Current practices in Europe on Emergency and Restoration

Drafting Team for the Network Code on Emergency and Restoration

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1. Introduction

In the context of developing the Network Code on Emergency and Restoration, ENTSO-E has collected existing rules and practices in the different synchronous areas, as thebasis for subsequent drafting work.

The aim of this document is to give, for each item related to the Emergency and grid Restoration subject, an overview of existing practices, focusing on information at regional/synchronous area level (Baltic, Continental Europe, Great Britain, Ireland/Northern Ireland and Nordic), identifying common/similar practices, significantly different ones, and the existing level of harmonisation.

The following documents were used to compile information on existing practices:

- for the Baltic area: Brell Synchronous Area agreements
- for the Continental Europe area:
  - Policy 3 “Operation Security” [issued in 03/2009] from the Operational Handbook
  - Policy 5 “Emergency Operations” [v1 issued in 08/2010] from the Operational Handbook
- for the Great Britain area: Grid Code
- for the Ireland/Northern Ireland area: EirGrid and SONI Grid Codes[1], Inter Jurisdictional Operating Procedures[2] and Operating Security Standards[3].
- for the Nordic area: Nordic System Operation Agreement

In this document, the subject of Emergency and Restoration is presented according to 4 axes:

- Awareness of System States & information exchange
- System Defence Plan
- System Restoration and Re-synchronisation
- Economic efficiency and regulatory aspect

However, all these items will not necessarily be part of the draft Network Code Emergency and Restoration, since they are already covered by other Network Codes, or because they are not related to cross-border issues.

[1] EirGrid Grid Code Version 5.0, in particular Connection Conditions 7 and 8, OC 4 and OC5. SONI Grid Code dated 20th July 2012, in particular Connection Conditions Schedule 1 and Operating Codes 4 and 7.
[2] EirGrid and SONI Inter Jurisdictional Operating Procedures
[3] EirGrid Operating Security Standards dated December 2011.

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2. Awareness of System States & information exchange

2.1. System state definition

Unambiguous inter-TSO communication is necessary in order to ensure that each TSO has an appropriate understanding of the system states of neighbouring systems. In order to support clear communication, definitions of system states are generally referred to in signed procedures and in bilateral/area agreements within synchronous areas, in some cases using harmonised definitions.

- In the Baltic area system states are as follows: Normal, Alert, Emergency and Blackout. These are classified in relation with the grid or load/frequency risk levels and urgency of actions related to the risk of propagation.
- In the Continental Europe area, Policy 5[4] defines four distinct system states: Normal, Alert, Emergency and Blackout. These are classified in relation to the grid or load/frequency risk levels and urgency of actions related to the risk of propagation.
- In both the Great Britain and Ireland/Northern Ireland areas, definitions of both Total and Partial Shutdown are contained in the applicable Grid Codes. In the Ireland/Northern Ireland synchronous area, Alert, Emergency and Blackout system states are defined in Jurisdictional policies which are currently shared and will be harmonised in the near future.
- The Nordic area uses the system states defined in the network code for operational security, although the specification of system states in the Nordic System Operation Agreement[5] may not be fully harmonized with the code. However:
    - With regard to power shortage situations, a different specification for system states exists in the Nordic SOA[6].
    - When preparedness is raised (within the TSO and its service providers) due to, expected extreme weather conditions for example, each TSO has their own specifications of different states and the action taken in those states.

2.2. System state assessment: tools and procedures

In real time operation, the first step for TSOs to ensure secure management of their grid is to be aware of the system state not only within their responsibility area but also in the neighbouring grids.

Across Europe mandatory processes exist these include:

a) **on line acquisition of system data** (measured values, states of switching equipment)

In all synchronous areas, the main tools used by TSOs to gather on line data are Supervisory Control And Data Acquisition (SCADA) systems. These systems allow operators, through specific displays and events, warnings & alarms, to visualize, monitor and react to at least the following values in their observability area: power flows (including transit and export-import direction), frequency, voltage (on busbars, generator terminals, connection points), measured values and states of switching equipment and short-circuit power[7]. Alarms are generated in the case of security thresholds violations. When the real time measurement of the loading or the voltage of a network element has breached this threshold, the corresponding alarm is displayed on the screen of the dispatcher and can activate a bell in the control room.

[4] OH, Policy 5 - Chapter A, Definitions
[5] Nordic SOA – Appendix 1: "Specifications"
[6] Nordic SOA - Appendix 9: "Rules for managing power shortages during high consumption, bottlenecks or disturbances"
[7] OH, Policy 3 – Chapter A

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b) periodic contingencies simulation

In addition, every TSO within ENTSO-E performs regular **automatic grid security assessment** in real time thanks to contingency analysis tools. The basis for these studies is N situation, determined by state estimation based on measurements and topology.

- In the Baltic area there are no real time contingency analysis tools.
- In the Continental Europe area[8], the real-time automatic N-1 simulation must run at least every 15 minutes. A list of constraints will be produced when the automatic N-1 security calculation, shows violations of pre-defined loading and voltage limits.
- In the Great Britain area the TSO is required to work to N-2 Security Standards. The real-time automatic N-2 simulation runs every 10 minutes.
- In the Ireland/Northern Ireland area automatic N-1 contingency analysis runs at minimum every 5 minutes and TSOs take appropriate preventative action to alleviate potential contingencies identified.
- In the Nordic area, the N-1 requirement is stated in the Nordic System Operation Agreement, but the agreement doesn't contain requirements for automatic simulation. Each TSO decides how to use periodic contingency simulation. For example, in Finland the simulation runs every ten minutes.

