APPENDIX – Policy 5: Emergency Operations

NEW - Appendix

History of changes

V0.1	draft	03-2008 After Brussels meeting	DT P5
V0.2	Draft		WG OS Warsaw, 24th April 2008
V0.3	Draft	After Lisbon meeting	DT P5 - 4th-5th December 2008
V0.4	Draft	01-2009	WG O&S
V0.5	Draft	04-2009/05-2009	After Rome + Paris
V0.6	Draft	10-2009 After WG OS remarks	Ad-hoc Vienna 10-2009
V0.7	Draft	01-2010 After linguistic revision and internal consultation	

1 GENERAL INTRODUCTION

1.1 ENTSO-E Regional Group Continental Europe (RG CE) new commitments for Emergency Operations

The investigation report related to the 4th November 2006 system disturbance pointed out the following issues:

Managing RG CE-wide or regional disturbances

The conditions for operating the system have changed quite significantly. Nowadays, the interconnected power system is operated closer and closer to its limit and all national systems are more and more interdependent. It implies a specific attention to the impact on cross-border disturbances or consequences of national disturbances to the whole continental interconnected system. A number of issues in the context of TSO behaviour have to be pre-defined and harmonised within TSOs. RG CE should define possible scenarios, procedures and principles that have to be followed by TSOs to prevent any incident, in emergency conditions to limit propagation, and to allow a quick restoration.

At least the following issues shall be included:

- Coordination of national defence plans, especially load-shedding criteria
- Management of over-frequency conditions
- Harmonisation of reenergisation criteria
- Resynchronisation principles
- Coordination of load-frequency control management
- Coordination and communication procedures.

Coordination of defence and restoration plans

The defence plans have usually been designed to manage power imbalance and related frequency drops at country level. Usually, the defence and restoration plans involve DSOs, industrial customers and generators. However, the liability and the regulatory and legal framework are not always clearly defined in each country and are not homogeneous throughout RG CE. Therefore, a clear contractual or regulatory framework must be defined to determine the liability and role of each partner in the defence plan more precisely: TSO, DSO, generators, industrial customers, and public authorities.

The RG CE Operation Handbook, which already gives certain principles on this subject, must be refined in order to guarantee coherence and adequacy of each TSO's defence and restoration plans at the RG CE level.

Resynchronisation

Taking into account that each hypothetical splitting of the RG CE interconnected power systems would happen along different border line(s) which are difficult to predict, it is not possible to develop relevant, universal co-ordination procedures applicable to different scenarios. Thus, the decentralised approach seems to be preferable, even if it inherently includes the risk of unsuccessful attempts, which imply a certain danger for the power systems due to oscillations triggered by them (which was also the case on November 4th). This risk is unavoidable if the resynchronisation is supposed to be carried out quickly. However, it is recommended that all TSOs ensure that their most important substations are equipped with relevant synchronising devices preferably remotely controlled from TSO control centre directly. The basic common principles are developed for the first time.

Load frequency control management

The Operation Handbook does not yet define principles for the different load frequency control modes or states. However, in disturbances involving several TSOs, coordination of the control area frequency controllers of different TSOs might have a significant influence on the rapidity of system restoration. Therefore, the benefits and possible impacts of these different control modes or states have to be thoroughly analysed and their application should be predefined. RG CE proposes principles and defines strategies for the different control modes/states of frequency control with a special attention to the frequency control mode for LFC".

Recommendation #2 of the investigation report related to 4th November 2006.

Policy 5 ("Emergency Operations") has to be extended with a "Master Plan" defining principles of operation and TSOs' responsibilities to manage RG CE-wide or regional disturbances.

Additionally the following aspects have to be considered:

- *TSOs have to reconsider their defence plans and load shedding philosophy and take into account the significant amounts of generation tripped during disturbances with large frequency deviation*
- *The restoration and reenergisation process has to be explicitly coordinated by TSOs regarding DSOs actions and the related responsibilities and duties of involved parties must be clarified within a national framework*

This appendix intends to detail the new commitment the TSOs consider as essential for RG CE power system security.

1.2 Power system conditions that can lead to emergency operation and to blackout

Such a classification scheme is depicted in figure 1 and, in the following paragraphs, a short description of each stability problem is provided in accordance with the CIGRE definition.

It must be noticed that such a classification is important for understanding the underlying causes of the problem in order to develop appropriate design and operating procedures, during large disturbances or blackout, all these instability phenomena can appear simultaneously or successively in a very complex manner. This is particularly true in highly stressed systems and for cascading events; as systems fail one form of instability may ultimately lead to another form.

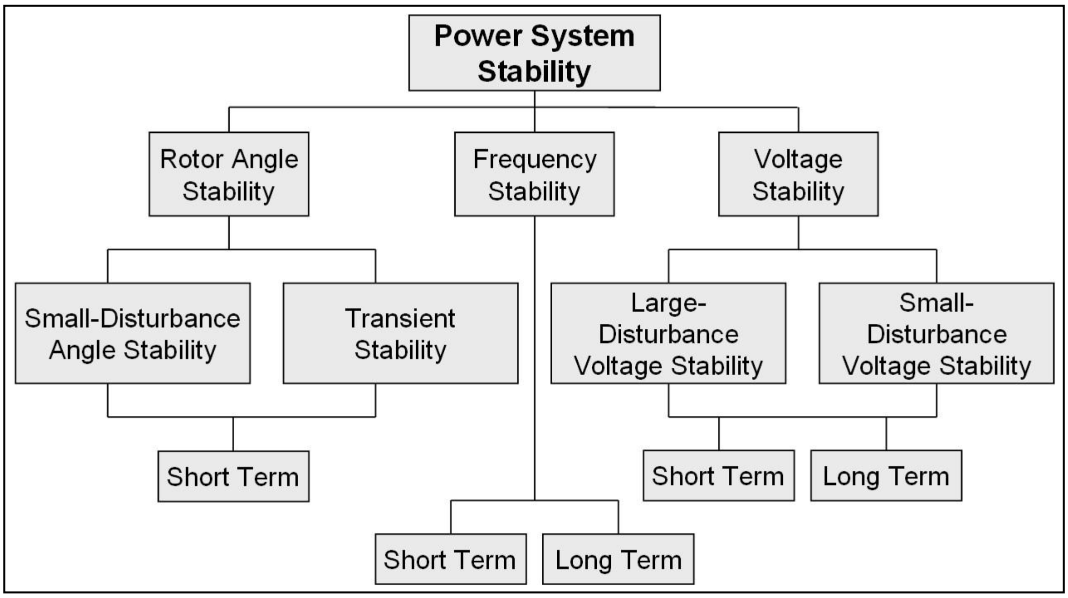


FIGURE 1: CLASSIFICATION OF POWER SYSTEM STABILITY

Rotor angle stability

Rotor angle stability refers to the ability of synchronous generators of an interconnected power system to remain in synchronism after a disturbance. It depends on the ability to maintain/restore equilibrium between electromagnetic torque and mechanical torque of each synchronous machine in the system and depends on the initial operating state of the system. Instability that may result occurs in the form of increasing angular swings of some generators leading to their loss of synchronism with other generators.

The change in electromagnetic torque of a synchronous generator following a perturbation can be analysed in two components, a synchronising torque component, in phase with rotor angle deviation, and a damping torque component, in phase with the speed deviation. System rotor angle stability necessitates the existence of both components. Lack of sufficient synchronising torque results in aperiodic or non-oscillatory instability, while lack of sufficient damping torque results in oscillatory instability.

Rotor angle stability problems can be divided into small-disturbance and transient stability sub-categories.

Small-disturbance (or small-signal) rotor angle stability

For this sub-category of instability, a power system is considered stable if it is capable of maintaining synchronism under small disturbances. The size of the disturbances allows the linearization of system equations for the purposes of analysis. The stability problem is usually associated with insufficient damping of electromechanical oscillations. Small disturbance rotor angle stability problems may be either local or global.

➔ Local problems concern a small part of the power system and are usually associated with rotor oscillations of a single power plant against the rest of the power system. Such oscillations are called local plant mode oscillations.

➔ Global problems are caused by the interaction among large groups of generators and have widespread effects. They involve oscillations of a group of generators in one area against a group of generators in another area. These oscillations are called inter-area mode oscillations. The time frame of interest, for small signal rotor angle stability, is on the order of 10 to 20 seconds following a disturbance.

Large-disturbance rotor angle stability or transient stability

Transient rotor angle stability refers to the ability of the generators to maintain synchronism after a severe disturbance (such as a short circuit on a transmission line or bus). Instability is usually in the form of aperiodic angular separation due to insufficient synchronising torque, manifesting as first swing instability. The time frame of interest in transient stability studies is usually 3 to 5 seconds following the disturbance and the resulting system response involves large excursions of generator angles and is influenced by the non-linear power-angle relationship. It may extend to 10-20 seconds for very large systems with dominant inter-area swings.

As shown in figure 1, both types of rotor angle stability are classified as short-term phenomena.

Frequency stability

Frequency stability is related to the ability of a power system to maintain steady frequency following a severe disturbance resulting in a significant imbalance between production and consumption. Instability that may result occurs in the form of sustained frequency swings leading to tripping of generating units and/or loads.

In large interconnected power systems, this type of situation is most commonly associated with situations following splitting of systems into islands. Stability in this case is a question of whether or not each island will reach a state of stable operating equilibrium with minimum unintentional loss of load. It is determined by the overall response of the island as evidenced by its mean frequency, rather than relative motion of machines.

Frequency stability problems are associated with inadequacies in equipment responses, poor coordination of control and protection equipment or insufficient generation reserve respectively excessive load imbalance.

During frequency excursions, the time constants of the processes and devices participating will range from fraction of seconds (corresponding to the response of devices such as under-frequency relays and generator controls and protections) to several minutes, corresponding to the response of devices such as prime mover energy supply systems and load voltage regulators. In this sense, frequency stability may be a short term or long term phenomenon.

Voltage stability

Voltage stability refers to the ability of a power system to maintain acceptable voltages at all buses in the system under normal conditions and after a disturbance and depends on the ability of the system to supply the active and reactive load through the operating grid.

Instability that may result occurs in the form of a progressive fall or rise of voltages at some buses. A possible result of voltage instability is the loss of load in an area, or tripping of transmission lines and other elements by their protection systems leading to cascading outages. Loss of synchronism of some generators may result from these outages or from operating conditions leading to violation of field current limit.

Moreover, a progressive drop in bus voltages is a phenomenon appearing due to rotor angle instability. As an example, the gradual loss of synchronism as rotor angles between two groups of machines approach or exceed 180° would result in very low voltages at intermediate points in the network, close to the electrical centre. The voltages near the electrical centre rapidly oscillate between high and low values.

The above issues show that a distinction between voltage and rotor angle instability is not always clear. However, such a distinction is important for the understanding of the underlying causes of the problem and the development of appropriate design and operating procedures.

The driving force for voltage instability is usually the loads; in response to a disturbance, power consumed by the loads tends to be restored by the action of motor slip adjustment, distribution voltage regulators, tap-changing transformers, and thermostats. Restored loads increase the stress on the high voltage network by increasing the reactive power consumption and causing further voltage reduction. Voltage instability occurs when load dynamics attempt to restore power consumption beyond the capability of the transmission network and the connected generation.

As for the case of rotor angle stability a categorisation to large and small disturbance voltage stability can be applied. In addition, because the time frame of interest for voltage stability problems may vary from a few seconds up to tens of minutes due to the fact that the dynamic of instability depends on high dynamic elements such as induction motors, electronically controlled loads, SVC, HVDC converters, voltage controller and limitations of generators so much as slower acting equipments as on load tap changers, generator current limiters, thermostatically controlled loads or secondary voltage control, this phenomenon may be considered short term or long term, according to figure 1.

2 Links between the Policy 3 "Operation security" and the Policy 5 "Emergency Operations"

The *Policy 3 "Operation security"* aims at defining the core of the rules for a secure operation of the RG CE synchronised interconnected power system, covering mainly continental Europe. It deals with any technical and organisational obligation of TSOs with a view to co-operating in the implementation of all requested actions for a secure system operation. The N-1 principle with the notion of "no cascading outside my borders" is the key rule to operating in the best way - and to maintain the best availability of the system from operational planning to real time. This policy covers the normal operational conditions including after normal contingencies (loss of a single network element) and some exceptional contingencies. Another consequence of the N-1 principle is the trigger for the TSOs to "be aware of the risks" whatever the possibilities or not to cope with the future system constraints (notion of ASAP) and then to inform neighbours and cooperate far in advance to minimise the risks of collapse.

In case of deterioration of the operational situation, the TSO refers to *the Policy 5 "Emergency operations"* that includes the warning procedures based on system states.

Nevertheless, even in the respect of such committed rules and having deeply analysed the risk of operation at the planning stage, some events can occur endangering the system to varying degrees of seriousness: multiple trip of system elements (lines, generation units, busbars) due to faults of network elements or storms, earthquake, terrorist or cyber attack, etc. In normal operation, TSOs cannot take into consideration all possible events for which remedial actions are affordable in terms of costs. However, as these situations could have a major effect on the security of their system and on the interconnected system with a large impact on customers, they have prepared in advance a specific set of rules, called defence plans with detailed remedial actions and procedures. These specific rules can be considered as the ultimate remedial actions TSOs are able to implement in order to save the system without any guarantee of success. As a consequence, TSOs have also to implement a set of rules called restoration plans in order to tackle a disturbed situation to a blackout situation and be able to get the system back to normal insofar as possible .

