European Network of
Transmission System Operators
for Electricity

SPECIAL PROTECTION SCHEMES

ENTSO-E SUBGROUP “SYSTEM PROTECTION AND DYNAMICS”

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Content

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1 INTRODUCTION

This report complements the report "Technical background and recommendations for Defence Plans in the Continental Europe Synchronous Area".

Defence plans, System Protection Schemes and Special Protection Schemes cover aspects of power system security. They all have in common that the focus of the protection is on the power supply capability rather than on a specific equipment. The terminologies are therefore often used interchangeable. This report is aimed to

- define the terms Defence Plan, System Protection Scheme and Special Protection Scheme
- provide guidelines and rules for the implementation of Special Protection Schemes within ENTSO-E
- provide examples of applied Special Protection Schemes within ENTSO-E

2 CLASSIFICATION OF SYSTEM STATES AND CONTINGENCIES

For purposes of analyzing power system security it is first of all helpful to conceptually classify the system operating conditions into system states [Figure 1]:

- **Normal State:** All system variables are within the normal range and no equipment is being overloaded. The system operates in a secure manner and is able to withstand predefined contingencies without violating any of the constraints.
- **Alert State:** If the system parameters are still within admissible ranges but the system does not any more meet the criteria given for a secure state, i.e. it is no longer 'n-1' secure, the system is considered to be in an 'alert' state (or endangered state). Typically, the system reaches this state after a 'n-1' contingency. This state requires application of remedial actions without any delay in order to come back to the secure state, i.e. to comply with the 'n-1' rule.
- **Emergency State:** As consequence of contingencies beyond (n-1), extreme or unforeseen contingencies, the individual variables that describe the overall system state could violate admissible operational limits and hence the system is considered to be in an 'emergency' state (a disturbed state). A system being in an emergency state might not be able to fulfill its function with respect to consumer supply and power transits, but is not blacked out. However, there is the risk of system collapse

mainly due to the loss of stability. Therefore relevant actions must be taken immediately to bring back the system into acceptable conditions.

- **Blackout State:** A 'blackout' state is characterized by almost total absence of voltage in a certain area of the transmission system as a consequence of tripping of generating units due to abnormal variation of voltage and/or frequency which occurred during the emergency state. Once the system enters the blackout state the restoration plan shall be activated as soon as possible.

- **Restoration:** The restoration plan aims to reduce the duration of power system interruptions (as consequence of blackouts) by reenergizing the backbone transmission system as fast as possible, which allows gradual reconnection of generating units and, subsequently, supply to customers. Prompt and effective power system restoration is essential for the minimization of downtime and costs to the utility and its customers, which mount rapidly after a system blackout.

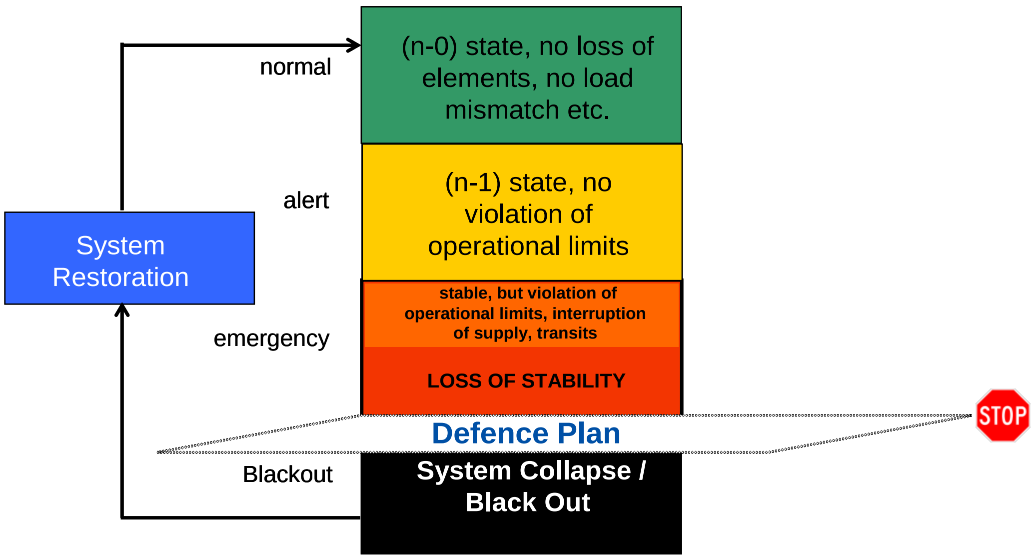

Figure 1: Classification of System States

Next, for elaborating economical and robust power system security concepts, the contingencies that involve transitions between the system states have to be classified as well.

