FINGRID



FOR CONFIRMATION BY THE ENERGY AUTHORITY

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# Grid Code Specifications for power-generating facilities VJV2024



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# 1 Introduction

This document contains the Grid Code Specifications for power-generating facilities (hereinafter referred to as “Specifications”) required by Fingrid Oyj (hereinafter referred to as “Fingrid”), by virtue of the system responsibility imposed on Fingrid, of power-generating facilities connected to the Finnish power system.

The Specifications are based on the European Network Code (EU Commission Regulation 2016/631), to which Fingrid has made national additions and clarifications. The aim of the European network codes is to guarantee equal and non-discriminatory conditions for competition on the internal energy market, to ensure system security and to create harmonised connection terms for grid connections.

On a national level, the purpose of the Grid Code Specifications for Power Generating Facilities is to ensure that:

- the power generating facility withstands the voltage and frequency fluctuations occurring in the power system,
- the power generating facility supports the operation of the power system during disturbance situations, and operates reliably during and after such situations,
- while synchronised to the power system, the power generating facility does not cause any adverse impacts to the other installations connected to the power system, and
- the relevant network operator and Fingrid obtains the data on the power generating facility, necessary in the planning of the power system and its operation and in the maintaining of system security.

The requirements set out in sections 3–10 concern both synchronous power generating modules and power park modules. The requirements set out in sections 11–15 concern all power generating facilities that have synchronous generators connected directly to the grid. The requirements set out in sections 16–20 concern all power generating facilities whose generated electric power is supplied into the power system partly or completely through a power converter. If other types of power generating facilities are to be connected to the power system, Fingrid will determine their requirements separately.

Power-generating facilities must comply with the following in addition to these grid code specifications:

- Fingrid’s General Connection Terms, as applicable on the date of connection
- The terms and conditions of the main grid contract
- The connection terms and conditions imposed by the relevant network operator
- The requirements imposed on the basis of the Network Code for Emergency and Restoration (NC ER, European Commission Regulation (EU) 2017/2196)

- The requirements set for each (reserve) marketplace when providing ancillary services

## 2 Terms and definitions

**Underexcitation limiter (UEL):** A limiter of AVR in a synchronous generator, intended to maintain a sufficient generator excitation current so that synchronous operation is maintained.

**Discrete reserve power-generating facility:** A power generating facility which is designed to operate only during exceptional or disturbance situations of the power system or in island operation.

**Generator transformer:** A synchronous power-generating module's transformer, through which the power generated by the generator, is supplied into the power system.

**Terminal voltage of generator:** See terminal voltage.

**Hybrid power-generating facility:** A power-generating facility where plant sections of different types, such as facilities with different primary energy sources (solar, wind, hydro) or grid energy storage systems, are connected to a single connection point, and the active or reactive power supplied to the connection point, is controlled by a single, central controller.

**Automatic voltage regulator (AVR):** An automatic voltage regulator controls the reactive power generated by the power generating facility by using either the terminal voltage of the generator or the voltage of the connection point as a reference point.

**K-factor:** Defines a power park module's fault current in relation to the remaining voltage during a fault.

$$k = \frac{\frac{\Delta I_{\mathrm{q}}}{I_{\mathrm{n}}}}{\frac{\Delta U}{U_n}}$$

where $\Delta I_{\mathrm{q}}$ is the additional reactive fault current injected by a power park module, $I_{\mathrm{n}}$ the power-generating facility's nominal current, $\Delta U$ is the voltage change during the fault, and $U_{\mathrm{n}}$ is the network's nominal voltage.

**Commissioning tests:** A power generating facility's commissioning tests related to the Grid Code Specifications for Power Generating Facilities.

**Relevant operator (RO, KVT in Finnish):** The entity appointed by and representing the power-generating facility owner. The RO is responsible for the operation of the power-generating facility in the electricity network. At all times, the RO must know the operating state of the power-generating facility and have the right and possibility to control the power-generating facility and change its operating point and control mode, and authorise or limit any controls issued outside the power-generating facility.

**LFSM-O:** LFSM-O is the active power control mode in which the power-generating facility's active power begins to be decreased automatically above a certain frequency.

**Limited Frequency Sensitive Mode – Under-frequency (LFSM-U):** LFSM-U is the active power control mode in which the power-generating facility's active power begins to be increased automatically below a certain frequency.

**Terminal voltage:** The terminal voltage is the voltage of the generator busbar.

**Power-generating facility owner:** A party whose power generating facility is connected to the power system.

**Connection point:** Ownership limit as specified in the connection agreement.

**Relevant network operator**: The operator of the network to which the power-generating facility is connected. The relevant network operator must hold a valid Energy Authority permit to operate an electricity network.

**Connection agreement:** An agreement between the power generating facility owner and the relevant network operator, specifying the terms and conditions for connecting the power generating facility to the relevant network operator's network.

**Reactive power:** Imaginary component of the apparent power; unit Mvar.

**Reactive power capacity:** The highest reactive power measured at a connection point that the power-generating facility can continuously generate or consume without a time limit.

**Slope:**The relative change of reactive power generated by a power generating facility in relation to the voltage change.

**Minimum output ($P_{min}$):** The minimum output of a power generating facility is the smallest possible active power production level of the power generating facility measured at a connection point, at which power the power generating facility can operate continuously without a time limit.

**Rated reactive power ($Q_n$):** A power-generating facility's rated reactive power is the reactive power used as the base value for voltage or reactive power control in the power-generating facility in accordance with the reactive power capacity requirement.

**Rated capacity ($P_{max}$):** A power-generating facility's rated capacity is its highest active power production level measured at the connection point, at which power the facility can operate continuously without a time limit; the rated capacity has been specified in the connection agreement or otherwise determined by the relevant network operator and the power-generating facility owner.

**Normal operating voltage:** The voltage at the connection point as specified by the relevant network operator (voltage corresponding to 100% value). Expressed as a per unit value, the normal operating voltage is 1.0 pu.