The rules, all in line with their grid codes or national legislations, and in co-operation with their neighbouring TSOs, are the core content of the 'Emergency operations" policy.

The structure of policies "Operation security" and mainly "Emergency operations" are organised as follows:

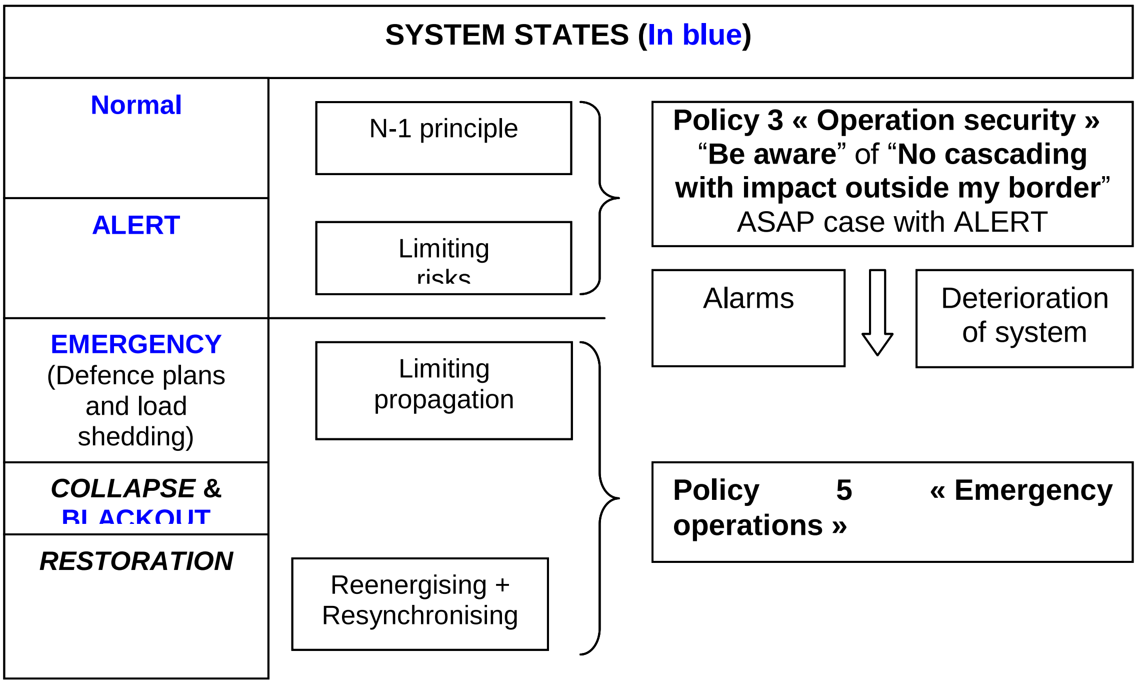


FIGURE 2: LINK BETWEEN POLICY 3 AND POLICY 5

Policy 5, “Emergency operations”, complements Policy 3, “Operation security”. The appendix chapter 3 details the system states and the operational transition evolutions such as collapse and restoration. The resynchronisation is an issue after blackout but also can occur after an emergency state like the split of the RG CE system.

The “emergency operations” policy aims at creating a common framework of co-operation for any emergency situation that eases to render maximal assistance to another TSO in trouble in order to limit any propagation of incidents “no cascading outside my borders”, which could lead to a wide collapse of the RG CE interconnected network.

This policy deals with

1. The awareness and the inter-TSO communication of abnormal operational conditions of “Emergency”, and “Restoration” after a blackout.
2. The management of the system in case of inter-TSO emergency operational conditions, the so-called defence plan
3. The restoration of the whole synchronous RG CE system after blackout or split

The introduction of such system situations as “Emergency” and “Restoration” aims at facilitating the announcement by any TSO to its neighbours and to the others when its own system is in trouble. Strong inter-TSO co-operation is obviously requested in case of blackout with the restoration to be accomplished as soon as possible. The standards and guidelines of the “emergency operations” policy define actions to be rapidly, even urgently, carried out manually or automatically at national level by the TSO in trouble and by other TSOs involved or requested for assistance. The inter-TSO co-operation remains essential and vital in such system situations.

3 AWARENESS OF SYSTEM STATES

3.1 Background

The awareness of the conditions of power system operation when it goes to critical stages is of utmost importance for dispatchers and operators of control rooms to anticipate any action and inter-TSO coordination securing the functioning and, in the worse cases, the integrity of the system as long as possible. Dedicated tools and bi-multilateral procedures are set up between neighbours and non-adjacent TSOs in order to share a common picture of risks experienced in real time by one (or more) TSO(s). A system states classification is assessed to this end with the criticality of operational conditions.

3.1.1 Historic

Wide-area disturbances originate usually regionally from: a regional loss of major generating source(s) or of critical transmission line(s), an unbalance in voltage and reactive power, a contingency that can spread due to additional sequence of events with a low probability of occurrence.

Quick information exchanges during critical situations or established disturbances enable TSOs to:

- Limit the risks of degradation due to unawareness of the situation
- Control their spread and contribute to recovering the balances
- Prepare and/or put strategies into operation

Recommendation #4 of the investigation report related to 4th November 2006

RG CE has to set up an INFORMATION PLATFORM allowing TSOs to observe in real time the actual situation of the whole RG CE system in order to quickly react during large disturbances.

3.1.2 Purpose

The purpose of this chapter is, on the one hand, to define in a harmonised way the wording and the meaning of the identification of each system situation and, on the other hand, to define rules to exchange this information among TSOs.

This will allow TSOs to quickly and easily express to the other TSOs the situation of their own system or to be aware about the situation of the other systems in order to prevent any cascading consequences or quickly react during large disturbances.

This information and these rules are not solely for the benefit of the grid users (DSOs, producers, consumers)

3.1.3 State definition

When we are speaking about a system situation, we have to take into consideration the following states:

- **Base state** = real-time state or forecasted state. This is the state of the system the operator has to deal with;
- **Contingency state** = state after any contingency occurred on the base state. The definition of the types of contingencies is given in Policy 3 (P3-A1-D2).

3.1.4 Grid or load/frequency risk

In the classification of the system state, we have to distinguish four kinds of risk level:

- **Grid risk level**: takes into consideration the adequacy of the base state or the contingency state to the operational criteria (transmission and voltage) defined in Policy 3;
- **Load/frequency risk level**: takes into account the adequacy of the base state or the contingency state to the load/frequency performances defined in Policy 1;
- **IT risk level:** takes into account the availability of all needed IT infrastructure allowing the TSO to make risk assessment of the system situation;
- **Out of range event risk level**: takes into account the occurrence of out of range event like extreme weather conditions, terrorist attack, natural disaster etc.

3.2 System State classification and communication

3.2.1 System State classification (Refer to P5-A-D1)

Regarding the objective of the use of these definitions, the number of states has been designed to be as limited as possible and the meaning as clear as possible. We propose to use the same wording and definition of state classification both for grid or load/frequency risk level.

Explanations of system states definitions:

- **Normal:** All criteria are fulfilled for the base and contingency states. All parameters are within normal limits, taking into account remedial actions effects.
  The state of a given system is considered as normal when all its parameters (frequency, voltages, loadings) are *within secure operational limits.* Following any event of the contingency list (Cf. Policy 3) all operational criteria are fulfilled, taking into account effects of predefined remedial actions. This refers to the real-time system state as well as the forecasted one in the time horizon of control room activity.
- **Alert**: Risk for neighbouring systems in case of occurrence of a contingency. Base state (N) security is OK (system is stable for frequency, transmission limits and voltage but risk if evolution of flows and increase of loads, deterioration of voltage). Concerns on IT components that weakens the observability of power system. At least for one contingency state the (N-1) security is non-compliant. Available remedial actions are duly to be applied without delay to comply again with N-1. TSO has serious delay *uncertainties* to come back to a normal state if a new contingency occurs. Possible remedial actions are only ASAP. In case such actions are not available, there is a high probability of entering a more dangerous state once system operating conditions change due to a new contingency or simply the gradual increase of load: the state can go to a more dangerous state, firstly “Emergency”. Consideration is taken for possible disturbed states originating from weather conditions, principal and back-up SCADA unavailability, security calculations unavailability, lack of generation reserve, steady unbalanced system with no further reserve etc.
- Emergency: The system is strongly disturbed. Risk to neighbouring systems in the base state. Criteria (frequency, transmission limits or voltage) are not fulfilled in the base state and make the system not viable. System parameters are outside of the acceptable ranges. *Global security is endangered*. Available and prepared actions are undertaken immediately without guarantee of total efficiency to limit propagation to neighbouring systems. In such a case, relevant actions must be taken immediately to bring back the system into acceptable conditions. They can include exceptional

manual or automatic actions, determined in defence plans, necessary to prevent a system collapse and to limit the risk of spreading a disturbance to other parts of a given system and to the neighbouring systems. These actions can include controlled disconnection of some load or generating units in order to come back to alert or normal state. Cascading and deterioration can be in progress but no blackout state: e.g. load shedding, splitting areas. The emergency state could result from the occurrence of event(s) due to a lack (of efficiency) of remedial actions. A system being in emergency state can lose some loads and can be split but is not blacked out (Refer 4th November 2006). However, if the emergency actions are not taken in time or are insufficient a system can collapse and enter the blackout state

- **Blackout**: Characterised by the almost or total absence of voltage in the transmission system and as a consequence of loss of load, disconnection of generating units or in house load operation. A blackout can be partial (if a part of the system is affected) or total (if the whole system is collapsed).

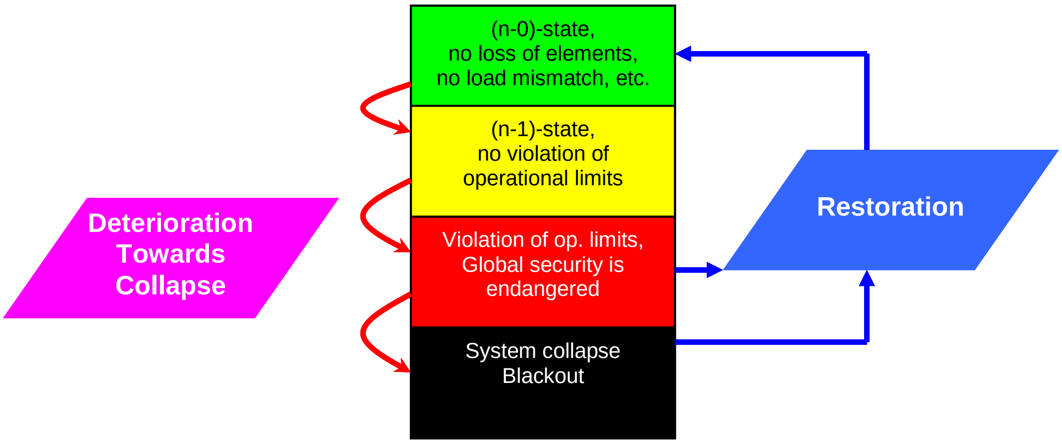


FIGURE 3: SYSTEM STATES CLASSIFICATION

Different *operational transitional evolutions* can affect the system as follows:

Collapse: rapid evolution to worse and critical operational situations

As far as the worst case is concerned, just before going to the blackout, the dynamics of the behaviour of the power system are too fast for any operator decision, co-ordination or manual actions. Automatic devices are put in operation to protect the equipment and integrity of parts of the network, whilst trying to prepare the best possible restoration of the power system. Local immediate action may prioritise preventing damage to the equipment involved, with the resulting system security being worsened, but in view of a quicker restoration of the system.

The collapse stops at an intermediate or final phase. The non-supplied parts of the network (out of voltage) and the topology are clearly identified. The number of tripped lines and tie-lines and of units disconnected or correctly islanded in house load operations are identified.

Restoration: from blackout or emergency states to normal state (Refer §5.2.1)

Once the system enters blackout state, the restoration plan is activated as soon as possible. While rebuilding the system from emergency state to a normal one, the system is also in a restoration situation.

The restoration procedures contain all the measures to reenergise the system.

In case of collapse, after a house load rejection, most of the generator units are operating in time-limited islanding conditions with self-consumption. Restoration involves restarting and synchronisation of generation units, load restoration and resynchronisation of all areas and help from neighbouring TSOs and includes all manual/automatic reconnection of the islanded power system. Available generation black start capacities are put into service.

3.2.2 System State communication

At any time, in real-time and in operational planning stage, each TSO has to communicate to the other TSOs the state of his own system, based on security risk assessment, taking into account internal or regionally coordinated remedial actions. This information has to be evaluated at each change of system state.

In case of the different system states *Alert, Emergency* and *Blackout,* TSO has to firstly launch messages, and secondly has to specify which risk level is encountered: grid or load/frequency, which contingency is concerned and the nature of the violated criteria in order to allow the other TSOs to assess the risk impact on their own system. In certain condition, like in case of frequency deviation, such pre-formatted messages could be launched automatically.

When a contingency affecting the responsibility area of one TSO occurs, it will have to evaluate the new situation with N-1 security calculations.

However, priority will be given to the management of the impact of this contingency on the new base state by applying the needed and prepared remedial actions.

The TSO assesses the new system state and the risk evaluation.

