconnection of the 380 kV line Redipuglia - Divaca	I - SL	
05:00	• **Import from UCTE system to Italy: 700 MW**		
05:16	• Reconnection of the 380 kV line Musignano - Lavorgo	I - CH	
05:38	• Reconnection of the 380 kV line Ponte - Airolo	I - CH	
06:00	• **Import from UCTE system to Italy: 2 100 MW**		
06:26	• Reconnection of the 220 kV line Mese - Gorduno	I - CH	
06:30	• Resupply of load via hydro generation units. Approximately 750 MW of thermal power plants were up and running at technical minimum power injection.	I	• North-western Italy almost completely energised and reconnected to the UCTE grid via the interconnection with France. • Mid-north Italy synchronous with the UCTE grid via the interconnection with Switzerland. • North-eastern Italy connected and supplied via the interconnection with Slovenia.
06:46	• Reconnection of the 220 kV line Sondrio - Robbia	I - CH	
07:00	• **Import from UCTE system to Italy: 3 490 MW**		
07:46	• Reconnection of the 220 kV line Pallanzeno - Morel	I - CH	
08:00	• **Import from UCTE system to Italy: 3 800 MW**	I	• Voice and data communication problems, switching problems from some Transmission Telecontrol Centres and lack of field information. • Failure of some disconnectors. • No progress in central-south Italy. In southern Italy most of the main thermal generation units still out of operation and unavailability of telecommunication systems. • GRTN adopted two strategies: o creating as many as possible islands in the southern Italy o proceeding step by step from north to south relying on interconnections with the UCTE grid and on the hydro generation units. • On-call personnel were sent to the most crucial substations and were instructed to carry out GRTN's operation instructions locally. • North Italy in a stable network situation.

Time	Events	Coun-try	Details
08:00 - 12:00	**STAGE 2:** **INTERMEDIATE STEPS**	I	
08:00	• Start of restoration process in the area of Rome	I	• Due to outage of telecommunication network: temporary loss of visibility on central-southern Italy by GRTN's SCADA system in Rome • Due to scarcity of available energy of generation pumping units, imports from the UCTE grid were increased to the permissible level • Due to expected exhaustion of hydro generation units, GRTN asked Distributors to activate the rotating load shedding plan in northern and central-northern Italy. The response to this request was not very significant. • On some locations the following problems arose which slowed down the restoration process: no possibility to energise lines due to expected high voltages, voltage instability during start up of hydro black-start units, failure to reclose lines due to violation of maximum allowed voltage phase angle.
08:05	• Reconnection of the 220 kV line Riddes- Valpelline	I - CH	
08:09	• Reconnection of the 220 kV line Avise - Riddes	I - CH	
08:21	• Reconnection of the 220 kV line Soverzene - Lienz	I - A	
09:00	• **Import from UCTE system to Italy: 4 440 MW**		
10:00	• **Import from UCTE system to Italy: 5 620 MW** • Load shedding of interruptible customers with and without advance notice by means of remote control in the regional control centres of Milano, Torino and Venezia	I	
11:00	• From 11:00 - 17:00 50 MWh/h reserve power delivery support from ELES to GRTN		• North Italian load nearly fully restored.
12:00 - 17:00	**STAGE 3:** **THE COMPLETE RESUPPLY OF THE MAINLAND**	I	
12:00 - 17:00	• Load shedding on rotating basis in northern and mid-northern regions to cover the load diagram and due to high power flows on the network section "North-Florence".	I	
12:44	• Reconnection of the 380 kV line Rondissone - Albertville 2	I - F	
13:17	• Rome area resupplied	I	
16:00	• **Import from UCTE system to Italy: 6 545 MW**		
16:48	• Energising of the busbars in Brindisi Cerano 380 kV substation.	I	
16:50	• Reconnection of 380 kV HVDC link Galatina - Arachtos	I - GR	• Agreement with HTSO (Greece TSO) on an import of 500 MW untill 07:00 at 29 September 2003. After that the scheduled programs were followed with the possibility of importing 500 MW extra.
17:00 - 21:40	**STAGE 4:** **FINAL STAGE AND THE RECONNECTION OF SICILY**	I	
	•		
17:30	• Reconnection of Sicily due to switching of the line Sorgente - Corriolo (it was inoperable before).	I	• The delay in the resupply of Sicily from mainland is related to the expected ramp to the 20:00 evening peak demand of the mainland of Italy.
21:40	• GRTN officially declared the end of the Italian system's emergency conditions.	I	• All customers in Sicily and in the rest of Italy supplied, i.e. 18 hrs 12 min. after the start of the disconnection of Italy from the UCTE grid.

