Interim Report of the Investigation Committee on the 28 September 2003 Blackout in Italy

Table of Contents

Disclaimer

The following Interim Report, based on the present state of the investigation and information made available concerning the Italian 28/09/03 Blackout, is issued by UCTE on behalf of its "Investigation Committee" ("Committee") and according to the agreed upon Terms of Reference of the said Committee. Nothing in this report shall or may be used in any court of law or other competent jurisdiction as evidence of misconduct, liability or other responsibility, whatever it may be, of any UCTE member in regard with the Italian 28/09/03 Black-out. The individuals having prepared and/or signed this report, as any other UCTE member, including its agents or representatives, shall not be liable in whatever manner for the content of this report, nor for any conclusion whatsoever that any person or third party, including any regulator, could draw from the said report. This report may not be used as evidence in any court of law or competent jurisdiction.

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 that 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.

The interim report gives a factual description of the sequence of events, followed by a technical analysis and the Committee's findings on the main causes of the incident. Several issues are listed that will be further investigated.

CONTEXT

It must be emphasized that the original function of the interconnected systems is to form the backbone for the security of supply and to reach its required high level at reasonable costs. To this aim the system has been developed in the past 50 years with a view to assure mutual assistance between national subsystems including common use of reserve capacities and, to some extent, to optimize 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 close to its limits as allowed by the security criteria. The blackout must be seen in this general context.

Nevertheless, the transmission system operators have in the last few years steadily improved the capability of the existing infrastructure to allow cross border exchanges; by using several measures such as, for example, computerised control and data acquisition, phase shifting transformers, coordination mechanisms and electronic data exchange between operators.

SEQUENCE OF EVENTS

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 failed as well.

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, for a short period. The allowable time period for this overload was about 15 minutes according to calculations by the experts.
At 03:11, a phone conversation took place between the Swiss co-ordination centre of ETRANS in Laufenburg and the Rome control centre of GRTN, the Italian transmission system operator. The purpose of the call was to request from GRTN countermeasures within the Italian system, in order to help relieving the overloads in Switzerland and bring the system back to a safe 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.

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 a very low system voltage in northern Italy and consequently, the trip of several generation plants in Italy.

Countermeasures were implemented within Italy in order to face a disconnection of the country and sudden loss of the import, for example automatic shedding of parts of the load. These measures were automatically activated, but, due to the loss of generation plants, it was impossible for the Italian system to operate separately from the UCTE network. About 2 minutes and 30 seconds after the disconnection of the country, the blackout was an unavoidable fact.

SECURITY AND RELIABILITY STANDARDS – SAFETY 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.

This rule also states that in case of loss of N-1 security the system must not only withstand the situation, but it is supposed to return to the N-1 secure state as soon as possible to resist a possible new event.

It implies that countermeasures must be identified and prepared at each moment and for each single incident, enabling the system to be brought back to a safe state when an incident occurs.

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 in Italy, which are 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 subject.

The Committee identified 4 main reasons for the fact that things did not go as foreseen.

MAIN REASONS FOR THE BLACKOUT

1. UNSUCCESSFUL RE-CLOSING OF THE LUKMANIER LINE BECAUSE OF A TOO HIGH PHASE ANGLE DIFFERENCE

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

2. LACKING A SENSE OF URGENCY REGARDING THE SAN BERNARDINO 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. Even together 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 the reason why the Italian system collapsed after its separation from the UCTE system. It was not the cause of the origin of the event.

4. RIGHT-OF-WAY MAINTENANCE PRACTICES

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

FURTHER WORK OF THE COMMITTEE

Several issues are listed in the report, which will be examined in the next stage. Apart from the measures to be undertaken as a result of the lessons drawn from the blackout, further investigation will go into the issues dealt with in this report.
Attention will also be given to the not yet fully investigated phases of the blackout: the period between disconnection and blackout in Italy and the behavior of the UCTE system outside Italy.

Moreover, lessons learnt and action to be undertaken after the blackout will be part of the already ongoing work of the various working groups of UCTE.

Introduction

INVESTIGATION COMMITTEE

The Investigation Committee is composed of:

- 5 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.

- 2 representatives of the transmission system operators for each of the involved countries:
  Austria,
  France,
  Italy,
  Slovenia and
  Switzerland.

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 *Federal Republic of Yugoslavia*, *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 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 first interim report is composed of 4 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. Overview of issues for further work.

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 SI) 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.

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 resistance, 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.

---

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

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 interim report will not consider commercial transactions, but only focus on physical data.

1 Factual Sequence of Events Italian Blackout 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 6651 MW
- Total load of Italy was 27 702 MW, this is: 24 064 load (excluding Sardegna) and 3638 MW pump load
- Powerflows at the borders with Italy:
  - Switzerland - Italy: 3610 MW
  - France - Italy: 2212 MW
  - Slovenia - Italy: 638 MW
  - Austria - Italy: 191 MW
- Scheduled exchange programs:
  - Switzerland - Italy: 3068 MW
  - France - Italy: 2650 MW
  - Slovenia - Italy: 467 MW
  - Austria - Italy: 223 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: 400 kV lines of Chevalet - Gavrelle, Gaudiere Rueyres, Chesnoy - Tabarderie, Menuel Terrettes 2, Terrettes - Tourbes 2, P. and la Praz phase shifter