This continuous assessment completed by manual load flow studies is essential to ensure TSOs that their grid is N-k compliant, taking into account potential influence on/from neighbouring systems and the efficiency of remedial actions.

In addition to the aforementioned mandatory processes, other processes are used by most TSOs to complete the "system picture" and to assess occurrence probability and possible consequences of contingencies as well as to **establish diagnoses in case of incident**, including Renewable Energy Sources (RES) forecast tools and lightning strike location tools. Fault locator tools or video monitoring of substations (for checking the switching of isolators in case of fully remote control) can also contribute to incident diagnosis and assist operators' decision making.

2.3. Information exchange between TSOs

The aim of inter-TSO communication is to provide relevant information to ensure appropriate mutual knowledge and understanding of the real time system states.
When their systems are constrained, TSOs within ENTSO-E have to inform at least all directly neighbouring TSOs about the state of their systems and give details about the situation, remedial actions already in progress and support requested.
The available means to report the state of the system and exchange information between TSOs are:

a) ENTSO-E Awareness System (EAS)[9]

b) Preformatted messages: Continental Europe[10], Great Britain and Nordic regional group use at least one of the following preformatted messages systems: fax, email, web-based tool.

c) Phone calls: all TSOs within ENTSO-E use phone calls to confirm with direct neighbouring TSOs about the non-normal state of its own system, and give details about the situation, remedial actions already in progress and support requested.

[8] Policy 3, Chapter A
[9] Memorandum of Understanding regarding a concept for the exchange of data for Operational TSO Business, dated on 18.02.2011, EAS Data Exchange And Delivery Agreement, EAS Usage Procedure
[10] Policy 5, Chapter A – S2.2

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2.3.1. System state communication: the ENTSO-E Awareness System (EAS)

EAS has been operation across of Europe since 4th of November 2013. This awareness system is an information platform allowing TSOs to have a real-time global view of the European Power transmission system in order to quickly react to actual operational needs. The main objectives of this tool are:

- In case of a stressed situation: to provide automatic or manual information to enable the TSOs to apprehend an endangered situation globally,
- In case of wide disturbance: to provide information to the TSOs to help them in identifying its origin, borders and to assist them for solving this disturbance.

In both cases, EAS enables TSOs to enhance their assessment of the nature and size of a disturbance, to speed up the decision making process limiting the risks of exacerbating the situation and to help cross-border cooperation.

EAS gathers and displays two types of data provided by all ENTSO-E TSOs:

- Automatic real time measurements of data: frequency (national and local), Area Control Error (instantaneous and 15min average), cross-border physical and commercial exchanges, scheduled and real-time control area balance.
- Qualitative indications (manually updated in most cases): System States (normal, alert, emergency, blackout and restoration), pre-defined messages providing additional information on the grid situation and free messages.

Harmonized application of EAS throughout Europe, including the System State declaration, is ensured through common procedures and training.

- The System States definitions in the procedures have been taken from the draft Operational Security Network Code (being precise that System States to be declared in EAS must be qualified as “Wide Area”).
- Pre-defined messages can also be used.

2.3.2. Other information means

To allow real time communication contact lists of at least neighbouring TSOs are available at all control rooms. These lists are an annex to the bilateral / multilateral contracts[11] between TSOs, or are exchanged and updated every year or in the case of change. This contact list includes different methods of communication (including landlines, private telephone network (TSO), mobile phone, satellite phone, FAX and email).

Addtional communication options are available to some TSOs for example: videoconference communication (TSC/CTDS) is available. Sometimes these lists contain the details for emergency / crisis communication (numbers, devices) and condition for their use.

2.3.3. Communications tests and training

- Most TSOs regularly test backup communication contacts and equipment to ensure their reliability (emergency numbers, satellite…).
- For many TSOs Communication in an emergency situation is a part of Inter TSO training.
- Good language knowledge is essential for effective and correct communication in emergency state (mostly English but not exclusively).

[11] For CE, OH, Policy 3 – A –S3

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- Mutual experience sharing is essential between operational staff
- It is important to prepare, organize and test two different communication channels[12] :
    - Operators have to focus on the exchange of information directly relevant to the operation of the power system, typically defense and restoration plans.
    - Crisis communication for non-operational purposes has to be managed separately by the TSOs (to disseminate information e.g. to the media).

2.3.4. Secure communication links

From a reliability point of view:

- Critical communication links are the responsibility of TSO's.
- There is redundancy in these critical communication links and availability of around at least 6 hours (depending on house load of communication nodes / substations) is expected in the case of blackout
- Many of the TSOs operate their own communication network (different types) to perform these critical communication links. This gives them direct influence on reliability and availability of communication. When part of the critical communication links is operated by an external provider, reliability and availability is ensured via the agreement with the TSO.
- All other means of communication depend on external providers; the availability and the redundancy of these is uncertain in practice. Usually a period of 2 hours is referred to.
- Operational training and practical experience show communication overloading (devices and operators) in the first period of failures.
- Availability of communications is a crucial factor for fast and effective system restoration.

2.4. Information exchange

2.4.1. DSOs and significant grid users (SGUs)

Currently, from a strict regional point of view, informing stakeholders about System States and grid situation is not mandatory. However, each TSO has setup its own organisation on this topic.