APPENDIX 3 – DAY-AHEAD CONGESTION FORECAST (DACF)

The main objectives of the DACF are to allow each TSO to carry out reliable load-flow forecasts in the operational planning phase and to identify possible congestions (on tie-lines or internal to its network), in the base state or as a result of the contingency analysis. For these purposes, it is necessary to exchange data among TSOs to take into consideration the influence of the neighbouring networks. Hence, one of the main tasks is to organise this data exchange, to agree upon the preparation of the data sets and to ensure the confidential treatment of the data. It is the responsibility of each "country" to test its network for congestions.

The procedure is as follows:

Each country provides to all other countries a forecasted load-flow data set of its grid, with the complete detailed network model in the area of interest: certainly all 380 kV and 220 kV elements (busbar couplers, nodes, lines, 380/220 kV transformers, injections into 380 kV or 220 kV nodes and loads from 380 kV or 220 kV nodes) in the data set as real models will require inclusion. No equivalents may be used at these voltage levels. Equivalent lines and transformers can be used for model networks of lower voltages, if they significantly influence the 380 kV or 220 kV level. The data format for exchanges is the "UCTE-format".

After all these data sets have been exchanged, each "country" is able to construct a load-flow model that represents the most probable state at the specified time, to perform a security analysis and to identify possible congestions. That model should preferably include all UCTE networks, but a "country" could also disregard the data sets of countries whose influence on its network is deemed negligible.

TSOs use the Electronic Highway (EH) and the EH-ftp server to exchange the DACF load-flow data sets and the network security analysis results.

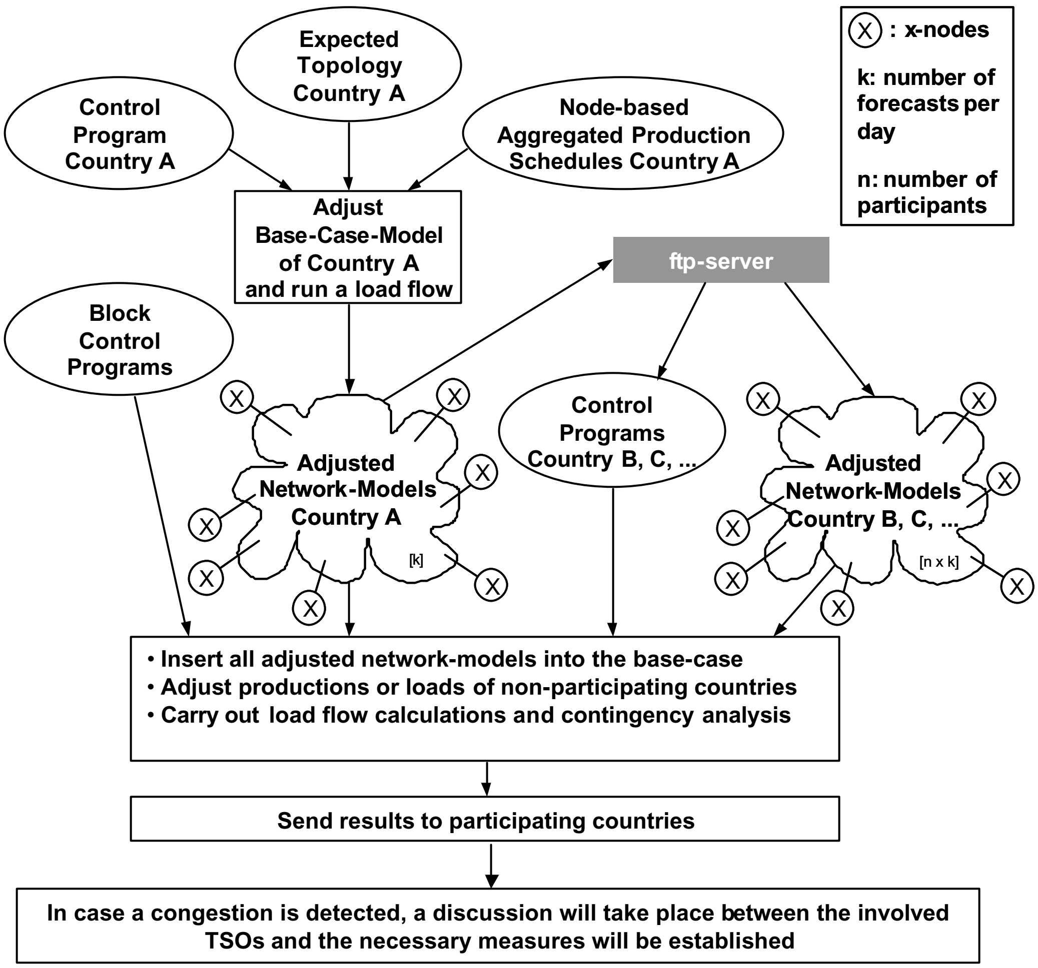


Figure A.1: DACF procedure