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Connection Code

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1 SCOPE OF APPLICATION

J.[1] The scope of application identifies which **Facilities** are governed by this **Connection Code**, along with other information for proper understanding of the specific provisions.

This **Connection Code** governs the technical conditions for the access of **Power-Generating Facilities** and **HVDC Systems** to the **Grids** of the **Member States**. The aim is to promote the correct functioning and safety of the **PAEM Electricity System.**

The subjects of this **Code** include:

a) the operational characteristics and performance of the **Grids** at the **Connection Points** (Chapter 2);
b) the procedure for the connection of **Power-Generating Facilities** and **HVDC Systems** to the **Grids** (Chapter 3);
c) the connection requirements that are common for all **Power-Generating Facilities** and **HVDC Systems** (Chapter 4);
d) the minimum necessary technical requirements for the design criteria and operational capabilities of:
   i. **Power-Generating Facilities** (Chapter 5);
   ii. **HVDC systems** (Chapter 6);
e) a set of guidelines for the definition of connection requirements for **Distributed Generation** (Chapter 7).

Specifically, the requirements of this Code apply to the **Power-Generating Facilities** and **HVDC Systems** that meet the following criteria:

a) systems that are not connected to the **Transmission System** as of the adoption date of this **Connection Code**;
b) existing systems in case of significant changes or partial/total reconstruction.

The relevant **TSO** evaluates the significance of a change or reconstruction based on information that are communicated by the **Power-Generating Facility Owner** and **HVDC System Owner** to the relevant **TSO** about the planned modifications[2]. The relevant **TSO** shall define a time period from receipt of the communication within which it will make a determination as to whether the modification constitutes a significant a change or reconstruction. After this period, in the absence of a communication from the relevant **TSO**, the change or reconstruction is considered not significant.

Concerning **Power-Generating Facilities**, it is specified that the relevant requirements apply to all the **Power-Generating Modules**, both synchronous and inverter-based, connected at the **Transmission System** or having a **Nominal Power** equal or higher than a given threshold, expressed in MW.

[1] J. : Justification

[2] A non-exhaustive list of changes that shall be deemed as significant considers the following. For **Synchronous Power-Generating Modules**: replacement of synchronous machine, renewal of voltage and/or frequency control equipment and of protection or control systems, change/replacement of thermal or hydraulic components. For **Inverter-based Power-Generating Modules**: replacement of wind turbines or inverters for a cumulative power of at least 10% of **Nominal Power**, replacement of control equipment. For **HVDC Systems**: change in transfer capacity, technology or configuration (monopolar, bipolar).

Each **Member State** shall define the effective date at which this **Code** goes into effect, along with:

a) the voltage levels that pertain to the respective **Transmission System** – 110kV shall be considered as the minimum value of operating voltage above which the **Network** is considered as **Transmission System**;
b) the **Nominal Power** threshold, which cannot be higher than 75MW – i.e. this Code applies by default to **Power-Generating Modules** with **Nominal Power** higher than 75 MW.

2 OPERATIONAL CHARACTERISTICS AND PERFORMANCE OF THE GRIDS AT THE CONNECTION POINTS

J. Operational characteristics and performance of the **Transmission System** at the **Connection Points** affect the design and the operation of **Power-Generating Facilities** and **HVDC System**. Harmonizing characteristics and performance within the interconnected **PAEM Electricity System** will provide access to the **Transmission System** in a transparent and non-discriminatory manner by potential stakeholders. Moreover, it facilitates the development and standardization of equipment.

The relevant **TSO** shall guarantee defined operational characteristics and performance of the respective **Grids** at the **Connection Points**. **Power-Generating Facilities** and **HVDC Systems** will preserve the **Grid** performance going forward by meeting the technical rules of this Code.

The relevant **TSO** shall define the operational characteristics and performance of the respective **Grid** at the **Connection Points** according to the requirements described below.

On an annual basis, the relevant **TSO** will review up and make publicly available information pertaining to the operational characteristics and performance of the respective **Grid** according to the **Operation Code**.

2.1 Operating Conditions and frequency ranges

The relevant **TSO** shall define the nominal frequency as well as the different **Operating Conditions** of the respective **Grid**. Provisions concerning the definition of the **Operating Conditions** are provided in the **Operation Code**.

For each **Operating Condition**, the relevant **TSO** shall define the respective frequency ranges within which the frequency is maintained.

Operating Conditions and respective frequency ranges shall be harmonized within **Member States** belonging to the same **Synchronous Area**.

2.2 Voltage levels

The relevant **TSO** shall define and make publicly available the values of nominal and operating voltages for each **Connection Point** and for each **Operating Condition**.

2.3 Other voltage characteristics

The relevant **TSO** shall define the following voltage characteristics that shall apply to normal **Operating Conditions**:

a) Total Harmonic Distortion (THD):
The relevant **TSO** shall define the maximum expected value of the THD expressed in percentage for each nominal voltage level of the respective **Grid**. The limits for THD shall be those specified on IEEE 519.

b) Unbalance of the three-phase voltage:
The relevant **TSO** shall define the maximum expected degree of unbalance of the three-phase voltage for each **Connection Point**. The degree of unbalance is usually defined by the percent ratio of the absolute value of the negative sequence voltage component to the absolute value of the positive sequence component, obtained by the transformation of the unbalanced 3 phase voltage quantities in the 3 symmetrical components (zero, positive, and negative sequences)[3]. Typical value of maximum unbalance is 1%.
Exceptional conditions that may result in higher values can be considered by the relevant **TSO** (e.g. phase interruption).

c) Flicker:
The relevant **TSO** shall define the maximum values of short-term flicker severity (P_{st}) and long-term flicker severity (P_{lt}) for each nominal voltage level of the respective **Grid**.

Limits for THD, dissymmetry and flicker shall be harmonized within **Member States** belonging to the same **Synchronous Area**.

2.4 Short-Circuit Current

The relevant **TSO** shall calculate and make publicly available the maximum and minimum values of **Short-Circuit Current** for each **Connection Point**. These values shall be updated on an annual basis by the relevant **TSO**.

The procedure for the computation of the maximum and minimum **Short-Circuit Current** shall be made publicly available by the relevant **TSO**. Moreover, the approach for determining these values should be harmonized among the **Member States** belonging to the same **Synchronous Area**.

3 CONNECTION PROCEDURE

J. Common procedures for the connection of **Power-Generating Facilities** and **HVDC Systems** to an **Integrated Power System**, from the request to the approval of connection, are required among the involved **TSOs**. This contributes to the access in a transparent and non-discriminatory manner across the same **Synchronous Area**.

[3] The decomposition method is based on the Fortescue's Theorem.

The relevant **TSO** shall define the procedure for connecting **Power-Generating Facilities** and **HVDC Systems** to the relevant **Grid.**

The procedure for requesting connection shall be made publicly available by the relevant **TSO** at the effective date of this **Code**. Any updates to the procedure must be made public in advance of the actual date of enforcement. The procedure must also be harmonized across the **Member States** to the extent possible.
The procedure shall involve the following parties:

d) the **Power-Generating Facility Owner** or the **HVDC System Owner** as applicant for the connection;
e) the relevant **TSO** and/or the relevant **National Regulator** – according to the relevant national regulation on the subject – as:
    i. the relevant entity in charge of evaluating the applications;
    ii. the grantor of the authorization to connect;
    iii. the entity that defines the technoeconomic conditions for obtaining the access and interconnections to the relevant **Grid**.

The procedure shall report the formal steps needed for being connected to the **Grid** of the relevant **TSO** and the related timing. The procedure shall cover the following phases:

a) Authorization phase: where a request for connection to the **Grid** is made by the applicant.
   The authorization procedure shall report the complete list of documents to be provided by the applicant. Such documents shall cover at least the following information:
    i. the company profile of the applicant;
    iii. the proposed **Connection Point** and details on the site of connection;
    iv. the certified technical documentation related to the **Power-Generating Facility** or an HVDC **System** relevant to the connection to the **Grid**;
    v. the details of the technical capabilities of the **Power-Generating Facility** or the **HVDC System** relevant to the connection to the **Grid**;
    vi. compliance with the connection requirements sets out in the relevant **National Grid Code**.

   The authorization document to connect shall report, at a minimum:
    i. the conditions of acceptance by the relevant **TSO**;
    ii. the necessary modifications to the original connection project, if any;
    iii. the cost of connection.

b) Realization phase:
    i. construction of the required **Network System for the Connection** by the relevant **TSO**. This is the set of plants and equipment, necessary for the connection of **Power-Generating Facility** and/or the **HVDC System** to the **Transmission System**, to be implemented in the **Transmission System** in the existing configuration to the **Connection Point**.
    ii. construction of the **Power-Generating Facility** or the **HVDC System** by **Power-Generating Facility Owner** or the **HVDC System Owner**.

c) Entry-into-service phase: application for the start-up of the **Power-Generating Facility** and/or an **HVDC System**.

The relevant TSO shall define an operational notification procedure to entitle a **Power-Generating Facility Owner** or an **HVDC System Owner** to operate its system. This procedure shall comprise three stages:

a) Operational notification to entitle the **Power-Generating Facility Owner** or the **HVDC System Owner** to energize its internal electrical network and auxiliaries and connect it to the **Connection Point**.
b) Operational notification to entitle the **Power-Generating Facility Owner** or the **HVDC System Owner** to operate its system connected to the **Grid** for a limited time period – to be defined by the relevant TSO – necessary to assess at least the technical data of the system and the compliance with requirements.
c) Operational notification to entitle the **Power-Generating Facility Owner** or the **HVDC System Owner** to operate its system connected to the **Grid** at the **Connection Point**. This operational notification shall be issued by the relevant **TSO** upon prior removal of all incompatibilities identified for the purpose of the previous point.

4 GENERAL REQUIREMENTS

J. This Chapter covers general requirements that are common to **Power-Generating Facilities** and **HVDC Systems**, e.g. (not exhaustive list), schemes of connections, general scheme for protections.

General requirements apply to **Power-Generating Facilities** and **HVDC Systems** as per Chapter 1. Specific requirements for **Power-Generating Facilities** and **HVDC Systems** are given in Chapters 5 and 6 respectively. The relevant **TSO** can define additional requirements to those given in this **Code**.

4.1 Preliminary provisions

Connecting **Power-Generating Facilities** and **HVDC Systems** to the **Grid** shall not give rise to any degradation in the performance or reliability of the **Grid** itself and shall contribute to the safety and quality of the service according to the capabilities of the facility and system.

The design of the **Network System for the Connection** shall be executed such that it shall not negatively affect the operation of the **Grid** or damage the other **Facilities**.

Respective materials and components of **Power-Generating Facilities** and **HVDC Systems** shall be designed and manufactured in compliance with the national and international standards in force concerning safety and protection of people and things.

4.2 Technical documentations

The **Power-Generating Facility Owner** and the **HVDC System Owner** are responsible for the drafting, updating and formal communication to the relevant **TSO** of:

a) the technical documentation for the **Network System for the Connection** to the **Grid** that shall comprise:
   i. single-line diagram and planimetry;
   ii. technical descriptions, manuals and test data for each equipment;
   iii. schemes and descriptions of control, operation and protection equipment and systems.

b) the documentation of the **Power-Generating Facility** or the **HVDC System** that shall comprise the technical data of the equipment belonging to the **Power-Generating Facility Owner** and the **HVDC System Owner** which are relevant to the **Grid** operation.

The **Operating Regulation Document** shall be signed between the **Power-Generating Facility Owner**, the **HVDC System Owner** and the relevant **TSO** in order to:

a) define the respective responsibilities with regards to the operation and control of the facility and system sections which are functional to the **Grid**;
b) define specific connection requirements in addition to those given in this **Code** and in the relevant National regulation, if deemed necessary;
c) define derogations to the requirements of this **Code**.

4.3 Schemes for connection to the Grid

The relevant **TSO** shall define the procedure for the identification of the technical solution for the connection of the **Power-Generating Facility** and **HVDC System** to the **Grid.**

The procedure considers at least the following steps:

a) identification of the connection to the grid and definition of the connection voltage level;
b) identification of the point and technical configuration of the insertion in the **Grid**;
c) definition of switching devices and of the **Network System for the Connection**;
d) definition of functional and property limits.

4.4 Protection system

The design and operation of **Power-Generating Facilities** and **HVDC Systems** shall consider the technical features and performance of the **Grid** protection system. Accordingly, the **Operating Regulation Document** shall report the requirements for the protection system.

The protection system of **Power-Generating Facilities** and **HVDC Systems** shall:

a) guarantee the following general criteria:
    i. coordination with **Grid** protection system;
    ii. backup protections where needed;
    iii. monitoring;
    iv. contribution to identification of faulty element(s).

b) be organized according to:
    i. protection at **Connection Point**;
    ii. protection against faults that are outside the **Power-Generating Facility** and **HVDC System;**
    iii. protection against faults that are inside the **Power-Generating Facility** and **HVDC System;**
    iv. protection of connection lines between **Connection Point** and the **Grid** (when present).

The **Operating Regulation Document** shall define the calibration of protection equipment.

4.5 Communication system

The **Power-Generating Facility** and **HVDC System** shall be integrated into the control process and operation (in real time and in deferred time) of the **Grid**. This is achieved by exchanging data and information between the **Power-Generating Facility** and **HVDC System** and the relevant **TSO** relevant facilities.

The **Power-Generating Facility Owner** and the **HVDC System Owner** are required to provide measurements and signals, to ensure:

a) the real-time observability of the facility itself and the system operation functions;
b) the availability of historical operations and performance of the facility itself in deferred time.

The relevant **TSO** shall define the detailed list of data, data formats, communication protocols and interfacing modes that must be compatible with its own control system.

The relevant **TSO** may require the **Power-Generating Facility Owner** and the **HVDC System Owner** to install dedicated equipment for remote control.

4.6 Derogations

The relevant **TSO** may, at the request of a **Power-Generating Facility Owner** or an **HVDC System Owner**, grant derogations from one or more provisions of this **Code** for existing and prospective **Power-Generating Modules** or **HVDC Systems** in accordance with:

a) the modalities *mutatis mutandis* reported in this **Code**;
b) the criteria for granting derogations to be published by the relevant **TSO** on its website and available to all existing and prospective **Power-Generating Facility Owners** or **HVDC System Owners**.

If a **Power-Generating Facility Owner** or an **HVDC System Owner** is unable to comply with any provision of this **Code**, it shall, without delay, report such non-compliance to the relevant **TSO** and request for a derogation from such provision. The request for a derogation shall at least include the following information:

a) the version of the **Code** against which the non-compliance or predicted non-compliance is identified;
b) the identification of the provision which the **Power-Generating Facility Owner** or the **HVDC System Owner** is, or will be, unable to comply with;
c) the identification of the **Module(s)** or part(s) of the **HVDC System(s)** in respect of which a derogation is sought and the nature and extent to which the non-compliance exists;
d) the demonstration that the requested derogation would have no adverse effect on the relevant **Grid** and cross-border trade.
e) the reason(s) for the non-compliance requiring derogation; and,
f) the date by which compliance will be achieved (if remedy of the non-compliance is possible).

On receipt of any request for a derogation by the **Power-Generating Facility Owner** or the **HVDC System Owner**, the relevant **TSO** shall:

a) promptly consider the request. If it considers that the request is incomplete, the **Power-Generating Facility Owner** or the **HVDC System Owner** shall submit the additional required information within a period defined by the relevant **TSO**. If the **Power-Generating Facility Owner** or the **HVDC System Owner** does not supply the requested information within that time limit, the request for a derogation shall be deemed withdrawn.

b) assess the request for a derogation, considering the defined criteria made available on its website.
c) request an opinion from an independent expert, if necessary;
d) issue a reasoned decision concerning a request for a derogation within a period defined by the relevant **TSO** from the day after it receives the request, which may be extended by a period defined by the relevant **TSO** following the request of further information to the **Power-Generating Facility Owner** or the **HVDC System Owner**. Where the relevant **TSO** grants a derogation, it shall specify its duration.
e) communicate its decision to the relevant **Power-Generating Facility Owner** or the **HVDC System Owner**.
f) revoke a decision granting a derogation if the circumstances and underlying reasons no longer apply.

The relevant **TSO** shall:

a) keep a register of all derogations which have been granted, identifying:
   i. the requirement or requirements for which the derogation is granted or refused;
   ii. the content of the derogation;
   iii. the reasons for granting or refusing the derogation;
   iv. the consequences resulting from granting the derogation.
b) on request from any **Power-Generating Facility Owner** or the **HVDC System Owner**, provide a copy of such register of derogations.

5 REQUIREMENTS FOR GENERATORS

5.1 Operating ranges

5.1.1 Frequency ranges

> **J.** In an interconnected **Electricity System**, frequency is the parameter with the largest cross-border impact, since deviations from its nominal value occur everywhere at the same time and affect all **Power-Generating Modules** regardless of voltage levels. For this reason, harmonized frequency ranges are fundamental, especially the range for unlimited operation which needs to be identical for sharing the burden of deviations equally.