3.2.3 Communication tool framework

Following recommendation #4 of the IC of November 4th disturbance, one (or several) information platform(s) for RG CE wide (or regional) awareness system(s) should be designed. Its main purpose is to provide a way "to realise by a simple steady-state visualisation a comprehensive overview of the operation of the entire highly-meshed Central European system". This system should allow the dispatchers to "see" what's going on beyond their own control area and have indications to interpret and anticipate the evolution of the overall system".

One feature of this tool among others is to provide, as a first step, a way to exchange:

- Indication flags (e.g. LFC modes, system states)
- Real-time measurements for each control area: exchange power (schedule and real), area control error (ACE), frequency and wind power infeed where significant
- Short pre-formatted messages

A further step would involve the ability to restrict the recipient list (if this feature proves to be relevant) and the ability to complete the pre-formatted messages with appropriate fields or free comments.

3.2.4 General scope of inter-TSO communication

The aim of inter-TSO communication is to provide to the TSOs an appropriate mutual knowledge and understanding of the real-time and short-term foreseen system states.

A relevant level of information exchange relating to the actions that are put into operation or the evolution of the system condition is necessary during normal or disturbed situation in order to:

- anticipate the consequences of the evolutions of neighbouring TSO environments that are to be taken into consideration (e.g. topology changing near the borders),
- limit the worsening of a stressed situation and prevent the extent of the phenomena,
- ask for implementation of cross border countermeasures to limit the consequences of a disturbance,
- coordinate defence, restoration, resynchronisation and/or reenergisation processes,
- have quick, reliable and univocal means of communication (to be defined) for the transfer of the necessary information (e.g. transferring the system states during an emergency state).

Thus, the communication is based on pre-established multi-lateral procedures that determine:

- the conditions in which it has to be activated,
- the concerted actions (topology changes, generation pattern changes with redispatching, transfer capacity reduction or curtailment, etc.) that can be implemented to arrange the flows, manage the voltage, or restore the load-generation balance,
- the possible means that can be solicited,
- the appropriate telecommunication facilities (phone, fax, EMS, awareness system…) that are to be used and the information templates (e.g. grid scheme to fax) that are to be exchanged.

These procedures are regularly updated and improved, and new means of coordination are envisioned at regional and RG CE-wide level. Coordination platforms are emerging providing quick messaging and alarm means, and global overview by use of new tools, such as awareness system, and regional supervision covering sets of TSOs that are involved in integrated markets.

Inter-TSO communication is done by default in the English language. To do so, the dispatcher is helped with an English glossary with operational terms (Refer to Policy 8 “Training”).

3.2.5 Conditions to send messages

If a TSO considers a significant risk for neighbours, messages are sent. Messages can mean a call for coordination.

3.2.6 Time frames and related messages to send

The time frame has to be defined in order to launch messages in due time to neighbours or to the RG CE community. It should be established depending on the possible anticipation explaining that the situation will quasi-certainly occur. This situation can be assessed from operational planning till near real time. Messages sent far in advance contribute to improving any insecure operation, allowing the endangered TSO to speed-up regional coordinated actions.

3.2.7 Content of messages

The pre-formatted messages list can be structured into a tree to ease the choice of the relevant message to send in stressed operational situations. The list is not exhaustive

- <u>LOAD / IMBALANCE</u>
  - **Frequency deviation**
    - Frequency deviation higher than 200 mHz
    - Frequency deviation higher than 1 Hz
  - **Generation reserve**
    - Margin below required minimum
      - Primary reserve
      - Secondary reserve
      - Etc.
    - Loss of more than 3000 MW
    - Imbalanced system with no margin available anymore
  - ***Loss of load (over-frequency risk)***
    - E.g. National actions for energy savings
    - Etc.
  - ***Load shedding***[1]
    - Manual load shedding
    - Automatic load shedding
- <u>GRID</u>
  - **Voltage**
    - Areas in out of voltage range - risk of voltage collapse in N-1
    - Areas in out of voltage range - worsening evolution expected
  - **Flows**
    - Relevant N-1 violation (Refer to Policy 3)
    - Flows beyond security limits - worsening evolution expected
- <u>OUT OF RANGE EVENT</u>
  - **Grid split**
    - Partial islanding within a control area
    - Large (cross-border) splitting
  - **Critical event (weather / disaster / ...)**
    - Out of range types of contingency (P3-A1-D2) - worsening evolution expected
- <u>IT DISTURBANCE</u>
    - Security analysis unavailable
    - SCADA (principal and back-up) not available
- <u>OTHERS</u>
    - Blackout
    - Restoration in progress
    - Back to normal state

[1] Load shedding is more considered as an action, rather than a signal to send to TSOs. Load shedding is always a consequence of a very stressed operational situation. Load shedding is intended to clear the situation. Messages are sent for the situations taking place before load shedding.

4 System Defence plan in case of emergency state

4.1 Introduction

The security of operation is defined as the capability to assure a normal functioning of the power system, to limit the duration and number of disturbances, to prevent any large disturbance, and to limit the consequences of a large collapse when it occurs with also the view to ease the restoration of the system after blackout to normal operation.

This part is related to emergency state with the associated information process and remedial actions.

The RG CE defence plan is mainly based on the national defence plans, which are obligations for TSOs through regulations (grid codes). Defence plans can be defined as a set of coordinated measures, which aim to keep the integrity of the system in case of abnormal system conditions resulting from extreme contingencies.

In this document, one develops the procedures and related actions under the survey of the control rooms and the needed coordination between TSOs in real-time operation. It is understood that roles of other very rapid devices are not explained in this document.

When the means for margins (case of lack of generation) and predefined remedial actions may not be sufficient for secure operation of the system (e.g. after failure of a network element, an occurrence of new disturbance within the N-1 recovery period or a multiple contingency) the system is considered to be in insecure conditions: limits of voltage, of current, of frequency and balance reserves can be violated consequently.

The objective of a RG CE-wide defence plan with all commitments for automatic devices is to set up technical recommendations and rules for automatic actions to manage critical system conditions to prevent the RG CE power system or parts of it from the loss of stability and cascading effects leading to major blackouts. The set of rules shall be developed with respect to various physical phenomena, which affect different TSOs or even have a global influence on RG CE.

A general approach has to be ensured independent from organisational structures and for a system wide implementation at all voltage levels including generation, transmission, distribution and customers.

4.2 Real-time coordination for remedial actions in case of emergency conditions

Stressed power system conditions can be followed by unexpected sequence of low-probability outages. TSOs are sometimes forced to operate the power system closer to its stability limits and not in its most robust operating state. TSOs cannot always anticipate and predict the sequence of events of low-probability disturbances that renders power systems more vulnerable to blackouts. In case of inadequate reactive power support resulting in extremely low voltages, overloads on transmission lines and subsequent operation of distance or other types of protecting relays may occur. Sometimes the inadequate coordination of relay settings and other protective devices or systems results in a sequence of unexpected events ending in blackout.

The separation of the power system into different parts can happen at any time and under all conditions of loading levels. The break-up of the system (like on 4 November 2006) or in worse case the blackout (like in Italy in 2003) is a result of a more or less rapid succession of contingencies insufficiently analysed ahead or in real time or not predictable due to their exceptional character like weather changes with peaks of load out of forecasts, hurricanes, lightning, common modes of faults in transmissions substations or in power plants. The worst result is a lack of electricity supply in the involved regions for all the consumers and the installations connected to the network.

In general, the following issues draw the attention of dispatchers of control rooms as potential *causes of emergency in the system*. Serious uncertainties about returning to normal operation are caused by:

- Flows on network elements and tie-lines beyond security limits (overload situation, e.g. due to unforeseen flows)
- Lack of (short-term) primary, secondary or other reserve power (reduced generation, e.g. caused by outages of units or by lack of cooling water or by restricted transmission capacities)
- Lack of reactive power leading to a critical voltage level (low or high)
- Lack of observability and controllability (e.g. loss of SCADA system, malfunction of load-frequency-control, loss of control system)
- Indications of instabilities such as voltage drop, frequency drop, un-damped power swings or increase of voltage phase angles.

As by definition, emergency state refers to a situation occurring in real time, only curative remedies can be considered (preventive remedies have already been implemented at this stage). The availability and the efficiency of such curative remedies are not guaranteed at all and the time period to implement them cannot always allow optimising their identification, some of them even need to be automated.

As the efficiency of these remedies can not always be correctly and co-ordinately assessed in real time once needed, each TSO needs to develop specific procedures dealing with the potential emergency conditions defined above which could occur in their responsibility area. The aim of these procedures is to give to the operators in the control centre the specific action he has to undertake under each condition (or criteria).

As some conditions (criteria) activating the defence plan and the associated remedies could have a regional, even a wide RG CE influence, it is of importance that TSOs coordinate their defence plan on a bilateral, multilateral, regional and up to RG CE-wide level.

Policy 5 will specify the rules and guidelines for the management of remedies with RG CE-wide influence. TSOs will have to deal with inter-TSOs influencing remedies based on bilateral up to regional procedures. These procedures should, on the one hand, allow each involved TSO to know and take into account the influence of the emergency remedies from the defence plan of one TSO on his responsibility area and should, on the other hand, define which emergency remedies coming from a neighbouring TSO can be included in the defence plan of one TSO.

Due to the lack of time and the stress level and the amount of actions to be undertaken once one TSO is in emergency state, these procedures should also minimise the level of coordination and information exchange needed among TSOs during the application of each individual defence plan. When coordination and information exchange is needed, the procedures should then clearly define which information, with which tool and to whom.

As already mentioned before, launching the emergency state and then applying the emergency remedies defined in the defence plan has to be done by the TSO after his own risk assessment, taking into account the application of internal or regionally coordinated remedial actions as defined in Policy 3.

In case of emergency state, each TSO will realise his best effort in applying all available actions, up to load shedding, on internal, regional or RG CE-wide level. Maximum support will be applied among TSOs in order to enhance the success of stabilising the situation and get back as soon as possible to a new secure base state.

Emergency remedial actions for defence plan

Remedial actions are classified by TSOs under their individual approach in accordance with their grid codes. TSOs consider in all cases an escalation of measures - post event/curative and preventive.

Some of the following measures are not always available due to national legal frameworks.

(Non-exhaustive list) – Link to appendix of Policy 3 (§5):

- **Load/frequency constraints**
  - Start or stop generation units
  - Start or stop pump storage units
  - Increase or decrease (automatically or on request) production level of generating unit or pumps
  - Adapt active LFC control mode
  - Use of manual or automatic load shedding
  - Changes of voltage regulator set points on transformers at distribution level

- **Power Flow Constraints**
  - Topology changes (network reconfiguration)
  - Use of phase shifter transformers
  - Cancellation of maintenance (grid elements urgently backed to operational service)
  - Changes in the pattern of reactive power flow:
    - Within own grid
    - With the support of neighbouring TSOs
  - Automatic unit trip triggered by line outage
  - Deployment of tertiary reserves
  - Contracted generation redispatch within the TSO’s own control area
  - Cross-border redispatching with neighbouring TSOs
  - Counter-trading with neighbouring control areas
  - Intervention in scheduling
  - Management of loop flows (e.g. by using DC links of Baltic Sea)
  - Freezing of scheduled exchanges
  - Schedule of exchange reduction
  - Reduction of interconnection capacities
  - Start-up of tertiary reserve (hydro, pumping, rapid thermal units and others)
  - Pump trip
  - Manual load shedding of interruptible loads (customers)
  - Automatic shedding of interruptible customers triggered by line outages
  - Manual load shedding of domestic loads
  - Automatic shedding of loads

- **Voltage Constraints**
  - Requesting maximum or minimum values of generation for active and reactive power (P and Q)
    - Reduction of active power in favour of additional reactive power output
  - Manual tap changing of 380/220-kV-transformers
  - Adjusting of power flows
  - Switching on/off shunt reactors or capacitors
  - Preventive start of units with provision of additional reactive power
  - Line opening in case of high voltage conditions (off-peak periods)
  - Stop of voltage and reactive power optimisation
  - Stop of maintenance, switching-on of all elements previously in maintenance
  - Limitation of intraday trade (influence on transits)
  - Blocking of OLTC (on load tap changers) of transformers

- Changes of voltage regulator set points on transformers at distribution level
- Manual load shedding of interruptible loads (customers)
- Manual load shedding of domestic loads
- Automatic load shedding

Remedial actions – summary table in appendix

The following table “Alert & Emergency actions – Current practices” in appendix presents a non-exhaustive list of remedial actions to be applied to the power system in case of emergency condition. It contains an indication about escalation of the remedies, from non-costly to costly actions, from seconds to hours of delay of reaching full effectiveness of the remedies and with indication of the influence, from internal to RG CE-wide:

- Escalation of remedial actions
- Delay of full effectiveness of remedies
- From topology changes to load shedding
- From internal influence to RG CE-wide influence

This complements the table in the appendix of Policy 3, “Remedial actions – best practices”.