- In the Baltic area, information towards grid users is mandatory, but there is no specific alert system and it is not demanded in the grid code. TSOs are obligated to inform.
- In the Continental Europe area, the Policy 5 only recommends that TSOs to keep generating units and DSOs (as minimum) involved in defence and restoration process informed of critical system states, but without any indication about means to be used. Close cooperation is necessary on the one hand with DSOs in the process of setting coordination and realisation of the under-frequency load shedding systems, and on the other hand with generating units and DSOs in the case of system restoration and on-site Black Start tests.
- In the Great Britain area, the Grid Code[13] sets out the requirements for the exchange of information in relation to operations and/or events on the Total System which have had or will have an operational effect on the Transmission System or a User's system. The Grid Code also states that for each Black Start Station, a Local Joint Restoration Plan will be produced jointly by the TSO, the relevant Generator and DSO. Each Local Joint Restoration Plan will detail the agreed method and procedure for re-energisation of part of the Total System and meet complementary local demand so as to form a power island.

[12] For CE, OH, Policy 5 – C –S1.3
[13] Operating code 7 and 9

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- In Ireland, an Alert system[14] is required under the Grid Code, which signals to users the system state. In Northern Ireland, although informing users is mandatory under the SONI Grid Code, a defined format for this communication is not specified.
- In the Nordic area there are no requirements or specifications in the Nordic System Operation Agreement. There is a requirement in the national legislation to provide the necessary information to the relevant parties, but it is not specified in detail. In Sweden, the TSO is obliged to inform the nation about incidents that have an impact on important functions of the society. The Power Exchange's Rulebook for the Physical markets (specifically appendix 5 "Market Conduct Rules", chapter 5) contains requirements for informing about events that have an impact on the market. These requirements apply to TSOs as well.

2.4.2. Information for the public

Such information exchange relies also on crisis organisation, defined at country level, and set up at least in an Emergency situation. TSOs, according to national legislation, need to communicate information regarding the current situation as soon as possible. Typical communication channels are: internet, press releases, radio broadcasts, etc.

[14] Eirgrid grid code

3. System Defence Plan

Defence plans can be defined as a set of coordinated measures, which aim to maintain the integrity of the system in case of abnormal system conditions resulting from extreme contingencies.

The objective of defence plans is to set up technical recommendations and rules for manual and automatic actions to manage critical system conditions to prevent the European power system, or parts of it, from the loss of stability and cascading effects leading to major blackouts.

In general, TSO actions for the defence plans can be divided into:

- inter-TSO actions: actions that are coordinated between TSOs (chapter 3.1)
- TSO actions: actions that are set up at TSO level (chapter 3.2)

In the case of an emergency state these actions shall prevent the system from further damage and can be curative or preventive. Especially in interconnected power systems the coordination of actions is of crucial importance.

3.1. Inter TSO actions: basic principles

Each TSO is expected to run their own system in such a way that they do not cause problems to their neighbours. A dimensioning fault on a subsystem shall not cause serious operational disturbances in other subsystems. Neighbouring TSOs shall offer maximal possible assistance to support the constrained TSO, and with respect to the security of their systems, to limit the propagation of the disturbance.[15]

In case of Alert or Emergency state, TSOs experiencing constraints in their network shall adopt all internal measures and ask for coordinated measures from other TSOs with which cooperation is agreed to relieve the constraint.[16]

In all areas, procedures with all neighbouring TSOs are part of inter-TSO agreements and contain various actions to achieve mutual assistance. These agreements are reviewed and up-dated regularly, to take into account changes in the network, evolutions of defence plans and adapt organisation when needed.

In addition, several TSOs in Europe have such procedures agreed with both neighbouring and other TSOs. These measures must be applied as quickly as possible, so as to avoid further deterioration of the system state.

Since TSOs are supposed to provide maximal assistance through tie lines in case of an emergency situation experienced by neighbouring TSOs, the tie lines are considered as the backbone of the interconnected system. For this reason, disconnection from the interconnected system with opening of tie lines should be considered as the remedial action of last resort and will only be undertaken after coordination with the neighbouring TSOs, ensuring that this action will not endanger the remaining interconnected system. Keeping interconnections in operation as long as possible must be consistent with operating constraints. Therefore any manual opening should be announced and duly prepared in coordination with neighbouring TSOs[17].

In addition, the usage of HVDC links in these extreme situations is covered in some areas:

- In the Great Britain and in the Ireland/Northern Ireland areas, Emergency Assistance protocols exist with respect to HVDC interconnectors. These are described in Interconnector Agreements between TSOs. HVDC interconnector flows may be reduced in extreme cases when one of the parties foresees a difficulty in meeting the expected demand on its system, or foresees a difficulty in maintaining security on its transmission system.

[15] For CE, OH, Policy 5 - B-S5.1
[16] For CE, OH, Policy 5-B-S4 and Policy 3
[17] For CE, OH, Policy 5 – B – S5.2

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- Similar protocols exist in the Nordic area, both on the HVDC interconnectors inside the Nordic synchronous area and on the interconnectors to neighbouring synchronous areas. These protocols include manual regulation actions to assist the neighbouring TSO as well as automatic functions such as emergency power control (EPC), oscillation damping and frequency control.

3.2. Management of system frequency

3.2.1. Normal operating frequency range

A frequency deviation from the nominal frequency results from an imbalance between generation and demand that occurs continually during normal system operation or after an incident. Currently different frequency ranges for normal operation apply in different Synchronous Areas.

When the frequency deviates from the normal operating frequency range, specific emergency remedial actions are used (see chapter 3.2.2, 3.2.3 and 3.2.4).