**Step-up transformer:**A transformer between the busbar and connection point of a power park module, the transformer of which the transformer power is generated through by the power park module, is supplied into the power system.

**Numerical:**Data is indicated digitally as numbers in a computer-readable and modifiable format; for example, a measurement time series in commissioning testing.

**Apparent power:** Product of voltage and current at fundamental frequency; unit MVA.

**House load:** Apparent power consumed by the house load equipment of a power generating facility. House load equipment covers those power generating facility equipment and machines that are needed at the power generating facility to generate electricity or heat and electricity, to maintain the capability for generation, and to eliminate or reduce the adverse environmental impacts of the facility.

**Minimum regulating level:** The minimum output if the availability of primary energy does not impose restrictions.

**pu:** per unit value. A variable is compared to a predetermined base value.

**Black start capability:** The ability of a power generating facility to start electricity generation by means of its own power source, without any external power supply from the electricity network.

**Power System Stabiliser (PSS):** Power system stabiliser. An additional function of an AVR, aiming to improve the damping of low-frequency power oscillations with regard to local facility-level oscillation and inter-area oscillation of the power system.

**Active power:** Real component of the apparent power; unit MW.

**Reserve power-generating facility:**A power generating facility which is only used during disturbances in the power system and for restoring the power system to the normal state after disturbances as well as for the management of power balance in the power system in situations where all commercially available resources have been used.

**Droop:**Relative change of active power generated by a power generating facility in relation to the frequency change.

**Power park module:** A power park module means a unit or an economic ensemble of units generating electricity, which is either non-synchronously connected to the network or connected through power electronics, and that also has a single connection point to a transmission system, distribution system including closed distribution system, or HVDC system.

**Maximum regulating level:** The rated capacity if the availability of primary energy or ambient temperature does not impose restrictions.

**Synchronous condenser**: a synchronous machine used to increase the short-circuit power and produce the reactive power needed to control the system's voltage. The synchronous condenser receives its rotational energy from the power system during synchronous operation. It does not have an engine to continuously drive the shaft of the synchronous machine. The synchronous condenser is not capable of continuously producing active power and is, therefore, not a power-generating facility.

**Control mode:** Various modes of control of a power generating facility, such as constant active power control, frequency control, constant reactive power control, or constant voltage control.

**Frequency control:** A power generating facility controls its active power generation in relation to the frequency of the power system defined by a specified droop. In this way, the power generating facility supports the maintenance of frequency stability in the power system.

**Synchronous power-generating module:** An indivisible set of installations which can generate electrical energy such that the frequency of the generated voltage, the generator speed and the frequency of network voltage are in a constant ratio and thus in synchronism.

**Mode:** See control mode.

**Production power:** Active power production generated by a power generating facility at a specific time.

**Turbine generator:** A combination of turbine and generator that converts the kinetic energy of the medium flowing through the turbine into electrical energy.

**Wind turbine generator:**A power generating unit which converts the kinetic energy of wind into electrical energy.

**Wind power park module:**A power-generating facility with one or more wind turbine generators.

**Specifications:** Grid Code Specifications for power-generating facilities VJV2024.

**Grid-forming converter:** Based on its control mode, the converter acts as a voltage source connected in series with the source impedance. Grid-Forming Control (GFC) aims to help maintain a constant angle of the voltage source, as described by the converter's control system, when changes occur rapidly. Grid-Forming (GFM) generally refers to the control features of the Grid-Forming converter (GFMI or GFI).

**Power-generating facility:** A facility built for power generation, capable of supplying electric power to the connection point. A power-generating facility is built around one or more power-generating units and includes, depending on the form of power generation, the equipment and systems required for the production of energy, the power-generating facility level control and automation system, the internal electricity network of the power-generating facility, the generator, step-up and house load transformers, and other auxiliary equipment of the power-generating facility.

**YLE:** Fingrid's General Connection Terms.

**Over-excitation limiter:** A limiter of AVR, intended to prevent the overexcitation of the generator and generator transformer by limiting the excitation current.

# 3 Scope

These Specifications shall apply to those power-generating facilities connected or to be connected to the Finnish power system where the rated capacity of the power-generating facility is at least 0.8 kW. The Specifications vary according to the power generating facility’s method of connection, the power generating facility’s rated capacity and the connection point’s voltage level.

The Specifications are applied to new power generating facilities to be connected to the power system, but they shall also apply to existing power generating facilities when their technical characteristics are changed. Notification of a change must be given in compliance with the procedure outlined in section 6.2.

The power-generating facility owner is responsible for fulfilling and maintaining the VJV2024 Specifications if the power-generating facility’s connection contract was signed after the VJV2024 adoption date or the facility’s binding procurement agreement was signed after 1 July 2025. Otherwise, the power-generating facility owner must fulfil and maintain the specifications that were in force when the power-generating facility’s connection agreement was concluded. The Specifications shall be fulfilled at the connection point or at a point defined separately by a specific requirement.

The Specifications are staggered according to type categories based on the power generating facility’s rated capacity and the connection point’s voltage level. The type categories applied in this document are presented in Table 3.1.

**Table 3.1. The power-generating facility's type classification based on rated capacity and the connection point's voltage level.**

| Type category | Connection point's voltage level | Term /condition | Power-generating facility's rated capacity $P_{max}$ |
|---|---|---|---|
| Type A | The connection point's voltage level is less than 110 kV[1] | and (*) | The power-generating facility's rated capacity is at least 0.8 kW but less than 1 MW. (0.8 kW ≤ $P_{max}$ <1 MW) |
| Type B | The connection point's voltage level is less than 110 kV[1] | and (*) | The power-generating facility's rated capacity is at least 1 MW but less than 10 MW. (1 MW ≤ $P_{max}$ < 10 MW) |
| Type C | The connection point's voltage level is less than 110 kV | and (*) | The power-generating facility's rated capacity is at least 10 MW but less than 30 MW. (10 MW ≤ $P_{max}$ < 30 MW) |
| Type D | The connection point's voltage level is at least 110 kV | or (+) | The power-generating facility's rated capacity is at least 30 MW ($P_{max}$ ≥ 30 MW) |

[1] Regardless of the connection point's voltage under the connection agreement, the voltage level of the connection point of type A and B power generating facilities is considered to be the voltage level to which the power generating facility's main transformer is connected or the voltage level to which the power generating facility is connected directly without a main transformer.