ALERT&EMERGENCY OPERATIONS	**Time delay**	**Preventive Curative**	**Automatic Manual**	
Predefined automatic action (generation trip or load redistribution/cutting in case of outage)	a few seconds	C	A	Internal
Topology modification via breakers	a few minutes	P/C	M	Internal
Topology modification via switchers	minutes or hours: depending on the availability of grid operator	P/C	M	Internal
Transformer tap position modification	a few minutes	P/C	M	Internal
Capacitor and reactors switching on/off	a few minutes	P/C	M	Internal
PST tap position modification	a few minutes	P/C	M	Internal/ Inter-TSOs
Load redistribution (coordination TSO/DSO)	a few minutes	P/C	M	Internal
Management of loop flows (e.g. by DC links)	minutes	C	M	Inter-TSOs
Mvar production modification on generation units	a few minutes	P/C	M	Internal
Pump trip/starting	a few minutes	P/C	M	Internal
Internal redispatching of generation units (internal redispatching)	a few minutes	P/C	M	Internal
Start/Stop generation unit	minutes or hours: depending on the unit	P/C	M	Internal
International redispatching of generation units of neighbouring TSOs	a few minutes	P/C	M	Inter-TSOs
Outage restitution	many hours: depending on the restitution delay	P/C	M	Internal
Limitation of exchange capacity		P	M	Inter-TSOs
Contractual manual load shedding	a few minutes	P/C	M	Internal
Cross-border exchange modification (curtailment)		P/C	M	Inter-TSOs
Non contractual automatic/manual load shedding	a few minutes	P/C	M	Internal
MV voltage settings down (5%)	a few minutes	C	M	Internal
(Automatic) disconnection of border lines	a few seconds	C	A/M	inter-TSOs/ RG CE
Blocking of OLTC	a few minutes	C	A	Internal
LFC working control state	a few minutes	C	A/M	RG CE
Automatic load shedding	a few minutes	C	A	RG CE

4.3 Inter-TSO coordination for RG CE wide appropriate common action

4.3.1 Tie line operation in emergency conditions

TSOs are supposed to provide maximal assistance through tie lines in case of emergency situation experienced by neighbouring TSO. Tie lines between control areas are considered the backbone of the interconnected system. That is why it is crucial to keep interconnected operation of the whole system as long as possible, thus contributing to solidarity of synchronously interconnected grids.

Moreover, any tie lines openings may substantially change operating conditions of not directly neighbouring TSOs, especially in emergency conditions. During severe disturbances there is usually no time to check properly the consequences of any change in network configuration and of the opening of a tie line, which can result in significant load flow changes in a distant part of synchronous interconnection. Such risks need to be communicated to the potentially influenced TSOs. This is why the opening of tie lines should be avoided as a defence plan measure in emergency operation. The exceptions can be only predefined, duly prepared in a coordinated way (between involved TSOs) with automatic (or manual) openings, which under given operating conditions improves the situation or contributes to speed up of a restoration sequence.

The underlying assumption to the above strategy is that tie lines are adequately equipped with protection systems (as any internal lines), which trip them once the system operating conditions become dangerous for system elements (especially generating units), for example in case of unacceptable inter-area oscillations. This is according to the general rule that in order to prevent the propagation and deterioration of an incident, protective devices must be installed for the rapid elimination of faults affecting any given element of electrical facilities.

With respect to the security of persons, an urgent opening can be carried out in cases of physical danger to human beings or installations without prior information to neighbouring TSOs involved.

To keep the interconnection in operation as long as possible is of utmost importance, but shall be consistent with the operating constraints.

4.3.2 LOAD SHEDDING

General framework of load shedding

1. Automatic load shedding shall be applied in a curative way by all TSOs in case of RG CE-wide frequency drop.

There is no doubt at all about the will of TSOs solidarity to cope with a RG CE-wide frequency drop. But the load shedding equipments are not systematically connected to the TSOs' grids, but often to the DSO grids. Obligations of load shedding are also ruled by grid codes. Therefore TSOs are not in a position to hand on the total responsibility of load shedding effectiveness that requires the full coordination with DSOs. Moreover any full harmonisation of national rules at RG CE level will need a long while before full clearance.

The new set of RG CE rules is defined as guidelines due to the short-term impossibility to commit TSOs to new harmonised standards that are not exclusively in their hands.

2. Load shedding can be applied by an individual TSO for its own purpose in a curative or a preventive way. No effect on neighbouring systems is presumed in this case.

   2.1. Automatic load shedding to face local unbalance production/consumption (This scheme is similar to the RG CE scheme).

   2.2. Manual (or automatic) load shedding to relieve excessive load on network elements or to prevent voltage collapse (if in line with local legislation). Local automatic devices can exist for alleviating loads on overloaded lines, or to maintain voltage in the normal ranges preventing voltage collapse. The load shedding is either manual or automatic: the automatic is curative; the manual is often a preventive measure applied in advance.

The same existing load shedding equipments can be used for RG CE (depending on the domestic TSO policy) or for individual TSO's purposes.

Load shedding plan

The load shedding policy of RG CE shall take into account the existing technologies of present equipments. Due to the large variety of types of devices, and the basic physical relation of the frequency behaviour after sudden power deficit and the effects of modern and old type load shedding relay characteristics on the dynamic behaviour, it is preferred to prevent and forbid:

- Any artificial or natural time delay of load shedding relays that has adverse effect due to the rather high derivative of the frequency in case of power deficits in separated areas.
- The risk of overcompensating the load imbalance that can be reduced by almost linear activation of load shedding (approximation by small frequency steps with small share of load shedding).

Although a mandatory amount of load shedding up to 50 % of the load cannot be justified physically, it is proposed as a guide, that the amount of 50% of total load to be operated under load shedding relays can be linked to a maximum amount which can be achieved without leading to the occurrence of (voltage) stability problems. It seems to be a common practice in many systems worldwide, except in the USA, where 30% is applied since improvements after the blackout of 2003.

The amount of load shedding of 50 % is considered a conservative value. Even though the probability of activation of the full volume of load shedding is very low this potential should be available in order to have sufficient margin to protect the system against collapse. The effort of RG CE for system security should be oriented at the practise worldwide. In addition to that, dynamic system calculations performed for various systems all around the world prove the efficiency of this standard setting.

It has to be taken into account that some modern generation units are more sensitive against unusual frequency and voltage conditions in the grid (e.g. CCGT, wind farms and other renewable energy sources - RES). Consequently, there is the need to take these into account with respect to the total amount of load shedding and to have a potential of 50 % load shedding in order to compensate an increasing load imbalance, when generation units trip due to transients in the network during or after an incident.

It was agreed to treat risks due to insufficient performance of generation units as follows:

- The RG CE-wide load shedding scheme shall be designed under the assumption of full compliance of the grid requirements by generators (disconnection criteria: f= 47.5 Hz).
- In case of non-fulfilment of grid requirements by generation units in a certain area, the respective TSOs are obliged to organise an extra amount of load shedding according to their disconnection criteria (especially frequency thresholds and amount of units disconnected above 47.5 Hz). These measures shall avoid extra burden on the community by non-compliance of generators connected in certain grid areas.
- The respective TSOs have to take care for the correct behaviour of generation units connected to the grid by legally binding connection rules. (This problem concerns especially CCGT, wind farms and other RES.)
- During or after a severe incident there might occur extreme network conditions, which are beyond the grid requirements to generators. The resulting risk of unit trip has to be taken into account, with respect to the additional potential of load shedding by all partners.

This approach corresponds with the principle of solidarity and fairness, which also implies considering the system as a whole, and not to open tie lines during emergency conditions. In contrast, the strategy of system splitting by the opening of tie lines during emergency conditions means limitation of the solidarity, which is not primarily in line with basic RG CE rules.

Different control areas or countries with specific characteristics might require a different approach and individual TSOs have developed for many years a respective load shedding plan above 49 Hz and below 48.5 Hz for local considerations. But in this case these individual TSOs shall avoid negative influence on each other. On the other hand, this has also to be avoided in case of specific characteristics of dispersed generations, which requires special solutions in certain areas.

Harmonisation of load shedding can be expressed as follows:

- Harmonised rules and a common approach have to be preferred. Individual solutions have to be considered very carefully as they do not correspond to the regulatory framework, the European-wide market and the compliance monitoring process. Therefore, a common framework for everybody is needed.
- Furthermore, individual solutions are possible with respect to specific requirements, which go beyond the harmonised rules.
- Specific countermeasures are necessary with respect to insufficient performance of dispersed generation in certain areas. It is up to each TSO to identify the corresponding extra amount of load shedding to mitigate such a loss of production in the transient phase of the frequency drop.

The following figure was agreed as a basis for rules for load shedding schemes. The individual load shedding schemes should be designed in such a way that the load to be shed has to be for all the individual steps above the red area and below the yellow area as shown in the figure below.

Under-frequency load shedding – RG CE general plan

- Load shedding of customer consumption is allowed at 49.2 Hz and mandatory at 49.0 Hz and a stepwise 50 % of the nominal load should be operated under load shedding relays in the range 49.0 to 48.0 Hz.
- At 49 Hz at least 5% of total consumption should be shed, which should be complemented for each individual TSO according to the loss of generation at this stage induced by the frequency drop due to non-compliance with grid requirements.
- Below 49.0 Hz, the stepwise load shedding plan should be complemented by an individual mitigation of the loss of generation. TSOs should adapt their own load-shedding plan in order to compensate the additional loss of generation.
- Frequency steps should be smaller than or equal to 200 mHz (depending on number of steps and characteristic of load shedding relays)
- In each step of UFLS, it is advised a disconnection of not more than 10% of the load (depending on number of steps and characteristic of load shedding relays) except if considering the additional loss of generation.
- Maximum disconnection delay should be 350 ms including breakers operation time. No intentional time delay should be added.
- Frequency measurements for load shedding should be maintained at a maximum inaccuracy of 100 mHz.
- Automatic disconnection of pumps should be activated below 49.8 Hz:
- If 49.2 Hz < frequency < 49.8 Hz, then delay <= 10 s;
- If frequency <= 49.2 Hz, then delay = 0 s.
- *Below 49.2 Hz all pumps should be disconnected*

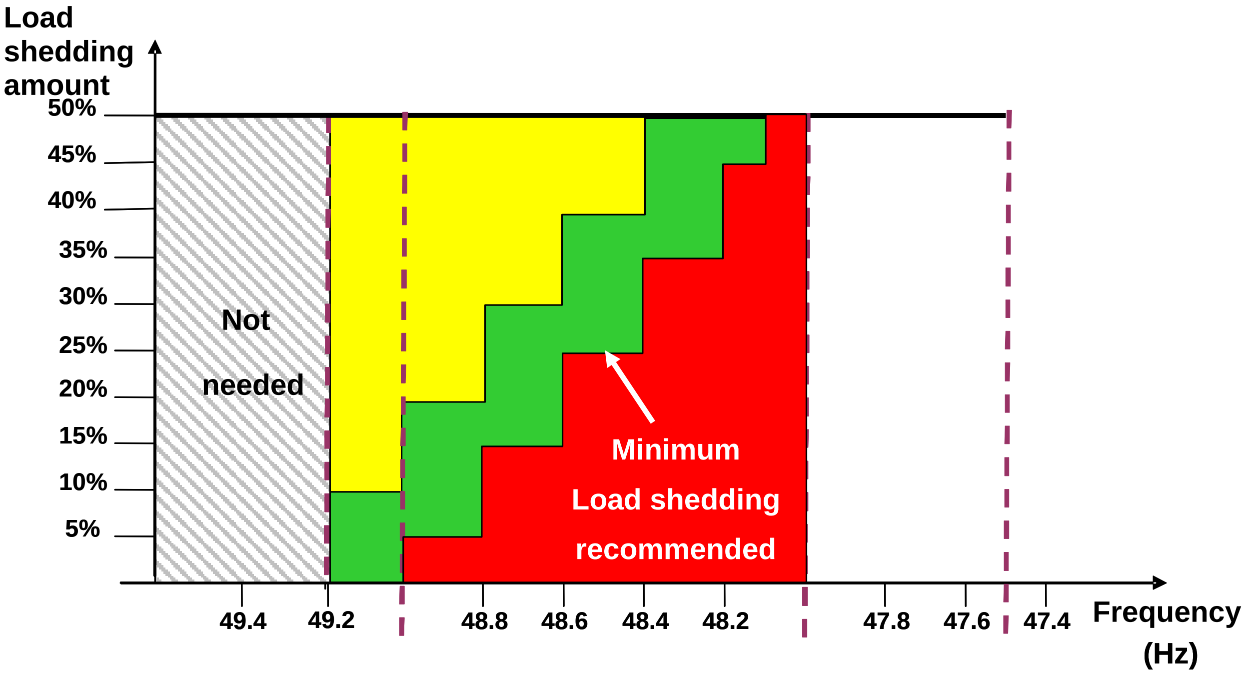


FIGURE 4: SYSTEM STATES CLASSIFICATION

The green band is the most recommended situation, although the yellow one can be reached but could have adverse effects on neighbouring systems or on the behaviour of the RG CE-wide power system. The border between the green and the red area should be considered as the minimum values.

5 System restoration process: general overview

5.1 Preliminary remark

As far as system restoration is concerned, it is virtually impossible to predict how a potential blackout will develop or where the RG CE power system will be split in case of large disturbance. Such consequences often represent the final stage of complex processes resulting from a succession of multiple events, which are difficult to assess beforehand. After a serious collapse since initial conditions for the reconstitution process are highly variable, it is not possible to establish in advance a predefined overall RG CE restoration plan of the power system, which will be comprehensive in every detail. The detailed procedures of restoration of each TSO's control area power system are the subject of national restoration plans, which are well developed by individual TSOs on national level although they are based on similar principles:

- Provision of black start capability of generation units (either by dedicated black start units or by the units in house load operation)
- Ability of generation units regarding such house load operation
- Reenergising the transmission grid by generation units or with the help of neighbouring systems (respectively bottom-up or top-down principles with resynchronisation of islands)
- Stepwise reenergising of distribution grids and customer load
- Provision of parallel switching devices in TSO studied substations

Moreover the recent major disturbances highlight that the restoration of the system as complex as it is, was achieved in a satisfactory manner (i) for its effectiveness (the RG CE grid has always been finally restored thanks to a very rapid coordination of TSOs), and (ii) for the time delay (for the November 4th, after about 1 hour the RG CE-wide system was fully resynchronised and stable).