- Baltic system works synchronously to IPS/UPS (Russia, Ukraine, Moldova…) system. Brell synchronous area agreements describe emergency management including frequency violations. Operational limit for frequency is 50.00 ± 0.05 Hz. In case frequency deviation of 50.0 ± 0.2 Hz, the normal operational limit must to be reached within 15 minutes.
- In the Continental Europe area, absolute frequency deviation must not exceed 200 mHz[18].
- In the Great Britain area, the normal operational limit for high frequency is 50.2 Hz and the normal operational limit for low frequency is 49.8 Hz. The statutory limits from the Security & Quality of Supply Standards are 49.5 Hz for low frequency and 50.5 Hz for high frequency.
- In the Ireland/Northern Ireland area, the normal operating range is 49.8 to 50.2 Hz[19]. Generators and Interconnectors are required to operate continuously at normal rated output between 49.5 Hz and 50.5 Hz.
- In the Nordic area, the normal operating range is 50.0 ± 0.1 Hz.

3.2.2. High frequency management (above normal operating frequency upper limit)

- In the Baltic area, in case of high frequency the plan is to: automatically limit production in thermal stations, wind park output to zero. Higher than 1 Hz frequency deviation it is allowed to separate part or whole Baltic from united synchronous area.
- In the Continental Europe area, in cases where the system frequency is higher than 50.2 Hz for more than one minute, the individual load frequency secondary controller has to be frozen. 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[20], prior to the frequency leader being designated (§ 4.1.3) or upon an instruction from the frequency leader. Before frequency leader designation, TSOs are allowed to manually and/or automatically activate additional reserve (e.g. (i) through starting pumped-storage power plants and/or (ii) activating tertiary reserve and/or (iii) decreasing the level of active power generation by activating extra primary reserve if available) in order to speed up the stabilisation of the system. These measures have to be taken with care not to create congestion[21].
- If system frequency in Great Britain rises above 50.15 Hz a generation reduction of 300MW will be instructed at 50.15 Hz, 50.20 Hz & 50.25 Hz. Where frequency is >=50.3 Hz generators are obligated by

[18] OH, Policy 1 Appendix 1, A7)
[19] EirGrid Grid Code CC8.2.1
[20] OH, Policy 5 – B – S6.1
[21] OH, Policy 5 – B – S6.2 and S6.3 modified in B-S5, S6 and S7 in 2014 release of Policy 5

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the Grid Code not to take actions which would increase frequency. If frequency rises above 50.3 Hz National Grid will reduce infeeds from interconnectors. If frequency rises above 50.4 Hz generators are required to take independent action to protect generating plant.

- In Ireland and Northern Ireland, runback facilities are implemented on both HVDC Interconnectors - should the frequency rise above a preset level, the import flow into the system will be reduced or the export flow will be increased. A Special Protection Scheme (SPS) is also in place. In addition to the runback facilities and SPS, a suite of high-frequency settings for generators in Ireland and Northern Ireland have been agreed and implemented. The settings are staggered to allow for a controlled reduction of high frequency, rather than all generation disconnecting at once and are implemented across all of the large (>100MW) generators on the island of Ireland.
- In the Nordic area, manual down-regulation (manual Frequency Restoration Reserve (FFR-M), 15 min activation time) is available for the TSOs in the common Nordic merit order list (Nordic regulation power market). Down-regulation is activated in price order, taking into account congestions in the grid. Emergency power control on HVDC connections is activated in several different steps at frequencies over 50.3 Hz. Various national/TSO-system protection schemes (including HVDC emergency power control). Disconnection of power plants starts at 52.0 Hz.

3.2.3. Low frequency management (below normal operating frequency lower limit)

- In the Baltic area, in case of low frequency it is planned: Automatic load shedding (Two steps, rapid and slow, depending of the deviation speed. Summary about 60% of consumption). Power station generators house loading and Islanding. Higher than 1 Hz frequency deviation it is allowed to separate part or whole Baltic from united synchronous area.
- In the Continental Europe area, if the system frequency is lower than 49.8 Hz during more than one minute, the individual load frequency secondary controller has to be frozen. 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[22], before frequency leader designation (§ 4.1.3) or on frequency leader instruction. Before frequency leader designation, TSOs are allowed to manually and/or automatically activate manually and/or automatically additional reserve (e.g. (i) through stopping pumped-storage power plants and/or (ii) activating tertiary reserve and/or (iii) increasing the level of active power generation by activating extra primary reserve if available) in order to speed up the stabilisation of the system. These measures have to be taken with care not to create congestion[23].
- In the Great Britain area, at 49.7 Hz generators are obligated by the Grid Code not to take actions which would further reduce system frequency. Open Cycle Gas Turbines are available to fast start via low frequency relays set at 49.5 or 49.6 Hz. Automatic low frequency demand disconnection of up to 60% Average Cold Spell Demand in England and Wales; 40% in Scotland via low frequency relays. Frequency settings and demand blocks are reviewed regularly. The first block of Low Frequency Demand Disconnection is set at 48.8 Hz. There are up to 9 blocks.
- In the Ireland/Northern Ireland area, low frequency deviations are addressed by automatic MW output adjustment of generators operating under governor droop. If this is not sufficient to restore system frequency to within normal operating limits, at predefined low frequency thresholds frequency response of pumped storage units; static reserve from DC Interconnectors, and contracted interruptible load are triggered. Automatic low frequency demand disconnection/load shedding is initiated when system frequency falls to 48.85 Hz and up to 60% of load for each TSO is disconnected in discrete blocks. Load shedding/demand disconnection is balanced between both TSOs as set out in the Inter

[22] OH, Policy 5 – B – S6.1
[23] OH, Policy 5 – B – S6.2 and S6.3 modified in B-S5, S6 and S7 in 2014 release of Policy 5

Jurisdictional Operating Procedures. (TSO determined settings are implemented by DSOs). The two systems remain interconnected until all automatic low frequency load shedding has been implemented.