All **Power-Generating Modules** shall be designed, built and operated to be capable of remaining connected to the **Grid** within the frequency ranges, and minimum time periods specified by the relevant **TSO**, according to the following scheme and represented also in Table 5-1:

a) a range around the nominal frequency of the **Synchronous Area** with unlimited time period of operation;
b) at least one range with frequency below the nominal frequency of the **Synchronous Area** with limited time period for operation to be specified by the relevant **TSO**;

c) at least one range with frequency above the nominal frequency of the **Synchronous Area** with limited time period for operation to be specified by the relevant **TSO**.

The frequency values are considered at the **Connection Point**. In defining frequency ranges and time periods, the relevant **TSO** shall consider the applicable international standards for products on frequency-related capabilities.

The relevant **TSO** and the **Power-Generating Facility Owner** may agree on wider frequency ranges, longer minimum times for operation or specific requirements for combined frequency and voltage deviations to ensure the best use of the technical capabilities of a **Power-Generating Module**, if it is needed to preserve or to restore **Grid** security. The **Power-Generating Facility Owner** shall not unreasonably withhold consent to such request(s) if economically and technically feasible.

Table 5-1. Minimum time periods for which a Power-Generating Module must be capable of operating for frequency deviating from the nominal value of the Synchronous Area without disconnecting from the Grid

		Frequency range	Time period for operation
f of the Synchronous Area	b)	F_{flow2} Hz – F_{flow1} Hz	To be specified in minutes by the relevant TSO
	a)	F_{flow1} Hz – F_{fhigh1} Hz	Unlimited
	c)	F_{fhigh1} Hz – F_{fhigh2} Hz	To be specified in minutes by the relevant TSO

Frequency ranges and time periods shall be harmonized within **Member States** belonging to the same **Synchronous Area**. Indicative frequency ranges and time periods are reported in Table 5-2.

Table 5-2 Minimum time periods for which a Power-Generating Module must be capable of operating for frequency deviating from the reference 1 pu calculated on a nominal value of 50 Hz or 60 Hz without disconnecting from the Grid

Frequency range	Time period for operation
0.96 pu – 0.97 pu	30 minutes
0.97 pu – 0.98 pu	To be specified by each **TSO** but not less than 30 minutes
0.98 pu – 1.02 pu	Unlimited
1.02 pu – 1.03 pu	30 minutes

5.1.2 Voltage ranges

J. Though voltage is a local parameter, voltage ranges are critical to secure operation of an **Integrated Power System** within a **Synchronous Area**. The lack of coordinated ranges between adjacent interconnected **Grids** would lead to uncertainty in operation, especially when beyond normal state.

All **Synchronous Power-Generating Modules** shall be designed, built and operated to be capable of remaining connected to the **Grid** within the ranges of the voltage at the **Connection Point** specified by the relevant **TSO** according to the following scheme and represented also in Table 5-3:

a) a range around the base voltage with unlimited time period of operation;
b) at least one range with voltage below the base value with limited time period for operation to be specified by the relevant TSO;
c) at least one range with voltage above the base value with limited time period for operation to be specified by the relevant TSO.

Voltage ranges are expressed by the ratio between the voltage at the **Connection Point** to the base voltage. The relevant **TSO** can define different sets of voltage ranges and respective time periods according to different voltage base levels. In defining voltage ranges and time periods, the relevant **TSO** shall consider the applicable international standards for products on voltage-related capabilities.

The relevant **TSO** and the **Power-Generating Facility Owner** may agree on wider voltage ranges, longer minimum times for operation or specific requirements for combined frequency and voltage deviations (simultaneous overvoltage and underfrequency or simultaneous undervoltage and overfrequency) to ensure the best use of the technical capabilities of a **Power-Generating Module**, if it is needed to preserve or to restore **Grid** security. The **Power-Generating Facility Owner** shall not unreasonably withhold consent to such request(s) if economically and technically feasible.

Table 5-3. Minimum time periods during which a Power-Generating Module must be capable of operating for voltages deviating from the reference 1 pu value at the Connection Point without disconnecting from the Grid.

	Voltage range	Time period for operation
b)	U_{low2} pu – U_{low1} pu	To be specified in minutes by the relevant TSO
a)	U_{low1} pu – U_{high1} pu	Unlimited
c)	U_{high1} pu – U_{high2} pu	To be specified in minutes by the relevant TSO

Voltage ranges and time periods shall be harmonized within **Member States** belonging to the same **Synchronous Area**. Indicative voltage ranges and time periods are reported in Table 7-4.

Table 5-4. Minimum time periods during which a Power-Generating Module must be capable of operating for voltages deviating from the reference 1 pu value at the Connection Point without disconnecting from the Grid.

Voltage base for pu values	Frequency range	Time period for operation
110 kV – 400 kV	0.85 pu – 0.90 pu	60 minutes
	0.90 pu – 1.05 pu	Unlimited
	1.05 pu – 1.10 pu	30 minutes

5.2 Immunity to grid disturbances

5.2.1 Fault-Ride-Through Capability

J. In the case of a fault on the **Transmission System** level a voltage drop will propagate across large geographical interconnected areas. Failure to ride through faults for **Power-Generating Facilities** (i.e. tripping) can create major system instability with cross-border implications. This requirement defines capability for **Power-Generating Facilities** to be tolerant to such faults.

Power-Generating Modules shall be capable of remaining connected to the **Grid** and continue to operate in a stable manner, when the actual course of the phase-to-phase voltages at the **Connection Point**, during a fault, is maintained over a **Fault-Ride-Through** voltage-against-time profile to be specified by the relevant **TSO** according to Figure 5-1.

The relevant **TSO** shall specify the parameters that define each point of **Fault-Ride-Through** voltage-against-time profile of Figure 5-1 for:

a) **Synchronous Power-Generating Modules** and **Inverter-based Power-Generating Modules**;
b) Symmetrical and asymmetrical faults.

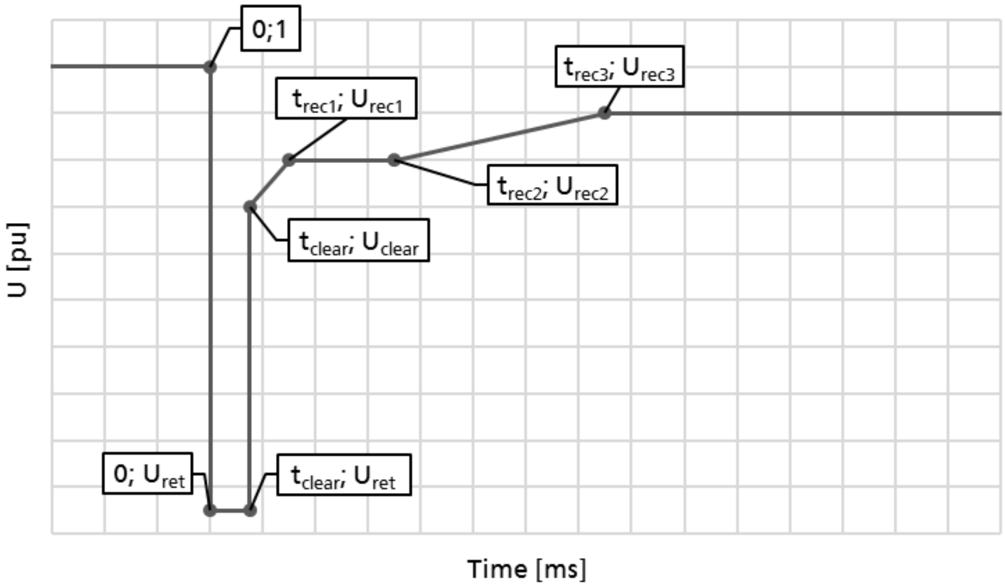


Figure 5-1. Fault-ride-through profile of a Power-Generating Facility. It is expressed as the phase-to-phase voltages on the Transmission System voltage level at the Connection Point during a fault as a function of time before, during and after the fault.

In the area below the **Fault-Ride-Through** voltage-against-time profile, the disconnection of the **Power-Generating Modules** due to the intervention of the protection system referred to Article 5.5.3 is acceptable.

The installation of ad-hoc undervoltage protection that traces and implements the described **Fault-Ride-Through** voltage-against-time profile is not permitted. In particular, the under-voltage protection shall be set by the **Power-Generating Facility Owner** according to the technical limits of the **Power-Generating Modules**, unless the relevant **TSO** requests other settings.

Power-Generating Modules shall comply with the **Fault-Ride-Through** voltage-against-time profile for any pre-fault or post-fault value of **Short-Circuit Power** between the minimum and maximum values of the **Short-Circuit Power** expected in the **Connection Point**[4].

The **Fault-Ride-Through** requirement does not consider the disconnection from the **Transmission System** imposed by operating conditions and / or **Transmission System** protection that shall be implemented through equipment and related parameters defined by the relevant **TSO**.

All the **Fault-Ride-Through** voltage-against-time profiles shall be harmonized within **Member States** belonging to the same **Synchronous Area**. Indicative frequency **Fault-Ride-Through** voltage-against-time profiles are given in Figure 5-2 and Figure 5-3.

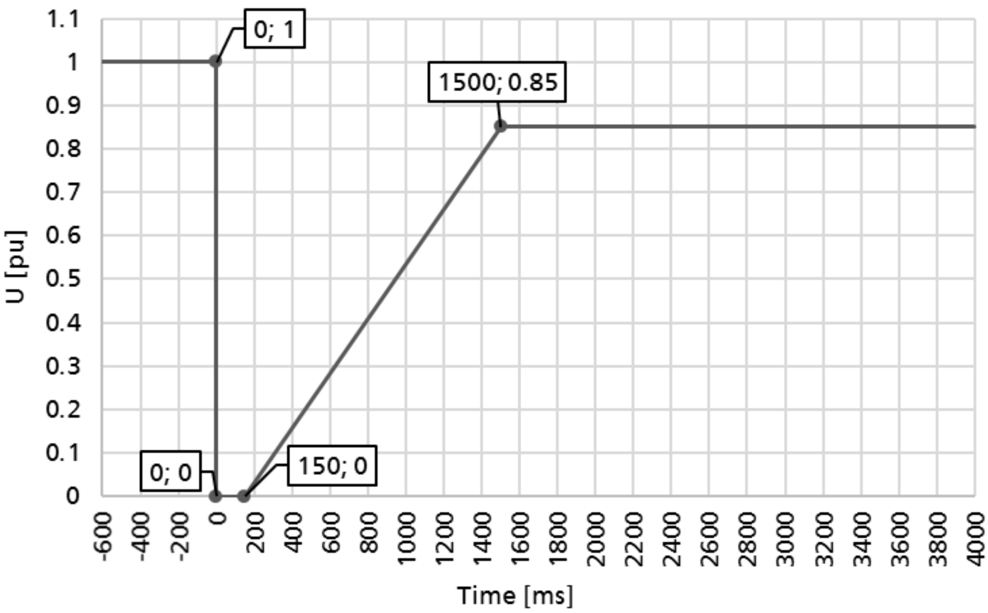


*Figure 5-2. Minimum limits of Fault-ride-through capability for the **Synchronous Power-Generating Modules**.*

[4] Refer to Section 2.4 for Short-Circuit Current values.

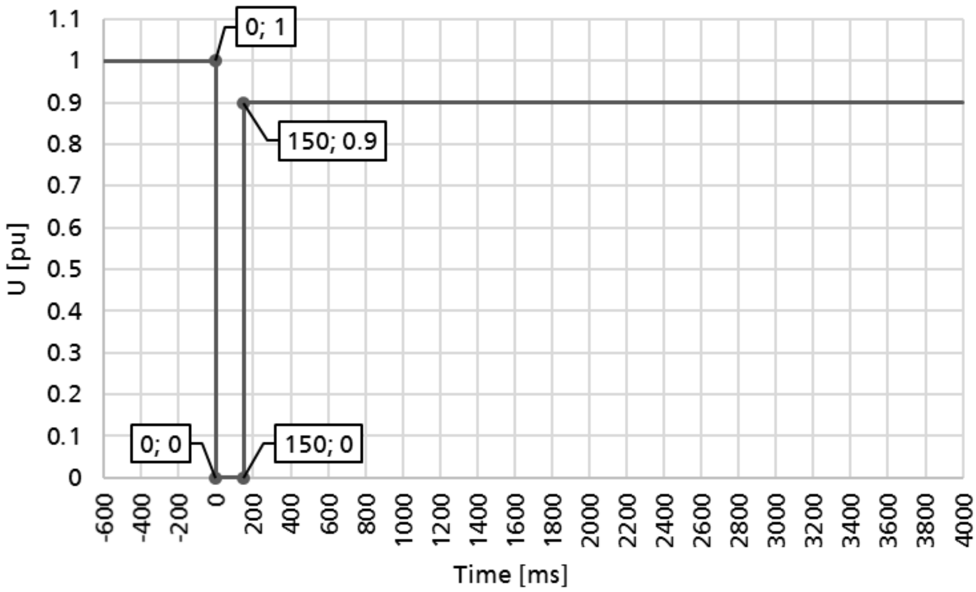


*Figure 5-3. Minimum limits of Fault-ride-through capability for the **Inverter-based Power-Generating Modules**.*

5.2.2 Rate-of-change-of-frequency withstand capability

J. Rate-of-change-of-frequency withstand capability may be relevant during significant load-generation imbalances (e.g. disconnection of large **Load Facilities** or **Power-Generating Modules**, or system splits) because of low system inertia caused by (amongst others) increasing shares of inverter-based **Power-Generating Facilities**, usually renewables. Avoiding the disconnection of **Power-Generating Modules** in case of large rate of change of frequency contributes to stabilization and restoration of the **Transmission System** to a normal operating state.

A **Power-Generating Module** shall be capable of staying connected to the **Transmission System** and operating at rates of change of frequency up to a value specified by the relevant TSO, unless disconnection was triggered by rate-of-change-of-frequency-type loss of mains protection.

The rate-of-change-of-frequency withstand capability shall be harmonized within **Member States** belonging to the same **Synchronous Area**. A value of rate of change of frequency of 2.5 Hz/s computed over a 5 cycles time window is a typical threshold value.

5.3 Stability and control of the system frequency

5.3.1 Control of target active power

J. Changes in active power output around a target value and the behavior during transient of target value variations may result in load imbalances and hence in frequency deviations in a **Synchronous Area**. Requirements defining the performance of **Power-Generating Facilities** in target active power control contribute to maintaining system stability and security by minimizing deviations of frequency.

A **Power-Generating Module** shall be capable of maintaining constant output at any value of target active power between the declared minimum and maximum active power output, except where the power output follows the changes specified in Articles 5.3.2, 5.3.3, and 5.3.4 of this **Connection Code**.

The relevant **TSO** can define the values of maximum error within which the control system of **Power-Generating Modules** must control the active power with respect to constant target values and during changes in the target value.

5.3.2 Effects of environmental and operating conditions on the active power capability

J. Environmental and operating conditions may lead to variations in maximum active power output of **Power-Generating Modules**. Defining admissible variations contributes to limiting load imbalances and hence frequency deviations too.

When a **Synchronous Power-Generating Module** is operating in under-frequency condition, a reduction in the maximum active power output from maximum active power declared to the relevant **TSO** is allowed. This practice must be justified by proven technical reasons.

The relevant **TSO** shall define the maximum admissible percentage reduction of active power output for under-frequency conditions in its **Control Area.** This defines the lower limit above which the maximum active power that can be supplied by **Power-Generating Modules** must always remain.

In defining the admissible active power reduction from the maximum output, the relevant **TSO** shall:

a) clearly specify the ambient conditions applicable; and,
b) take account of the technical capabilities of **Power-Generating Modules**.

Typical values of admissible active power reduction from maximum output in under-frequency conditions fall within the boundaries indicated in Figure 5-4:

a) below 0.98 pu falling by a reduction rate of 2% of the maximum capacity at 1 pu per 0.02 pu frequency drop;
b) below 0.99 pu falling by a reduction rate of 10% of the maximum capacity at 1 pu per 0.02 pu frequency drop.

Figure 5-4 represents the boundaries in which the capability can be specified by the relevant TSO according to the previous specifications. That is: from frequency in the range 1-0.99pu the **Power-Generating Module** shall not show any reduction in maximum power output. With frequency below 0.99pu, the area within which the relevant TSO can define the capability is given.

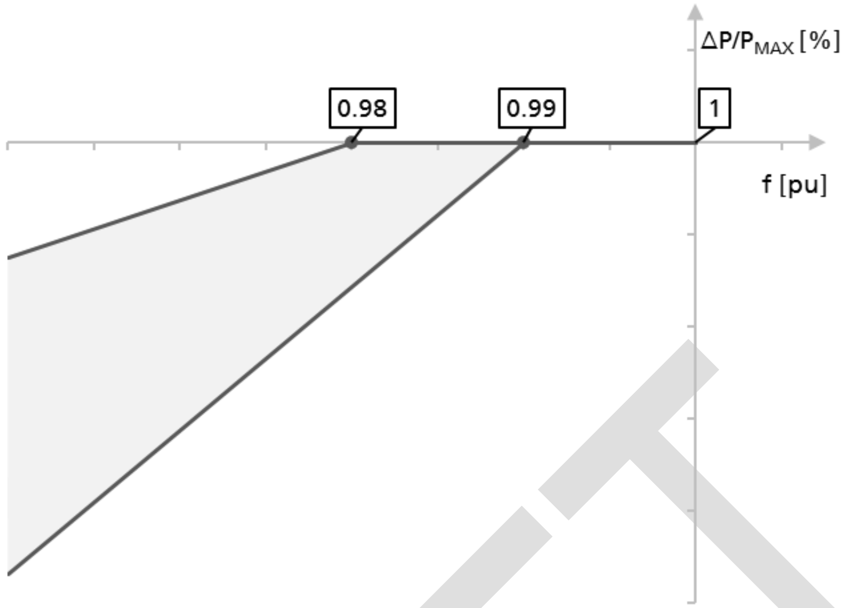


Figure 5-4. Maximum power capability reduction with falling frequency. The percentage value of the reduction refers to the maximum active power of Synchronous Power-Generating Module.