The rated capacity of synchronous power-generating modules shall be classed according to the size of the installations and include all the components of a power-generating facility that normally run indivisibly, such as separate alternators driven by the separate gas and steam turbines of a single combined-cycle gas turbine installation. A facility that includes several such combined-cycle installations shall be assessed on the basis of the size of one installation, and not on the facility's aggregated capacity.

The rated capacity of a power park module shall be classed on the basis of the rated capacity agreed upon for the power-generating facility with the relevant network operator and Fingrid. Such a power generating facility includes one or more power park units, which are collected together to form an economic unit and which have a single connection point. The rated capacity of a power park module may be limited by software to a value lower than the aggregated nominal rated capacity of the power park modules in the power generating installation.

The rated capacity of a hybrid power-generating facility must be classed on the basis of the rated capacity agreed upon for the power-generating facility with the relevant network operator. Such a power-generating facility consists of two or more plant sections that have one connection point and share a controller that controls the active power or reactive power supplied to the connection point. The plant sections can be power park modules based on primary energy sources, synchronous power-generating modules, or grid energy storage facilities. The rated capacity of the power park modules of a hybrid power-generating facility may be limited by software to a value lower than the aggregated nominal rated capacity of the power park modules in the installation. The rated capacity of the synchronous machine sections is classed according to the installation's size.

Offshore power generating facilities that are connected to the power system shall meet the requirements for onshore power generating facilities, unless the connection of the power generating facility is via a high voltage direct current connection. In this case, the connection conditions are determined according to the requirements applying to these power-generating facilities and the grid code specifications for direct current connections.

In terms of energy storage systems, these Specifications apply solely to pump storage power generating modules; other types of energy storage systems are beyond the scope of the Specifications, for instance battery storage.

With regard to power generating facilities linked to the networks of industrial sites, power generating facility owners, network operators of industrial sites and relevant network operators whose network is connected to the network of an industrial site shall have the right to agree on conditions for disconnection of such power generating facilities together with critical loads, which secure production processes, from the relevant network operator's network. Exercising this right must be co-ordinated with Fingrid.

Power-generating facilities for combined heat and power production embedded in the networks of industrial sites must fulfil the requirements related to active power control and frequency control only with regard to section 10.2.3, where all of the following criteria are met:

- the primary purpose of those facilities is to produce heat for production processes of the industrial site concerned;
- heat and power-generating is inextricably interlinked, that is to say any change of heat generation results inadvertently in a change of active power generating and vice versa.

The Specifications do not apply to discrete reserve power generating facilities if they operate in the system for less than five minutes per calendar month while the system is in normal system state. Parallel operation during maintenance or commissioning testing of reserve power generating facilities and the power system shall not count towards the five-minute limit. Maintenance is considered to be periodic, repeated operating tests that have been scheduled in advance (e.g. a one-hour test run between 8–9 a.m. on the first Monday of every month).

The requirements do not apply to synchronous condensers. The technical specifications for synchronous condensers must be agreed upon separately with Fingrid and the relevant network operator.

# 4 Confidentiality

Confidentiality obligations have been laid down explicitly in European Commission Regulation 2016/631, Article 12, and these obligations are applied nationally to these Specifications:

*"Article 12*

*Confidentiality obligations*

*1. Any confidential information received, exchanged or transmitted pursuant to this Regulation shall be subject to the conditions of professional secrecy laid down in paragraphs 2, 3 and 4.*

*2. The obligation of professional secrecy shall apply to any persons, regulatory authorities or entities subject to the provisions of this Regulation.*

*3. Confidential information received by the persons, regulatory authorities or entities referred to in paragraph 2 in the course of their duties may not be divulged to any other person or authority, without prejudice to cases covered by national law, the other provisions of this Regulation or other relevant Union law.*

*4. Without prejudice to cases covered by national or Union law, regulatory authorities, entities or persons who receive confidential information pursuant to this Regulation may use it only for the purpose of carrying out their duties under this Regulation."*

## 5 Specific study requirements

The power generating facility owner shall request from Fingrid the assessment of a need for a specific study during the preliminary planning stage of the power generating facility if the power generating facility belongs to type category D (table 3.1). The assessment of the need for a specific study is a part of the assessment of the requirements for connecting the power-generating facility to the grid and it must be carried out before signing the connection agreement. Fingrid recommends that the power-generating facility owner request the assessment of the specific study requirements before signing a binding procurement agreement for the main components of the power-generating facility, as specific studies may affect the selection and dimensioning of the power-generating equipment and the project's timetable.

Fingrid assesses the need for a specific study in at least the following areas:

- Subsynchronous interaction
- Geomagnetically induced currents
- Dampening of power fluctuations
- Low minimum short-circuit power at the connection point
- Converter interaction phenomena
- The need for specific network protection scheme or another protection solution
- The need for a control solution operated from outside the power-generating facility; and
- Power quality

If the technical execution of a power generating facility connection requires specific studies, the power generating facility owner shall conduct the studies in co-operation with Fingrid and the relevant network operator no later than during the planning stage of the power generating facility grid connection. If there is no adequate prior evidence of the conformity of the technology used at the power-generating facility that Fingrid can use in its assessment, it may be necessary to conduct some specific studies before signing the connection agreement. The power generating facility owner is responsible for executing and co-ordinating the specific studies.

If the specific studies indicate that the connection of the power generating facility requires specific measures in order to ensure the technical feasibility of the power generating facility, the measures are treated as equivalent to the Specifications, and the power generating facility owner is responsible for their execution.