- In the Nordic system, the frequency controlled disturbance reserve (FCR-D) is used for frequency regulation in the range of 49.5 – 49.9 Hz and is activated automatically by the system frequency. Manual up-regulation (15 min activation time) is available for TSOs:
  - FRR-M (Manual disturbance reserve, mainly gas turbines, used to restore FCR-D)
  - commercial up-regulation bids on the common Nordic merit order list (the Nordic regulation power market)
  - emergency power control on HVDC connections is activated in several different steps at frequencies below 49.8 Hz
  - load shedding starts in several different steps below 48.8 Hz
  - disconnection of power plants starts below 47.5 Hz.

3.2.4. Under frequency load shedding (UFLS) current practices

Current practices regarding under frequency load shedding are summarized here:

- TSOs organize in coordination with DSOs (or with other involved parties) the regular checking (at least once a year) of the load shedding plan in order to ensure the predicted load shedding when applied.
- TSOs are expected to implement load shedding in an evenly distributed way.
- TSOs are expected to implement a UFLS plan that avoids disconnecting feeders with connected dispersed generation according to criteria that should be defined bilaterally between TSO and DSO.

3.2.5. User equipment frequency behaviour

Requirements for equipment in case of frequency deviation are different in every synchronous area and usually there are differences between countries. Usually it concerns only main/big generating units over the specified amount of MVA (also different in each county).

Even if new standards will be mandatory after the RfG Network Code enters into force, already existing units will still follow the current behaviour. Future system defence plans will thus have to take into account both capabilities.

3.2.6. Power shortages / manual load shedding

The amount of load to be disconnected is determined by the warning issued by the TSO. The DSOs are obliged to carry out the load shedding when required by the TSO, according to the percentage instructed by the TSO, and distributed as uniformly as possible inside their grid. The DSOs can rotate the load shedding inside their grid.

3.3. Voltage control and Reactive Power management

System defence plans shall include critical voltage levels and all reactive power compensation capabilities. It has to also include remedies to keep voltages between critical limits. Both manual and automatic remedies are necessary. Reactive power compensation can be achieved automatically or manually.

In a defence plan to prevent voltage collapse risk, TSOs use typically the following measures:

- blocking the transformer tap changers
- load reduction by reducing voltage on the secondary side of transformers (typically -5% Un)
- undervoltage load shedding relays at certain points on the network. These are reviewed and updated as required. The TSOs are responsible for determining the setting of the UVLS relays.

– manual load shedding
– special measures include lowering of active power output of units to widen available reactive power range (according to the PQ diagram)
– automatic disconnection of shunt reactances in case of low voltage.
– HVDC EPC .
– instructing simultaneous tapping of generator transformers

3.4. Consideration of specific grid user needs in defence plan

All TSOs consider specific grid user needs when designing their defence plans; national legislation typically describes conditions for specific grid user needs. Coordination with DSOs is typically required.

Civil safety (including nuclear safety) are of highest importance. Therefore, the priority for TSO defence plans is to maintain power supplies to nuclear power plants, where applicable. It is also high priority to maintain power supplies to national strategic facilities, e.g. hospitals, power plants, airports and factories with potential environmental impacts, gas pumping station etc.

3.5. Market emergency stop

In the event of an emergency situation, TSOs have the possibility to interrupt or, in cooperation with power exchanges, stop the Day-ahead and Intraday markets. As one of the last resorts TSOs can reduce the scheduled programs arranged by the market and thus reduce the commercial exchanges if the current system situation does not enable any further market activity.

Since an interruption of the market would affect a whole sector of the economy, the provision of simultaneous information to all participants about the interruption has to be ensured. During the interruption a load-following operation of generation will need to be performed under instruction of TSOs until the market can be restored. Sending out the information about the interruption and the load-following operation is the TSOs responsibility.

- Great Britain: In the event of a Total or Partial Shutdown, the TSO will inform[29] Users and the Balancing Settlement Code Company that the TSO intends to implement a Black Start. The TSO shall inform the Balancing Settlement Code Company the time and date that the Total or Partial Shutdown (at least 5% of forecast national load) commenced. Following this and in accordance with the provisions of the Balancing Settlement Code, the Balancing Settlement Code Company will determine the Settlement Period with effect from which the Market is suspended.
- Nordic and Baltic system: The day ahead and intraday markets are operated normally as long as possible. In case the physical transmission capacity is unexpectedly reduced (trip of line for example), all trades carried out in the markets will remain valid, as well as the exchange between bidding zones. When necessary, the TSOs will reduce cross border flows by applying counter trading[30].
- In Ireland and Northern Ireland, the market is settled ex-post and specific rules[31] are defined for settlement in the event that Black Start procedures have been initiated.

3.6. Secured functions of control rooms - Back up of Control Room facilities

During specific events such as environmental disasters, technical problems or terroristic attacks, leading into a temporary or permanent unavailability of the main control room, the operation has to continue using back up facilities.

[29] Operating code 9 of The Grid Code and Section G of the Balancing Settlement Code refer
[30] Nordic SOA - appendix 8 "Managing transmission limitations between subsystems"
[31] The Single Electricity Market (SEM) Trading and Settlement Code Version 13.0

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Currently, all over Europe, each TSO operates at least one back up control room for the possible unavailability of the main control room. These back up control rooms are geographically separate (not in the same building) and offer equal functionality including independent power supply sources. During normal operation these redundant control rooms are usually unmanned and are tested regularly, in most areas at least once a year.