5.3.3 Active power reduction at abnormal overfrequency and underfrequency

J. Persistent load imbalances cause frequency deviation to increase leading to deterioration of system stability and security of **PAEM Electricity System**. **Power-Generating Facilities** are commonly requested to contribute in removing such imbalances. This requirement defines the capabilities of **Power-Generating Facilities** to control the variation of their active power output in response to abnormal over-frequency and underfrequency.

Power-Generating Modules shall be capable to regulate the active power output in response to wide variations of the frequency in over- and underfrequency according to operating modes called **Limited Frequency Sensitive Mode-Overfrequency (LFSM-O)** and **Limited Frequency Sensitive Mode-Underfrequency (LFSM-U)**.

The relevant **TSO** shall characterize the frequency threshold and droop that characterize **LFSM-O** and **LFSM-U** operating modes in accordance with Figure 5-5 and Figure 5-6:

a) P_{MAX} is the maximum active power output of the **Power Generation Module**. ΔP is the variation in the active power production of the **Power Generation Modul**e. f_n is the nominal frequency of the **Grid** and Δf is the frequency deviation occurring in the **Grid**.
b) in **LFSM-O** (Figure 5-5), at over-frequencies where Δf is greater than Δf_1, the **Power-Generation Module** shall provide a negative variation of active power production according to a droop setting equal to s_2. Typical values for the frequency threshold $\Delta f_1/f_n$ are between 1.004 pu and 1.01 pu inclusive, and the droop setting s_2 are between 2% and 12%.
c) in **LFSM-U** (Figure 5-6), at under-frequencies where Δf is lower than Δf_1, the **Power Generation Module** shall provide a positive variation of active power production according to a droop equal to s_2. Typical values for the frequency threshold $\Delta f_1/f_n$

are between 0.996 pu and 0.99 pu inclusive, and the droop setting s_2 are between 2% and 12%.

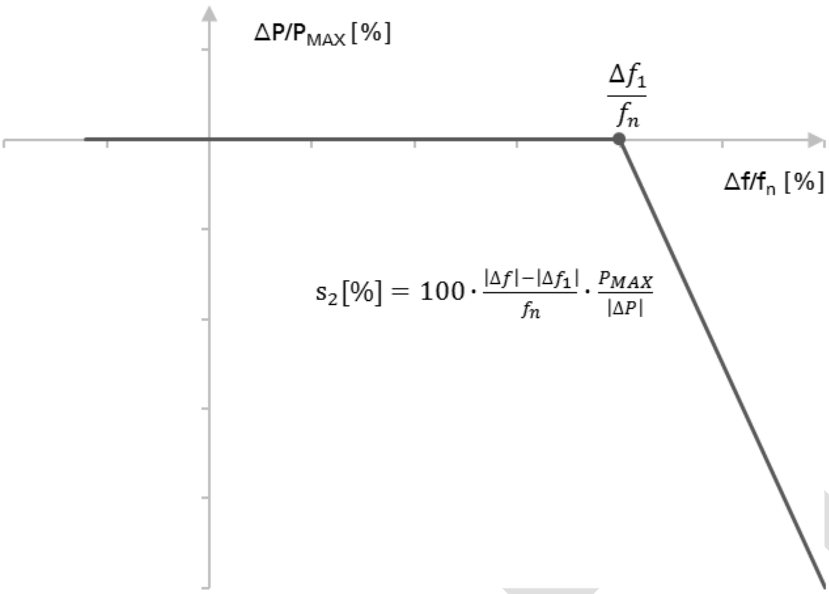


Figure 5-5. Active power frequency response capability of Power Generation Modules in LFSM-O mode.

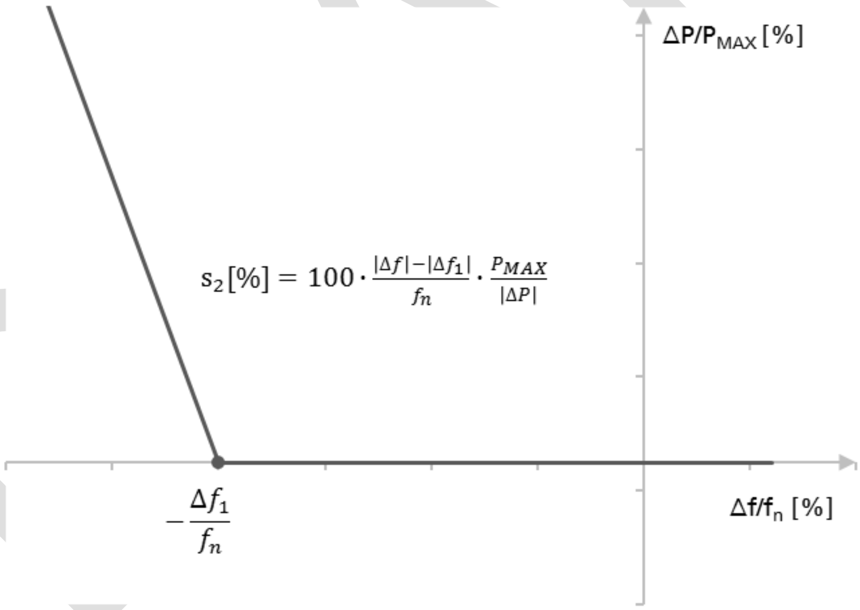


Figure 5-6. Active power frequency response capability of Power Generation Modules in LFSM-U mode.

"ANNEX A – Further specifications on LFSM-O/LFMS-U Calculation" provides further specifications and an example of calculation for **LFSM-O** and **LFSM-U**.

A **Power-Generating Module** shall be capable of activating the power frequency response as fast as technically feasible with an initial delay that shall not be greater than 2 seconds. **Power-Generating Facility Owner** shall justify larger delay by providing technical evidence to the relevant **TSO**.

The **Power-Generating Modules** shall be capable of operating stably during **LFSM-O** and **LFSM-U** operation.

With reference to the operation in **LFSM-O** mode:

a) **Power-Generating Modules** shall be capable of either continuing operation at minimum regulating level when reaching it or alternatively further decreasing active power output according to the request of the relevant **TSO**.
b) The **LFSM-O** setpoint will prevail over any other active power setpoints.

With reference to the operation in **LFSM-U** mode:

a) **Power-Generating Modules** shall be capable of providing a power increase up to their maximum capacity.
b) The actual delivery of active power frequency response shall consider:
    i. the ambient conditions when the response is to be triggered;
    ii. the operating conditions of the **Power-Generating Module**, in particular limitations on operation near maximum capacity at low frequencies and the respective impact of ambient conditions according to Article 5.3.2; and,
    iii. the availability of the primary energy sources.

LFSM operating mode is not required by such **Power-Generating Modules** that do not have the capability of regulating the power output with regards to frequency variations due to technology limitations. Such technology limitations shall be demonstrated by the relevant **Power-Generating Facility Owner.**

The relevant **TSOs** of the same **Synchronous Area** shall harmonize the **LFSM modes** settings to minimize unplanned power flow between the interconnected countries in response to a change in system frequency.

5.3.4 Active power response to normal frequency variations

J. Persistent load imbalances cause an increase in frequency deviation leading to deterioration of system stability and security of **PAEM Electricity System**. **Power-Generating Facilities** are commonly requested to contribute to removing such imbalances. This requirement defines the capabilities of **Power-Generating Facilities** to control the variation of their active power output in response to normal frequency variations.

Power-Generating Facilities shall be capable of operating in the **Frequency Sensitive Mode (FSM)**, which determines a variation in the active power output with respect to the programmed value of target active power in response to normal frequency variations of the **Grid**.

FSM operating mode is not required by such **Power-Generating Modules** that do not have the capability of regulating the power output with regards to frequency variations due to technology limitations. Such technology limitations shall be demonstrated by the relevant **Power-Generating Facility Owner.**

The relevant **TSO** shall define the parameters that characterize the **FSM** in accordance with Figure 5-7 and Table 5-5, considering that:

a) In case of overfrequency, the active power frequency response is limited by the minimum regulating level of the **Power Generation Module**.

b) In case of underfrequency, the active power frequency response is limited by the maximum active power output (P_{MAX}) of the **Power Generation Module**.
c) ΔP is the variation in the active power production of the **Power Generation Module**. f_n is the nominal frequency of the **Grid** and Δf is the frequency deviation in the **Grid**.
d) In case of frequency variation higher than the **Frequency Response Deadband**, the contribution of active power not supplied must be recovered according to a scheme similar to the one shown in Figure 5-7.
e) The actual delivery of active power frequency response shall consider:
   i. the ambient conditions when the response is to be triggered;
   ii. the operating conditions of the **Power-Generating Module**, in particular limitations on operation near maximum capacity at low frequencies and the respective impact of ambient conditions according to Article 5.3.2; and,
   iii. the availability of the primary energy sources.

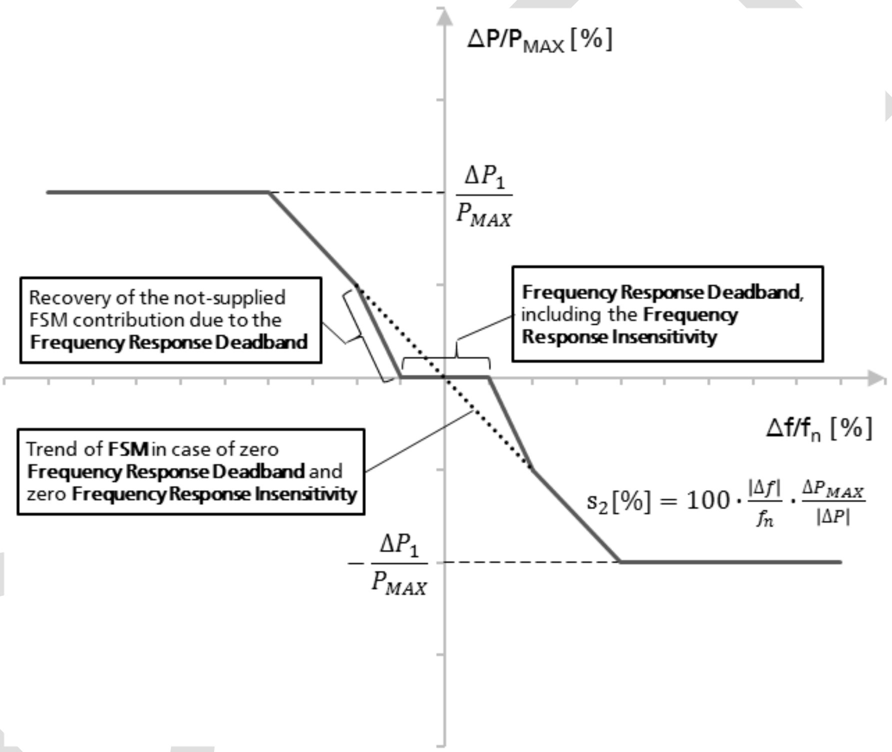


Figure 5-7. Active power frequency response capability of Power-Generating Modules in FSM. The figure represents the changes in active power output that a Power-Generating Module shall be capable of provide according to frequency variations. The Power-Generating Module shall be irresponsive to frequency variations in the range of the Deadband. For frequency deviations larger than the Deadband the Power-Generating Module shall reduce (over-frequency) or increase (under-frequency) the active power charge according to the given droop. The relevant TSO can specify settings of the droop in order to recover not-supplied FSM contribution due to the Deadband.

Table 5-5. Typical parameters for active power frequency response in FSM (explanation for Figure 5-7)

Parameters	Typical ranges
Active power range related to maximum capacity $\Delta P_1/P_{MAX}$	1.5 – 10%

Frequency Response Insensitivity of the regulators	$\lvert\Delta f_i\rvert$	10 – 30 mHz
	$\lvert\Delta f_i\rvert/f_n$	0.02 – 006%
Frequency Response Deadband		0 – 500 mHz
Droop s_1		2 – 12%

The relevant **TSO** shall define the period for which the **Power-Generating Module** shall be capable of providing full active power frequency response. In specifying the period, the relevant **TSO** shall consider the active power headroom and primary energy source of the **Power-Generating Module.**

In the event of frequency step changes, the **FSM** mode shall be activated by the **Power-Generating Module** according to a curve above or at most in correspondence with the line shown in Figure 5-8 and in accordance with the parameters specified by the relevant **TSO** based on the technology-dependent limitations of the **Power-Generating Modules**. Typical values of the parameters are reported in Table 5-6.

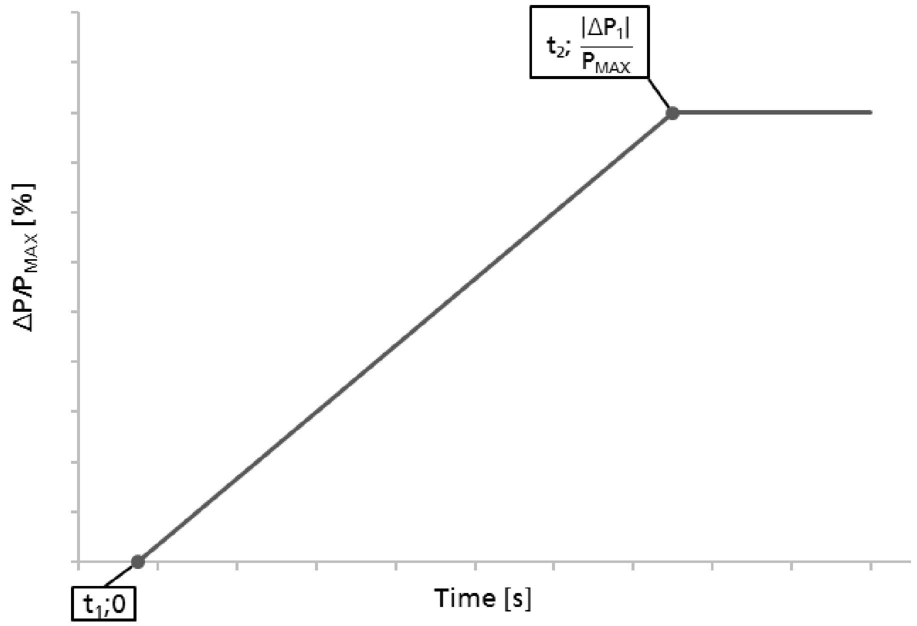


Figure 5-8. Active power frequency response capability.

Table 5-6. Typical parameters for full activation of active power frequency response resulting from frequency step change (explanation for Figure 5-8).

Parameters	Typical values
Active power range related to maximum capacity $\Delta P_1/P_{MAX}$	1.5 – 10%
For **Power-Generating Modules** with inertia, the maximum admissible initial delay t_1 unless justified otherwise	2 sec

Maximum admissible choice of full activation time t_2, unless longer activation times are allowed by the relevant **TSO** for reasons of system stability	30 sec

In order to monitor the operation of FSM, the **Power-Generating Modules** shall be able of transferring in real-time and in a secured manner at least the following signals to the **National Control Center** of the relevant **TSO**:

a) status signal of **FSM** (on/off);
b) scheduled active power output;
c) actual value of the active power output;
d) actual parameter settings for active power frequency response; and,
e) droop and **Frequency Response Deadband**.

The relevant **TSOs** of the same **Synchronous Area** shall harmonize the **FSM modes** settings to minimize unplanned power flow between the interconnected countries in response to a change in system frequency.

5.3.5 Frequency restoration control

J. Restoring frequency to the nominal value while releasing reserves activated due to frequency deviations and adjusting cross-border power exchanges to target values needs dedicated capabilities from **Power-Generating Facilities**. These requirements need to be coordinated with system operation provisions.

The relevant **TSO** defines the technical requirements of **Power-Generating Modules** for the provision of the system service that aims at restoring the frequency to its nominal value and at maintaining the scheduled cross-border power exchanges of a synchronous area.

The relevant **TSOs** of the same **Synchronous Area** shall harmonize the requirements of frequency restoration control functionalities for **Power-Generating Modules**.

5.3.6 Synthetic Inertia for inverter-based generation

J. Inverter-based **Power-Generating Facilities** do not have inherent capability to resist / slow down frequency changes. This will result in larger **Rate of Change of Frequency** during high energy production from inverter-based **Power-Generating Facilities** and hence leading to possible system stability and security issues of the **PAEM Electricity System**. This requirement takes counter measures by introducing, for inverter-based **Power-Generating Facilities**, the capability of providing **Synthetic Inertia** during very fast frequency deviations.

Inverter-based Power-Generating Modules shall be capable of providing **Synthetic Inertia** during very fast frequency deviations upon request from the relevant **TSO**.
The relevant **TSO** shall specify the operating principle of control systems installed to provide **Synthetic Inertia** and the associated performance parameters.