According to ENTSO-E Policy 3 a contingency is defined as the trip of one single or several network elements (including generation units and loads) that cannot be predicted in advance. A scheduled outage is not a contingency. An “old” lasting contingency is considered as a scheduled outage. It is differentiated between

- Normal type of contingency (loss of one single element)
- Exceptional type of contingency (uncommon loss of particular elements based on the one hand on the design of the network structure and on the other hand on the probability of the event)
- Out-of-range type of contingency (failure with high impact and low probability which is not taken into account due to exceeding dimensioning efforts in the single TSO´s network)

In this regard normal and exceptional type of contingencies are contingencies which have been specifically foreseen in the planning and operation of the system, and against which specific measures have been taken to ensure that the power system functions in terms of customer supply and scheduled power transits are not affected within given limits.

Normal and exceptional type of contingencies must not endanger the security of interconnected operation. After any of these contingencies the operational condition within the TSO´s responsibility area must not lead to the triggering of an uncontrollable cascading outage propagating across the borders or having an impact outside the borders: “no cascading with impact outside my border”. After normal and exceptional type of contingencies the power system generally enters into the alert state, but is not allowed to pass into the red part of the emergency state (i.e. exceptional type of contingencies might lead to the violation of operational limits with regional impact, but the loss of stability is not accepted)

All contingencies beyond normal and exceptional type of contingencies are defined as “Out-of-range type of contingencies”**.** These are rare contingencies that often result from exceptional technical malfunctions, *force majeure* conditions, common mode failures or human errors. As well as being rare, out-of-range contingencies vary significantly with respect to their causes and consequences and thus they are hardly predictable and not currently specifically defined in the design and planning policies of most utilities. Due to the physical nature of large synchronously interconnected transmission systems, out-of-range contingencies can be accompanied by the removal of multiple components, cascading of outages or loss of stability followed by widespread interruption to electricity users’ supply or, in the worst cases, a system blackout. In order to limit the impact of out-of-range contingencies a so called “Defence Plan” can be implemented in the network (see chapter 3).

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3 Definition of Terminology: Defence Plan, System Protection Scheme and Special Protection Scheme

To contain normal type of contingencies the so called 'n-1' rule is common practice in most large power systems worldwide. This concept is characterized by a pre-defined redundancy of power system elements which ensures a sufficient safety margin and robustness to operate the power system. Given that the transmission system loading is moderate also exceptional type of contingencies can often be handled due to this robustness. As long as normal and exceptional type of contingencies are "secured" by means of redundancy and the "normal" power system control capabilities (e.g. PST, HVDC controls, FACTS controls etc) no automatic protection measures to preserve the system integrity and to avoid the violation of operational limits are required. However, manual actions have to be taken to re-establish the normal state.

On the other hand it is not economical to design a power system arbitrarily redundant, in fact it is necessary to find a technical and economical trade-off between investment cost, operation cost and power system security needs.

Possible reasons that might restrain sufficient redundancy in transmission systems are:

- The power system spans a large geographical area, so that the application of the 'n-1' rule would lead to non - justifiable economical efforts
- Trends such as the changeover to a competitive market environment, i.e. facilitating large electrical energy trades across wide areas, large scale penetration of renewables and missing incentives to build power plants at locations that consider system needs as well bring the power system closer to its technical limits. The increasing stress on the existing infrastructure gradually reduces the safety margins respectively requires new infrastructure to maintain the same level of redundancy and robustness in parts of the grid The latter might be blocked due to economical reasons and / or the difficulty in obtaining permits for new transmission infrastructure projects.
- In some power systems an "overlay structure", e.g. strong HVDC links, are in operation or planned. Due to economic reasons these strong links might not be inherently redundant.

If there is a lack of redundancy other measures are necessary to contain normal and exceptional type contingencies and to provide acceptable system performance. The entity of these measures can be pooled under the name **'Special Protection Schemes'**.

Special Protection Schemes are often **'event based'** and counteract on a limited number of critical contingencies, that have been identified beforehand, e.g. through offline studies. In this regard 'event based' means, that the Special Protection Scheme is designed for

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operation only upon the recognition of a particular combination of events and is thus based on the direct detection of the event (e.g. loss of a line). It anticipates unacceptable system conditions resulting from normal or exceptional type of contingencies and aims to stabilize the system in the alert state by means of dedicated automatic controls [Figure 2].

It should to be noticed that also selected system quantities can be monitored and used to trigger the Special Protection Scheme (response based), but in contrary to System Protection Schemes, which will be discussed subsequently, the power system is not necessarily in a emergency state or close to instability, even though there might be a risk to enter the emergency state.

For this reason Special Protection Schemes are mainly applied in weak and / or highly loaded systems where the 'n-1' rule is not met (at least partially) and where normal or exceptional type of contingencies exceed the robustness of the system and thus bring the system directly from the normal state to the emergency state or even to the blackout state.