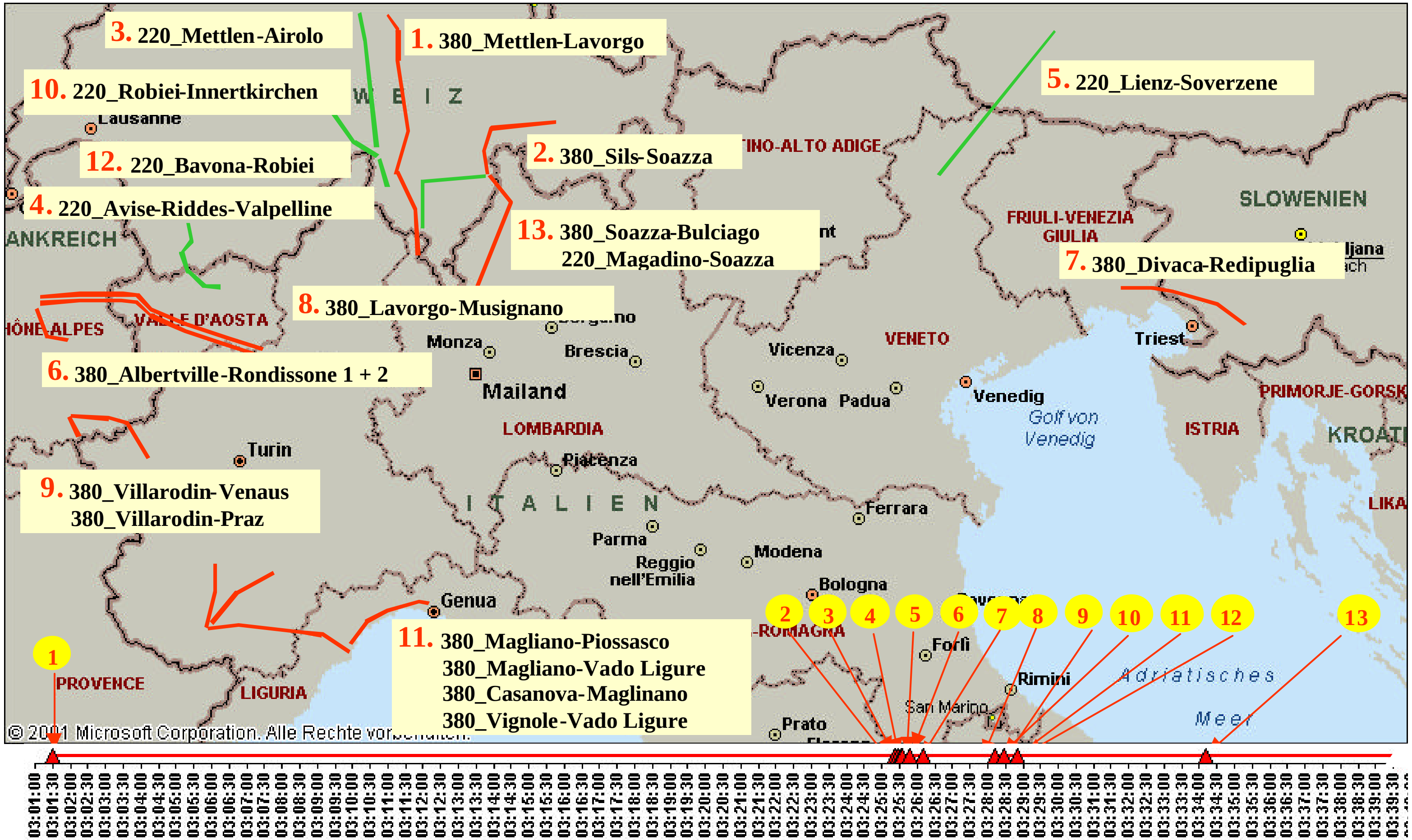
- Slovenia: 220 kV line Podlog - Obersielach to Austria

- Austria: 220 kV line Obersielach to Slovenia.

OVERVIEW OF SEQUENCE OF EVENTS

A graphical overview of the sequence of the most important events is given in the next picture.
In an Appendix a tabular overview containing the details of the factual sequence of events is given.

Overview of sequence of events



2 Technical Analysis of the Events

2.1 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 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, which was mainly generated in France, Germany and Poland in terms of 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.

The specific problem in 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 mainly 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, which is difficult to be controlled by the Swiss operator by its own means.

During the time before the blackout the Swiss grid was also in a highly stressed condition and the Swiss grid was operating close to the security limit given by the commonly agreed UCTE standards (N-1 Security).

2.2 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. There exist several types of stability phenomena in electrical power systems that 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
- loss of synchronism due to angle instability
- oscillatory instability causing self exciting inter-area-oscillations
- exceeding of the allowed frequency range (over and under frequency)
- voltage collapse

As the consequences of instability can be dramatic, its prevention is an important aspect in electrical power systems. Though several means exist and are applied in 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 leading to a complete malfunction of the electricity supply of consumers through the grid. During such a blackout, which large power systems have experienced worldwide, mostly a combination of the above mentioned stability phenomena occurs

2.3 CONTRIBUTION OF STABILITY PROBLEMS TO THE BLACKOUT IN ITALY

2.3.1 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 depending on that their lengths and subsequently the line sag is also increased. This leads to less distance between the conductors and ground or trees which are 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 consequently are loaded higher and possibly overloaded risking successive tripping.

First line tripping at 03:01:42 h: 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 decrease of distances 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-re-closing 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 a too high phase angle (42^0), which resulted from the still 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 h: 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 °C
- an assumed wind speed of 0,6 m/s
- the maximum conductor temperature of 80 °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

Fig. 1 shows the maximum admissible operation time in overload condition depending on the line current. In the time interval between 3:05 and 3:25 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 590A 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 Silz - 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.