5.4 Stability and control of the system voltage

5.4.1 Reactive Power Capability

J. Reactive power is a key component in terms for voltage stability, and fundamental for cross-border power trading. Although the influence of **Power-Generating Facilities** on overall system voltage stability varies with location, harmonizing reactive power capabilities contributes to secure planning and operation of the **Integrated Power Systems** within the same **Synchronous Area**.

The relevant **TSO** shall specify reactive power capability at maximum capacity and reactive power capability below maximum capacity.

5.4.1.1 Reactive power capability at maximum capacity

With regards to reactive power capability at maximum capacity, the relevant **TSO** shall identify the U-Q/P_{MAX}-profile, which identifies the boundaries within which a **Power-Generating Module** shall be capable of providing reactive power at its maximum capacity. The U-Q/P_{MAX}-profile shall be defined according to the following principles and in consistence with Figure 5-9:

a) the dimensions of the U-Q/P_{MAX}-profile envelope shall be within the Q/P_{MAX} range and voltage range specified by the relevant **TSO**.
b) the position of the U-Q/P_{MAX}-profile envelope shall be within the limits of a fixed outer envelope to be defined by the relevant **TSO.**
c) the relevant **TSO** shall define the above-mentioned profiles for (i) **Synchronous Power-Generating Modules** and (ii) **Inverter-based Power-Generating Modules**.

The relevant **TSOs** of the same **Synchronous Area** shall harmonize the dimensions of the inner and outer envelopes. Typical values for the outer envelope, Q/P_{MAX} range and voltage range of the U-Q/P_{MAX}-profile envelope of S**ynchronous Power-Generating Modules** and **Inverter-based Power-Generating Modules** are reported in Table 5-7.

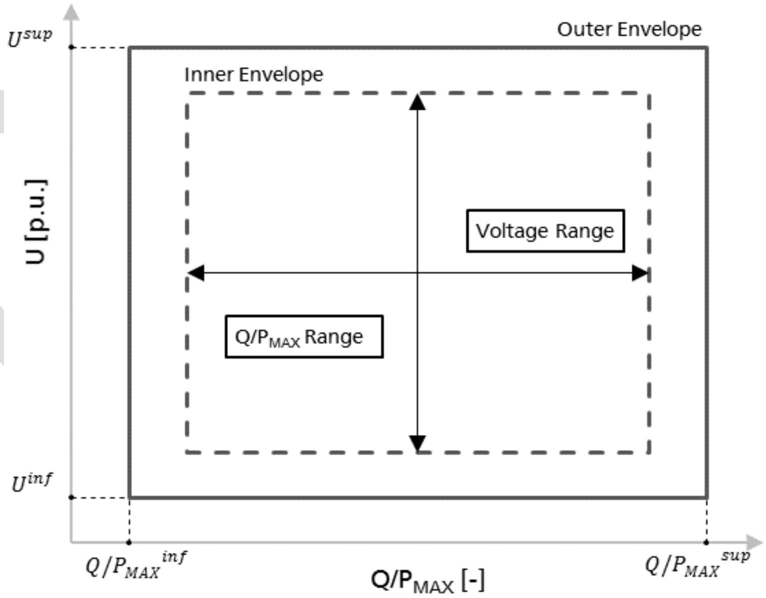


*Figure 5-9. U-Q/P_{MAX}-profiles to be defined by the relevant **TSO**.*

Table 5-7. Typical parameters for the U-Q/P_{MAX}-inner and outer envelopes profile of Figure 5-9.

Parameters	Synchronous Power-Generating Modules	Inverter-based Power-Generating Modules
Definition of Inner Envelope		
Q/P_{MAX} Range	0.95 – 1.08	0.66 – 0.95
Voltage Range	0.150 – 0.225	0.150 – 0.225
Definition of Outer Envelope		
U^{sup}	1.100	
U^{inf}	0.875	
Q/P_{MAX}^{inf}	- 0.500	
Q/P_{MAX}^{sup}	+ 0.650	

A **Power-Generating Module** shall be capable of moving to any operating point on the surface within its U-Q/P_{MAX} profile in appropriate timescales to target values requested by the relevant TSO.

5.4.1.2 Reactive power capability below maximum capacity

Synchronous Power-Generating Modules shall be capable of operating at every possible operating point in the P-Q-capability diagram of the alternator of **Synchronous Power-Generating Modules**, at least down to minimum stable operating level when operating at an active power output below the maximum capacity ($P < P_{MAX}$).

With regards to **Inverter-based Power-Generating Modules,** the relevant TSO shall define a P-Q/P_{MAX}-profile, which identifies the boundaries within which an **Inverter-based Power-Generating Module** shall be capable of providing reactive power below its maximum capacity. The P-Q/P_{MAX}-profile shall be defined according to the following principles and in consistence with Figure 5-10:

a) the dimensions of the P-Q/P_{MAX}-profile envelope shall be within the Q/P_{MAX} range specified by the relevant **TSO**.
b) the active power range of the P-Q/P_{MAX}-profile envelope at zero reactive power shall be 1 pu.
c) the P-Q/P_{MAX}-profile can be of any shape and shall include conditions for reactive power capability at zero active power.
d) the position of the P-Q/P_{MAX}-profile envelope shall be within the limits of a fixed outer envelope to be defined by the relevant **TSO**.

The relevant **TSOs** of the same **Synchronous Area** shall harmonize the dimensions of the inner and outer envelopes. Typical values for the Q/P_{MAX} range and voltage range of the U-Q/P_{MAX}-profile envelope for **Inverter-based Power-Generating Modules** are provided in Table 5-8.

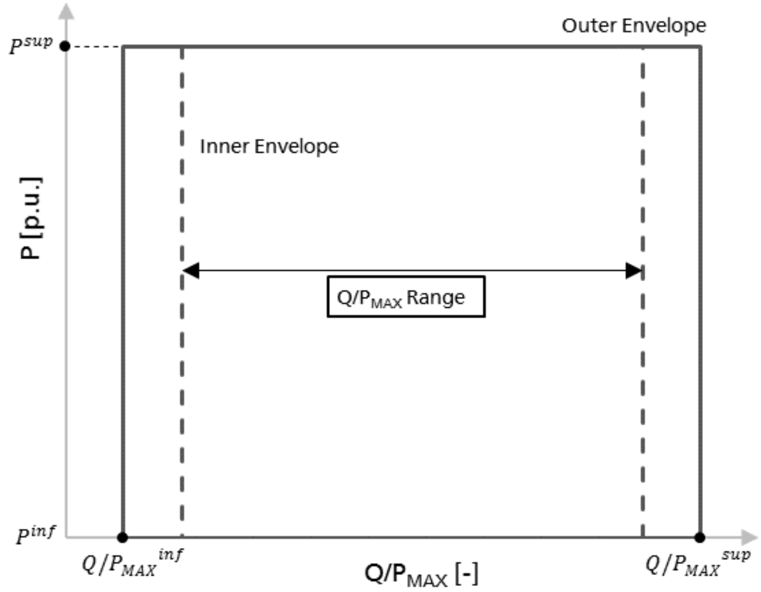


Figure 5-10. P-Q/P_{MAX}-profile to be defined by the relevant TSO for Inverter-based Power-Generating Modules.

Table 5-8. Typical parameters for the U-Q/P_{MAX}-inner and outer envelopes profile of Figure 5-10.

Parameters	**Inverter-based Power-Generating Modules**
Definition of Inner Envelope	
Q/P_{MAX} Range	0.75
P Range	1
Definition of Outer Envelope	
P^{sup}	1.000
P^{inf}	0.000
Q/P_{MAX}^{inf}	- 0.350
Q/P_{MAX}^{sup}	+ 0.400

When operating at an active power output below maximum capacity ($P<P_{MAX}$), the **Inverter-based Power-Generating Module** shall be capable of providing reactive power at any operating point inside its P-Q/P_{MAX}-profile.

An **Inverter-based Power-Generating Module** shall be capable of moving to any operating point on the surface within its U-Q/P_{MAX} profile in appropriate timescales to target values requested by the relevant TSO.

5.4.1.3 Reactive power compensation

Where there is a line or a connection cable between the **Connection Point** of the **Power-Generating Facility** and the high-voltage terminals of the step-up transformer, if requested by the relevant **TSO**, the **Power-Generating Facility Owner** shall compensate the reactive power demand of the line or cable.

5.4.2 Voltage control modes

J. The absence of voltage control for **Power-Generating Modules** can lead to voltage instability which can spread to neighboring **Electricity Systems** and become a cross-border issue.

Synchronous Power-Generating Modules shall be equipped with an excitation control system – namely the **Automatic Voltage Regulator (AVR)** – that can provide constant alternator terminal voltage at a selectable setpoint without instability over the entire operating range of the **module**.

The parameters and settings of the **AVR** shall be agreed upon by the synchronous **Power-Generating Facility Owner** and the relevant **TSO**. These shall include:

a) bandwidth limitation of the output signal;
b) under- and over-excitation limiter;
c) a stator current limiter;
d) a **PSS** function to attenuate power oscillations.

Inverter-based Power-Generating Modules shall contribute to the voltage control. The following control modes shall be implemented:

a) Voltage control mode:
   i. the **Module** shall be capable of contributing to voltage control at the **Connection Point** by providing reactive power exchange with the **Transmission System** with a setpoint voltage covering a range [U_{REG_MIN}; U_{REG_MAX}] in steps no greater than ΔU_{REG} defined by the relevant **TSO**. Typical values for U_{REG_MIN}, U_{REG_MAX} and ΔU_{REG} are 0.95, 1.05, and 0.01.
   ii. The reactive power output shall be zero when the voltage value of the **Transmission System** at the **Connection Point** equals the voltage setpoint.
   iii. The setpoint may be operated with or without a deadband selectable in a range defined by the relevant **TSO**.
   iv. Achieving 90% and 100% of the change in reactive power output requested by the relevant **TSO** within time $t_{REG\_90\%}$ and $t_{REG\_100\%}$, respectively, to be specified by the relevant **TSO**, with an accuracy of 5% of the value of the maximum reactive power that can be delivered by the **Module**. Typical values of $t_{REG\_90\%}$ and $t_{REG\_100\%}$ lay within the range 1-5 sec and 5-50 sec, respectively.

b) Reactive power control mode:
   The **Module** shall be capable of setting the reactive power setpoint anywhere in the given reactive power range, with setting steps defined by the relevant **TSO**, by controlling the reactive power at the **Connection Point** to an accuracy defined by the relevant **TSO**.
   Typical steps should not exceed 5 MVAr of full reactive power, and typical accuracy should be within plus or minus 5 MVAr of the full reactive power.

The relevant **TSO** shall define the principles and performance for the switching between the two modes, as well as the modes and procedures for communicating the voltage reference values.

5.4.3 Short circuit contribution during faults for inverter-based generation

J. This requirement is critical to both restoring voltage immediately after faults and to injecting enough current quickly enough for system protections to function reliably.

Inverter-based Power-Generating Modules shall be capable of providing **Fast Fault Current** at the **Connection Point** in case of balanced (3-phase) and unbalanced (1-phase or 2-phase) faults.

The relevant **TSO** shall define the requirements for **Fast Fault Current**. These shall consider: (i) how and when a voltage deviation is to be determined; (ii) the characteristics of the **Fast Fault Current**; and (iii) the timing and accuracy of the **Fast Fault Current**.

5.5 Management of the power system

5.5.1 Synchronization and Re-synchronization

J. Conditions for **Power-Generating Modules** to connect and inject power to the **Grid** after intentional operation interruptions or disconnections due to protection system intervention need to be defined in order to avoid the risk of instability of the **Modules** or negative effects on the security of the **PEAM Electricity System**. Specific conditions can be considered for the **Modules** that are necessary to restore normal operating conditions following disturbances.

The entry into service of a **Power-Generating Module**, after an intentional shutdown or following the intervention of the protection system, is allowed only under the following conditions:

a) authorization given by the relevant **TSO**;
b) operating frequency and voltage at the **Connection Point** within the ranges specified in Section 5.1.

The **Module** shall be equipped with synchronization devices. Related settings shall be agreed to by the relevant **TSO** and the **Power-Generating Facility Owner**. They shall include: voltage, frequency, phase angle range, phase sequence, and deviation of voltage and frequency.

Once connected to the **Grid**, the **Power-Generating Module** can gradually increase its power output up to the target value in accordance with the gradient agreed to by the relevant **TSO**.

5.5.2 Ramping limits

J. Changes of target active power output must exhibit suitable ramping characteristics (i.e. rate of change of active power) since a too fast or a too slow variation may lead to degradation of the quality of the frequency control service.

The rates of change of active power output (ramping limits) for a **Power-Generating Module** shall be limited in both an up and down direction. The value of the minimum and maximum ramping limits shall be agreed upon with the relevant **TSO** considering the specific characteristics of the **Power-Generating Module**, the prime mover technology, and the primary energy resource.

Typical values of the ramping limits fall within the range 1÷20% per minute of the **Nominal Power.**

The relevant **TSOs** of the same **Synchronous Area** shall harmonize the requirements on the ramping limits.

5.5.3 Protection systems

J. Proper protection to the **Transmission System** is essential for maintaining stability and security of the **PAEM Electricity System**. Protection schemes shall not aggravate disturbances but limit their consequences within the same **Synchronous Area**.

The requirements stated in this Article 5.5.3 are in addition to the general requirements on the protection already described in Section 4.4.

The protection schemes needed for protecting the **Grid** shall be specified by the relevant **TSO**, considering the characteristics of the **Module**. The definition of and any change to protection schemes needed for protecting the **Power-Generating Module** and the **Grid** as well as the settings relevant to the **Module** shall be coordinated and agreed to by the relevant **TSO** and the **Power-Generating Facility Owner**. They are reported in the **Operating Regulation Document**.

The protection system of a **Power-Generating Module** has priority over operational controls, considering the security of the **Grid** as well as the health and safety of the working personnel and citizens and limiting any potential damage to the **Module**.

With reference to internal electrical faults, the protection schemes and settings shall include the following protection:

a) external and internal short circuit;
b) asymmetric load (negative phase sequence) [IEEE code 46];
c) stator and rotor overload [IEEE code 495 and 49R];
d) over-/under-excitation [IEEE code 40];
e) over-/undervoltage at the **Connection Point** [IEEE code 27 and 59];
f) over-/undervoltage at the alternator terminals [IEEE code 27G and 59G];
g) inter-area oscillations [IEEE code 78];
h) inrush current;
i) asynchronous operation (pole slip) [IEEE code 78];
j) protection against inadmissible shaft torsions (for example, subsynchronous resonance);
k) **Power-Generating Module** line protection;
l) unit transformer protection [IEEE code 87T, 87REF];
m) back-up against protection and switchgear malfunction [IEEE code 51/27 and 50BF];

n) over fluxing (U/f) [IEEE code 24];
o) reverse power [IEEE code 32R];
p) Rate of change of frequency withstand capability; and,
q) neutral voltage displacement [IEEE code 59N – 50V0].

With reference to external electrical faults, a **Power-Generating Module** shall be equipped with a protection system capable of separating it from the **Grid** if the external fault cannot be correctly eliminated by **Grid** protection. The schemes and settings shall therefore be coordinated with those of **Grid** protection and are, therefore, established by the relevant **TSO**.

5.5.4 Control systems

J. Control systems are defined individually for **Power-Generating Modules**. Nevertheless, harmonization of the principles and methodology, especially for disturbed system operating conditions, are crucial for guaranteeing the stability of the **PAEM Electricity System**.

The schemes and settings of the different control devices of a **Power-Generating Module** shall be coordinated and agreed upon by the relevant **TSO** and the **Power-Generating Facility Owner**. They are reported in the **Operating Regulation Document**.

Any changes to the schemes and settings subsequent to the phase of first connection shall be agreed upon with the relevant **TSO**.

5.5.5 Priority ranking of control and protection actions

J. The definition of a ranking is recommended to specify which capabilities shall take precedence (i.e. avoid conflicts) when designing the protection and control schemes of **Power-Generating Modules**. Harmonizing the ranking among the **Member States** is important for achieving a common basis for operational strategies to ensure secure operation of the **PAEM Electricity System**.

The **Power-Generating Facility Owner** shall organize the protection and the control devices of its **Facility** in accordance with the following priority ranking (from highest to lowest):

a) **Grid** and **Power-Generating Module** protection;
b) **Synthetic Inertia**, where applicable;
c) frequency control;
d) power limitation; and,
e) ramping limits.

5.5.6 Power Quality

J. Harmonization of requirements regarding potential disturbances in the electric power supplied by **Power-Generating Modules** contributes to guarantee targeted quality of the supply within **PAEM Electricity System**.

The **Power-Generating Facility Owner** shall provide all the data related to causing disturbances. Based on this data, the relevant **TSO** shall evaluate the effects on the **Grid**, considering the minimum short-circuit power on the **Grid** itself.

The maximum levels of emission of disturbances granted to the single **Power-Generating Facility** which connects to the **Grid**, or which intends to make significant modifications to the already existing **Facility**, are set by the relevant **TSO**.

Depending on the connection site and **Grid** conditions, the relevant **TSO** has the right, at a later stage, to request that the **Power-Generating Facility Owner** install additional compensation systems in order to guarantee the achievement of target quality standards.