Regarding power supply, various technologies are implemented e.g. batteries or diesel generators. This equipment is tested on an annual basis at minimum.

- In Continental Europe, it is mandatory to back-up control room functions. These functions shall be activated in less than three hours and tested at least once per year. Moreover these functions (SCADA/EMS systems, communication systems of control rooms, Load Frequency Control equipment...) must ensure that TSOs are able to know the status of any component of their power system after a blackout (e.g. tripped grid elements, islanded areas, blacked-out areas, generation units in correct house-load operation and ready to re-energise, units having difficulty in supplying their house load and thus in urgent need of an external source of voltage, Black Start capabilities...)[32].
- In Great Britain, the maximum duration for transfer from main to back-up control centre is 1 hour.
- In Northern Ireland, arrangements are required under the SONI Grid Code whereby the TSO may transfer functions of the TSO control centre to an alternative control facility. In Ireland, although the Emergency Control Centre is referred to, there is no specific obligation imposed on the TSO in the EirGrid Grid Code. Both TSO control rooms have a full back-up control room, each one regularly tested and used a number of times each year.
- In the Nordic and in the Baltic area, there are no direct requirements in the Nordic System Operation Agreement for the TSOs to operate a back-up control room. However, the agreement's requirements on how the TSOs shall run their own subsystem without disturbing the neighbouring subsystems, indirectly imply that backing up the control room functions is more or less required. Each TSO has backed up their control functions in the way and to the extent necessary, taking into account possible national requirements (such as in Sweden) and to maintain tests.

[32] OH –Policy 5 - B-S3.1, 3.3 and C-S2.1

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4. System Restoration and Re-synchronisation

4.1. Restoration plans

4.1.1. Restoration plans

Restoration plans[33] consist of a set of actions implemented after a disturbance with large-scale consequences to bring the system from emergency or blackout system state back to normal state. Restoration actions are launched once the system is stabilised following implantation of the system defence plan. Restoration of the system is achieved through a framework of a very complex sequence of coordinated actions which is studied and, as far as possible, prepared in advance. TSOs a trained in how to use the framework and it undergoes regular testing.

Restoration plans have also to be set up considering available generators and HVDC capabilities in the TSO's area.

4.1.2. Re-energisation strategies after a blackout

The restoration process for re-energisation in the case of blackout is based on two main principles all over Europe:

- *Bottom-up*: disturbed areas are restored by self re-energising the area in parts ready for re-synchronisation with another area, using Black Start units and/or units in house load operation with island operation capability.
- *Top-down*: a separated severely disturbed system is re-energised using external voltage sources, using tie lines to transfer the power from a secure system. In this case, the constrained TSO has to guarantee that it will respect the limits of active and reactive flows on interconnection line(s) agreed in bilateral agreements.

The current practises are:

- In the Baltic area, restoration plans are top-down.
- In the Continental Europe[34] and the Nordic areas, both methodologies are employed (in some cases both methodologies are applied in parallel), taking into account the existing situation (availability of Black Start units and units in house load operation within TSO's responsibility area, expected duration of both strategies, situation of the voltage in the neighbouring grid).
- In Great Britain area restoration plans are bottom-up.
- In the Ireland/Northern Ireland area, once Black Start generators become available, restoration paths to initial target generators will be energised and initial load restoration will be required to stabilise the restoration paths. The TSO specifies the load restoration steps required in terms of magnitude and location and the relevant DSO load coordinator will implement these. Close coordination between the TSO and DSO will be necessary, particularly at early stages of restoration for stability and to minimise frequency and voltage deviations.

4.1.3. Reconnectioning generators and shed load

In all areas, the TSO has to coordinate the reconnection of generators tripped due to abnormal frequency excursion and of shed load.

[33] OH, Policy 5 - C - D1
[34] For CE : OH, Policy 5 - C - S1.2

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In case of loss of generation[35], the TSO reconnects generators, based on the instructions of frequency leader where applicable, keeping adequate margins of the downward balancing reserve sufficient at least to cope with the next generation power to reconnect. The reconnection of generators is managed step by step in order to minimize the impact on the frequency deviation and the reserve margins. The process of reconnecting generators has to be done stepwise in blocks of maximum power defined by the TSO with respect to the operating reserve of the TSO's own grid.

Some TSOs (Fingrid) allow generating units up to a specified size to reconnect to the power system as soon as they are able to do it, without asking for permission.

In Ireland/Northern Ireland and Great Britain, the TSOs coordinate all generation and load reconnection with the generators and the DSOs following a Blackout. Although automatic frequency restoration of shed load is enabled in Ireland/Northern Ireland following localised/small scale load shedding, no automatic load reconnection is allowed following a blackout and automatic frequency restoration relays are to be switched off. No generation reconnection is allowed without instruction from the TSO.

For installations connected to DSOs' grids the local and remote reconnection has to be agreed in advance, for the main units this will be in cooperation between the TSO and DSOs. Automatic reconnection of generators is forbidden in some areas through national legislation.

In the case of shed load[36], the TSO does not re-energise the (shed) load when frequency is below 49.8 Hz, for the main system (except for regional islands) keeping a generation margin sufficient at least to cope with the next block of load to re-energise. The re-energising of the load is managed step by step in order to minimise the impact on the frequency deviation and the reserve margins.

TSOs have to coordinate the reconnection of shed load with DSOs (§ 4.1.6). Local and remote reconnection of customers' loads has to be agreed in advance in cooperation between the TSO and its DSOs.