# 6 Compliance monitoring process of the Specifications, continuous monitoring, and related responsibilities

This section describes the compliance monitoring process of the Specifications for all synchronous power-generating modules and power park modules as well as continuous monitoring of the power-generating facilities' compliance and operational notification procedure. Moreover, this section defines the responsibilities, obligations and rights of the power generating facility owner, relevant network operator and Fingrid during the compliance monitoring process and continuous monitoring. The details of the responsibilities, obligations and rights for specific requirements are recorded in sections 7–20 of this document.

The power generating facility owner must take into account that the Specifications compliance process described in this document does not include the power generating facility's connection process in its entirety. The compliance process is described solely in terms of verifying the system's technical capabilities. The power generating facility owner must always agree on the connection with the relevant network operator before the connection is planned. The power generating facility owner and the relevant network operator conclude a connection agreement that specifies the detailed connection terms. A connection cannot be made without the relevant network operator's permission.

In these Specifications, the relevant network operator means a network operator with a valid Energy Authority permit to operate an electricity network. If the network operator at the power-generating facility's connection point does not have the permit mentioned above, the party that holds the rights and bears the responsibilities defined in the Specifications shall be the operator of the network to which the power-generating facility connects directly or via a connection network. Said operator shall hold a network permit. A conformant connection point acc. to the Specifications for a power-generating facility is a connection point in a network that holds an Energy Authority permit.

## 6.1 Responsibilities, obligations and rights during the compliance monitoring process and during continuous monitoring

### 6.1.1 Responsibilities, obligations and rights of the power-generating facility owner and the relevant network operator

The power generating facility owner is responsible for the compliance monitoring process and fulfilment of the Specifications as well as for the associated costs. The power generating facility owner is responsible for fulfilling and maintaining operations according to the Specifications throughout the power generating facility's lifetime.

The power generating facility owner shall notify the relevant network operator of the planned test schedules and procedures to be followed for verifying the power generating facility's compliance with the Specifications, in due time and prior to their launch. The relevant network operator shall specify the date of the notification. The relevant network operator shall approve in advance the planned test schedules and procedures. Such approval by the relevant network operator must be given in a timely manner and shall not be unreasonably withheld. The relevant network operator may participate in such tests and record the performance of the power generating facility.

The relevant network operator has the right specify additional requirements if they are needed because of an electricity network located close to the power generating facility. Potential conflicts between the Specifications and the additional requirements specified by the relevant network operator shall be resolved between Fingrid and the relevant network operator.

The relevant network operator shall supervise the compliance monitoring process of the Specifications during the power generating facility project, and take care of the data exchange required by the process with the power generating facility owner and Fingrid. The relevant network operator shall verify the data supplied by the power-generating facility owner and assess whether the power-generating facility is in compliance with the Specifications, and shall notify the power-generating facility owner of the outcome of the assessment.

The relevant network operator shall have the right to request that the power-generating facility owner carry out compliance checks, tests and simulations according to a repeat plan or general scheme or after any failure, modification or replacement of any equipment which may have an impact on the power-generating facility's compliance with the Specifications.

The relevant network operator shall make publicly available a list of information and documents to be provided as well as the requirements to be fulfilled by the power generating facility owner within the framework of the compliance process.

The relevant network operator shall make public the allocation of responsibilities between the power generating facility owner and the network operator for compliance testing, simulation and monitoring.

The relevant network operator may totally or partially delegate the performance of its compliance monitoring to third parties. In such cases, the relevant network operator shall continue ensuring compliance with the confidentiality obligations (chapter 4), including entering into confidentiality commitments with the assignee.

If compliance tests or simulations cannot be carried out as agreed between the relevant network operator and the power-generating facility owner due to reasons attributable to the relevant network operator, then the relevant network operator shall not unreasonably withhold the operational notification according to the compliance monitoring process (section 6.4).

The power generating facility owner shall maintain the operation of the power generating facility in accordance with the Specifications also after the accepted execution of the compliance monitoring process of the Specifications. If the power generating facility owner discovers that the operation of the power generating facility is in conflict with the Specifications, the power generating facility owner shall inform the relevant network operator and Fingrid of this without delay, and take the necessary measures to eliminate the conflict.

The relevant network operator shall inform the power generating facility owner and Fingrid without delay if the relevant network operator discovers at any stage of the power generating facility project or during the normal operation of the power generating facility that the power generating facility derogates from the Specifications.

### 6.1.2 Fingrid's responsibilities, obligations and rights

The responsibilities, obligations and rights of the relevant network operator apply to Fingrid when the power generating facility is connected to Fingrid's grid.

If Fingrid receives information or discovers that the power generating facility derogates from the Specifications at any stage of the power generating facility project or during the normal operation of the power generating facility, Fingrid may require additional clarifications and measures to correct the derogation. If the shortcomings in the operation of the power generating facility related to the Specifications influence the operation of the power system, Fingrid, as the transmission system operator, has the right to restrict the operation of the power generating facility and to impose conditions related to the operation of the power generating facility. Fingrid has the right to keep the restrictions imposed in force until the shortcomings detected in the operation of the power generating facility have been corrected and the capability of the power generating facility to fulfil the Specifications has been verified.

Fingrid's representative has the right to participate in commissioning testing when the power generating facility is connected to the electricity network of a third party.

## 6.2 Amendment of power-generating facility technical characteristics

If changes are made to a type C or D power generating facility which is in operation or to the equipment or systems influencing its technical characteristics, the power generating facility owner shall, before making the changes, inform the relevant network operator of the changes and of their impact on the capability of the power generating facility to fulfil the Specifications.

It is the relevant network operator's responsibility to evaluate and set new requirements for the equipment and systems being changed, in accordance with the Grid code Specifications for Power Generating Facilities valid at the time.

The relevant network operator must update the existing connection agreement to include information about the equipment to be changed and the Specifications to be applied. If the relevant network operator considers the scope of the change (modernisation or replacement of equipment) to be such that it requires a new connection agreement, the network operator must agree on the terms of a new connection agreement with the power generating facility owner.