The criteria for the evaluation of the emission limits shall include (refer to Section 2.3):

a) Unbalance of the three-phase voltage;
b) Total Harmonic Distortion (THD);
c) Flicker.

5.5.7 Simulation models

J. Power system studies are performed by the relevant **TSOs** at different stages of their evaluations (e.g. planning, operational planning, real-time operations). Dedicated provisions define a common set of simulation models and related features that the relevant TSO require to implement and update interconnected power system models.

At the request of the relevant **TSO**, a **Power-Generating Facility Owner** shall provide simulation models for its **Power-Generating Modules** with a level of detail adequate to reflect the behavior of the **Module** in:

a) steady-state simulation;
b) electromechanical simulation; and,
c) electromagnetic transient simulation.

The request of the relevant **TSO** shall include:

a) the specification of the format in which models are to be provided by the **Power-Generating Facility Owner**;
b) the provision of documentation on a model's structure and its block diagrams;
c) an estimate of the minimum and maximum short circuit capacity at the **Connection Point** as a simplified equivalent of the **Transmission System**;
d) the parameterizations and limitations of the model; and,
e) the specific sub-models of the components.

Upon request of the relevant **TSO**, the **Power-Generating Facility Owner** shall provide measurement recordings of the **Module**'s performance in order to compare the response of the models with those recordings.

5.6 Management of emergency situations

5.6.1 Black start

J. Black Start Service is needed from an appropriate number of **Power-generating Facilities** to restore an **Electricity System** to a stable condition following major critical disturbance. Harmonization of this requirement for **PAEM Electricity System** may be given in principle since details pertain to each single **TSO**.

The **Power-Generating Module** with **Black Start Capability** shall meet the following requirements:

a) Be capable of starting from shutdown without any external electrical energy supply within the maximum time agreed with the relevant **TSO**.
b) With reference to frequency:
   i. be able to synchronize within the limits defined in Article 5.1.1;
   ii. be capable of operating in **LFSM-O** and **LFSM-U**, as specified in Article 5.3.3; and,
   iii. be capable of controlling frequency in case of over-frequency and under-frequency within the whole active power output range between minimum regulating level and maximum power, as well as at such level to continue to supply the in-house loads.
c) With reference to voltage:
   i. be able to synchronize within the limits defined in Article 5.1.2;
   ii. be capable of automatically regulating dips in voltage caused by connection of demand facilities; and,
   iii. control voltage automatically during the restoration phase of the **Grid.**
d) Be capable of operating in parallel with other **Power-Generating Modules** within an **Island**.

5.6.2 Load-rejection and quick re-synchronization

J. These capabilities are required to contribute to restoration of an **Electricity System** after major disturbances. Its absence could lead to cross-border consequences on the **PAEM Electricity System** with large disturbances and inadequate capability for fast restoration (with unequal burden sharing).

In case of disconnection from the **Grid**, **Power-Generating Modules** shall be capable of performing the re-synchronization in line with the protection strategy agreed upon by the relevant **TSO** and the **Power-Generating Facility**.

If the time for re-synchronization is greater than fifteen (15) minutes, the **Power-Generating Module** shall be capable of operating in **Load-rejection** and therefore trip to house load from any operating point in its P-Q-capability diagram. The identification of the operation in **Load-rejection** shall not be based exclusively on the switchgear position signals of the relevant **TSO**, but also on actual measures of the power production of the **Power-Generating Module**.

Power-Generating Modules shall be capable of continuing operation in **Load-rejection**, regardless of any auxiliary connection to the **Grid**. The minimum time of operation in **Load-rejection** shall be specified by the relevant **TSO**, taking into consideration the specific characteristics of prime mover technology.

5.6.3 *Remote control for Defense Plan participation*

J. Critical situations in a **Grid**, which can in turn propagate to the whole **Synchronous Area**, require **TSOs** to have the possibility to remotely instruct **Power-Generating Modules** for specific actions as part of national **Defense Plan**.

Power-Generating Facility Owners may be requested by the relevant **TSO** to install remote monitoring and control devices in their **Modules** to provide special functions for preserving or restoring system operation or security. The relevant **TSOs** shall provide the functional and technical characteristics of such additional devices.

5.7 Monitoring and Information exchange

J. Having adequate and harmonized monitoring and information exchange procedures between the **Power-Generating Facility Owners** and the relevant **TSO** is a prerequisite for appropriate system operation as well as for appropriate operation of the **PAEM Electricity System** and to facilitate the resolution of cross-border issues.

Power-Generating Facilities shall be capable of monitoring their operation of, and exchanging information with, the relevant **TSO** according to different specifications and purposes.

a) Real-time monitoring:
The facility shall be integrated in the control and operations procedures in real-time of the **Grid** by the relevant **TSO**. Accordingly, dedicated equipment (**RTU**) can be requested by the relevant **TSO** to be implemented by the **Power-Generating Facility Owner** to perform remote control, remote monitoring, remote operations actions. The technical specifications of the **RTU** shall be defined by the relevant **TSO.**

b) Fault recording and monitoring:
To provide recording and monitoring of dynamic system behavior during faults, **Power-Generating Facilities** shall be equipped with dedicated equipment which meets the following requirements:
   i. the capability to record (i) voltage, (ii) current, (iii) active power, (iv) reactive power, and (v) frequency;
   ii. the technical characteristics agreed upon by the **Power-Generating Facility Owner** and the relevant **TSO**.

c) Information exchange for quick return in service:
Following an outage, the **Power-Generating Facility Owner** shall notify the relevant **TSO** about:
   i. the availability of the facility excluded during the outage, the causes that led to the disconnection and those that prevented its return into service;
   ii. the time needed to return into service;
   iii. the recordings of the fault or disturbance which precipitated the outage.

d) Information exchange for fault reconstruction:
To the purpose of fault reconstruction, the **Power-Generating Facility Owner** shall provide to the relevant **TSO** with the following**:**
   i. the recordings detected by disturbance recorders;

ii. recordings of electromechanical transients;
iii. recordings of local signals.

The detailed list of data and information with respective specifications, and the exchange methods for the above-mentioned elements, are agreed upon by the **Power-Generating Facility Owners** and the relevant **TSO**, and they are reported, for each **Power-Generating Facility**, in the **Operating Regulation Document**.

5.8 Compliance monitoring

J. Requirements that covers compliance procedures are fundamental to establishing procedures in a transparent and non-discriminatory manner across the **PAEM Electricity System**. This contributes to a more competitive market for the electricity sector of the **Member States**.

The **Power-Generating Facility Owner** shall ensure that each **Module** complies with the requirements of this chapter for its entire life.

The relevant **TSO** shall evaluate the compliance of the **Module** and shall keep the **Power-Generating Facility Owner** informed about the outcome of the compliance assessments that shall include:

a) Information and documentations provided by the **Power-Generating Facility Owner** to the relevant **TSO**;
b) Verification and compliance tests executed by the relevant **TSO**;
c) Compliance simulations.

In addition, the **TSO** can consider self-certification tests executed by the **Power-Generating Facility Owner**. The TSO shall define the procedures for self-certification tests.

5.8.1 Information and documentation

The **Power-Generating Facility Owners** shall provide the relevant **TSO** with information and documents that describe the characteristics of the **Modules** within the **Facility**.

The list shall be harmonized by the relevant **TSOs** of the same synchronous area and shall at least include the followings:

a) General information about the facility;
b) Primary energy source, energy conversion process, module and facility efficiency;
c) the technical constraints related to the conversion process which limit the performance of the module, and any environmental constraints;
d) the main characteristics for identifying flexibility in operation;
e) the characteristics of the module and facility necessary to characterize the electrical behavior. These are the characteristics needed to perform static and dynamic calculations;
f) the characteristics of the control systems and the capability curves. These are needed to characterize the capacity for providing system services;
g) data on failure rates;
h) the ability to provide emergency operations related capabilities.

The **Power-Generating Facility Owner** shall provide the necessary information and documents to the relevant **TSO**:

a) at the time of connection request in accordance with Chapter 3;
b) following changes to the technical data of the **Modules** resulting from changes in the technical capabilities or operational accidents or faults;
c) whenever requested by the relevant **TSO**.

5.8.2 Verification and compliance tests executed by the relevant TSO

The relevant **TSO** shall execute verification and compliance tests to ascertain the validity of the declarations issued by the **Power-Generating Facility Owner** and the compliance with the requirements set in this **Code**.

The relevant **TSO** communicates the annual plan for the implementation of the verification and compliance tests and the results of the same. In consideration of the importance that the controlling systems and the relative parameters, the **TSO** has the right to execute tests on their functionality at any time.

The relevant **TSO** shall define the standard procedures for executing the tests differentiating between synchronous and inverter-based **Power-Generating Modules**. At a minimum, the procedures shall include the followings:

a) the level and control functions of the active and reactive power injected into the **Grid**;
b) the performance of systems for frequency and voltage control in emergency conditions;
c) the functions of automatic disconnection of the **Modules**;
d) the requirements pertaining to capabilities and actions required during emergency operation and restoration actions;
e) the functionality of the **Protection** devices which need to coordinate with the **Protection** devices installed on the **Grid**.

5.8.3 Compliance simulations

In addition to the verification of the information and the compliance tests as per the above paragraphs, the **TSO** can assess the compliance of a **Power-Generating Facility** with the requirements set forth in this **Connection Code**, and by relying on the simulations of the performance of **Power-Generating Facility** carried out by the **Power-Generating Facility Owner** using the simulation models referred to in Article 5.5.7.

6 REQUIREMENTS FOR HIGH-VOLTAGE DIRECT CURRENT SYSTEMS

6.1 Operating ranges

6.1.1 Frequency ranges

J. J. In an interconnected **Electricity System**, frequency is the parameter with the largest cross-border impact, since deviations from its nominal value occur everywhere at the same time and affect all **Power-Generating Modules** regardless of voltage levels. For this reason, harmonized frequency ranges are fundamental, especially the range for unlimited operation which needs to be identical for sharing the burden of deviations equally.

HVDC Systems shall be designed, built and operated to remain connected to the **Transmission System** within the frequency ranges and minimum time periods specified by the relevant **TSO** – if the **HVDC System** is embedded in the **Grid** – or by the relevant neighboring **TSOs** – if the **HVDC System** interconnects two or more **Grids** – according to the following scheme, which is also presented in Table 6-1:

a) For an HVDC **System** within the same **Synchronous Area** or connecting two or more asynchronous **Transmission Systems** operating at the same frequency:
   i. a range around the nominal frequency of the **Synchronous Area** or of the connected asynchronous **Transmission Systems** with unlimited time period of operation;
   ii. at least one range with frequency below the nominal frequency of the **Synchronous Area** or of the connected asynchronous **Transmission Systems** with limited time period for operation to be specified by the relevant **TSO(s)**;
   iii. at least one range with frequency above the nominal frequency of the **Synchronous Area** or of the connected asynchronous **Transmission Systems** with limited time period for operation to be specified by the relevant TSO**(s)**.

b) For an **HVDC System** connecting two or more asynchronous **Transmission Systems** operating at different frequencies, the ranges and minimum time periods shall be defined at the **Connection Point** of each terminal of the **HVDC System**:
   i. a range around the nominal frequency of the **Transmission System** connected to the terminals of the **HVDC System** with unlimited time period of operation;
   ii. at least one range with frequency below the nominal frequency of the **Transmission System** connected to the terminal of the **HVDC System** with limited time period for operation to be specified by the relevant **TSO(s)**;
   iii. at least one range with frequency above the nominal frequency of the **Transmission System** connected to the terminal of the **HVDC System** with limited time period for operation to be specified by the relevant TSO**(s)**.

The frequency ranges are considered at the **Connection Point**. In defining frequency ranges and time periods, the relevant **TSO(s)** shall consider the applicable international standards for products on frequency-related capabilities.

The relevant **TSO** and the **HVDC System Owner** may agree on wider frequency ranges, longer minimum times for operation, or specific requirements for combined frequency and voltage deviations to ensure the best use of the technical capabilities of an **HVDC System**, if it is needed to preserve or to restore **Grid** security. The **HVDC System Owner** shall not unreasonably withhold consent to such request(s) if economically and technically feasible.

Table 6-1. Minimum time periods for which an HVDC System must be capable of operating for frequency deviating from the nominal value without disconnecting from the Transmission System.

			Frequency range	Time period for operation
a)		i.	F_{flow2} Hz – F_{flow1} Hz	To be specified in minutes by the relevant **TSO**(s)

	same *f* at all the terminals of the HVDC System	ii.	$F_{f\mathrm{low1}}$ Hz – $F_{f\mathrm{high1}}$ Hz	Unlimited
		iii.	$F_{f\mathrm{high1}}$ Hz – $F_{f\mathrm{high2}}$ Hz	To be specified in minutes by the relevant **TSO**(s)
b)	different *f* at the terminals of the HVDC System	i.	same as above but each range and minimum time period is defined for each terminal of the HVDC System by the relevant TSO in accordance to the *f* of its Electricity System	
		ii.		
		iii.		

Frequency ranges and time periods shall be harmonized within **Member States** belonging to the same **Synchronous Area**. Indicative frequency ranges and time periods are reported in Table 6-2.

Table 6-2 Minimum time periods for which an HVDC System must be capable of operating for frequency deviating from the reference 1 pu calculated on a nominal value of 50 Hz or 60 Hz without disconnecting from the Transmission System.

Frequency range	Time period for operation
0.94 pu – 0.95 pu	60 seconds
0.95 pu – 0.98 pu	longer than established times for generation as per Table 5-2 (> 30 minutes) but ≤ 90 minutes
0.98 pu – 1.02 pu	Unlimited
1.02 pu – 1.03 pu	longer than established times for generation as per Table 5-2 (> 30 minutes) but ≤ 90 minutes
1.03 pu – 1.04 pu	> 15 minutes

6.1.2 Voltage ranges

J. J. Though voltage is a local parameter, voltage ranges are critical to secure operation of an **Integrated Power System** within a **Synchronous Area**. Lack of coordinated ranges between adjacent interconnected **Grids** would lead to uncertainty in operation, especially when beyond normal state.

An **HVDC Converter Station** shall be designed, built and operated to be capable of remaining connected to the **Transmission System** within the ranges of the voltage at the **Connection Point** specified by the relevant **TSO** in accordance with the following scheme, and also represented in Table 6-3:

f) a range around the base voltage with unlimited time period of operation;
g) at least one range with voltage above the base value with limited time period for operation to be specified by the relevant TSO.

Voltage ranges are expressed by ratio of the voltage at the **Connection Point** to the base voltage. The relevant **TSO** can define a different sets of voltage ranges and respective time periods according to different voltage base levels. In defining voltage ranges and time periods, the relevant **TSO** shall consider the applicable international standards for products on voltage-related capabilities.

The relevant **TSO** and the **HVDC System Owner** may agree on wider voltage ranges, longer minimum times for operation or specific requirements for combined frequency and voltage deviations (simultaneous overvoltage and underfrequency or simultaneous undervoltage and overfrequency) to ensure the best use of the technical capabilities of an HVDC **System**, if it is needed to preserve or to restore **Grid** security. The **HVDC System Owner** shall not unreasonably withhold consent to such request(s) if economically and technically feasible.

Table 6-3. Minimum time periods during which an HVDC System must be capable of operating for voltages deviating from the reference 1 pu value at the Connection Point without disconnecting from the Transmission System.

	Voltage range	Time period for operation
a)	U_{low1} pu – U_{high1} pu	Unlimited
b)	U_{high1} pu – U_{high2} pu	To be specified in minutes by the relevant TSO at the Connection Point

Voltage ranges and time periods shall be harmonized within **Member States** belonging to the same **Synchronous Area**. Indicative voltage ranges and time periods are reported in Table 6-4.

Table 6-4. Minimum time periods during which an HVDC System must be capable of operating for voltages deviating from the reference 1 pu value at the Connection Point without disconnecting from the Transmission System.

Reference voltage for pu values	Voltage range	Time period for operation
110 kV – 400 kV	0.85 pu – 1.118 pu	Unlimited
	1.118 pu – 1.15 pu	≥ 20 minutes

6.2 Immunity to grid disturbances

6.2.1 Fault Ride Through Capability

J. In the case of a fault on the **Transmission System** level, a voltage drop will propagate across large geographical interconnected areas. Failure to ride through faults for **HVDC Converter Stations** can create major system instability with cross-border implications. This requirement defines capability for **HVDC Converter Stations** to be tolerant to such faults.

HVDC Converter Stations shall be capable of remaining connected to the **Transmission System** and shall continue to operate in a stable manner in the following conditions:

a) when the actual course of the phase-to-phase voltages at the **Connection Point** during a symmetrical fault is maintained over a **Fault-Ride-Through** voltage-against-time profile to be specified by the relevant TSO according to Figure 6-1; and,
b) unless the protection scheme for internal faults requires the disconnection of the **HVDC Converter Station** from the **Transmission System**. Such undervoltage protection schemes shall be set by the **HVDC System Owner** to the widest possible technical capability of the **HVDC Converter Station**.