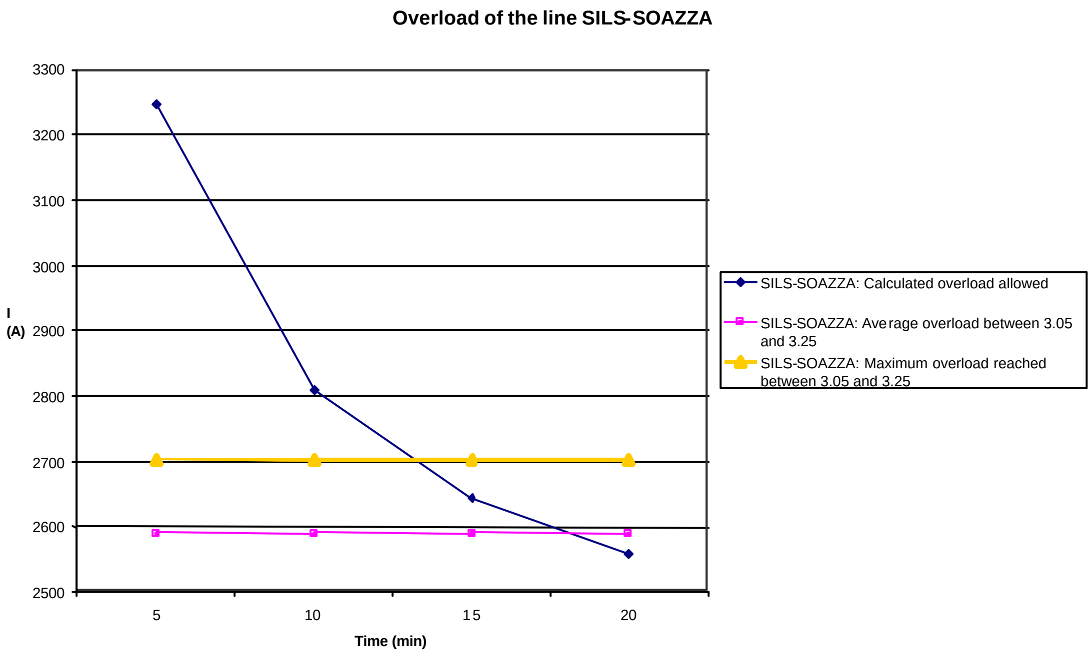


Fig. 1: Overload Capability of the 380 kV line Silz – Soazza

Third line tripping at 3:25:25 h: 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 h: 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.

2.3.2 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 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 shows frequency, voltage and reactive power in Heviz (Hungary) and frequency in Uchtelfangen (Germany) recorded by WAMS. The internal clocks WAMS' recording devices are synchronised by GPS.

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

the Italian grid lost its synchronism at 03:25:26 h

The voltage in Heviz began to decrease and 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. The voltage settled back to a nominal value and the reactive power approached zero, indicating that:

the Italian grid went separated at 03:25:33 h.

The loss of synchronism of the Italian grid and the almost simultaneous disconnection of all remaining interconnection lines is confirmed by the time behaviour of active power on the borderlines France – Italy (see Fig. 3). By decelerating of the Italian voltage phasor the angle between the voltages at the substations of the borderlines increase. Due to this, the active power flow on the border lines, France-Italy, increase up to the maximum value, which is reached at a phase angle of 90^0 according to the law of physics. The following phase proceeds very rapidly: the active power flow on the line decreases and the voltages of the Italian grid and UCTE main grid reach phase opposition. In this state the line protection devices identify 3-phase short circuits on the remaining borderlines, which are almost simultaneously disconnected without delay.

2.4 CONDITION IN THE UCTE MAIN GRID AFTER SEPARATION

Though the event had no severe consequences apart from in Italy, it should be mentioned that even the whole UCTE main grid was in an endangered condition. Due to disconnection of Italy, the automatic control function of the UCTE main grid had to manage a sudden power surplus equal to the previous export to Italy. The frequency was accelerated for up to nearly 50,25 Hz and stabilised at around 50,20 Hz. The situation could be managed thanks to regular automatic control functions in generation units and in the grid operating centres.

However, some generating units were shut down in an uncoordinated manner by an over frequency criteria or tripped by voltage drop.

Moreover, Fig. 2 shows that a generator lost its synchronism. Immediately after the disconnection of Italy, all recorded quantities in Heviz (Hungary) showed continuous oscillations which disappeared after a time period of 55 seconds. Obviously a generation unit in the proximity of Heviz lost its synchronism and was accelerated by up to around 52 Hz according to the turbine control function. The frequency of slipping corresponds to the oscillation of recorded quantities in Heviz. Presumably the asynchronous running generator was disconnected manually from the grid after 55 seconds.

After the disconnection of Italy the global load flow situation changed significantly and led to an unpredicted flow pattern. 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 Belgian increased significantly. Therefore the grid operators immediately took various emergency precautions mainly by directing power units to new generation schedules, which were necessary to bring the transmission grid back to a safe condition.

2.5 CONSEQUENCES FOR THE ITALIAN POWER SYSTEM

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. A preliminary estimation of the dynamic effects on the Italian grid during and after loss of synchronism was carried out using the dynamic model of the complete UCTE power system. The first results show severe conditions at least in the northern part of Italy. The dynamic interaction between the Italian grid and the UCTE main grid during the last seconds before separation led to a fast voltage collapse in the grid.

The voltage drop in particular, significantly affects the operation of the power units. For example, the voltage quality of the auxiliary supply of generation units may transiently become insufficient. By this, the function of various internal processes of generation units may be disturbed by failure of feedwater pumps, coal mills, combustion air pump, etc. Mainly due to this transient voltage collapse a number of units tripped within a relatively short time range; 21 out of 50 large thermal units were lost before the 47.5 Hz threshold was reached.

Thus the initial power deficit of the Italian power system, equal to the loss of import power increased dramatically by the tripping of a number of units. This condition was no longer manageable by automatic load shedding. Though about 10.000 MW of load was disconnected by automatic load shedding, the blackout occurred around 2 minutes and 30 seconds after islanding.