But it has shown to the RG CE community that coordination, although satisfactory, could be improved. As a consequence, special care is needed to improve the set of OH rules for restoration operations with further in-depth rules for inter-TSO coordination based on such past critical experiences.

5.2 Introduction

5.2.1 Framework of the restoration process

The grid situations that are to be considered as starting points of the restoration process are based on the consequences of large disturbances that can result in a splitting of the RG CE grid into many asynchronous areas or in an abnormal situation experienced throughout the whole grid even kept integer with only one area.

Within one area (which can be the RG CE-wide system) the kinds of consequences that can be encountered are:

- Blackout (no remaining voltage)
- Frequency deviation (system unbalanced) >200 mHz, longer than 1 minute.
- Stable and balanced situation <200 mHz but near this value, either for the RG CE wide system with the need of common manual actions, or for a specific area with

eventual loss of consumption and/or production, but with no impact on neighbouring TSOs.

Once the system enters into such a situation, the restoration plan is activated as soon as possible. While rebuilding the system from an emergency or blackout state to come back to a normal state, the system is considered to be in a restoration process.

The restoration procedures contain all the measures to reenergise the system.

Restoration involves restarting and synchronisation of generation units, load restoration and resynchronisation of all areas and help from neighbouring TSOs and includes all manual/automatic reconnection of the islanded power system. Available generation black start capacities are put into service in addition to the units in house load operation.

After a large-scale collapse when the grid can be constituted with islanded areas or with an area in voltage collapse, the set of action for restoration consists of a very complex series of coordinated procedures, studied, prepared and as far as possible tested in advance.

During the implementation of these actions, the power system is most of the time in an evolving situation, meaning that the dispatcher has to deal with continuous and important changes in the consumption and production level and also in his grid topology. Moreover the margins to the static and dynamic operational limits of the power system are often very weak. Ensuring the stability of the power system is then a critical factor of this process, also taking into consideration that the restoration process should be finalised with a limited time delay.

The roles and responsibilities in the restoration plan can be divided into two parts:

- Inter-TSO roles and responsibilities: which have to be defined in the RG CE Operation Handbook Policy 5
- TSOs vs. other stakeholders (distributors and generators): which have to be defined at national level (Cf. chapter 6 of this appendix)

At this stage it is important to introduce the notion of *disturbed area*. This is the area in trouble affected by a large incident which can be either a part of the control area of a TSO, its full control area, a disturbed zone comprising several TSOs' control areas partly or totally included. This area shall be considered as a small or large synchronous island. That means also that a TSO can work simultaneously on more than one asynchronous grid if the split line cuts its control area into parts. This area is asynchronous compared to the (other) synchronism(s) of the (other) main system(s) alive at the same time. This area is the wide RG CE system itself if it has been kept integer after a large disturbance or after its final resynchronisation.

5.2.2 Main steps

The main process considers the following sequences of operation. This process can be applied whatever the grid situation, split or not (see scheme hereafter and overview of the process more detailed in § 5.3).

Step 1: From *Blackout* to *Reenergisation*

In case of blackout, each TSO (based eventually on bi-multilateral agreement; this process also requires dispatchers to be well trained) reenergises its own control area.

- With two possible different approaches: top-down or bottom-up
- Based on the result of the application of one of both approaches by each TSO, the location of the split line will change and could influence the coordination for

restoration with the selection of the frequency leader and resynchronisation leader (see hereafter the restoration process).

Step 2: ***Frequency management of large deviation within an area***

In case of frequency deviation > 200 mHz for more than 1 minute, under the lead of the area's frequency leader => come back near 50 Hz.

In case of lost load: under the lead of individual TSO => restart the reenergisation of the shed load

- By increasing the production, then reenergising the load step by step in order to minimise the impact on the frequency deviation and the reserve margins of generation units in respect of the grid operational limits

Step 3: ***From stable split areas to resynchronisation***

In case of split areas under the lead of the area's resynchronisation leader => resynchronise the areas.

Step 4: ***Towards final recovery of load*** **and** ***LFC in Normal operation***

- Return to ACE near zero.
- Coming back to normal operation for LFC. The basic principle is that previous power exchanges schedules are no longer respected by the TSOs. Rescheduling will be intuitive and agreed between neighbouring TSOs and executed by the dispatchers of every area, based on reserve availability and with a common goal of bringing the frequency of the grid back to the reference value of 50 Hz, and restore power exchanges with an ACE near zero.

Restoration process

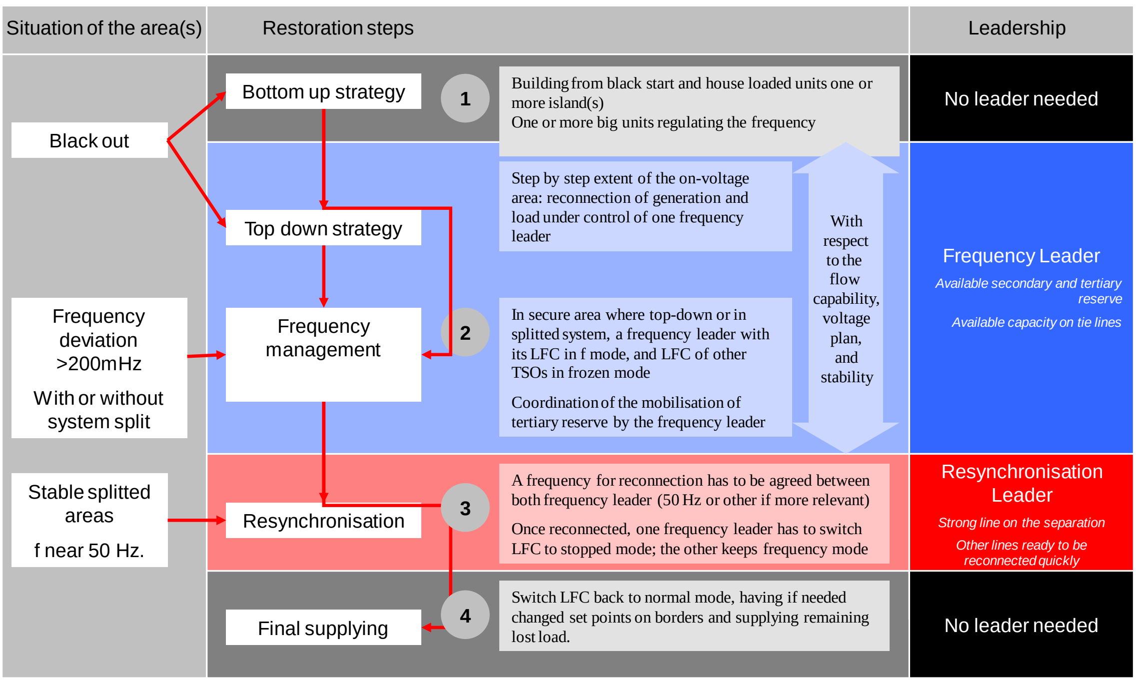


FIGURE 5: RESTORATION PROCESS

Within each area affected by incident, the starting point of the restoration process is to consider the emergency state or blackout and shall be taken at one step of this scheme regarding the actual grid situation resulting from the disturbance: frequency deviation management as the consequence of the large disturbance, split areas stable with convenient management of the frequency, and final recovery of the loads. The RG CE grid can experience different successions of these steps.

5.2.3 Coordination to be implemented within each area

During the restoration process, the leadership of the coordinated actions shall be well identified in order to have an efficient process.

Two kinds of coordination can be requested depending on the operational situation of the system: (i) a prior level with a leader for frequency management into the insulated areas if it involves at least two TSOs and (ii) a second level with a leader for resynchronisation of insulated areas.

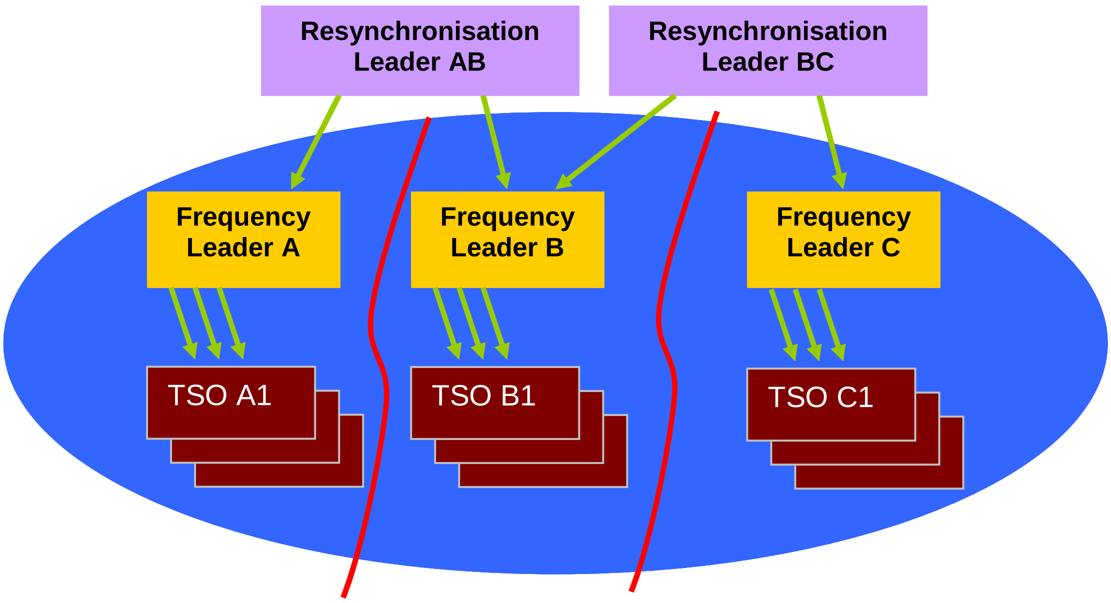


FIGURE 6: RESTORATION PROCESS

5.2.4 Frequency leader implementation

Draft procedure to activate the frequency leader (Delta f > 200 mHz)

In advance

- To select in advance the biggest TSOs best placed to launch the first analysis of the situation by a conference call. Their selection would be based on their involvement in a disturbed area and their size in term of K factor for the primary control.
  The yearly updated list adopted for 2009 is as mentioned above for the minimal values of the "Primary Control Reserve P pi " and of the "K ri Factor".

  For the following countries, the perimeter of control block includes the following partials:
  Belgium (Elia) + SOTEL (L)

Germany (Amprion) + CEGEDEL (L) + TIWAG Netz AG (A) + VKW-Netz AG (A) + EnBW TNG (A)
Spain (REE) + ONE (Maroc) + SONELGAZ (Algérie) + STEG (Tunisie)
Bosnia-Herzegovina + EPBiH (Elektroprivreda Bosne i Hercegovine) + (ISO BiH) EPHZBH (Elektroprivreda HZ Herceg Bosne) + ERS (Elektroprivreda Republike Srpske)
or is reduced by the following partials:
Austria (VERBUND APG) - TIWAG Netz AG (A) - VKW-Netz AG (A) - EnBW TNG (A)
Italy (Terna Sp.A.) - Sardinia Island, connected to RG CE by a DC cable (not synchronous with ENTSOE Regional Group Continental Europe)

Country	**Country**	**TSO**	**Ppi**	**K ri Factor**
Short			MW	MW/Hz
DE	Germany	Amprion	662	5892
FR	France	RTE	608	5407
ES	Spain	REE	389	3462
IT	Italy	Terna S.p.A.	321	2854
PL	Poland	PSE-Operator	166	1474
NL	The Netherlands	TenneT	111	986
BE	Belgium	Elia	97	867
CZ	Czech Republic	CEPS	91	808
CH	Switzerland	swissgrid	74	654
RO	Romania	Transelectrica	63	560
AT	Austria	VERBUND APG	62	552
GR	Greece	HTSO/DESMIE	59	521
PT	Portugal	REN	50	443
RS	Serbia	JP EMS	43	386
BG	Bulgaria	ESO-EAD	43	379
HU	Hungary	MAVIR Zrt	42	370
SK	Slovak Republic	SEPS	29	259
DK-W	Denmark West	Energinet.dk	26	234
SI	Slovenia	ELES	15	130
BA	Bosnia-Herzegovina	ISO BiH	13	117
HR	Croatia	HEP-OPS	12	110
UA	West Ukraine	NDC-WPS Ukrenergo	8	82
MK	FYROM	MEPSO	7	60
AL	Albania	OST	6	53
ME	Montenegro	EPCG	2	20

- To install in advance a permanent common phone number for a phone conference. The device calls automatically the 4 other TSOs just after the initiative of the first TSO to activate the phone conference.

After incident

Scenario 1: Same delta f (same frequency) for the TSOs of the conference call.