The relevant TSO shall specify:

a) The parameters that define each point of **Fault-Ride-Through** voltage-against-time profile of Figure 5-1 for **HVDC Converter Stations**.
b) voltage levels (U_{block}) at the **Connection Points** under specific conditions of the **Transmission System** whereby the **HVDC System** is allowed to block, that is remaining connected to the **Transmission System**, with no active and reactive power contribution for a time frame that shall be as short as technically feasible, and which shall be agreed between the relevant **TSOs** and the **HVDC System Owner**.

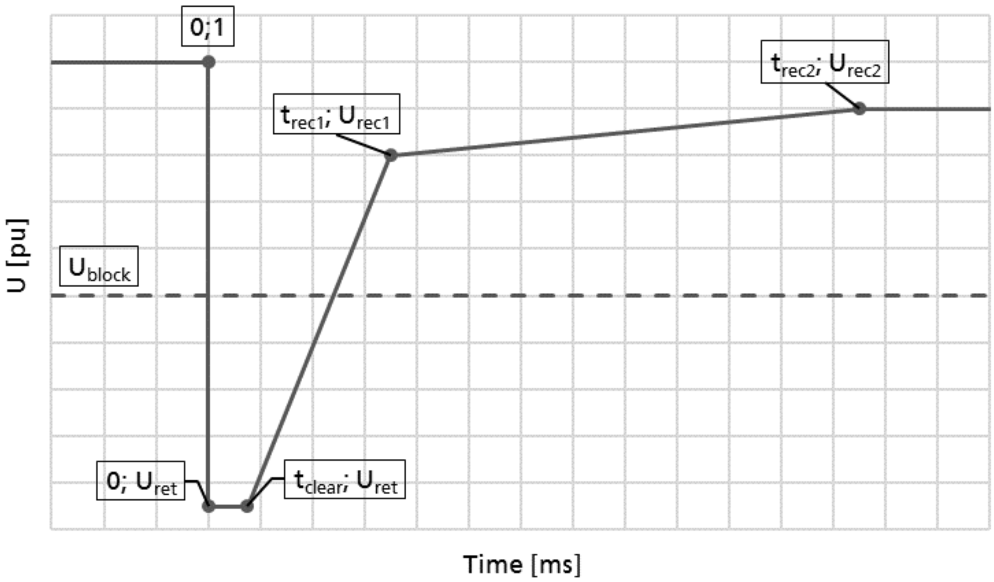


Figure 6-1. Fault-ride-through profile of an HVDC Converter Station.

HVDC Systems shall comply with the **Fault-Ride-Through** voltage-against-time profile for any pre-fault and post-fault value of **Short-Circuit Power** between the minimum and maximum values of the **Short-Circuit Power** expected in the **Connection Point**. In this regard, the relevant **TSO** shall specify and make publicly available such minimum and maximum values of **Short-Circuit Power** expected in each node of the **Transmission System**.

All the **Fault-Ride-Through** voltage-against-time profiles shall be harmonized by the relevant **TSOs** of all the **Interconnected Member States** no later than 24 months from the effective date of this **Code** and according to a criterion agreed by the **Parties**. A criterion may be the selection of the largest curve among the ones specified by the relevant TSO.

In case no harmonization of the **Fault-Ride-Through** voltage-against-time profiles is agreed by the **Interconnected Member States**, the limits specified in Figure 6-2 may be adopted by the relevant TSO.

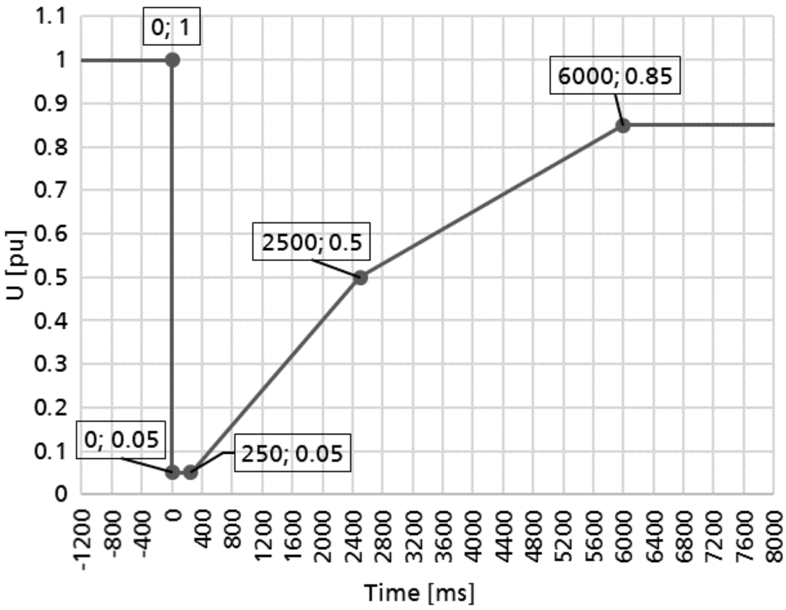


Figure 6-2. Fault-ride-through profile of an HVDC Converter Station. The diagram represents the lower limit of a voltage- against-time profile at the Connection Point, expressed by the ratio of its actual value and its reference 1 pu value in per unit before, during and after a fault.

6.2.2 Rate of change of frequency withstand capability

J. Rate of change of frequency withstand capability tends to become relevant during significant load-generation imbalances (e.g. disconnection of large **Load Facilities** or **Power-Generating Modules**, or system splits) because of low system inertia caused by (amongst others) increasing shares of inverter-based **Power-Generating Facilities**, usually renewables. Avoiding the disconnection of **HVDC Converter Stations** in case of large rate of change of frequency contribute to stabilization and restoration of the **Transmission System** to normal operating states.

An HVDC **System** shall be capable of staying connected to the **Transmission System** and operate at rates of change of frequency within a range of values specified by the relevant **TSO.**

Rate of change of frequency withstand capability shall be harmonized within **Member States** belonging to the same **Synchronous Area**. A range of values of rate of change of frequency between – 2.5 and + 2.5 Hz/s (measured at any point in time as an average of the rate of change of frequency for the previous 1 s) computed over a 5 cycles time window is a typical threshold value.

6.3 Stability and control of the system frequency

6.3.1 Control of target active power

J. Changes in active power output around target value and behavior during transient of target value variations may result in load imbalances and hence frequency deviations in a **Synchronous Area**. Requirements defining the performance of **HVDC System** in target active power control contribute to maintaining system stability and security by minimizing deviations of frequency.

An **HVDC System** shall be able to adjust the transmission of active power in each direction of the power flow to a target value communicated by the relevant **TSO(s)**. The detailed technical specifications of control of target active power shall be defined during the connection procedure (Chapter 3) of the **HVDC system**, and they shall at least include the following elements:

a) minimum values of the active power for each power flow direction through the **HVDC System**, below which active power transmission capacity is not requested;
b) maximum and minimum power step size for adjusting the transmitted active power;
c) maximum delay within which the **HVDC System** shall be capable of adjusting the transmitted active power upon receipt of request from the relevant **TSO**;
d) specifications on the expected operation in the event of disturbances at the **Connection Point** of one or more **HVDC Converter Stations**;
e) capability of fast active power reversal from the maximum active power transmission capacity of the **HVDC System** in one direction to the maximum active power transmission capacity of the **HVDC System** in the other direction, with the related rules, conditions, and time of activations.
f) control functions enabling the relevant **TSOs** to modify the transmitted active power for the purpose of cross-border balancing among different **Control Areas**;
g) ramping rate of active power adjustments;
h) remedial action for activating / blocking frequency regulation.

6.3.2 Maximum loss of active power

J. Operating conditions may lead to reduction in active power injection of **HVDC Systems**. Defining admissible reductions contributes in limiting load imbalances and hence frequency deviations.

An **HVDC System** shall be configured in such a way that its loss of active power injection in the same **Synchronous Area** shall be limited to a value specified by the relevant **TSOs** for their respective load frequency **Control Area**, based on the **HVDC System**'s impact on the **Electricity System**.

Where an **HVDC System** connects two or more **Control Areas**, the relevant **TSOs** shall consult each other in order to set a coordinated value of the maximum loss of active power injection, considering common mode failures.

6.3.3 Participation in frequency control

J. Persistent load imbalances cause frequency deviation to increase leading to deterioration of system stability and security of the **PAEM Electricity System**. **HVDC Systems** are requested to contribute in removing such imbalances. These requirements define the capabilities of

HVDC Systems to control the variation of their active power output in response to: (i) abnormal over-frequency, (ii) abnormal under-frequency, (iii) normal frequency variations.

HVDC Systems shall be equipped with the facilities to provide **Synthetic Inertia** during fast frequency deviations upon request of the relevant **TSO**, by rapidly adjusting the active power injected or withdrawn from the AC side of the **Transmission System**.

The relevant TSO shall agree with the **HVDC System Owner** regarding the performance parameters of the control systems installed to provide **Synthetic Inertia**.

HVDC System shall be able to operate in the **FSM** which determines a variation in the adjustment of active power with respect to the programmed value of target active power in response to contained variations in the frequency of the **Transmission System**. The adjustment of active power is limited by the minimum and maximum continuous active power, which the **HVDC System** can exchange with the **Transmission System** at each **Connection Point** as agreed between the relevant **TSO** and the **HVDC System Owner**.

The relevant TSO shall define the parameters that characterize the **FSM** for the **HVDC System** connected to their **Grids** in accordance with Figure 6-3 and Table 6-5 and considering that P_{MAX} is the maximum active power transmission capacity of the **HVDC System** to which ΔP refers, and it coincides with the maximum continuous active power, which the **HVDC System** can exchange with the **Transmission System** at each **Connection Point**. ΔP is the variation in the active power output from the HVDC System. f_n is the nominal frequency in the AC-side of the **Transmission System** where the FSM service is provided and Δf is the frequency deviation in the AC-side of the **Transmission System** where the FSM service is provided.

In case an **HVDC System** connects two or more **Control Areas** or **Synchronous Areas**, in **FSM** operation the **HVDC System** shall be capable of adjusting the full active power frequency response at any time and for a continuous time period.

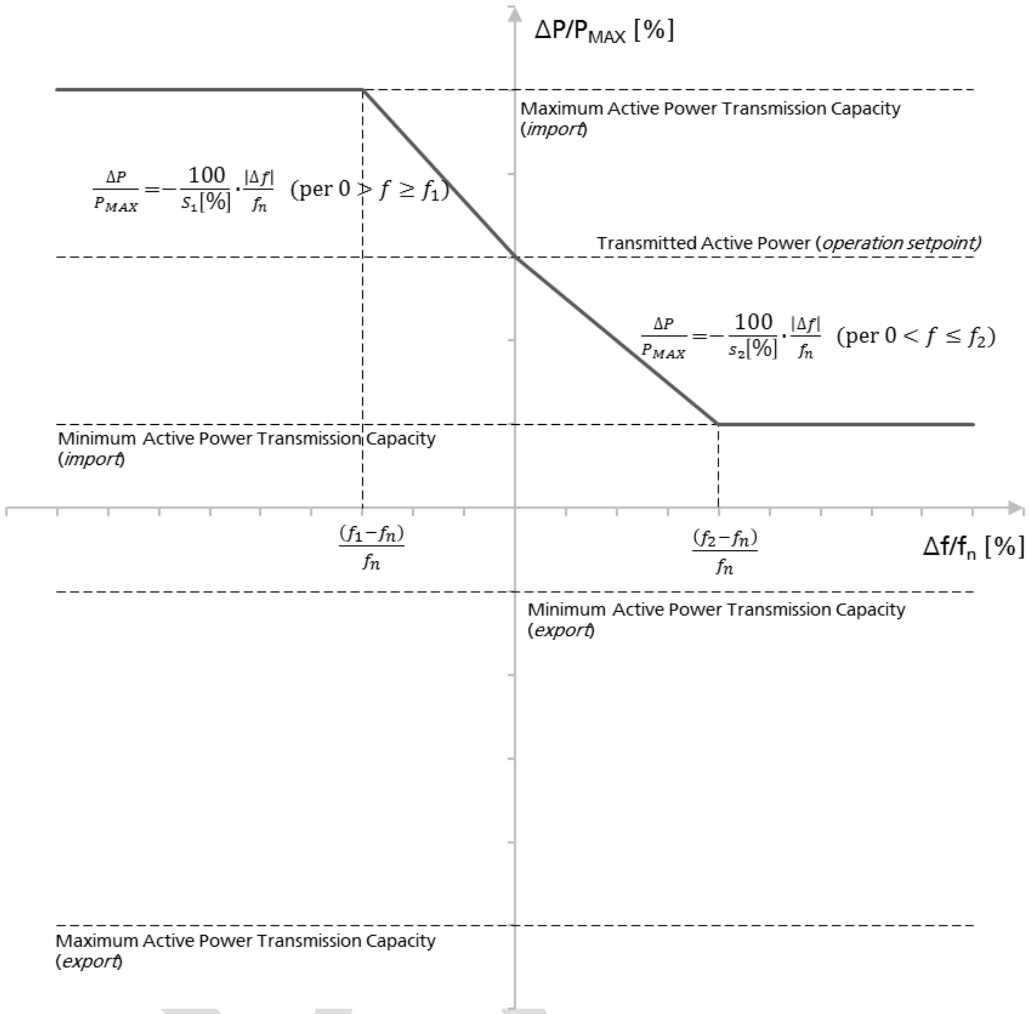


Figure 6-3. Active power frequency response capability of HVDC System in FSM illustrating the case of zero Frequency Response Deadband and insensitivity with a positive active power setpoint.

Table 6-5. Parameters for active power frequency response in FSM (explanation for Figure 6-3)

Parameters	Typical ranges
Frequency Response Insensitivity of the regulators Δf	max 30 mHz
Frequency Response Deadband	0 – ±500 mHz
Droop s_1	min 0.1%
Droop s_2	min 0.1%

In the event of frequency step changes, the power frequency response of the **FSM** mode shall be activated by the **HVDC System** in such a way that the response is at or above the solid line shown in Figure 6-4 and in accordance with the parameters specified by the relevant **TSO** based on the technology-dependent limitations of the **HVDC System**. Typical values of the parameters are reported in Table 6-6.

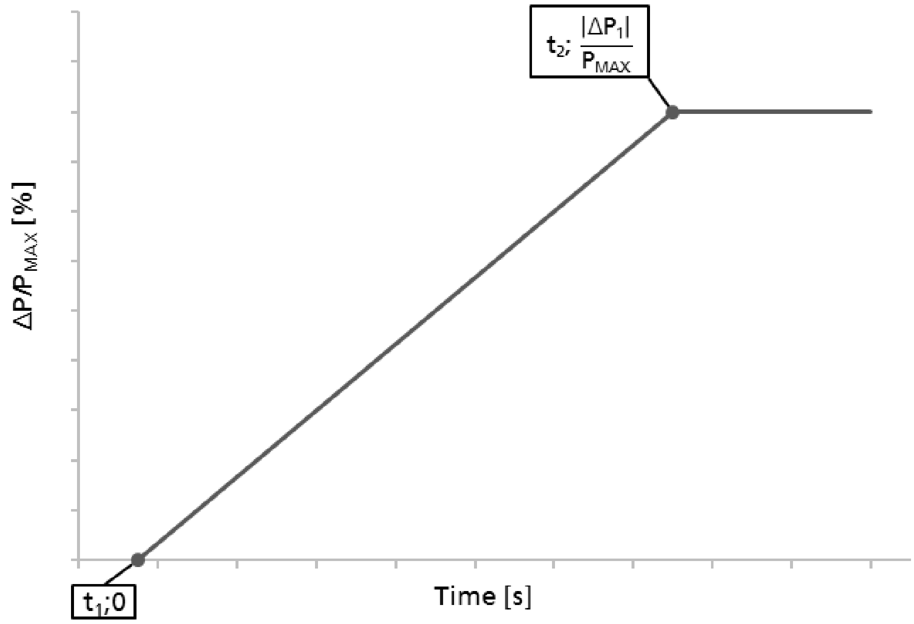


Figure 6-4. Active power frequency response capability.

Table 6-6. Parameters for full activation of active power frequency response resulting from frequency step change (explanation for Figure 6-4).

Parameters	Typical values
Maximum admissible initial delay t_1	0.5 sec
Maximum admissible choice of full activation time t_2, unless longer activation times are allowed by the relevant **TSO**	30 sec

HVDC System shall regulate the active power output with the **Transmission System** with respect to the programmed value of target active power to transmit in response to the AC-side of the **Transmission System(s)**, during both import and export, with the modes called Load **LFSM-O** and **LFSM-U**.

The relevant TSO shall define the actual frequency threshold and droop that characterize the **LFSM-O** and **LFSM-U** modes for the **HVDC System** connected to their **Grids** in accordance with Figure 6-5 and Figure 6-6:

a) P_{MAX} is the maximum active power transmission capacity of the **HVDC System** to which ΔP refers, and it coincides with the maximum continuous active power, which the **HVDC System** can exchange with the **Transmission System** at each **Connection Point**. ΔP is the variation in the active power output from the **HVDC System**. f_n is the nominal frequency in the AC-side of the **Transmission System** where the **FSM** service is provided and Δf is the frequency deviation in the AC-side of the **Transmission System** where the **FSM** service is provided.

b) In **LFSM-O** mode, typical values for the frequency threshold $\Delta f_1/f_n$ are between 1.004 pu and 1.008 pu inclusive, and the droop s_3 adjustable from 0.1% upwards.
c) In **LFSM-U** mode, typical values for the frequency threshold $\Delta f_1/f_n$ are between 0.996 pu and 0.99 pu inclusive, and the droop s_4 adjustable from 0.1% upwards.