If the relevant network operator and the power generating facility owner cannot agree on the connection terms, the matter must be taken to the Finnish Energy Authority. The Energy Authority must decide whether the connection agreement that is in effect should be amended or a new one should be drawn up, as well as the extent to which the Specifications must be complied with.

## 6.3 Power-generating facility projects progressing in stages

The power generating facility owner shall take into account the trend in the generation capacity of the power generating facility during the various stages of the project, and the final rated capacity of the power generating facility. With power generating facility projects progressing in stages, the Specifications are determined on the basis of the final rated capacity of the power generating facility.

It is the power generating facility owner's responsibility to verify that the power generating facility fulfils the Specifications if at least one of the following conditions are met:

1) the rated capacity of the power generating facility or the connection point's voltage level exceeds the type limit related to the Specifications, shown in table 3.1 ,

2) the structure or functionalities of the power generating facility change in a way which affects the technical characteristics and functionalities of the power generating facility.

## 6.4 Compliance monitoring process of Specifications and operational notification procedure for power-generating facilities

### 6.4.1 Compliance monitoring process and operational notification procedure for a type A power-generating facility

The operational notification procedure for the connection of each new type A power generating facility must include submitting an installation document. The power generating facility owner shall ensure that the required information is filled in on the installation document obtained from the relevant network operator and is submitted to the network operator.

Separate installation documents shall be provided for each power generating facility. The power generating facility owner may rely upon equipment certificates, issued as per Regulation (EC) No 765/2008, for compliance monitoring.

The relevant network operator shall ensure that the required information can be submitted by third parties on behalf of the power generating facility owner.

The relevant network operator shall specify the content of the installation document. The installation document must contain at least the following information:

a) the location at which the physical connection is made;

b) the date of the connection;

c) the rated capacity of the installation in kW;

d) the type of primary energy source;

e) reference to equipment certificates issued by an authorised certifier used for equipment that is in the site installation;

f) as regards equipment for which an equipment certificate has not been received, information shall be provided as directed by the relevant network operator; and

g) the contact details and signatures of the power-generating facility owner and the installer.

The power generating facility owner shall ensure that the relevant network operator and Finnish Energy Authority are notified about the permanent decommissioning of a power generating facility. The relevant network operator shall ensure that such notification can be made by third parties, including aggregators.

### 6.4.2 Compliance monitoring process and operational notification procedure for type B and C power-generating facilities

In the operational notification procedure concerning the connection of type B and C power generating facilities, the use of equipment certificates issued by an authorised certifier is permitted.

For the purpose of the operational notification procedure for the connection of each new type B power generating facility, a power generating facility document (Table 7.1), which shall include a statement of compliance, shall be provided by the power generating facility owner to the relevant network operator.

For the purpose of the operational notification procedure for the connection of each new type C power-generating facility, power-generating facility documents (Tables 7.2 and 7.3), which shall include a statement of compliance, shall be provided by the power-generating facility owner to the relevant network operator.

In the statement of compliance, the power-generating facility owner shall indicate each delivered document or file name in the reference column in the table in chapter 7 and confirm with a signature that the power-generating facility fulfils the set Specifications.

A separate independent power generating facility document from a power generating facility shall be provided for each power generating facility.

The power generating facility owner shall perform commissioning tests to verify that the power generating facility operates in compliance with the Specifications and shall provide the relevant network operator with data conforming to the Specifications after the commissioning tests.

Once the power-generating facility owner has carried out the measures required by the compliance monitoring of the Specifications, the relevant network operator shall review the data delivered by the power-generating facility owner and give a statement of the compliance monitoring of the Specifications. The relevant network operator, on acceptance of a complete and adequate power generating facility document, shall issue a final operational notification to the power generating facility owner.

After the giving of a final operational notification, the relevant network operator shall deliver the data conforming to the Specifications to Fingrid. If the relevant network operator refuses to issue a final operational notification, the reasons for such refusal and measures required to rectify the matter must be presented to the power generating facility owner.

The documentation and delivery of power-generating facility data is specified in chapter 7. The real-time measurements and instrumentation are specified in chapter 9. The compliance monitoring of the Specifications by means of commissioning tests is specified in chapters 14 and 19. Modelling requirements and compliance monitoring are specified in chapters 15 and 20.

The measures related to the compliance monitoring of the Specifications shall be successfully completed no later than 12 months from the date on which the power generating facility supplied active power to the power system for the first time.

The power generating facility owner shall ensure that the relevant network operator and Finnish Energy Authority are notified about the permanent decommissioning of a power generating facility.

### 6.4.3 Compliance monitoring process and operational notification procedure for a type D power-generating facility

#### 6.4.3.1 Phases in the compliance monitoring process

The power-generating facility owner and the relevant network operator must carry out a compliance monitoring process and operational notification procedure for a type D power-generating facility in stages according to Table 6.1. The procedure presented in Table 6.1 is described in detail in stages in the sub-sections of this section. The implementation of the compliance-monitoring process as part of a power-generating facility project must be agreed upon as early as possible during the project's preliminary planning phase, as described in section 6.4.3.2.

Once the power-generating facility owner has carried out the measures conforming to the Specifications in each stage in the required scope, the relevant network operator shall verify the data supplied and confirm the execution of the required measures in each stage, as well as deliver the energisation operational notification (EON) or operational notification required after each stage to the power-generating facility owner. The relevant network operator shall supervise the compliance monitoring process of the Specifications, including the commissioning tests, during the power generating facility project, and take care of the data exchange required by the process with the power generating facility owner and Fingrid. The relevant network operator shall deliver the data conforming to the Specifications to Fingrid after the confirmation of each stage of the process.

The documentation and delivery of power-generating facility data is specified in chapter 7. The real-time measurements and instrumentation are specified in chapter 9. The compliance monitoring of the Specifications by means of commissioning tests is specified in chapters 14 and 19. Modelling requirements and compliance monitoring are specified in chapters 15 and 20.