- All TSOs: Check frequencies in available awareness system(s), appropriate setting of traffic lights by all involved TSOs; check topology for tripped elements.
- Each involved TSO sends information (fax, e-mail, phone call) about its situation to the predefined/nearest “information collector” of the 5 TSOs.
- One of the 5 TSOs is the first to launch the conference call.
    - Check with direct neighbours of no split.
    - Identify the area where the frequency deviation originated.
    - Selection of the frequency leader based on the criteria of P5-C-3.2.
- Confirmation of its appointment by the frequency leader to the TSOs.
- Information about the chosen strategy from 5 TSOs to all TSOs (at least to all TSOs which sent situation reports).
- Further strategy (e.g. return to schedules) to be settled between control areas and control blocks.

Scenario 2: different delta f (different frequencies) for the 5 TSOs of the conference call.

- All TSOs: Check frequencies in available awareness system(s), appropriate setting of traffic lights by all involved TSOs; check of topology for tripped elements.
- Each involved TSO sends information (fax, e-mail, phone call) about its situation to the predefined/nearest “information collector” of the 5 TSOs.
- One of the 5 TSOs is the first to launch the conference call.
    - Check with direct neighbours to detect the split line(s).
    - Selection of frequency leaders by disturbed areas based on the criteria of P5-C-3.2.

5.3 Description of the actions to be achieved for each step

5.3.1 Step 1: from blackout to reenergisation

In the restoration process, two main principles can be considered in case of blackout:

- “Bottom-up” principle
- “Top-down” principle

The choice of the strategy is to be chosen based on criteria.

For both strategies, the actions and the technical specifications allowing their application have to be clearly defined in commonly agreed procedures or documents, whether at national or international level. A special care concerns the prior actions to be implemented to prepare the reenergisation process and ensuring the full control of the behaviour of the system during all the phases of the restoration process.

5.3.1.1 Area restoration criteria

The TSOs of the affected area should define clearly the criteria that will be used to decide whether the top-down reenergisation principle will be preferred to the bottom-up principle in case of application of the restoration plan.

These criteria are the rotating power reserves, transfer capacities, available active and reactive power, the maximal power that could be restored using this way within the area. One TSO can consider it preferable to wait for external sources from the neighbouring less affected area instead of launching the bottom-up process, if it considers that this will save time:

- In case a stable part of a (foreign) network is available, and is strong enough to be used, the “top-down” principle can be the fastest way to restore the voltage. It can depend also on bi-multilateral agreements.
- If not, the “bottom-up” principle can be the fastest way.

The process of implementing these criteria should be defined in bi- or multi-lateral agreements among neighbouring TSOs.

Notice that the two approaches could be launched at the same time in different parts of the blacked out area in case of a large area being affected. It is up the TSO to decide.

5.3.1.2 “Bottom-up” principle

Description: (i) using the black start units capability that can be started autonomously or using generation units correctly housed loaded with the aim of (ii) the recreation of a backbone and then (iii) reenergising step by step the grid with voltage, (iv) enabling stepwise other generating units to be reconnected and to feed-in consumption progressively during the whole restoration process.

In this principle, the reenergisation of the blacked out power system is done by in-house load power plants or black start power plants. This principle will mainly be applied in case of large blackouts if external help coming from stable systems is not available or if the criteria commonly defined among TSOs for their application are not met.

Each TSO has to define scenarios allowing the reenergisation of the power system within its control area, using the available means at its disposal (including distribution and generation means within its control area). It will define, coordinate and prepare all the needed actions among the main affected stakeholders of this area (power plants, grid distributors, industrial grid users taking into account, on the one hand, the operating limits of the system and, on the other hand, prioritisation rules of reenergisation for the strategic load and units (nuclear power plants, thermal power plants, …) in accordance with grid codes.

With respect to frequency management each TSO takes charge of the reenergisation of its own grid with its own available means. It is up to the TSO to use one or more generating units to regulate the frequency, while the others keep a constant generation. When the island covers the main part of the TSO’s control area it is up to the TSO to choose the LFC[2] control mode (in normal control mode, in frequency control mode) in order to share the contribution to frequency regulation with all the units of the control area.

During this process, different sub-systems could be managed in parallel by the concerned TSO within its control area.

The TSO will be responsible for the coordination of:

- The balance, stability and security of each sub-system when proceeding to the restoration;

[2] In the core of Policy 5, the different states or modes of LFC have been mentioned as load frequency secondary control to prevent confusion with primary control.

- The resynchronisation of individual sub-systems in order to build more stable islands;
- The resynchronisation of its control area or parts of it to other areas.

5.3.1.3 "Top-down" principle

Description: using the voltage on lines remaining connected to a stable part of the system and spreading the voltage by steps, and progressively reenergising consumption with available (foreign) sources. In fact, it is a way to extend progressively the energised part of the system (at the end no resynchronisation would be needed between the two areas).

In this principle the restoration of the blacked out power system is done using directly available voltage in the surrounding grid. This principle will mainly be applied in case of local blackout.

It seems preferable that the TSO responsible for the blacked out area will be in charge of the coordination actions among the different involved stakeholders (DSOs, generators and other TSOs). These actions will have to allow the restoration of the full system without danger to the system.

5.3.1.4 Initial settings: main principles

The required actions will be carried out in order to guarantee the efficiency of the restoration process. The goal of these actions is to control, as much as possible, the level of active and reactive power that will be restored when the new part of the system is reenergised.

These actions will cover the automatic or manual presetting of the grid (initial topology and generation units ready) in order to optimise the starting point of the restoration, the management of the reenergisation of the grid equipment and the reconnection of the loads, taking into account the active and reactive and stability margins of the available generating units, the transmission and voltage limits of the different grid equipments and the characteristics of the already re-fed loads.

As the localisation of the blacked out part of system and the border with the still alive system is unpredictable, the restoration plan should define different system scenarios with highest probability of occurrence. The definition of the sequences of the actions to be undertaken in these scenarios has to be such that it will allow the operators in charge of the restoration process to easily decide which scenario is the most appropriate regarding the reality and to easily deal with the difference between the scenario and the reality without affecting the efficiency of the whole process. Therefore TSOs will develop together complementary bilateral principles based on their grid configurations and own operational rules.

5.3.1.5 Scheme of a process

Toward standards/guidelines:

- Identifying the extent of the blacked out area and the state of the grid (present topology, collapse parts)
- Identifying the possible reenergisation sources (units in house load or number of units dedicated to black start, and safe network)
- Deciding on the reenergisation strategy (bottom-up or top-down principle as mentioned above)
- In each part, depending on the strategy:
    - Bottom-up: a bottom-up strategy can be applied only within each own TSO's area separately.
    - Top-down: A TSO having at disposal a neighbouring safe part of grid coordinates its reenergisation process requesting from the neighbouring safe TSO authorisation to reconnect stepwise its network in the extent of what the safe TSO can provide.

- Bilateral agreements/principles have to be prepared between neighbours to perform the fastest ways of restoration
- During such restoration processes the consumption and production are balanced together with the aim of returning to the reference frequency of 50 Hz under the responsibility of the area's frequency leader, with respect to voltage of the system.

5.3.1.6 LFC control modes/states [and exchange programs management advices]

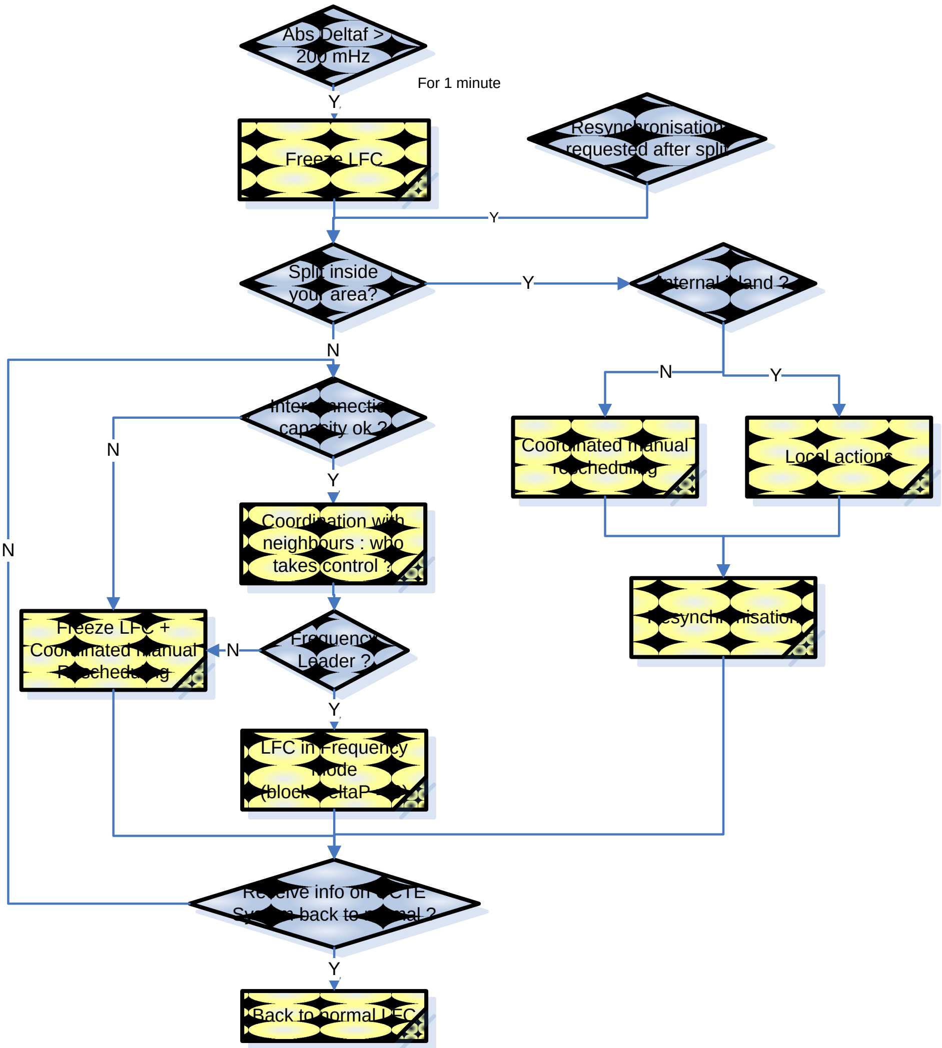
In case of bottom-up strategy

The LFC is kept in stopped control state. The TSO makes sure that sufficient generation reserve is provided by the generation units that can regulate the frequency, whereas the others are driven by power regulation. When the island is large enough (covering the main part of the control area), LFC can be switched to frequency control mode.

In case of top-down strategy

The LFC of the area being reenergised is in stopped control state.

5.3.2 Step 2: Frequency management of large deviation within an area



Frequency leaders : limited number of TSOs having sufficient reserves to control frequency, preference to largest K-factors

Manual rescheduling = change generation/activate reserves in order to bring frequency back to 50 Hz and without overloading the system (order of magnitude K deltaf)

FIGURE 7: FREQUENCY MANAGEMENT OF LARGE DEVIATION WITHIN AN AREA

Following RG CE wide area disturbance resulting in splitting of the RG CE synchronous grid, the frequency deviation reaches a new equilibrium by balancing the system (or a part of it), not necessarily at nominal frequency (50 Hz). In such a case, there is a need to bring the frequency back to nominal value, this being a precondition for resynchronisation of two systems and for other actions, which allow for a return to normal operating conditions. This requires coordinated operation of the different TSOs within every area (whole RG CE or parts of it in case of splitting).

The basic principle is that previous schedules are no longer respected by TSOs in this kind of case. Rescheduling will be intuitive and agreed (in real time and step by step) between neighbouring TSOs (in order to avoid overloading of network elements) and executed by the dispatchers of every control area, based on reserve availability and within a common goal to bring *rapidly* the frequency of a system back to *around* 50 Hz.

Every TSO applies its own procedure with respect to what is considered in accordance with grid codes.

It is assumed that this procedure is applied as soon as possible once the new, post-disturbance equilibrium is reached in order to restore primary control reserve necessary for coping with any new outages.

5.3.2.1 Scheme of the process

LFC management

The TSOs switched their LFC into stopped, frozen control states or frequency control mode and control the producers in an appropriate manner to reach 50 Hz, taking care of the induced flows, especially at their border.

Toward TSOs' common standards/guidelines

- Deviation higher than 200 mHz for more than 1 minute implies that:
  - The TSOs switched their LFC into frozen control state (automatically or manually).
  - The generators and market actors need to be informed of the situation and *to freeze their programs* (according to grid codes)
- Identifying the extent of the impacted area, and the state of the available power reserve for each impacted TSO area and communicate this information to the other TSOs
- Identifying the TSO that should play the role of the frequency leader of the area based on the following criteria (P5-C-S3.2)
  - High amount of generation reserve that can be mobilised within a very few minutes (upward in case of under-frequency situation, downward in case of over-frequency situation), and a large free secondary reserve capability (its half band in the perspective to be in a frequency control mode);
  - Capacity margin of tie lines (in export in case of under-frequency situation, in import in case of over-frequency situation);
  - Acquisition of frequency values at least of direct neighbouring grids, and, if possible, of non-direct neighbouring grids that are part of the same (a)synchronous system by measurements (phone calls, conference calls, etc.)
- The frequency leader acts as well by:
  - Switching its LFC into frequency control mode
  - Activating its own reserves (secondary and tertiary)
  - Asking for contribution from the other impacted TSOs taking into account their available reserves, with respect to the induced inter-TSO flows
- The other TSOs have to keep their LFC in frozen control state (to avoid swings) and to keep their programs frozen (only following instructions from the leader). TSOs are allowed to manually override the frozen output signal of load frequency secondary controllers to use its communication/signalling channels to power plants in order to speed-up the stabilisation of the system. Refer to P5-C-S3.3 for the return to normal operation.
- In the specific case of two (or more) split areas with the need of resynchronisation of grids, the frequency leaders of areas (remember that an area can contain several TSOs control areas or part of them) are informed prior to the resynchronisation process (see below the process to be followed up by the resynchronisation leader), and based on their proper coordination, they switch their own LFC to appropriate control state (inside an area: only one in frequency control mode and the others in frozen control state).