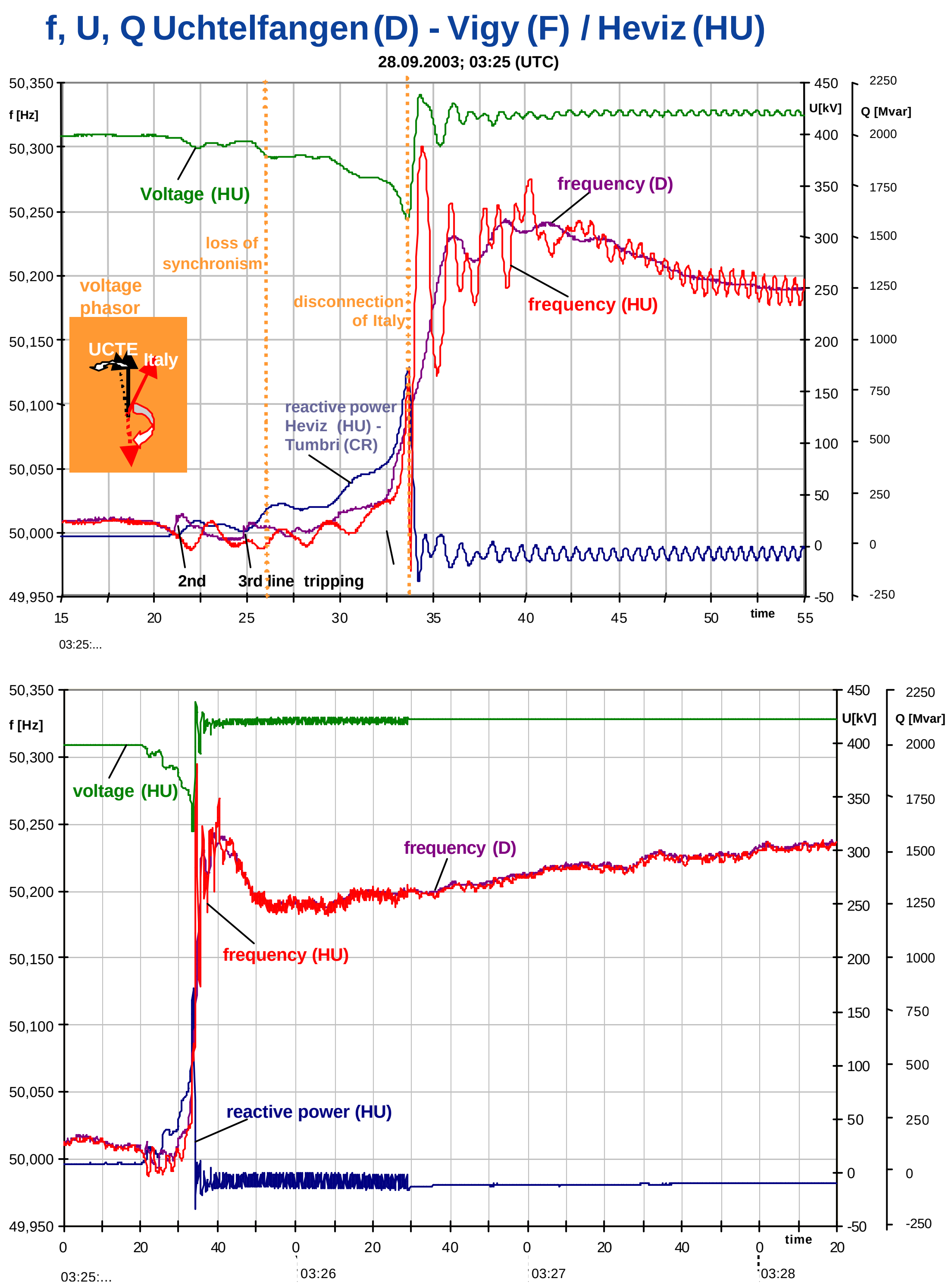


Fig 2: Recordings from WAMS in Heviz (Hungary) and Uchtelfangen (Germany)

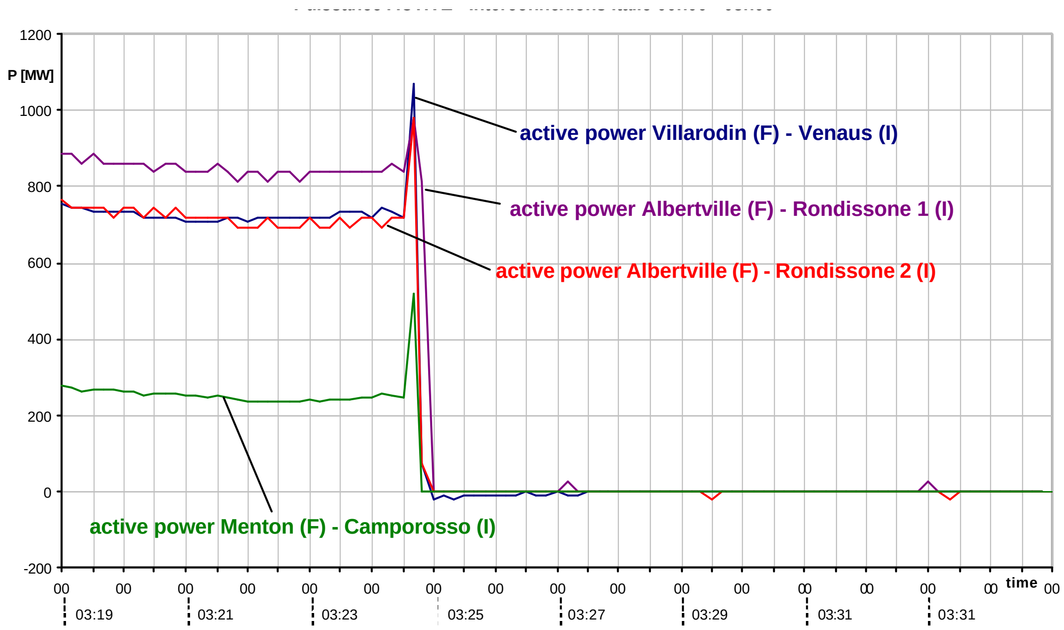


Fig 3: Active power flow on border lines France – Italy

2.6 COMPARISON WITH THE INCIDENT ON 20-05-93

On 20-05-93 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 islanding 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, which was a crucial element in the dramatic consequences of the recent 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 much more severe angle stability problem; prior to the first line trip 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 in case of higher power import to Italy for example. By this the overall stability margin of the interconnected power system will be reduced and its consequences should be observed very carefully.