The power generating facility owner shall ensure that the relevant network operator and Finnish Energy Authority are notified about the permanent decommissioning of a power generating facility.

**Table 6.1. Compliance monitoring process of the Specifications, operational notification procedure and schedule requirements for type D power-generating facilities.**

| Process stage | Condition | Schedule requirement and additional information |
|---|---|---|
| Stage 0 (Preliminary planning)<br>• Agreeing on specific studies (chapter 5)<br>• Compliance monitoring process, including monitoring methods and follow-up<br>• Technical specifications | The information required for the implementation of the power-generating facility is completed, and technical planning can begin. | At the earliest possible stage before signing the connection agreement. |
| Energisation operational notification (EON) | The physical grid connection is ready for commissioning. | The connection must be implemented according to the terms of the connection agreement. Upon receiving the EON, the power generating facility owner shall have the right to energise the network beyond the connection point. |
| Stage 1 (Planning):<br>• Planning data<br>• Modelling data<br>• Required calculations<br>• Project-specific preliminary setpoints<br>• Delivery of real-time measurement data<br>• Statement of compliance | The power generating facility owner can deliver the Stage 1 data as soon as they are available. | The Stage 1 data must be provided as early as possible—at least 6 months prior to the planned start of electricity production—so that an interim operational notification for the power-generating facility can be processed.<br><br>The data to be delivered is listed in section 7.4. |
| Interim operational notification (ION) | The power-generating facility owner has delivered the Stage 1 data and carried out a real-time measurement. The continuous recorder system and any remote control connections have been tested and are in operation.<br>The relevant network operator has confirmed the implementation of the required measures. | Upon receiving an interim operational notification (ION), the power generating facility owner shall have the right to operate the power generating facility and generate power to the connection point for not more than 18 months. |
| Stage 2 (Commissioning and compliance):<br>• Changes and updates to Stage 1 data<br>• Planning and | The relevant network operator has given an interim operational notification (ION) | The power generating facility owner must deliver the commissioning testing plan to the relevant network operator no later than 2 months before the planned start of the tests. |

| | | |
|---|---|---|
| implementation of commissioning testing<br>● Reporting of test results<br>● Validation of modelling data<br>● Final setpoints of control devices and protection<br>● Statement of compliance | | The commissioning tests shall be performed in an approved manner within 9 months and the Stage 2 measures within 12 months from the date on which the power generating facility supplied active power to the power system for the first time. The data to be delivered is listed in section 7.4. |
| Stage 3 (Review and approval):<br>● Review of delivered data<br>● Approval of the process | The power generating facility owner has delivered the Stage 2 data and carried out the measures, and the relevant network operator has confirmed that the required measures have been implemented. | The relevant network operator must review the delivered data and confirm that the required measures have been carried out.<br>The relevant network operator must deliver a statement on compliance with the Specifications no later than three months after receiving the Stage 2 data. |
| Final operational notification (FON) | The relevant network operator has confirmed the implementation of the Stage 3 measures. | Upon receiving the FON, the power generating facility owner shall have the right to operate the power generating facility and generate power to the connection point until further notice. |

### 6.4.3.2 Stage 0 (Preliminary planning)

The power-generating facility owner, Fingrid and the relevant network operator must agree at the earliest possible stage—during the preliminary planning stage of the project before signing the connection contract—upon compliance monitoring as part of the project.

The power-generating facility owner is responsible for arranging the kick-off meeting to discuss the compliance monitoring process. The kick-off meeting shall be attended by Fingrid and the relevant network operator. At the meeting,

- the initial technical data for the project and its key design principles shall be reviewed
- any specific studies, as referred to in chapter 5, shall be conducted to determine and consider the precise requirements applying to the project
- the attendees shall agree upon the practices related to following up and documenting the stages in the compliance monioring process
- the timetable for the compliance monitoring process shall be reviewed and compared with the timetable for the power-generating facility project

#### 6.4.3.3 Construction of a physical connection, and the energisation operational notification (EON)

A physical grid connection is implemented according to the connection agreement concluded between the power generating facility owner and the relevant network operator. When the connection is ready to be commissioned, the relevant network operator shall review compliance with the terms of the connection agreement and give the power-generating facility owner an EON.

The EON gives the power generating facility owner the right to energise the network and the auxiliaries of the power generating facility beyond the connection it controls. The EON does not entitle the facility owner to supply active power to the connection point.

#### 6.4.3.4 Stage 1 (Planning) and interim operational notification (ION)

In Stage 1, the power-generating facility owner shall deliver to the relevant network operator the data listed in section 7.4 and carry out real-time measurement in accordance with the instructions in chapter 9.

The power generating facility owner shall deliver a statement of compliance as part of the delivery of the Stage 1 data. In the statement of compliance, the power generating facility owner shall indicate each delivered document or file name in the reference column in Table 7.2 and confirm with a signature that the power generating facility fulfils the set Specifications. A statement of compliance issued by Fingrid's digital service may be used instead of a written statement of compliance.

The Stage 1 data must be provided as early as possible—at least six months prior to the planned start of electricity production—so that an interim operational notification for the power-generating facility can be processed. The data shall be submitted to Fingrid's digital service. The relevant network operator shall review the data submitted, except for the modelling data, which Fingrid shall review. After having the data approved and gaining Fingrid's approval of the modelling data, the relevant network operator shall confirm the implementation of the necessary measures and grant the ION to the power-generating facility owner.

The power-generating facility's continuous recorder system, real-time measurements, and, if applicable, the remote control connection must be tested and operational before the ION is granted to the power-generating facility owner.

The ION is valid for a period of 18 months, during which time the power generating facility owner shall have the right to operate its power generating facility and generate power to the connection point.

The period of validity of the ION may be extended on justified grounds for no more than 6 months. An extension of the period of validity must be requested from the relevant network operator and Fingrid, which may by a unanimous decision, extend the period of validity of the ION. If there is a still a further need to derogate from this, a request for such derogation must be requested in accordance with the procedure described in chapter 8.