With respect to the freezing of the LFCs in case of large frequency deviations (higher than 200 mHz), the freezing in case of a 200mHz deviation implies: sending the same signal as before to power plants to make sure that the "regulated" power plants will not jeopardise the situation by sending new but false signals to regulated power plants. All TSOs should start immediately free secondary reserves in the "right" direction and in their island. Split TSOs should not activate reserves without knowing in which part of islands their reserves are located.

They also will have the reaction to spend "a few" minutes to clarify the whole situation, identify the islands, appoint a frequency leader in each island to coordinate the ongoing frequency regulation back to a normal range of +- 200 mHz. No TSO should reactivate an LFC device in frequency control mode. All activations of reserves should be done by hand to make sure that flows forced by new activated reserves do not overload the weak grid. The natural reaction of TSOs to activate reserves in the right direction is acceptable. However, as long as these activations are not coordinated, care must be taken that they do not create congestions elsewhere.

Once appointed, the frequency leader should switch his LFC to frequency control mode. Having several TSO's that switch their LFC to frequency mode is not an option because this could lead to inter-area oscillations of high amplitude: due to the high time constant of LFC-regulators, slow but important power swings between areas could occur.

The primary reserve will be the best reserve to hold the frequency stable in the normal range of ± 200 mHz. If the frequency difference between both areas is too big, the frequency leaders should regulate their frequency by hand and/or by advice to their island TSOs.

Reconnection of dispersed generation: main principles.

With respect to the grid codes, the reconnection of dispersed generation after their trip has to be managed as far as possible by the TSOs in order to maintain the frequency without unexpected excursions, and to keep the flows and voltages within operational limits.

Reconnection of shed load: main principles

The reconnection of shed load has to be kept under control by TSOs. Automatic approaches should not jeopardise the frequency and cause a new frequency drop.

5.3.3 Step 3: from stable split areas to resynchronisation

The aim of this step is to merge two different synchronous areas into a wider one.

Ensuring the stability of the power system is then a critical factor of this process. The higher the working rotating power is, the better the stability of the system. However, the increase of power of units and the synchronisation of two areas are also highly risky events in the process. Failure of such coordinated actions could make the system unstable and lead to a new collapse of the system.

TSOs have to be able to identify different synchronous areas, with details of borders between two separated areas

For two neighbouring asynchronous areas, a resynchronisation leader has to be selected.

The choice of the resynchronisation leader depends on the kind of separation. The resynchronisation leader has to coordinate the resynchronisation process. He shall have all the following capabilities (P5-C-S4.1):

- Have at least one substation under his responsibility with a “high capacity” line to reconnect both areas
- Be able to acquire the values of both areas’ frequencies (by measurement or at least by phone)

- Be able to acquire the value of the voltage of both substations of the point of connection (by measurement)
- Be able to manage voltage deviation at least for the point of connection

The resynchronisation leader fulfils the following actions:

- He coordinates frequency leaders;
- He chooses the substation for resynchronisation which is one under his responsibility, and is equipped with PSD - parallel switching device (see below);
- He coordinates other lines available for a quick reconnection after the reconnection of the first line to strengthen rapidly the link between both areas.

The resynchronisation leader of two concerned areas, and in collaboration with the two frequency leaders of these respective areas, will apply the required actions in order to operate the resynchronisation under the following criteria.

5.3.3.1 Area resynchronisation criteria

Resynchronisation criteria (P5-C-S4.2):

- Both systems must be in a stable state and both frequencies must be near to 50 Hz, with a maximum tolerance of ±200 mHz to 50 Hz, to resynchronise as securely as possible. A frequency difference between two areas shall be below 150 mHz before using PSDs for synchronisation of areas. Both voltages shall be in the range of 380 - 420 kV.
- Use of 400 kV line(s) of high loadability.
- Make provisions for closing immediately a second line electrically close to the first line.
- To choose by preference a line for synchronisation not in the vicinity of large thermal units in operation.
- The resynchronisation leader gives orders to frequency leaders for actions in the proper direction to minimise the frequency and voltage deviation between both areas just at the time of resynchronisation.

Resynchronisation of split parts at RG CE level will occur either in case of RG CE-wide disturbance leading to splitting of the RG CE synchronous area, or in case of RG CE-wide restoration following RG CE-wide blackout, once several areas would have been reenergised. TSOs will have to define, validate and test the synchronisation criteria.

These criteria will define the voltage and frequency range and the acceptable voltage phase angle difference, voltage magnitude difference and frequency deviation between the involved areas.

These criteria will take care of the working rotating power and available active and reactive power in both areas.

First of all, the location of network split shall be identified by involved TSOs, which is done with the use of the awareness system, preformatted message or phone call. The network can be cut along control area borders (i.e. on tie lines) or within some control areas. If both are the case, using internal lines is recommended for resynchronisation (subject to the other requirements mentioned below) as there are less actions to be coordinated between two or more TSOs – the whole switching process can be managed by one TSO, which eases the process and saves time significantly.

As it is impossible to foresee the exact lines which trip during disturbance it is important to equip all tie lines and, most importantly, internal lines with devices allowing resynchronisation

(PSD – parallel switching devices), which preferably shall be remotely controlled. The control centre staff shall have online access to measurements from both ends of any tie line.

Resynchronisation shall be performed by TSOs with high transfer capacity (several lines) between separated areas and with easy access to regulation reserves of large power plants sufficient to influence the frequency difference between both areas to resynchronise. The process itself shall be carried out, if possible exclusively, on 400 kV lines preferably with high loadability, when both synchronised systems are in stable operating conditions with frequencies close to 50 Hz (maximum difference of 150 mHz) and voltages in the affected substations in the range of 380 – 420 kV (maximum voltage difference of 40 kV). The setting of PSD devices shall allow such differences in frequencies and voltages. After successful resynchronisation by one tie line the second one (and next ones) shall be switched on as soon as possible (remotely controlled from other terminal in the same control centre or by phone call – countdown are carried out if switchings are executed from different locations. Thus the whole process shall be duly prepared as one step.

5.3.3.2 Frequency management in case of resynchronisation and estimations of the tie line load

Since the danger of power swings causing a second grid split after the first attempt of reclosure depends, among other things, on the frequency difference at the moment of switching, it is of vital interest to maintain this difference as low as possible, compatible with the robustness of the system at the vicinity of the resynchronising substations and risks of instability.

The pending question is raised concerning the frequency deviation for the resynchronising of two systems: e.g. < 150 mHz for resynchronisation of big areas (for areas with loads of several thousand megawatts). For smaller islands a higher limit of e.g. 300 mHz could be considered. But such consideration of figures could be left to a preliminary check by simulation.

The management of the frequency within one area has to be done by adaptation of the generation pattern of this area

The higher the rotating power within one area, the bigger the amount of power needed to change a certain level of the frequency.

The TSO responsible for the coordination of the resynchronisation process – the resynchronisation leader – who is normally from one of the two TSOs being the frequency leaders of each respective area to synchronise, as mentioned before, will also coordinate the management of the frequency difference. As several grids can be involved in one area, both frequency leaders will have to contact other TSOs of their respective area in order to request them for more or less generation within the grid. These other TSOs of the area will inform their frequency leader on a continuous basis about the evolution of the available production reserves.

As far as resynchronisation is concerned, the usage of lines located electrically close to large generating units shall be avoided (or chosen with care) in order to prevent any risk of damage to these units in case of unsuccessful trial (high risk of oscillations and torsional stresses for generators).

Once two areas are resynchronised, by reclosing the first inter-area line, the frequency of both areas has become the same but important voltage phase angle differences could occur between the extremities of the remaining lines to be reclosed. The order of reclosing of these remaining lines will be determined using the ascending voltage phase angle difference ranking. If needed, in order to avoid instability or damage to the rotating source (units), the lines located near large generating units will be preferably put at the end of the list and the voltage phase angle differences would be managed by topology or generation pattern adaptation.

The formula to estimate the tie line load (P), once stabilised just after resynchronising, and the final common frequency (f) of the future resynchronised system is given only for a pedagogical background. It would be very difficult for a dispatcher to apply it in a stressed situation, considering the large uncertainties of the value of the K factor of each island:

P final=[K1K2/(K1+K2)]*(f2-f1)

f final=(K1f1+K2f2)/(K1+K2)

(f1,K1) and (f2,K2) respectively are the initial system frequencies and power network characteristics of countries as yearly stated[3].

f final: final frequency after resynchronising both areas.

P final: Final flow upon the tie line after resynchronising.

If the TSO is not able to apply the formula, the only way to resynchronise is to achieve the minimum of frequency deviation between both areas in order to prevent the tripping of the tie line.

Unit resynchronisation criteria

TSOs have as far as possible to check the synchronisation criteria of units.

These criteria will take care, on the one hand, of the P-Q capabilities of the unit and, on the other hand, of the working rotating power and available active and reactive power in the system where the new unit will be connected.

5.3.4 Step 4: towards final recovery of load and LFC in normal operation

Once the (disturbed) area (see definition of disturbed area in P5-C-D6) comes to a stable operation after resynchronisation, the involved TSOs coordinate their efforts to bring the system back to the reference frequency value of 50 Hz.

LFC back to normal

The return to normal LFC can only be done after confirmation that the system has been stabilised. This means that TSOs (for example under the leadership of the frequency leader) must take manual measures to bring their balance back to the programmed value. If needed (for example if some border lines remain out of service), TSOs will have to reschedule their programs manually, the only way to do so in these circumstances seems to be via bilateral discussions. Thus it can be advised that:

1. The frequency leader remains in frequency control mode and gives instructions to other TSOs in order for all TSOs to bring back their system balanced close to their exchange programs. The frequency leader is the last TSO to switch back to normal LFC.
2. If needed, programs can be rescheduled manually and on a bilateral basis.
3. Once all TSOs’ balances are restored (e.g. all ACEs within a certain range of deviation) => they switch back to normal LFC

[3] +ΔP=K1(f-f1) and -ΔP=K2(f-f2) => K1(f-f1)=-K2(f-f2)
f=(K1f1+K2f2)/(K1+K2)
ΔP=K1(f-f1)=K1((K1f1+K2f2)/(K1+K2)-f1)=[K1K2/(K1+K2)]*(f2-f1)
Pfinal=[K1K2/(K1+K2)]*(f2-f1)
f final=(K1f1+K2f2)/(K1+K2)

To reiterate, the basic principle is that previous schedules are no longer respected by the TSOs. Rescheduling will be intuitive and agreed between neighbouring TSOs (in order to avoid overloading of network elements) and executed by the dispatchers of every area, based on reserve availability and with a common goal of bringing the frequency of the network back to 50 Hz and restore power exchanges with an ACE near zero. Then every TSO applies its own procedure with respect to the market participants.

5.4 Other issues to be considered

5.4.1 Restoration communication requirements

According to the chapter on awareness and inter-TSO communication, a communication procedure is used to inform about the blackout status and activation of the restoration process among TSOs.

Due to the lack of time and the stress level and the amount of actions to be undertaken once one TSO is in restoration process, this procedure should also minimise and/or automate as much as possible the level of information exchange needed among TSOs or to other parties during the application of restoration plan. When coordination and information exchange is needed, the procedures should then clearly define which information, with which tool and to whom.

5.4.2 Power plants at stake

In a blacked out situation, each control centre will check the quality of islanding of power plants making sure that they are correctly in house load operation or are due to be urgently supplied back by an external voltage source, in order to allow more rapid resumption of generation of these plants as soon as network conditions allow them to do so. If not, measures will be taken to send a source of voltage towards these power stations thanks to black start capabilities of certain dedicated units and thanks to correctly house-loaded units. The action of re-feeding auxiliaries of generating units with network voltage can be prepared through a scenario that has proven to be robust. The control centres will then gradually be able to reconstitute safe areas to be reconnected.

5.4.3 Testing

As mentioned before, the restoration process is very complex. Moreover, the application of this process is not without risk.

This means that tests are of importance in the operability and efficiency.

Due to different TSOs' practices and based on different national regulations, the common proposed issues for testing the reenergisation are mentioned as standards in P5-C-S1.2.1) and as guidelines in P5-C-G1).

Tests could also refer in particular to:

- Load rejection efficiency (thermal plants) with successful consequent house load operation
- Duration required for predisposing the restoration paths
- Compensation for reactive power of lines (this is extremely important in case of AC cables)
- Efficiency checks of involved protection and automatic devices
- Check of all interfaces with generators and DSOs

Success of the partial tests is a necessary condition to plan and carry out a complete restoration path check.

During restoration tests, attention has to be paid to all units involved in order to identify all factors that could obstruct correct implementation of the procedures.

6 System emergency operations: Issues at stake with participating actors

Security of operation is a responsibility shared between TSOs and network users, mainly due to the behaviour of installations connected to the power system.