After the 28th of 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 deeper stability analyses, in order to identify possible conditions leading to stability problems and to define suitable countermeasures if necessary.

3 Analysis of Root Causes

In this section, 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.
An additional difficulty is that UCTE-wide tools used to predict the flow pattern (DACF) are still in development. As a consequence, the TSOs have to rely on real time security assessment[2].

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

Furthermore, the N-1 rule implies that, after a first incident, measures should be taken as soon as possible to return the system to the N-1 security state.

---

[2] *The relationship between commercial flows, DACF and real-time security analysis is explained in the introduction to the Report.*

The scheduling procedure is a deciding factor for the state of the network before the occurrence of the first line flashover at 3.01. 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 co-ordination 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 Swiss transmission 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 3.01, 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 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[3].

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 3500 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 TOO HIGH PHASE ANGLE DIFFERENCE

After a tree flashover on a line, it is in the majority of cases possible to manually reconnect the line. Indeed, after carbonization 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 coordinating 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.

---

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

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.
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 3:11[4], the ETRANS operators requested GRTN to decrease the control deviation by 300 MW[5]. The Italian control deviation[6] 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[7] also mentions that this communication shall be confirmed by fax[8].

The load flow analysis showed that this reduction could keep the San Bernadino line in admissible operative condition, under the prerequisite however, that rather positive 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.

---

[4] Registered by ETRANS at 3.10.47.
[5] See section on communication.
[6] The control deviation is (approximately) the difference between the scheduled import and the actual physical import.
[7] According to the trilateral emergency procedure between ETRANS, GRTN and RTE dispatchings.
[8] 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.

COMMENTS ON COMMUNICATION AND DATA EXCHANGE

Some comments on communication and data exchange between ETRANS and GRTN, which will be subject to further work, 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 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 handed over 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 [9]".*

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 of 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 the further work, 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[10] 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.

---

[9] *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"*

[10] *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 had no 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 (timely) 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.

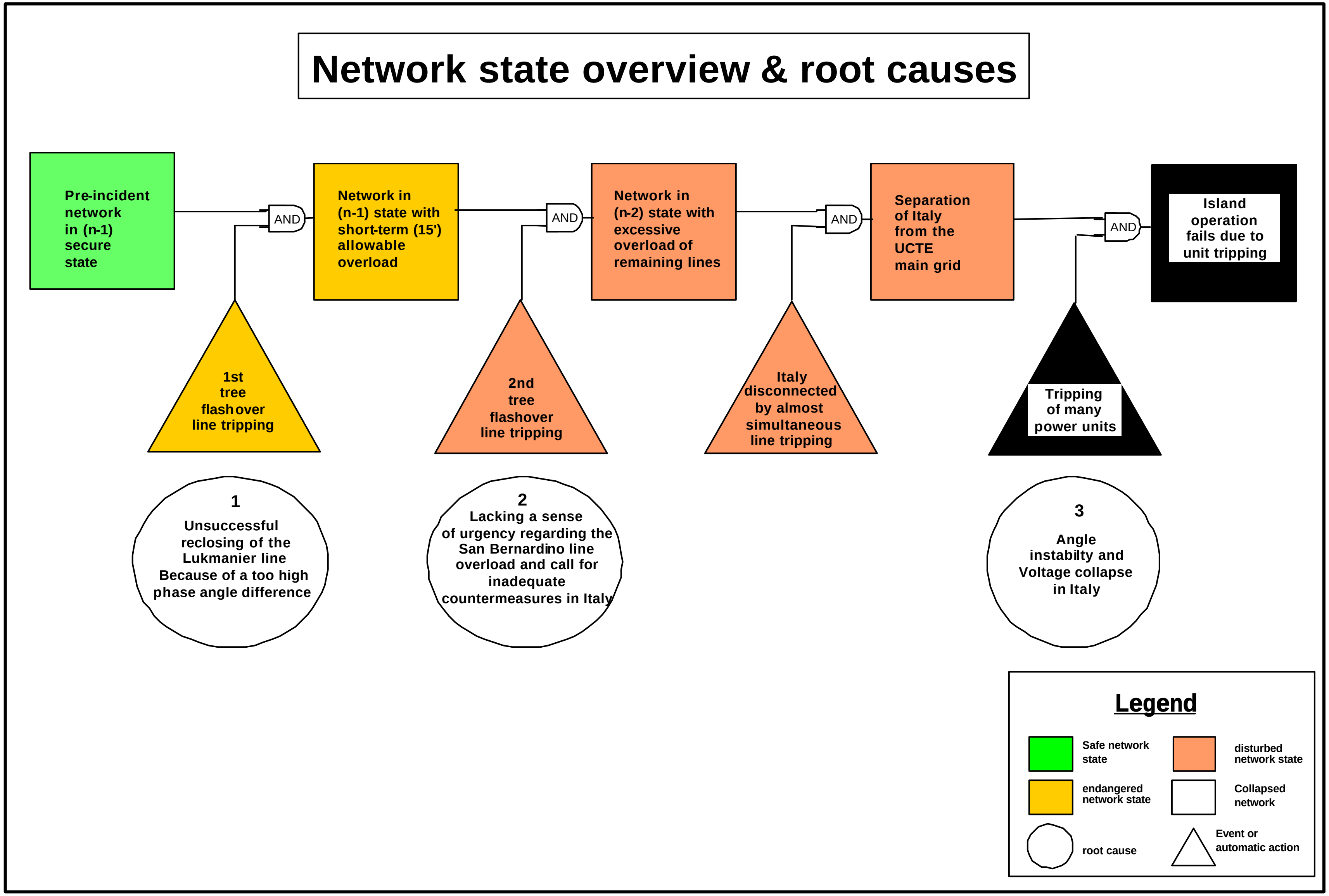
Concerning right-of-way maintenance, best management practices are defined and regulated on a country-by-country basis, taking into account geographic conditions, vegetation, climate, line and tower design, etc.