Possible applications of Special Protection Schemes can be summarized as follows:

- Improve power system operation, cope with operational difficulties imposed by particular power system characteristics,
- Operate power system closer to its limits and maintaining sufficient transmisssion capacity during planned outages,
- Contain normal or exceptional type of contingencies in case of insufficient safety margins (e.g. due to restrained possibilities to develop the transmission system properly, i.e. limited redundancy).

In order to cope with and to minimize the impact of 'out-of-range' contingencies, i.e. in particular to prevent a total system collapse, '**System Protection Schemes'** have been developed and implemented by many utilities. These schemes include a set of coordinated and mostly automatic measures to ensure fast reaction to large disturbances and to avoid their propagation through the system.

System Protection Schemes are thus designed to initiate the final attempt at stabilizing the power system when a wide spread collapse is imminent.

As the risk for system collapse results mainly from the possible loss of stability System Protection Schemes are generally designed to contain the different power system instability phenomena:

- Transient Instability
- Oscillatory Instability
- Frequency Instability
- Voltage Instability

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They should take predetermined, corrective action to avoid a specific phenomenon further aggravating the power system condition by spreading through the system. Each System Protection Scheme is thus fundamental to preserving system integrity and providing acceptable system performance in the case of a specific phenomenon.

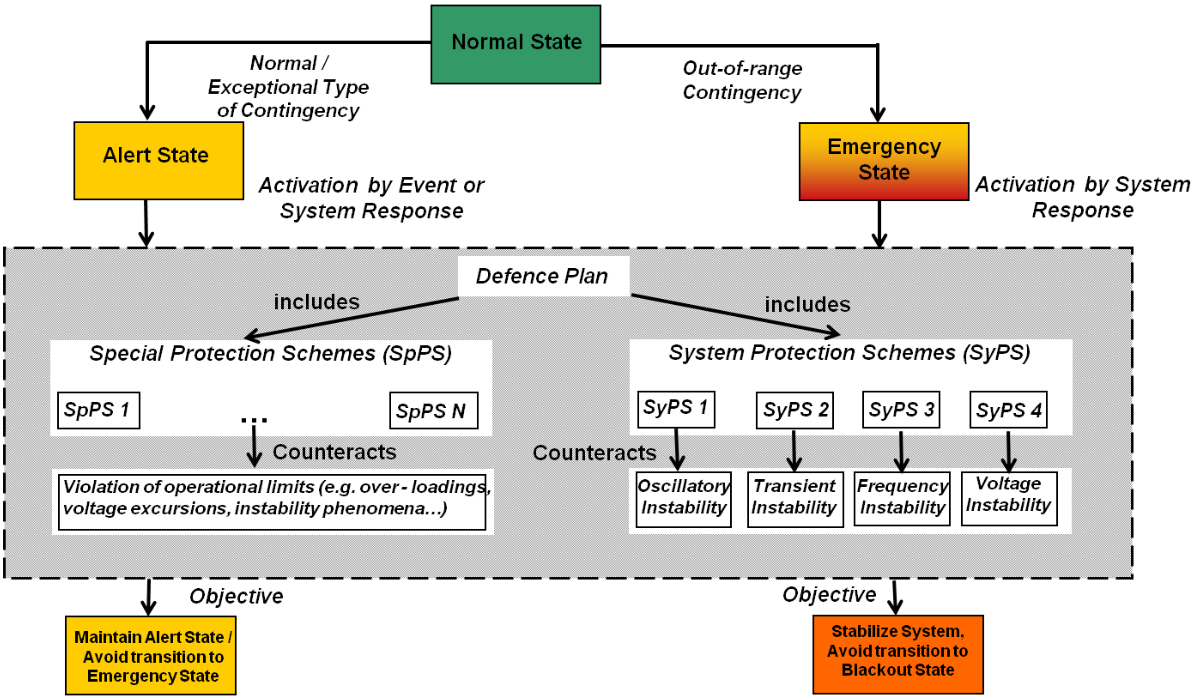

Figure 2: Definition of Defence Plan, System Protection Scheme, Special Protection Scheme

System Protection Schemes are generally **response based**: They use electric variables and initiate automatic stabilizing actions after the contingency has caused the measured quantities to exceed the admissible ranges, i.e. when the power system enters into the emergency state [Figure 2].

Special Protection Schemes and System Protection Schemes together compose a **Defence Plan.** A Defence Plan thus can include (not necessarily must include):

- A set of specific, event-based Special Protection Schemes in order to avoid the violation or operational limits or the loss of stability after normal or exceptional contingencies
- A set of coordinated, response-based and/or event based System Protection Schemes in order to avoid the loss of stability after “out-of-range” contingencies.

The measures taken by Special Protection Schemes or System Protection Schemes could be the same (e.g. load shedding, generation rejection etc.), but the underlying reason for their implementation is different.