6.4.3.5 Stage 2 (Commissioning and compliance):

In Stage 2, the power-generating facility owner carries out the planning and implementation of the power-generating facility's commissioning tests and delivers the data listed in section 7.4 to the relevant network operator. In addition, any possible changes and updates to the Stage 1 data shall be delivered to the relevant network operator during Stage 2.

The power-generating facility owner shall deliver a statement of compliance as part of the delivery of the Stage 2 data. In the statement of compliance, the power generating facility owner shall indicate each delivered document or file name in the reference column in Table 7.3 and confirm with a signature that the power generating facility fulfils the set Specifications. A statement of compliance issued by Fingrid's digital service may be used instead of a written statement of compliance.

The condition for the Stage 2 measures is an interim operational notification (ION). All Stage 2 measures must be completed while the ION is valid.

With respect to the planning of commissioning tests, the power generating facility owner must deliver the commissioning testing plan to the relevant network operator no later than 2 months before the planned start of the tests. The commissioning tests shall be performed in an approved manner within 9 months and the Stage 2 measures within 12 months from the date on which the power generating facility supplied active power to the power system for the first time. If the commissioning tests cannot be carried out within the stated time frame for a justified reason—for example, because the production is dependent on the weather—the power-generating facility owner may apply to extend the deadline for carrying out the tests, taking into account the validity period of the ION. The power-generating facility owner may request extra time from Fingrid and the relevant network operator, who can issue a unanimous decision to extend the deadline for conducting the commissioning tests and taking the measures for Stage 2.

6.4.3.6 Stage 3 (Review and approval) and final operational notification (FON)

In Stage 3, the relevant network operator reviews all data delivered during the process and confirms that the required measures have been carried out. The relevant network operator must deliver a statement on compliance with the Specifications no later than three months after receiving the Stage 2 data. If there are no comments to be made on the data delivered during the process, the relevant network operator must issue a final operational notification (FON).

The FON is valid until further notice and it entitles the power generating facility owner to use the power generating facility and to produce power to the connection point.

6.4.3.7 Limited operational notification (LON)

A limited operational notification procedure enters into effect when significant and unforeseen modifications take place at the power generating facility and affect its ability to fulfil the Specifications. A power generating facility owner to whom a FON has been granted shall inform the relevant network operator immediately in the following circumstances:

- the power generating facility is temporarily subject to either significant modification or loss of capability affecting its performance; or
- an equipment failure leading to non-compliance with some relevant Specifications is observed.

The power generating facility owner shall apply for a limited operational notification (LON) from the relevant network operator if the power generating facility owner reasonably expects the above-mentioned circumstances to persist for more than three months.

A LON shall be issued by the relevant network operator and shall contain the following information which shall be clearly identifiable:

- the unresolved issues justifying the granting of the LON;
- the responsibilities and timescales for the expected solution; and
- a maximum period of validity which shall not exceed 12 months. The initial period granted may be shorter with the possibility of an extension if evidence is submitted to the satisfaction of the relevant network operator demonstrating that substantial progress has been made towards achieving full compliance.

The FON shall be suspended during the period of validity of the LON with regard to the items for which the LON has been issued.

A further extension of the period of validity of the LON may be granted upon a request for a derogation made to the relevant network operator before the expiry of that period, in accordance with the derogation procedure described in chapter 8 .

The relevant network operator shall have the right to refuse to allow the operation of the power generating facility once the LON is no longer valid. In such cases, the FON shall automatically become invalid.

If the relevant network operator does not grant an extension of the period of validity of the LON when a request for derogation has been made or if it refuses to allow the operation of the power generating facility once the LON is no longer valid, the power generating facility owner may refer the issue for decision to the Finnish Energy Authority within six months after the notification of the decision of the relevant network operator.

# 7 Documentation and delivery of power-generating facility data

## 7.1 Data to be delivered for a type A power-generating facility

The relevant network operator specifies the data to be delivered for a type A power-generating facility, in accordance with the instructions in section 6.4.1.

## 7.2 Data to be delivered for a type B power-generating facility

The data specified in Table 7.1 shall be delivered on type B power generating facilities. Moreover, the data specified in Table 7.4 shall be delivered on synchronous power generating modules. The power generating facility owner shall submit this power generating facility data to the relevant network operator as electronic documents after the commissioning testing. The data to be submitted shall be clear and unambiguous in terms of its layout and structure. The relevant network operator shall deliver the data to Fingrid. The data shall be submitted to Fingrid's digital service.

The power generating facility owner shall deliver a statement of compliance as part of the data to be delivered. In the statement of compliance, the power generating facility owner shall indicate each delivered document or file name in the reference column in Table 7.1 and confirm with a signature that the power generating facility fulfils the set Specifications. A statement of compliance issued by Fingrid’s digital service may be used instead of a written statement of compliance.