Therefore, the Committee did not perform a technical audit of these practices.

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 optimize 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 of a too high phase angle difference.	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 to the origin of the events but was the cause that successful island operation Italy after its disconnection 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
Network in (n-1) state with short-term (15') allowable overload
AND
Network in (n-2) state with excessive overload of remaining lines
AND
Separation of Italy from the UCTE main grid
AND
Island operation fails due to unit tripping
1st tree flashover line tripping
2nd tree flashover line tripping
Italy disconnected by almost simultaneous line tripping
Tripping of many power units
1
Unsuccessful reclosing of the Lukmanier line
Because of a too high phase angle difference
2
Lacking a sense of urgency regarding the San Bernardino line overload and call for inadequate countermeasures in Italy
3
Angle instabilty and Voltage collapse in Italy
Legend
Safe network state
disturbed network state
endangered network state
Collapsed network
root cause
Event or automatic action

4 Overview of Issues for Further Work

The Committee's further work will address amongst others, the following issues:

- Definition of the short-term action to be undertaken to prevent a similar event
- Comparative analysis with the lessons learnt and action undertaken after the September 2000[11] incident
- Reassessment of involved TSOs' N-1 security management
- Examination of the dynamics and control behaviour of the UCTE network outside Italy after the blackout
- Assessment of the communication infrastructure between TSOs and analysis of the on-line data exchange between ETRANS and GRTN.

Concerning the following issues, lessons learnt and action undertaken after the blackout will be part of the already ongoing work of the various working groups within UCTE:

- Assess the adequacy of existing rules and agreements, possibly proposing improvements
- Take the dynamic aspects (voltage and phase angle stability) into account in the security analysis
- Take neighbouring networks into account in the security assessment process
- Intensify the use of real-time data exchange between TSOs.
- Evaluate the influence of the network's topology in relation to vulnerability and stability problems.
- Report on the restoration process in Italy.
- Justification of the extra installation of Wide Area Measuring Systems (WAMS)[12] devices
- Perform simulations on excessive overload and voltage collapse phenomena
- Further clarify the relationship between commercial trade and physical flows.

[11] In September 2000, an incident in the same area occurred but without direct consequences for the supply.
[12] WAMS are devices -synchronized by GPS- that register dynamic phenomena in the network and allow analysis of transient behaviour over a large area. Their data for the events of 28/9/03 have been used in this interim report.

5 Appendix

FACTUAL SEQUENCE OF EVENTS ITALIAN BLACKOUT ON SUNDAY 28 SEPTEMBER 2003

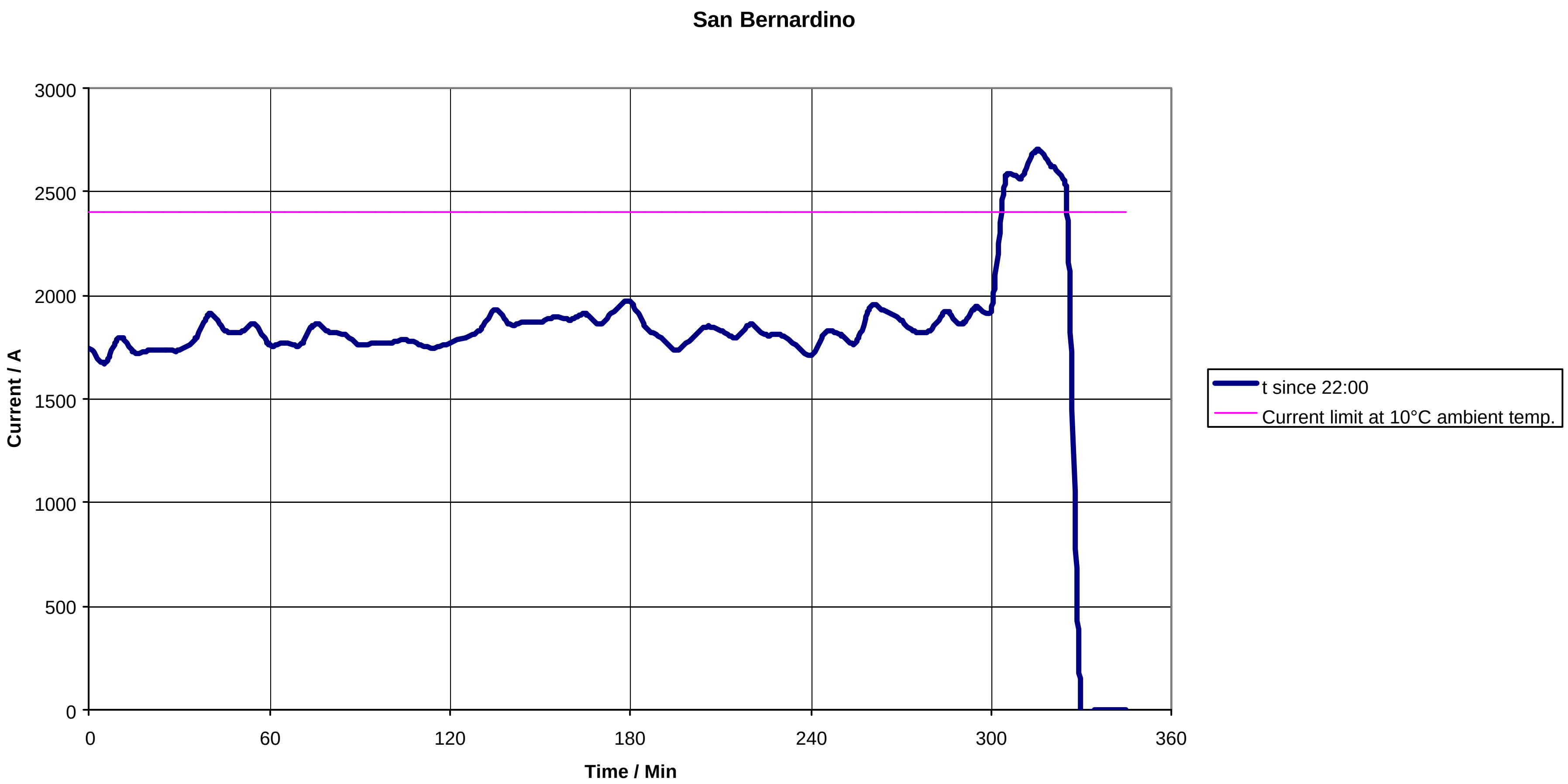
The following table shows with several time stamps the events that took place including some notable details.
The power flow that was transferred across each tripped line before the outage is shown between brackets in most cases.
The time indicated for each event might be inaccurate since there is no time synchronization between all protection devices.
The sequence of events at this time therefore should be considered to be preliminary.