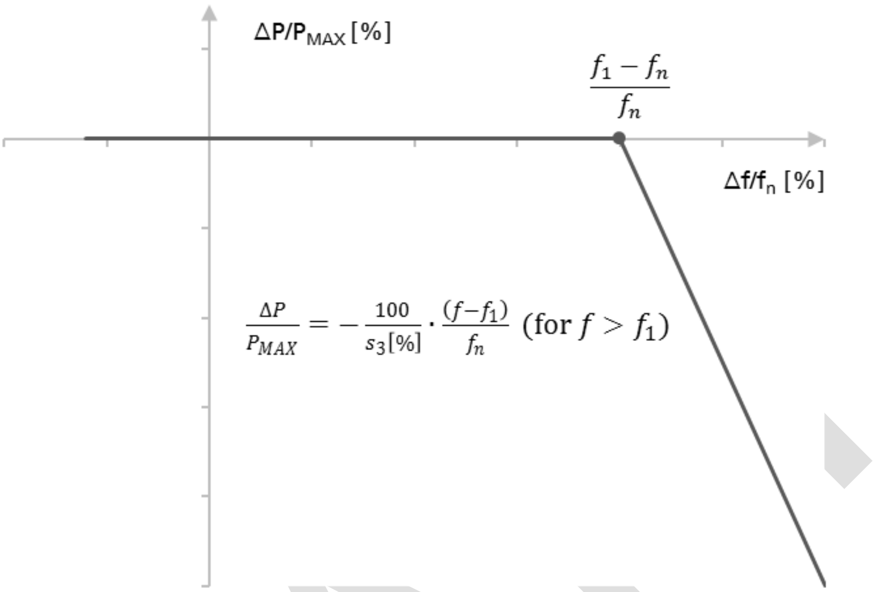


Figure 6-5. Active power frequency response capability of HVDC System in LFSM-O mode.

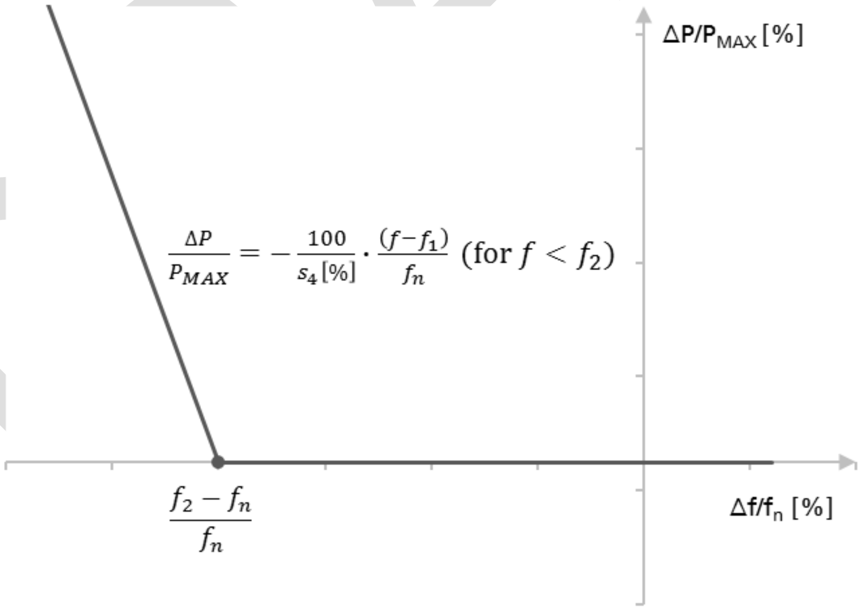


Figure 6-6. Active power frequency response capability of HVDC System in LFSM-U mode.

An **HVDC System** shall be capable of activating the active the power frequency response as fast as technically feasible with an initial delay for full activation determined by the relevant **TSO**.

With reference to the operation in:

a) **LFSM-O** mode, the **HVDC System** shall be capable of adjusting active power down to its minimum active power transmission capacity of the **HVDC System**.
b) **LFSM-U** mode, the **HVDC System** shall be capable of adjusting active power up to its maximum active power transmission capacity of the **HVDC System**.
c) both **LFSM-O** and **LFSM-U**, the **HVDC System** shall be capable of operating stably during

The relevant **TSOs** of the same **Synchronous Area** shall harmonize the **LFSM-O** and **LFSM-U** parameters to minimize unplanned power flow between the interconnected countries in response to a change in system frequency.

6.4 Stability and control of the system voltage

6.4.1 Reactive Power Capability

J. Reactive power is a key component for voltage stability and is fundamental for cross-border power trading. Although the influence of **HVDC Systems** on overall system voltage stability varies with location, harmonizing reactive power capabilities contributes to secure planning and operation of the **Integrated Power Systems** within the same **Synchronous Area**.

The relevant **TSO** shall specify reactive power capability and reactive power capability at the **Connection Points**, in the context of varying voltage.

6.4.1.1 Reactive power capability at maximum capacity

Regarding reactive power capability at maximum capacity, the relevant **TSO** shall identify the U-Q/P_{MAX}-profile, which identifies the boundaries within which the **HVDC Converter Station** shall be capable of providing reactive power at its maximum active power transmission capacity of the **HVDC System**. The U-Q/P_{MAX}-profile shall be defined according to the following principles and in consistence with Figure 6-7:

a) the dimensions of the U-Q/P_{MAX}-profile envelope shall be within the Q/P_{MAX} range and voltage range specified by the relevant **TSO**.
b) the position of the U-Q/P_{MAX}-profile envelope shall be within the limits of a fixed outer envelope to be defined by the relevant **TSO.**

The relevant **TSOs** of the same **Synchronous Area** shall harmonize the dimensions of the inner and outer envelopes. Typical values for the outer envelope, Q/P_{MAX} range and voltage range of the U-Q/P_{MAX}-profile envelope of **HVDC Convert Stations** are shown in Table 6-7.

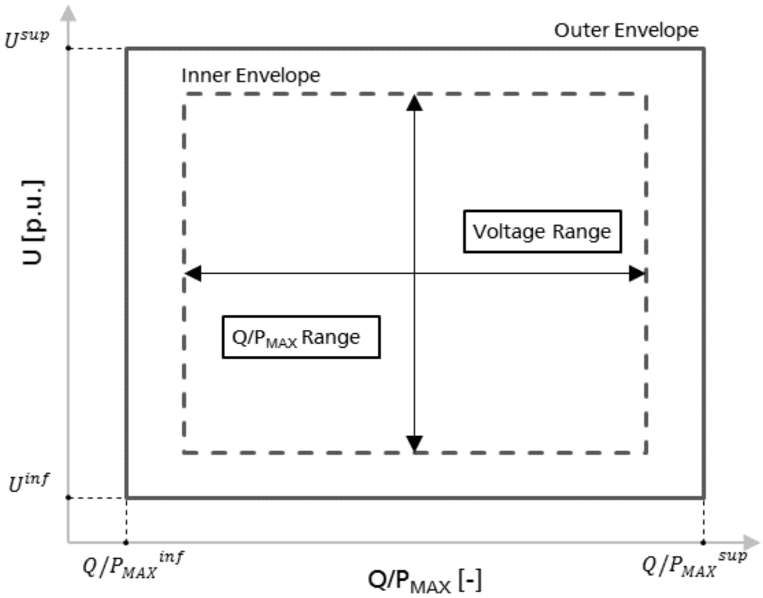


*Figure 6-7. U-Q/P_{MAX}-profiles to be defined by the relevant **TSO**.*

Table 6-7. Typical parameters for the U-Q/P_{MAX}-inner and outer envelopes profile of Figure 5-9.

Parameters	Typical Values
Q/P_{MAX} Range	0.95 – 1.08
Voltage Range	0.150 – 0.225
U^{sup}	1.150
U^{inf}	0.850
Q/P_{MAX}^{inf}	- 0.500
Q/P_{MAX}^{sup}	+ 0.650

An **HVDC System** shall be capable of moving to any operating point on the surface within its U-Q/P_{MAX} profile in appropriate timescales to target values requested by the relevant **TSO**.

6.4.1.2 Reactive power capability below maximum capacity

When operating at an active power output below the maximum active power transmission capacity of the **HVDC System** (P < P_{MAX}), the **HVDC Converter Station** shall be capable of operating in every possible operating point, as specified by the relevant **TSO**, and in accordance with the reactive power capability set out by the U-Q/P_{MAX} profile specified in Paragraph 6.4.1.1.

6.4.2 Voltage control modes

J. The absence of voltage control for **HVDC Systems** can lead to voltage instability which can spread to neighboring **Electricity Systems** and become a cross-border issue.

HVDC Systems, through their **HVDC Converter Stations** shall contribute to the voltage control. The following control modes shall be implemented:

a) Voltage control mode:
   i. the **HVDC Converter Station** shall be capable of contributing to voltage control at the **Connection Point** by providing reactive power exchange with the **Transmission System** to achieve a setpoint voltage covering a range [U_{REG_MIN}; U_{REG_MAX}] in steps no greater than ΔU_{REG} defined by the relevant **TSO**. Typical values for U_{REG_MIN}, U_{REG_MAX} and ΔU_{REG} are 0.95, 1.05, and 0.01.
   ii. The setpoint may be operated with or without a deadband selectable in a range defined by the relevant **TSO**.
   iii. Achieving 90% and 100% of the change in reactive power output requested by the relevant **TSO** within time $t_{REG\_90\%}$ and $t_{REG\_100\%}$, respectively, to be specified by the relevant **TSO**, with an accuracy of 5% of the value of the maximum reactive power that can be delivered by the **HVDC System**. Typical values of $t_{REG\_90\%}$ and $t_{REG\_100\%}$ lie within the range 0.1-10 sec and 1-60 sec, respectively.

b) Reactive power control mode:
   The **HVDC Converter Stations** shall be capable of setting the reactive power setpoint anywhere in the given reactive power range defined MVAr or in % of maximum reactive power, with setting steps defined by the relevant **TSO**, by controlling the reactive power at the **Connection Point** to an accuracy defined by the relevant **TSO** as a percentage of the full reactive power. The specification of the reactive power range defined by the relevant **TSO** shall consider the capabilities of the **HVDC System,** while respecting Article 6.4.1.

The relevant **TSO** shall define the principles and performance for the switching between the two modes as well as the modes and procedures for communicating the voltage reference values.

6.4.3 Short circuit contribution during faults

J. This requirement is critical to both restoring voltage immediately following faults and for injecting enough current quickly enough for system protections to function reliably.

HVDC Systems shall be capable of providing **Fast Fault Current** at the **Connection Point** in case of balanced (3-phase) and unbalanced (1-phase or 2-phase) faults.

The relevant **TSO** shall define the requirements for **Fast Fault Current**. These shall consider: (i) how and when a voltage deviation is to be determined; (ii) the characteristics of the **Fast Fault Current**; and (iii) the timing and accuracy of the **Fast Fault Current**.

6.5 Management of the power system

6.5.1 Energization and synchronization of converter stations

J. This requirement is needed to limit the potential disturbances generated by the energization and synchronization of the **HVDC Converter Stations**, which can have cross boarder impacts.

The energization or synchronization of an **HVDC Converter Station** to the AC **Transmission System** or the connection of an energized **HVDC Converter Station** to an **HVDC System** shall be performed to limit any voltage transient at the **Connection Point** and its propagation across the **Transmission System**.

The relevant TSO shall specify the maximum magnitude, duration and measurement window of the voltage transients for the **HVDC Converter Station** within its **Control Area**.

6.5.2 Protection systems

J. Proper protection of the Transmission System is essential for maintaining stability and security of the **PAEM Electricity System**. Protection schemes shall prevent from aggravation of disturbances but limit their consequences within the same **Synchronous Area**.

The requirements stated in this Article 6.5.2 are in addition to the general requirements on protection already described in Section 4.4.

The protection system of an **HVDC System** has priority over operational controls, considering the security of the **Electricity System**, as well as the health and safety of working personnel and citizens and limiting any potential damage to the **HVDC System**.

The protection schemes needed for protecting the **Grid** shall be specified by the relevant **TSO**, taking into consideration the characteristics of the **HVDC System**. The definition of and any change to protection schemes needed for protecting the **HVDC System** and the **Grid** as well as the settings relevant to the **Module** shall be coordinated and agreed upon by the relevant **TSO** and the **HVDC System Owner**.

The protection system of an **HVDC System** shall be organized according to the following categories:

a) Protection against internal faults, which shall respect the following conditions:
   i. Any component of an **HVDC System** shall be protected against stresses caused by failures not eliminated by the protection system of the **Transmission System** or not covered by it.
   ii. Each component, each subsystem, each **HVDC Converter Station** and the **HVDC System** shall be protected with coordinated systems that shall be capable of supporting and counteracting any abnormal operating conditions and any fault event. In particular, the safety measures of the protection systems shall be ensured even in the event of any failure to the telecommunications system.

iii. The design of the protection system shall consider the complete duplication of the protection devices.

b) Protection of the **Transmission System** shall respect the following conditions:
   i. Each **HVDC System** and its **HVDC Converter Units** shall be equipped with a protection system capable of separating them from the **Transmission System** in the event of faults in the **Transmission System** which have not been correctly eliminated.
   ii. The diagrams and settings of these protection systems shall be coordinated with those of the protection systems of the **Transmission Systems** and therefore established by the relevant TSO.

c) Additional specific protection systems, which include:
   i. Protection systems against power oscillations that cannot be controlled by the **HVDC System**.
   ii. Protection systems that prevent an **HVDC System** to entry into service in the absence of the minimum conditions for the **Transmission System** operation, and that disconnect the **HVDC System** if the last power link connecting the **HVDC System** to the **Transmission System** is opened.

6.5.3 Control systems

J. Control systems are defined individually for **HVDC Systems**. Nevertheless, harmonization of the principle/methodology contributes guaranteeing the stability of the **PAEM Electricity System**.

An **HVDC System** shall be equipped with a control system capable of managing and controlling in a coordinated way all the **HVDC Converter Units** of the **HVDC System**.

During the authorization phase of the connection procedure, the requirements, parameters, and settings of the main control functions of an **HVDC System** will be agreed and formalized between the **HVDC System Owner** and the relevant **TSO**.

The parameters and settings shall be implemented within such a control hierarchy that makes their modification possible if necessary. Those main control functions are at least:

a) synthetic inertia, if applicable as referred to in Article 6.3.3.
b) **FSM**, **LFSM-O**, and **LFSM-U** referred to in Article 6.3.3
c) reactive power control mode, if applicable as referred to in Article 6.4.1;
d) power oscillation damping capability, if applicable as referred to in Article 6.5.5;

For **HVDC Systems** linking various **Control Areas** or **Synchronous Areas**, the **HVDC System** shall be equipped with control functions enabling the relevant **TSOs** to modify the transmitted active power for the purpose of cross-border balancing.

The development and design of the control system of a **HVDC Converter Station** shall be based on the principle of redundancy and consider the complete duplication of the equipment. The redundancy shall include:

a) the measurement circuits, at least from the side of the transducer;
b) the systems for signal acquisition;

c) the telecommunication system;
d) the main processing units and all the equipment necessary for the command, control and protection of the **HVDC Converter Stations**.

6.5.4 Priority ranking of control and protection actions

J. The definition of a ranking is recommended to specify which capabilities shall take precedence (i.e. avoid conflicts) when designing the protection and control schemes of **HVDC Systems**. Harmonizing the ranking among the **Member States** is important to achieve a common basis for operational strategies to ensure secure operation of the **PAEM Electricity System**.

The **HVDC System Owner** shall organize the protection and the control devices of its **HVDC System** in accordance with the following priority ranking (from highest to lowest):

a) **Transmission System** and **HVDC System** protection;
b) active power control for emergency assistance;
c) **Synthetic Inertia**, if applicable;
d) automatic remedial actions as specified in Article 6.3.1;
e) **LFSM**;
f) **FSM** and frequency control; and,
g) power gradient constraint.

6.5.5 Power system stabilizers

J. Power system oscillations can spread across the borders of adjacent **Electricity Systems** and can result in dynamic instabilities if no harmonized measures are taken.

The **HVDC System** shall be capable of contributing to the damping of power oscillations occurring in the AC side of the **Transmission System** to which it is connected. The control system of the **HVDC System** shall not reduce the damping of power oscillations. The relevant **TSO** shall specify a frequency range of oscillations that the control scheme shall positively damp and the conditions of the **Transmission System** when this occurs. The selection of the control parameter settings shall be agreed upon by the relevant **TSO** and the **HVDC System Owner**.

6.5.6 Power Quality

J. Harmonization of requirements regarding potential disturbances in the electric power transferred by **HVDC System** contributes to ensure the targeted quality of the supply within **PAEM Electricity System**.

An **HVDC System Owner** shall ensure that the connection of its **HVDC System** to the **Transmission System** does not result in a level of distortion or fluctuation of the supply voltage on the **Transmission System**, at the **Connection Point**, exceeding the level specified by the relevant **TSO**.