4.1.4. TSO coordination in emergency frequency restoration

Emergency frequency restoration processes shall start after a severe disturbance with a frequency deviation higher than the maximum permissible or in case of system split.

- In the Continental Europe area, in case of frequency deviation higher than 200 mHz for more than 15 minutes, a frequency leader[37] shall be chosen within each synchronous area. This frequency leader is in charge of coordinating the emergency frequency restoration process within one synchronous area, by activating generation reserve within the area in trouble, together with TSOs in this area, in order to recover and maintain a frequency near to 50.0 Hz, with a maximum tolerance of +/- 200 mHz. The frequency leader defines the amount of power (upwards and downwards) to be requested from each TSO.

  As a default, the frequency leader is the TSO with the highest K-factor under operation (or referring to the most recent published value) within its LFC area. Besides this the following criteria shall also be considered:

  - High amount of generation reserve that can be mobilised within a very few minutes and a large free secondary reserve capability;
  - Capacity margin of tie lines;

[35] For CE : OH, Policy 5 - C – S3.7
[36] For CE: OH, Policy 5 - C – S3.5.1 and C – S3.6.
[37] OH, Policy 5 - C - S3.2.

- Acquisition of frequency values at least of direct neighbouring grids, and if possible of non-direct neighbouring grid that are parts of the same (a)synchronous system by measurements.

The Policy 5 also develops specific coordination principles for frequency management within a synchronous area, such as load frequency controllers used by TSOs, once the frequency leader has been nominated[38].

- In the Nordic, Ireland/Northern Ireland and Great Britain areas, TSOs coordinate the required actions, taking into consideration the current situation.

4.1.5. Re-synchronisation

For split situations, a re-synchronisation process has to be launched, after emergency frequency restoration.

- In the Baltic area, an agreement exists between TSOs regarding the resynchronisation leader. This agreement describes the condition under which resynchronisation takes place.
- In the Continental Europe area, re-synchronisation leader(s)[39] have to be selected for different synchronous areas (one leader for two areas) to re-synchronise these areas. It will have the following capabilities:
    - Have at least one substation under its responsibility with a "high capacity" line to reconnect both areas
    - Be able to acquire the values of both areas' frequencies
    - Be able to acquire the value of the voltage of both substations of connection point
    - Be able to manage the voltage deviation at least for the point of connection.

  The re-synchronisation leader will apply the required actions in order to operate the re-synchronisation under the following criteria:
    - Both systems must be in a stable state and both frequencies must be near to 50.0 Hz, with a maximum tolerance of +/- 200 mHz to 50.0 Hz, to re-synchronise 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 380 - 400 kV line(s) of capable of carrying a high load.
    - Make provisions for closing immediately at least a second line that is electrically close to the first line in order to strengthen the system connection.
    - Choose by preference a line for synchronisation not in the vicinity of large thermal units in operation.
    - The re-synchronisation leader gives orders to frequency leaders for appropriate actions to minimize the frequency and voltage deviation between both areas just at the time of re-synchronisation.
- In Ireland/Northern Ireland, resynchronisation of the two systems is not specified in Inter Jurisdictional Operational Procedures, but after separation, the two systems shall be re-synchronised as soon as practicable.
- In Great Britain, the synchronisation process is not specified in the Grid Code but established power islands shall be re-synchronised as soon as practicable.

[38] OH, Policy 5 - C-S2.3, S3.3 and S3.4
[39] OH, Policy 5 – C – D6.2 and C – S4.1

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- In the Nordic area, the synchronisation process is not specified in the Nordic System Operation Agreement. The TSOs agree bilaterally which one will be responsible for the synchronisation and how the synchronisation will be carried out. Voltages and frequencies in the two areas shall be close enough, it is normally the weaker area's responsibility to ensure this. If internal power islands exist, they are synchronised to the power system by permission from the TSO.

4.1.6. Role of DSOs and SGUs in restoration plan

In all countries, the overall system responsibility is assigned to the TSO. This includes the responsibility for operational security and restoration after disturbances. DSOs and SGU have to cooperate with the TSO during the preparation of defence and restoration plans and to follow the instructions of TSOs.

SGUs have to provide the TSO with all the necessary information in the case of restoration about their current status (including information about availability, house load operation, power plant condition and situation as well as the power plant control).

In the case of restoration the DSOs are responsible for restoring load following TSOs instructions and according to restoration plans. DSOs have to provide the TSO with all the necessary information about the current status of their network.

(1) Generator island operation capability

(2) Generator house load operation capability

(3) Black Start units

(4) HVDC Black Start capabilities

4.2. Restoration plans test

In order to have their restoration plan ready at any time, each TSO has to prepare in advance and keep updated the restoration plan. In ENTSO-E, all TSOs have to evaluate regularly their restoration plan.

In the Baltic, the Continental Europe, the Great Britain, the Ireland/Northern Ireland and the Nordic areas, restoration plans are evaluated by simulation or off-line calculations[43].

In addition real tests are also performed by some TSOs; the Black Start capabilities of generation units; the island operation (for parts of the transmission system); re-energisation paths.

4.3. Bilateral agreements for inter-TSO Coordination

In all areas, neighbouring TSOs have to prepare and agree in writing bilateral principles to be applied in the case of system restoration[44]. Such bilateral procedures are also agreed with the grid owner where different from the grid operator. These bilateral agreements allow detailing general principles described in “regional grid codes”, with all operational details that are necessary to perform system restoration after a full or partial blackout.