Time	Events	Country	Details
03:01:21	• Single phase to ground fault at 380 kV line Mettlen - Lavorgo • 380 kV line 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 tension	CH	• 2100 A (limit: 2400 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 co-ordination 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	• 1970 A (limit: 2400 A); this current earlier was 1200 A
03:08:23	• Attempt at Lavorgo to get 380 kV line Mettlen - Lavorgo into operation again	CH	• Because of too 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 in 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 co-ordination 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

Time	Events	Country	Details
03:25:21	• Protection of 220 kV line Mettlen - Airolo triggered at Airolo • Trip of 380 kV line Sils - Soazza line [1783 MW] after single phase to ground fault	CH	• Line was first disconnected at Sils, then at Soazza. • 2700 A (limit: 2400 A)
03:25:25	• Trip of 220 kV line Mettlen - Airolo at Airolo [740 MW]; at Mettlen the line stays connected and under tension	CH	• All circuits from Airolo were tripped, i.e. to the direction of Mörel, Ponte, Lavorgo and Mettlen. The canton Tessin is disconnected from the Swiss transmission system. • 3070 A (limit: 2400 A)
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 • Trip 220 kV line Riddes - Avise [281 MW] • Trip 220 kV line Riddes - Vallpelline [299 MW]	A I CH - I CH - I	• I still > 900 A on 220 kV line Lienz - Soverzene
03:25:32	• Trip of 400 kV line Albertville - La Coche • 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 20kV networks)	F 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]	A - I F - I	• I > 1200 A • Due to the tripped 220 kV line Lienz - Soverzene: voltage increase 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 increase exceeding 50,2Hz
03:25:34	• Trip of 400 kV line Albertville - Rondissone 1 at both substations [841 MW] • Trip of 400 kV line Albertville - Rondissone 2; disconnected	F - I F - I	• Single phase fault + automatic reclosure + finally three phase trip

Time	Events	Country	Details
	only at Rondissone [682 MW]		
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	SI - I I I	
03:25:42	• Trip of 220 kV line Divaca - Klece including 220 kV synchronous compensator in Divaca without tension	SI	• Increase of voltage on 380 kV and 220 kV level in the rest of the Slovenian network
03:26	• All circuits at 220 kV Fiesch disconnected	CH	• Fiesch without tension
03:28:08	• All connections at 380 kV Lavorgo without tension, including Lavorgo - Musignano [503 MW] • 220 kV line Gorduno - Mese [125 MW] without tension • 220 kV line Airolo - Ponte [191 MW] without tension • 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 SI - I	• Area of Tessin (South of Swiss) without tension
03:28:10	• Trip of 400 kV lines Villarodin - Praz and Villarodin - Venaus [712 MW]	F F - I	• 30 MW load was lost at Maurienne
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	
03:34:11	• Trip of 380 kV line Soazza - Bulciago; disconnected at Soazza [1205 MW]	CH - I	

The next graph shows the current on the 380 kV line Soazza - Sils (San Bernardino) with a maximum peak of about 2700 A. The tripping of this line was the second outage in Switzerland and resulted in playing - a decisive role in the blackout of Italy.