For evaluating the impact on the **HVDC System** connection on the **Grid**, the **HVDC System Owner** shall provide, at the time of connection request, all the project data relating to the emission of disturbances. Based on the data provided, the relevant **TSO** evaluates the effects on the **Grid** in conditions of minimum **Short-Circuit Power** on the **Grid**.

The maximum emission levels of distortion or fluctuation of the supply voltage granted to the **HVDC System** are set by the relevant **TSO** taking into account the planning values adopted by the relevant **TSO**, the **Short-Circuit Power** at the **Connection Point**, the characteristic data of the **HVDC System**, the emissions of other **Facilities** already connected to the same **Grid**, the emissions transferred from the rest of the **Grid**, and the forecast future emissions of new **Facilities** who have already begun the connection procedure according to Chapter 3.

6.5.7 Simulation models

J. Power system studies are performed by the relevant **TSOs** at different stages of their evaluations (e.g. planning, operational planning, real-time operations). Dedicated provisions define a common set of simulation models and related features that the relevant **TSO** require to implement and update interconnected power system models.

At the request of the relevant **TSO**, an **HVDC Facility Owner** shall provide simulation models of its **HVDC System** with a level of detail adequate to reflect the behavior of the **Module** in:

a) steady-state simulation;
b) electromechanical simulation; and,
c) electromagnetic transient simulation.

The request of the relevant **TSO** shall include:

a) the specification of the format in which models are to be provided by the **HVDC System Owner**;
b) the provision of documentation on a model's structure and block diagrams;
c) the specific sub-models of the components, which should contain at least, depending on the existence of the mentioned components:
    i. HVDC Converter Unit models;
    ii. AC component models;
    iii. DC Link models;
    iv. Voltage and power controller;
    v. Special control features if applicable e.g. power oscillation damping function, subsynchronous torsional interaction control;
    vi. Multi terminal control, if applicable;
    vii. **HVDC System** protection models as agreed between the relevant **TSO** and the **HVDC System Owner**.

The **HVDC System Owner** shall verify the models against the results of compliance tests carried out according to Section 6.8, and a report of this verification shall be submitted to the relevant **TSO**. The models shall then be used for the purpose of verifying compliance with the requirements of this **Code** including, but not limited to, compliance simulations as provided for in 6.8.2 and used in studies for continuous evaluation in system planning and operation.

Upon request of the relevant **TSO**, the **HVDC System Owner** shall provide measurement recordings of the **HVDC System**'s performance in order to compare the response of the models with those recordings.

6.6 Management of emergency situations

6.6.1 Black start

J. Black Start Service is needed from an appropriate number of **HVDC Systems** to restore an **Electricity System** to a stable condition following major critical disturbance. Harmonization guidance of this requirement for **PAEM Electricity System** may be given in principle since details pertain to each single relevant **TSO**.

The **Power-Generating Module** with **Black Start Capability** shall meet the following requirements:

a) In the instance where one **HVDC Converter Station** is energized, to energization of the busbar of the AC-substation to which another **HVDC Converter Station** is connected, within a timeframe after shutting down of the **HVDC System** will be determined by the relevant **TSOs**.
b) With reference to frequency, the **HVDC System** shall be able to synchronize within the limits defined in Article 6.1.1.
c) With reference to voltage the **HVDC System** shall be able to synchronize within the limits defined in Article 6.1.2.

The relevant **TSO** and the **HVDC System Owner** shall agree on the capacity and availability of the **Black Start Capability** and the operational procedure.

6.7 Monitoring and Information exchange

J. Having adequate and harmonized monitoring and information exchange procedures between **HVDC System Owners** and the relevant **TSO** is a prerequisite for appropriate system operation as well as for appropriate operation of the **PAEM Electricity System** and will facilitate the resolution of cross-border issues.

HVDC Systems shall be capable of monitoring the operation of, and exchanging information with, the relevant **TSO** according to different specifications and purposes.

Regarding instrumentation for the operation, each **HVDC Converter Unit** of an **HVDC System** shall be equipped with an automatic controller capable of sending/receiving instructions to/from the relevant **TSO**. This automatic controller shall be capable of operating the **HVDC Converter Units** of the **HVDC System** in a coordinated way. The automatic controller hierarchy per **HVDC Converter Unit** shall be specified by the relevant **TSO**.

The automatic controller of the **HVDC System** shall be capable of:

a) Sending the following signal types to the relevant **TSO**:
    i. Operational signals, providing at least the following:
        - start-up signals;

- AC and DC voltage measurements;
- AC and DC current measurements;
- active and reactive power measurements on the AC side;
- DC power measurements;
- **HVDC Converter Unit** level operation in a multi-pole type **HVDC System**;
- elements and topology status; and,
- **FSM**, **LFSM-O** and **LFSM-U** active power ranges.

ii. Alarm signals, providing at least the following:
- emergency blocking;
- ramp blocking; and,
- fast active power reversal.

b) Receiving the following signal types from the relevant **TSO**:
i. Operational signals, providing at least the following:
- start-up commands;
- active power set-points;
- **FSM** settings;
- reactive power, voltage or similar setpoints;
- reactive power control modes;
- power oscillation damping control; and,
- **Synthetic Inertia**.

ii. Alarm signals, receiving at least the following:
- emergency blocking command; and,

To provide fault recording and monitoring of dynamic system behavior, **HVDC Systems** shall be equipped with an appropriate instrumentation, which meets the following requirements:

a) capability of recording (i) AC and DC voltage, (ii) AC and DC current, (iii) active power, (iv) reactive power, and (v) frequency;
b) it shall include an oscillation trigger, specified by the relevant **TSO**, with the purpose of detecting poorly damped power oscillations.
c) the settings shall be agreed between the **Power-Generating Facility** and the relevant **TSO**; and,
d) it shall include arrangements for the **HVDC System Owner** and the relevant **TSO** to access the information according to communications protocols for recorded data to be agreed between the **HVDC System Owner** and the relevant **TSO** and harmonized between all the relevant **TSOs**. Typical standards which communication protocols shall comply with are IEC 60870-5 publications or other equivalent European or International Standards.

6.8 Compliance monitoring

J. Requirements that covers compliance procedures are fundamental for establishing procedures in a transparent and non-discriminatory manner across the **PAEM Electricity System**. This contributes to a more competitive market for the electricity sector of the **Member States**.

6.8.1 Information and documentation

The **HVDC System Owners** shall provide the relevant **TSO** with information and documents that describe the characteristics of their **HVDC Systems**. Such list of information and documents shall be made publicly available by the relevant TSO as well as the requirements to be met by the **HVDC System Owners** within the framework of the compliance process. The list shall be harmonized by the relevant **TSOs** and cover at least the following information, documents and requirements:

a) all the documentation and certificates to be provided by the **HVDC System Owner**;
b) details of the technical data on the **HVDC System** and **HVDC Converter Station** with relevance to the **Grid** connection;
c) requirements for models for steady-state and dynamic system studies;
d) timeline for the provision of system data required to perform the studies;
e) studies by the **HVDC System Owner** or the **Owner** of **VRE-units** connected through **HVDC Systems** to demonstrate the expected steady-state and dynamic performance in accordance with the requirements set out in the **Connection Code**;
f) conditions and procedures, including the scope, for registering equipment certificates; and,
g) conditions and procedures for the use of relevant equipment certificates, issued by an authorized certifier, by the **HVDC System Owner**.

6.8.2 Verification and compliance test of the relevant system operator

Each **HVDC System Owner** shall comply with the testing procedures for the verification of the compliance with the requirements set in this **Connection Code** to be defined by the relevant **TSO.** The tests shall demonstrate the technical capability of **HVDC Systems**:

a) to provide leading and lagging reactive power capability according to Article 6.4.1;
b) to operate in voltage control mode and reactive power mode in the conditions set forth in Article 6.4.2;
c) to continuously modulate active power over the full operating range between maximum active power transmission capacity of the **HVDC System** and minimum active power transmission capacity of the **HVDC System** of the **HVDC System** to contribute to frequency control; the same test shall verify the steady-state parameters of frequency regulations;
d) to continuously modulate active power to contribute to frequency control in case of large increase and drop of frequency in the same **Synchronous Area**; the same test shall verify the steady-state parameters of frequency regulations;
e) to continuously modulate active power over the full operating range according to Article 6.1.1;
f) to adjust the ramping rate of active power variations within its technical capabilities in accordance with instructions sent by relevant **TSO**;
g) to energize the busbar of the remote AC substation to which it is connected, within a time frame specified by the relevant **TSO**.

In addition to the verification of the information and the compliance tests as per the above paragraphs, the relevant **TSO** can assess the compliance of an **HVDC System** with the requirements set in this **Connection Code** also by relying on the simulations of the performance of **HVDC System** carried out by the **HVDC System Owner** based on the simulation models referred to in Article 6.5.7.

6.9 Additional requirements

J. This set will include some additional requirements for the mentioned systems.

6.9.1 Additional requirements for remote-end HVDC Converter Stations

Remote-end **HVDC Converter Stations** of an **HVDC System** shall be designed in such a way as to guarantee, at the **HVDC Interface Point**, the frequency and voltage ranges and minimum time periods specified in Section 6.1.

The relevant **TSO** and the remote-end **HVDC Converter Station Owner** may agree on wider frequency and/or voltage ranges or longer minimum times for operation to ensure the best use of the technical capabilities of an **HVDC System**.

The requirements relating to the **Reactive Power Capability** of the remote-end **HVDC Converter Station** shall be agreed with the relevant **TSOs** during the connection procedure (Chapter 3) of the **HVDC System**.

6.9.2 Additional requirements for VRE-units connected through HVDC Systems

VRE-units connected through **HVDC Systems** shall be designed with the same requirements valid for **Invert-based Power Generating Facilities** defined throughout Chapter 5 of this **Connection Code**, applicable at the **HVDC Interface Point** of the **VRE-units**.

The detailed requirements shall be defined by the relevant **TSO** during the connection procedure (Chapter 3) of the **Power Generating Facility**, in particular those related to the reference frequency and voltage at the **HVDC Interface Point** of the **VRE-units**.

7 GUIDELINES FOR DEFINITION OF REQUIREMENTS FOR DISTRIBUTED GENERATION

J. Increasing penetration of **Distributed Generation** (i.e. **Power-Generating Modules** connected at distribution level) may affect the reliability of the **Electricity Systems** of the same **Synchronous Areas**. Accordingly, coordinating and harmonizing connection requirements for **Distributed Generation** among **TSOs** contributes to preserving the quality of the supply. This Chapter provides a set of guidelines on the definition of connection requirements for **Distributed Generation**.

The relevant **Network** operator can agree and define with the relevant **TSO** the connection requirements for **Distributed Generation**. This can be justified by impacts at transmission level, and hence for cross-border issues, that a growing penetration of **Distributed Generation** can bring about.

The significance of **Power-Generating Modules** should be based on their size and their effect on the overall system. Accordingly, the relevant **DSO** or **TSO** shall make a distinction between different types of **Power-Generating Modules** by establishing different levels of requirements.

The methodology in distinguishing between different types of **Power-Generating Modules** should be harmonized among **Member Countries** belonging to the same **Synchronous Area**.

The requirements applicable **Distributed Generation** should be set at the level necessary to ensure capabilities of generation:

a) with limited automated response and resilience to operational events;
b) with limited control from the relevant **DSO** and with a corresponding level of data and information exchange with the local **DSO**;
c) with capabilities to avoid large-scale loss of generation over system operational ranges;
d) with requirements necessary for widespread intervention during system-critical events.

The requirements for **Distributed Generation** shall include:

a) minimum frequency and voltage operating ranges;
b) **Fault Ride Through** capability;
c) rate of change of frequency withstand capability;
d) **LFSM**;
e) constant output at target power;
f) active power reduction;
g) maximum active power reduction at underfrequency;
h) automatic connection and reconnection;
i) requirements for control systems;
j) scheme and settings of protection systems;
k) information exchanges;
l) voltage control system and reactive power capability;
m) post fault active power recovery;
n) reactive current injection (for **Inverter-based Power Generating Modules**).

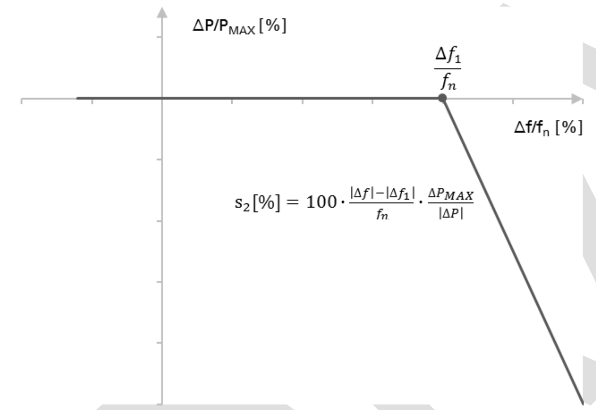
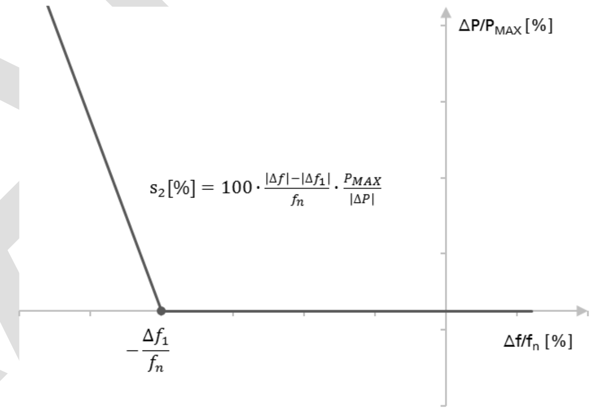
8 ANNEX A – FURTHER SPECIFICATIONS ON LFSM-O/LFMS-U CALCULATION

By principle, **LFSM-O** service can be provided by every **Power-Generating Module** in operation above its minimum regulating level. As it is to be understood as a minimum active power reduction at a specific (high) frequency any further reduction at this frequency, may it be due to a shortfall of the primary energy (e.g. wind) or due to **Grid** constraints is harmless, but would even support the effect of **LFSM-O**.

In contrast, the provision of **LFSM-U** service may be subject to further preconditions. An active power increase is possible only for **Power-Generating Modules** running below their maximum capacity. Typically, RES generation however is dispatched according to their maximum available primary energy, unless there are network constraints. **LFSM-U** capability shall not be understood as requiring **RES** generation to run at a reduced active power output just to be prepared for an increase in case of an unlikely low frequency event. The economic generation dispatch hence shall not be limited by **LFSM-U** performance.

Some numerical examples on LFSM-U and LFSM-O are reported in Table 8-1.

Table 8-1. Examples for LFSM-O and LFMS-U calculations for Power-Generating Modules.

LFSM-O		LFSM-U	
 $f_n = 50\ Hz$ $\Delta f_1 = 0.5\ Hz$ $P_{MAX} = 50\ MW$ $s = 5\%$ The Grid frequency increases of $\Delta f > 0$		 $f_n = 50\ Hz$ $\Delta f_1 = 0.5\ Hz$ $P_{MAX} = 50\ MW$ $s = 5\%$ The Grid frequency decreases of $\Delta f < 0$	
if $\Delta f < \Delta f_1$	LFSM-O not activated, and the Power-Generating Module shall follow the FSM requirements.	if $\lvert\Delta f\rvert < \Delta f_1$	LFSM-U not activated, and the Power-Generating Module shall follow the FSM requirements.
if $\Delta f \geq \Delta f_1$	e.g. $\Delta f = 0.7\ Hz$ LFSM-O is activated. $s = 100 \cdot \frac{\lvert\Delta f\rvert - \lvert\Delta f_1\rvert}{f_n} \cdot \frac{P_{MAX}}{\lvert\Delta P\rvert}$ $\lvert\Delta P\rvert = P_{MAX} \cdot \frac{100}{s} \cdot \frac{\lvert\Delta f\rvert - \lvert\Delta f_1\rvert}{f_n}$ The Power-Generating Module will react to the positive change of Grid	if $\lvert\Delta f\rvert \geq \Delta f_1$	e.g. $\Delta f = -0.9\ Hz$ LFSM-U is activated. $s = 100 \cdot \frac{\lvert\Delta f\rvert - \lvert\Delta f_1\rvert}{f_n} \cdot \frac{P_{MAX}}{\lvert\Delta P\rvert}$ $\lvert\Delta P\rvert = P_{MAX} \cdot \frac{100}{s} \cdot \frac{\lvert\Delta f\rvert - \lvert\Delta f_1\rvert}{f_n}$ The Power-Generating Module will react to the negative change of

	frequency with a decrease in active power equal to: $\lvert \Delta P \rvert = 50\ MW \cdot \frac{100}{5\ \%} \cdot \frac{0.7\ Hz - 0.5\ Hz}{50\ Hz}$ $\lvert \Delta P \rvert = 4\ MW$ The new set-point of the Power-Generating Module will be the initial active power output before the abnormal frequency deviation minus 4 MW		Grid frequency with an increase in active power equal to: $\lvert \Delta P \rvert = 50\ MW \cdot \frac{100}{5\ \%} \cdot \frac{0.9\ Hz - 0.5\ Hz}{50\ Hz}$ $\lvert \Delta P \rvert = 8\ MW$ The new set-point of the Power-Generating Module will be the initial active power output before the abnormal frequency deviation plus 8 MW