4.4. Consideration of specific grid user needs in restoration plan

In restoration plans, TSOs take into account specific grid user needs in accordance with national legislation and in coordination with DSOs when needed. At the early stages of restoration the first priority for TSOs is to ensure the operation of the Black Start and/or house load units. Once additional generators synchronise,

[43] For CE : OH, Policy 5 - C - S1.2.1.1
[44] For CE : OH, Policy 5 – C- S1.4

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priority loads should be reconnected. For the consumers on distribution grids the priority for the supplies is established by DSOs (e.g. hospitals, emergency services, airports, etc).

4.5. Market restoration

Market restoration can only take place after the restoration of the system. To reinitialise the market the transmission grid has to be, to the greatest possible extent, restored and stable.

To restart the market, TSOs have to ensure that all market participants receive accurate information about the exact time of the restart and about the procedure the TSO has decided to use.

So far no common rules exist and no regional or synchronous area has yet set up an obligatory detailed process description of how to conduct the market restoration process. Nevertheless some areas are following general rules:

- Great Britain: Following the TSO’s determination of the time when the Total System could return to normal operation, the Balancing Settlement Code Company shall determine, after consultation with the TSO, the Settlement Period when normal Market operation will be resumed.
- Nordic and Baltic system: It is up to the TSOs to evaluate when to increase the trading capacities for the intraday market if they have been reduced due to an event. It is also up to the TSOs to evaluate when to open the intraday market if it has been closed completely. The scheduled exchanges are resumed as soon as possible. Normal balance settlement rules apply regardless of market shutdown.
- In Ireland/North Ireland, the market will be restored upon notification to users that the system is no longer in a state of Blackout. It can also be restored as the Regulatory Authorities deem appropriate.

4.6. Ex-post analysis of system wide events

An Incidents Classification Scale (ICS) methodology is commonly applied by all ENTSO-E TSOs since 2010. According to this methodology, each TSO has to report grid and system disturbances on a four degree scale (0 to 3) corresponding to incidents of growing seriousness up to a general Europe wide incident. In general, reporting has to be done by the TSO in charge of the grid where the disturbance has occurred.

Criteria for determining the scale of an incident have been defined by using definitions from ENTSO-E network codes and IEC standards. Each criterion describes “factually” an event or a situation which is observable. Scales are compliant with “System States” definitions from the draft of Operational Security network code.

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5. Economic efficiency and regulatory aspect

5.1. Economic efficiency in defence and restoration plans

5.1.1. General principles

Economic efficiency is implicitly taken into account by TSOs in defence and restoration plans; these plans are designed with the objective to minimize the overall impact for the grid users utilizing the minimum possible resources. The complexity of this optimization problem is increased by the fact that these plans need to consider civil security issues identified typically by the responsible national authorities. In most countries, the minimization of the overall impact for the grid users is an objective that is imposed explicitly through national legislation.

5.1.2. Economic efficiency in defence plans

Economic efficiency is implicitly taken into account by TSOs in defence plans. Defence plans, and in particular load shedding (as a last resort), are designed with the objective to minimize the total load that needs to be shed taking into account the constraints that are presented in Chapter 3 (specific needs of grid users). These constraints are either imposed by the civil security requirements or the economic impact that an interruption has on certain grid users (as covered in the connection agreements of these grid users); coordination of TSOs with DSOs typically takes place in this aspect. Rotational load shedding is also applied with the objective to minimize the impact for the grid users.

Demand side response markets are either in place or under development in several countries. As part of their defence plans, TSOs procure interruptible load typically through tenders; economic efficiency is ensured through the tendering process. Interruptible load needs to meet certain pre-qualification criteria. Grid users with interruptible load contracts are to be shed first (before any other load is shed).

The economic efficiency is under regulatory scrutiny, for most TSOs through tariffs approval (see next section).

5.1.3. Economic efficiency in restoration plans

Economic efficiency is implicitly taken into account by TSOs in restoration plans; the objective of these plans is to minimize the time to restore the whole system back in operation with the minimum resources available taking into account the constraints that are presented in Chapter 4 (Specific needs of grid users). These constraints increase significantly the complexity of the problem; in order to select the optimum solution, TSOs analyse different scenarios; this analysis ensures that the most efficient option is selected.

Tendering/contracting procedures are in place in several countries regarding Black Start units; economic efficiency is ensured through the tendering/contracting process.

5.2. Regulatory aspects

5.2.1. Regulatory involvement in defence and restoration plans

Currently, regulatory involvement in Defence and Restoration plans has different levels of depth among European countries. All TSOs have an obligation to design defence and restoration plans and to have them in place, but in many countries, there is no requirement for them to be formally approved by the NRA; they are only transmitted for information.

For some TSOs the NRA has to approve some specific aspects used to design the Restoration plans, for instance:

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- the general criteria applied in defence and restoration plans (such as Steps of load shedding scheme, Settings of frequency relays for generators (under-frequency and over-frequency situation), Interruptibility services.
- justification for costs incurred for system defence and restoration, as part of the approval for the recovery of TSO costs.
- the target level for security of supply.

In other countries, the NRA approves either general overview of the Restoration plan or even the detailed restoration plan itself, either directly, or indirectly, since is part of the Grid Code approved by the NRA.

5.2.2. Transparency

For security reasons, none of the TSOs publish their detailed defence and restoration plans. Only general principles and basic content of the restoration plans are publicly available. Involved parties are always informed about therestoration plans they take part in, to give them specific instructions.

More generally, high level contacts are established between TSOs and administrative authorities in the case of Emergency (especially load-shedding activation or risk of activation) or Blackout situations.

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