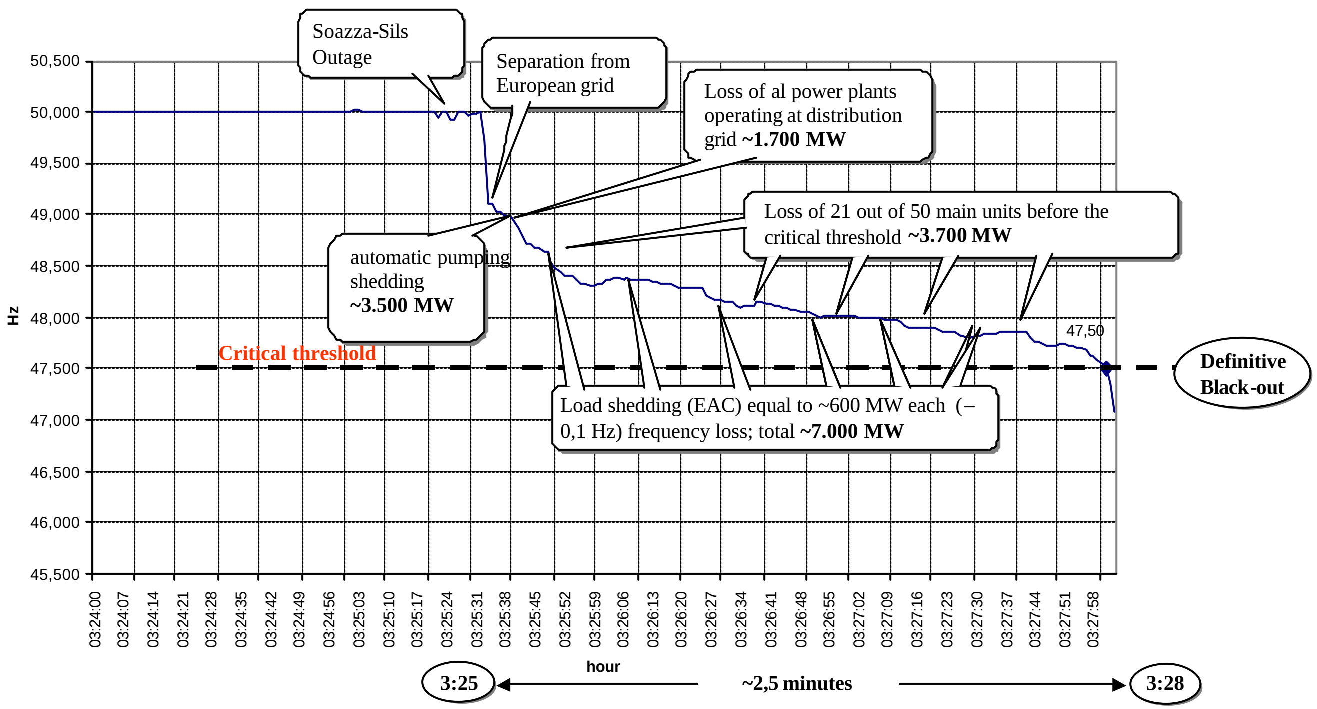


General Overview of the system collapse in Italy after disconnection

The following picture shows an overview on what happened with the frequency in Italy during the transition period which started with the disconnection of Italy with the UCTE grid at approximately 03:25:34. Some 10,000 MW of load was shed in Italy before Italy (including Sicily) was definitively in a blackout situation at 03:28. So this blackout was reality after about 2.5 minutes after disconnection of Italy from the UCTE grid. Sardinia and a limited number of load islands were not taking part of the Italian blackout mentioned.

Summing up the events within this short time interval after the disconnection: pumps were automatically shed and load shedding took place because of under frequency; generators got tripped within both the distribution grid and the high voltage grid.

Frequency behaviour in the transitory period



General overview of the restoration of the Italian system

A summary of events of the restoration process of the Italian system is given in the next table.

Time	Events
03:42	• Start of successive reconnection of interconnectors to Italy • Reconnection of the 380 kV line Soazza - Sils (CH)
03:47	• Reconnection of the 220 kV line Airolo - Ponte (CH - I)
03:48	• Reconnection of the 220 kV line Pallanzeno - Serra (CH - I)
04:05	• Reconnection of the 220 kV line Le Broc-Carros - Menton - Camporosso (F - I)
04:21	• Reconnection of the 220 kV line Divaca - Padriciano - Divacia (SI -I)
04:37	• Reconnection of the 380 kV line Soazza - Bulciago (CH - I)
04:52	• Reconnection of the 380 kV line Divaca - Redipuglia (SI - I)
05:17	• Reconnection of the 400 kV line Albertville - Rondissone 1 (F - I)
05:30	• Reconnection of the 380 kV line Lavorgo - Musignano (CH - I)
06:00	• **Import from UCTE system to Italy: 2100 MW**
06:27	• Reconnection of the 220 kV line Gorduno - Mese (CH - I)
06:18	• Reconnection of the 400 kV line Villarodin - Venaus (F - I)
06:48	• Reconnection of the 220 kV line Robbia - Sondrio (CH - I)
07:00	• **Import from UCTE system to Italy: 3490 MW**
08:00	• **Import from UCTE system to Italy: 3800 MW**
08:05	• Reconnection of the 220 kV line Riddes - Vallpelline (CH - I)
08:23	• Reconnection of the 220 kV line Lienz - Soverzene (A - I)
08:48	• Reconnection of the 220 kV line Riddes - Avise (CH - I)
09:00	• **Import from UCTE system to Italy: 4440 MW**

Time	Events
10:00	• **Import from UCTE system to Italy: 5620 MW** • Load shedding of interruptible customers with and without advance notice by means of remote control in the regional control centers of Milano, Torino and Venezia
11:00	• From 11:00 - 17:00 50 MWh/h reserve power delivery support from ELES to GRTN
12:45	• Reconnection of the 400 kV line Albertville - Rondissone 2 (F - I)
16:00	• **Import from UCTE system to Italy: 6545 MW**
16:40 - 23:52	• Load shedding of interruptible customers with and without advance notice by means of remote control in Middle-South of Italy to cover the load diagram and due to high power flows on the network section "North-Florence". In total 60 MW.
16:48	• Energisation of the busbars in Brindisi Cerano 380 kV substation.
16:50	• Agreement with HTSO (Greece TSO) on an import of 500 MW until 7:00 at 29 September 2003. After that the scheduled programs will be followed with a possible opportunity to import 500 MW extra.
17:10 - 23:52	• Load shedding of interruptible customers with and without advance notice by means of remote control in Tuscany to cover the load diagram and due to high power flows on the network section "North-Florence". In total 47 MW.
17:30	• Reconnection of Sicily due to switching on of the line Sorgente - Corriolo (it was unoperable before).
21:40	• Request to supply customers in Sicily.
23:00	• All customers supplied.