4 Guidelines and Rules for the Implementation of Special Protection Schemes within ENTSO-E

In a context of restrained possibility of network development and more intensive use of available generation and transmission facilities, the implementation of Special Protection Schemes might increase in future.

If a TSO relies on Special Protection Schemes to meet the specified power system performance levels these Special Protection Schemes must be highly reliable (protection grade reliability is required, with proper redundancy of the SPS elements). The application of Special Protection Schemes might have local, regional or over regional impacts. Provided that there is an influence on neighboring TSOs the realization of Special Protection Schemes has to be coordinated between the affected TSOs and detailed information (e.g. with respect to the modeling and the settings) have to be shared between the involved parties. Detailed system studies are necessary to design the SPS and to assess its impacts (see also Annex 6)

Based on these facts the recommendations regarding Special Protection Schemes <u>for drafting the new ENTSO-E codes are:</u>

- The unintended operation of a Special Protection Scheme, i.e. its operation without precedent event, should not cause system conditions worse than normal type of contingencies
- The malfunction of a Special Protection Scheme, i.e. its incorrect operation in case of the contingency it was designed for, should not cause system conditions worse than exceptional type of contingencies This might be solved by implementation of a independent back up system for SPS.
- The coordination process between the involved TSOs, the requirements with respect to operational functionality, the information exchange, the system design and the reliability of Special Protection Schemes etc. should be defined and incorporated

Further on it is recommended to document

- the installation of new Special Protection Schemes within ENTSO-E-CE.
- the operation of existing Special Protection Schemes within ENTSO-E-CE

and to update the list of active installations every two years (analogue to the PSS performance report).

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5 ANNEX: SPECIAL PROTECTION SCHEMES APPLIED WITHIN ENTSO-E

Table 1 shows selected examples of applied Special Protection Schemes within ENTSO-E [1].

Country	SpPS Action	Objective
Albania	Automatic Load Shedding initiated by loss of specified lines or violation of certain thresholds (voltage, line current)	Avoid propagation of disturbance by overloading of parallel transmission paths
Belgium	Loss of specified line → Immediate isolation of a 1000 MW generation unit	Prevent cascading outages and propagation of oscillations
Bulgaria	Emergency Trip of 1000 MW unit Kozloduy NPP → Automatic load shedding	Balancing of production and consumption → avoid propagation of disturbance and separation of Bulgarien EHV system
Denmark	HVDC runback + disconnection of filters in cases of 3 – phase trip signals	Avoid transient over – voltages, support restart of HVDC converter
Germany/Luxemburg	Automatic (partial) disconnection of a pump-storage hydro power station in pump operation mode in case of loss of transmission equipment	Prevent porpagation of disturbance and cascade trippings
Greece	Automatic load shedding schemes in case of predefined contingencies	Protect against voltage collapse
Italy	Inter – Alia Automatic Load Shedding Schemes	Prevent overloading, stability problems etc.
Poland	Preventive trip of pre-programmed generation units triggered by output signal of specified line protections if certain preconditions are fulfilled	Anticipate the loss of synchronism of generation groups, avoid propagation of disturbance
Romania	Automatic (post-event) rejection of generation units (HPP Portile de Fier)	Maintain dynamic stability in Portile de Fier area in case of branch trips, with minimum of preventive re – dispatch
Spain	-Trip of critical tie line between Spain and France under contingency condition - Generator rejection in case of line loss -Trip of tien lines with Morocco in case of stability loss Circuits Trip to under contingency,. Automatci Switching	- Prevent voltage stability problems - Avoid transient instability or overload - Avoid instalbility spread fron North African System to European system. Prevent overvoltage conditions as result of contigencies
Switzerland	Automatic centralized load shedding in Italy in case dedicated lines of the North South corridor between Switzerland and Italy are lost	- Prevent overloading of remaining lines, avoid cascading effects

6 ANNEX: BASIC DESIGN ASPECTS OF SPS

In general, the design process of a Special Protection Scheme can be broken dawn into the following components [6]:

- System study
- Solution development
- Design and implementation
- Commissioning and periodic testing
- Training and documentation

The system study is necessary to analyze the necessity of a Special Protection Scheme its operating functions, its regional or over-regional impacts and its coordination with other system protection and control schemes.

The system study shall define among others the limitations or restrictions in force, the identifying monitoring signals with corresponding locations and set points, the reliability and dependability levels. The requirements for Safety Integrity Level (SIL) and Probability of Failure on Demand (PFD) by IEC 61508 have to be defined as well.

Failure of the SPS to operate when required, or its undesired or unintentional operation in a case of contingency or normal condition of the power system can involve adverse impacts in system operation. Carrying redundancy or necessary local or remote backup functions out is an important requirement for reliability and safety of the system. During the design process the SPS architecture (flat or hierarchical, centralized or distributed, etc.) and the necessary data communication in harmony with levels of the reliability, redundancy and safety shall be determined.

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