Therefore it is relevant to highlight the essential role of (i) producers with their generation units (refer to the UCTE technical paper – definition of a set of "requirements to generating units") and of (ii) Distribution System Operators (DSOs) (mainly implementing the load shedding) as having a core role with TSOs for the secure operation of the power system.

In the investigation report for the 4th November 2006 disturbance, it is recommended to policymakers to adapt the regulatory frameworks:

Recommendation #5 of the investigation report related to 4th November 2006.

The regulatory or legal framework has to be adapted in terms of the following aspects:

- *TSOs should have control over generation output (changes of schedules, ability to start/stop the units)*
- *Requirements to be fulfilled by generation units connected to the distribution grid should be the same in terms of behaviour during frequency and voltage variations as for the units connected to the transmission network. These requirements should be applied also to units already connected to transmission and distribution grids*
- *Operators of generation units connected to the transmission grid must be obliged to inform the TSO about their generation schedules and intra-day changes of programmes prior to their implementation*
- *TSOs should receive on-line generation data connected to DSOs grids (at least 1 minute data)*

6.1 Generation behaviour and control

Certain TSOs do not have the latest generation schedules available even for generation units connected to their own grid which might lead to improper system security assessments. The increased flexibility given to market players by the regulatory framework has to be associated with the obligation for generators to provide to TSOs their generation schedules in due time.

Additionally, most TSOs do not have available real-time data on the power generated in the distribution grids. In view of the rapidly growing share of such generation, this has multi-dimensional consequences:

- No real-time knowledge of the total national balance between supply and demand,
- No real-time knowledge of the generation started in DSO grids and possible trip/reconnection in case of a frequency or voltage drop,
- No real-time knowledge of generation started in DSO grids and possible impact on grid congestion in the high voltage grid.

Additionally, certain TSOs do not have any control over the generation (e.g. cannot reduce or stop wind power generation). Bearing in mind the growing amount of installed power of wind generation, this situation could lead to serious power balance problems especially in over-frequency areas.

6.2 Requirements to DSOs for grid operational security

This chapter is important for TSOs. It has to be considered as an input for future discussions that could take place with DSOs and regulatory authorities for the sharing of responsibilities between TSOs and DSOs.

The transmission system operators (TSOs) within RG CE are responsible for providing and operating high- and extra-high voltage grids for long-distance transmission of electricity as well as for supply of lower-level regional distribution systems and directly connected(usually industrial) customers with energy-intense and sensitive production processes. Besides this transmission and supply task, it is also the TSOs' responsibility to ensure system security with a high level of reliability and quality. To perform a secure system operation and to meet the reliability and quality demands, the provision of several so-called system services is necessary.

System services refer to the services essential to the proper functioning of the electrical power transmission and distribution system as a whole provided by TSOs for connection users in addition to the transmission and distribution of electrical energy, which thereby determine the quality of power supply:

- Frequency stability
- Voltage stability
- System restoration after a disturbance
- System management

Due to the fact that TSOs cannot ensure the security of operation irrespective of the conditions of operation of power plants, TSOs call for a regular coordination with producers for the management of their units connected to the grid and with DSOs which contribute to the security of operation of the transmission power system. Load shedding and voltage management are two of the most significant related coordination issues needing DSOs' contribution that can be complemented with the management of (re) connection of dispersed generation out of the TSOs control.

Therefore the following chapter details the most relevant issues between TSOs and DSOs which have a significant impact on the management of the power system in insecure conditions, when the power system deteriorates. Rules and procedures aimed at avoiding cascading situations and at limiting their propagation or, in the worst case, easing restoration of the system from an emergency state (load shedding, voltage reduction, etc.) or blackout state to normal.

To ensure system security within the interconnected RG CE system and to provide a common security level it is essential that the TSOs within RG CE have a common understanding of these requirements to DSOs and a common set of rules is defined as a basis for bilateral agreements between each of the TSOs and DSOs connected to its grid.

This document will describe how DSOs have to support TSOs in normal and emergency grid situations. Due to the increased influence between the different voltage levels, DSOs and TSOs have to predefine processes and actions on both sides.

6.2.1 DSO issues viewed from TSOs for power system management in normal and mainly in insecure conditions

The requirements to DSOs defined in this document are essential for TSOs to manage:

- Causes of critical conditions
- Remedial actions to relieve or alleviate the operational risks for the power system

The scope of the power system management in normal and mainly in emergency conditions is related to the following issues:

- System balance (load / frequency management)
  - RG CE frequency management
  - Offer-demand imbalance management in parts of a control area
- Grid constraints/operational security
  - Congestion management (reduction of load flows of grid elements)
  - Voltage issues (Voltage management for DSO and provision of reactive power)
- Grid restoration
- Training

Three fields of actions must be effectively handled by DSOs:

- Generation unit management connected to distribution grid influences the EHV grids. Specific requirements are described for these generators in the document “requirements to generators”. DSOs have to consider these requirements in the management of their grid with more and more generators connected (e.g. respectively (i) in case of emergency conditions, in terms of reconnection, (ii) in relation to the system protections settings, voltage profiles, frequency deviation, etc).
- The load shedding as the most sensitive remedial action is of utmost importance in managing emergency conditions in case of frequency drop, voltage instability/collapse or grid congestion. Special care can be taken to check the coordination between TSO and DSO and the effectiveness and the settings of load shedding (UFLS – under frequency load shedding or UVLS - under voltage load shedding) equipments.
- Voltage issues are worth analysing due to the large extension of distributed generation that cannot in any case contribute to the voltage support as needed for the security of operation of the transmission grid.

The data requirements and process requirements are dealt with within this scope.

6.2.2 Requirements to DSOs for grid operation

The interconnected transmission grids face ever-growing unintended load flows, large changes of exchange programs and insecure grid situations as a result of the combination of these issues.

To operate grids in a secure manner and to be prepared for insecure grid situations, some predefined processes (incl. communication) and deduced requirements for data provision shall be coordinated between TSOs and DSOs in advance.

Clear rules according to existing laws or other obligations describe the common and respective responsibility of TSOs and DSOs that contributes to strengthening the grid operational security, to avoiding critical situations and to easing restoration of the grid after collapse.

6.2.2.1 Process requirements

TSOs and DSOs need to guarantee a coordinated reaction in insecure or emergency grid situations by predefined processes and rules. Therefore processes to support possible grid situations have to be established. These processes are related to the above-mentioned issues:

System Balance

- Normal requirements
    - Manual regulation of active power from generators connected to DSO grid upon request of TSO
- In emergency situations: Activation of UFLS
    - Predefined load shedding plans for automatic activation for each concerned substation (in MW or in % of local consumption) with DSOs
    - Installation of frequency relays to support UFLS plan. Technical requirements for equipment of automatic under-frequency load shedding (UFLS)
    - Regular checking of load shedding plan by TSOs and DSOs once a year. Regular checking of load shedding devices and settings at least once per five years.
- Activation of manual load shedding in DSO's grids on request of TSO (depending on legal basis)
- Coordination by TSO for the reconnection of shed load with DSOs. Local and remote reconnection of customers loads to be agreed in advance in cooperation between TSOs and DSOs. Automatic reconnection to be avoided. (Cf. Policy 5 - C – S3.7)

UFLS is ruled as follows:

UFLS of customer consumption is allowed at 49.2 Hz and mandatory at 49.0 Hz and a stepwise 50 % of the nominal load should be operated under load shedding relays in the range 49.0 to 48.0 Hz

- At 49 Hz at least 5% of total consumption should be shed, which should be complemented for each individual TSO according to the loss of generation at this stage induced by the frequency drop due to non-compliance with grid requirements
- Below 49.0 Hz, the stepwise load shedding plan should be complemented by an individual mitigation of the loss of generation including the distributed generation.
    - Frequency steps shall be smaller than or equal to 200 mHz (depending on number of steps and characteristic of load shedding relays)
    - In each step of UFLS, disconnection of not more than 10% of the load (depending on number of steps and characteristic of load shedding relays) except if considering the additional loss of generation.
    - Maximum disconnection time of 350 ms including switchgear operation time without additional intended time delay.
    - Frequency measurements for load shedding should be maintained at a maximum inaccuracy of 100 mHz.

Grid constraints/Operational security

- Topology adaptations in DSO grid;
- Shifting of load from one substation to another on TSO request;
- Manual regulation of active power from generator connected to DSO's grid on request of TSO;
- Voltage management
    - Activation of reactive power reserve from generators connected to DSO grid or by switching on their compensation installations (capacitors, reactors, SVC, etc.)
    - Voltage reduction in DSO grids within acceptable limits and blocking of voltage control by tap changers *(on TSO/DSO connecting transformers or at lower voltage levels inside areas of DSO's responsibility);*
- Load shedding

- Installation of voltage relays in DSO grid for under-voltage load shedding (UVLS) in DSO grid areas with low voltage levels (high consumption of reactive power)
    - Predefined plans for manual load shedding in DSO grid coordinated under request of TSO especially designed for solving local overload problems in the upper level of the TSO grid (depending on legal basis)
    - Activation of such manual load shedding in DSO grid upon request of TSO
    - Installation of special protection schemes aiming at automatic load shedding in grid areas in case of overload on lines or on transformers (depending on legal basis)
    - Regular checking of load shedding plan by TSOs and DSOs once a year Regular checking of load shedding devices and settings at least once per five years;
- Coordination of protection schemes between TSO/DSO/generators/large consumers.

Grid restoration

- Grid restoration plan with detailed instructions for DSO (updated on a regular basis). These plans should be tested periodically in coordination between TSO/DSO/generators/large consumers;
- Coordination with DSOs in case of black start generators connected to DSO grid, if not managed directly by TSOs;
- Restoration of DSO grid (manual or by automatic sequences);
- Resynchronisation procedures with DSO grid in case of island operation after blackout;
- Reenergising procedures in DSOs grid with preliminary permission of TSO;
- Non-authorised automatic (re)connection of dispersed generation at least in case of high frequency (if possible).

In cases where all defence actions taken by TSOs and DSOs are not sufficient to avoid a blackout, the grid restoration and/or regional reenergising actions should be prepared in advance between all participating parties in the respective area of the TSO with, if possible, step by step procedures.

Training

- Common training sessions with participation of TSO and DSO dispatchers should be established to prepare operators for better coordination in case of emergency and blackout.
- Program of these sessions should be agreed in advance and can be based upon RG CE OH Policy 8. Special attention should be drawn to TSO dispatchers/DSO operators cooperation in the grid states alert, emergency and blackout

6.2.2.2 Data requirements

To organise and operate the above-mentioned processes, the TSOs need the following data in different time horizons and for each connection point between TSO and DSO grids to ensure their responsibility of grid security. The size of relevant generators, which have significant impact on grid security, is a threshold to be defined by the responsible TSO in all voltage levels.

Grid development

- Long term / yearly grid planning coordination – new lines, transformers, power plants/wind parks in DSO grid;
- Installed generation capacity in DSO grids.

Year till day-ahead: operational planning

- Yearly grid planning coordination – new lines, transformers, power plants/wind parks in DSO grid;
- Grid parameters to support grid reduction calculations for grid models representation of DSO grids for online calculations – global representation of constant data or online data to be received;
- Outage planning (yearly, monthly, weekly) between TSOs/DSOs/large consumers and relevant generators (including at least DSO lines and substations which have an influence on TSO grid or are influenced by TSO grid).

Day ahead

- Outage planning between TSOs/DSOs/large consumers and generators > Pmin (as mentioned before) (including at least DSO lines and substations which have an influence on TSO grid or are influenced by TSO grid);
- Generator schedules and output limits for relevant generators in DSO grid;
- At least one value as the sum of planned free generator reserve capacity connected to DSO grid, for each generator at DSO level, instead of giving real-time data, provide for spinning reserve to TSO for system emergency reserves;
- Planned load transfers between substations or transformers injecting in DSO grids, manual or automatic activation
- Load forecast for some connection points when significant variation expected by DSO (shift of load) if necessary from TSO viewpoint.

Online

- Present schedules of relevant generators in DSO grid;
- Measurements (P, Q) of transformers injecting in DSO grid;
- Measurements (P, Q) of DSO lines which have an influence on the TSO grid, if needed for security analysis;
- Measurements (P, Q) of relevant DSO lines which are influenced by actions in TSO grid;
- Measurements (U) of DSO substations which are influenced by actions in TSO grid or which have an influence on TSO grid;
- Actual position of tap changers for transformers feeding into DSO grid;
- Actual configuration of DSO lines and substations which are influenced by actions in TSO grid or which have an influence on TSO grid (e.g. in case of transferring loads from one substation to a neighbouring one);
- Measurements of relevant power plants (P, Q [net/gross]) and position of tap changers on block transformers in DSO grid;
- As an alternative, at least one value as sum of free generator reserve capacity connected to DSO grid, for each generator at DSO level instead of giving real-time data (provision of spinning reserve to TSO for system emergency reserves)
- Provisions for mutual rapid warning and exchange of information on system states - “awareness system”;
- Signalling for different grid states or automatic reactions to DSOs
    - To activate generator reserve capacity in power plants in DSO grids (in MW)
    - Stop of voltage regulation in DSO grid (lack of reactive power in TSO grid) e.g. blocking of tap changers, reduction of U reference (U minus 5%) in DSO level
    - To activate manual load shedding (in MW).

The list of DSO lines and substations, which have an influence on the TSO grid or can be influenced by the TSO grid should be agreed between TSOs and DSOs and regularly updated.