**Table 7.1. Data to be delivered for a type B power-generating facility.**

| **1 General data** | Ref |
|---|---|
| **1.1** Single line diagram | |
| **1.2** Structure | |
| Type of power generating facility (e.g. wind power, solar power, biomass, gasification) | |
| Basic data (e.g. on wind power park module: tower height, rotor diameter, converter powered etc.) | |
| **1.3** Location data (municipality, area, connection point, coordinates) | |
| **1.4** Diagram of common service architecture (CSA) and information security plan | |
| **2 Technical details of transformers:** | |
| **2.1** Number, supplier and type details of the power generating facility's transformers | |
| **2.2** Documentation and data sheets of transformers | |
| Power [MVA], current [A], transformation ratio [primary, secondary], short-circuit impedance [%], short-circuit resistance [%], vector group and earthing details, control range and step of on- or off-load tap-changer [%, %], number of steps of on- or off-load tap-changer and selected step [quantity, step] | |
| **3 Technical details of power generating facility:** | |
| **3.1** Number, supplier and type details of power-generating units | |
| **3.4** Documentation and data sheets of power-generating units | |
| Apparent power [MVA], rated capacity [MW], maximum output [MW], minimum output [MW], current [A], voltage [V], | |
| Electric parameters of synchronous machines (resistances, reactances, and related time constants) see Table 7.4 | |
| **3.5** Dependence of production power on operating conditions (e.g. wind velocity, temperature) | |
| **3.6** Potentially used compensation devices and/or devices used for the correction of power factor | |
| Number, type, rated values of devices (power, current, voltage, frequency) | |
| If used for the filtering of harmonics, data on the structure and tuning frequency | |
| **4 Power generating facility operational characteristics:** | |
| The following items may be replaced, for example, by the manufacturer's device documents, testing documentation according to the IEC 61400-21 standard or other testing documentation | |
| **4.1** Data on the power generating facility's reactive power capacity and PQ diagrams of generators | |
| **4.2** Data on the power generating facility's ability to operate at undervoltage and overvoltage | |
| **4.3** Data on the power generating facility's ability to operate at underfrequency and overfrequency | |
| **4.4** Data on the power generating facility's ability to operate during voltage disturbances | |
| **4.5** Data on the power generating facility's fault current injection during a voltage disturbance | |
| **4.6** Data on the power generating facility's active power control characteristics | |
| **4.7** Data on the power generating facility's voltage control characteristics | |
| **5 Protection details of the power generating facility:** | |
| **5.1** Relay protection diagram of the power generating facility | |
| **5.2** Final relay protection setpoints of the power generating facility | |
| **5.3** Data on the operating principle of island protection | |
| **6 Commissioning documents:** | |
| **6,1** Commissioning records | |
| **6,2** Final setpoint values and mode of voltage control | |
| **Statement of compliance** | |

The power generating facility owner's representative confirms with a signature that the documents referred to in this table's reference details prove that the power generating facility meets the Specifications set for it.
Place, date, signature and printed name:

## 7.3 Data to be delivered for a type C power-generating facility

For type C power-generating facilities, the data specified in Tables 7.2 and 7.3 must be delivered. Moreover, the data specified in Table 7.4 shall be delivered on synchronous power generating modules. The power generating facility owner shall submit this power generating facility data to the relevant network operator as electronic documents after the commissioning testing. The data to be submitted shall be clear and unambiguous in terms of its layout and structure. The relevant network operator shall deliver the data to Fingrid. The data shall be submitted to Fingrid's digital service.

Fingrid shall verify the modelling data from the power-generating facility. Notwithstanding the aforementioned obligation to submit the modelling data to Fingrid only after commissioning, Fingrid recommends submitting the modelling data to Fingrid for review well in advance (at least 6 months) before the installation is commissioned.

The power generating facility owner shall deliver a statement of compliance as part of the data to be delivered. In the statement of compliance, the power generating facility owner shall indicate each delivered document or file name in the reference column in tables 7.2 and 7.3 and confirm with a signature that the power generating facility fulfils the set Specifications. A statement of compliance issued by Fingrid’s digital service may be used instead of a written statement of compliance.

## 7.4 Data to be delivered for a type D power-generating facility

### 7.4.1 Delivery and schedule of power-generating facility data

The power-generating facility owner shall deliver power-generating facility data on type D power-generating facilities to the relevant network operator in accordance with the compliance monitoring process of the Specifications for the power-generating facility, specified in section 6.4.3:

1) The data specified in Table 7.2 shall be delivered in Stage 1 of the compliance monitoring process. Moreover, the data specified in Table 7.4 shall be delivered on synchronous power generating modules.

2) The data specified in Table 7.3 shall be delivered in Stage 2 of the compliance monitoring process.

The power generating facility owner shall submit this power generating facility data to the relevant network operator as electronic documents after the compliance monitoring process of the power generating facility. The data to be submitted shall be clear and unambiguous in terms of its layout and structure. The relevant network operator shall deliver the data to Fingrid. The data shall be submitted to Fingrid's digital service.

The power generating facility owner shall deliver a statement of compliance as part of the data to be delivered. In the statement of compliance, the power generating facility owner shall indicate each delivered document or file name in the reference column in tables 7.2 and 7.3 and confirm with a signature that the power generating facility fulfils the set Specifications. A statement of compliance issued by Fingrid’s digital service may be used instead of a written statement of compliance.

### 7.4.2 Data to be delivered

The data to be delivered on type D power-generating facilities is specified in Tables 7.2 and 7.3. Table 7.4 specifies the additional data to be delivered on synchronous power generating modules. With some of the data to be delivered, the tables make reference to the sections of this document where the topic and the data to be delivered have been elaborated.

**Table 7.2. Data to be delivered for type C and D power-generating facilities. The data in the table for type D power-generating facilities must be delivered in Stage 1 of the compliance monitoring process.**

| | Stage 1 (Planning) | | Ref |
|---|---|---|---|
| 1 | General data | | |
| **1.1** | Name and contact details of project, connection point, relevant network operator and contact details | | |
| **1.2** | Single line diagram | | |
| | | The main components of the power generating facility and the electricity network that connects the components | |
| | | Electric parameters of the components and conductors presented in the single line diagram | |
| **1.3** | Type data | | |
| | | Power generating facility's production type and fuel (e.g. wind power, hydropower, condensing power [coal]) | |
| | | Basic data (e.g. on wind power park module: tower height, rotor diameter, converter powered etc.) | |
| **1.4** | Location data (municipality, area, connection point, coordinates) | | |
| **1.5** | Diagram of common service architecture (CSA) and information security plan | | |
| 2 | Technical data | | |
| **2.1** | Number, supplier and type details of power-generating units | | |
| **2.2** | Documentation and data sheets of power-generating units | | |
| | | Production units' apparent power [MVA], rated capacity [MW], minimum output [MW], current [A], voltage [V], frequency [Hz] | |
| | | Data specified in Table **7.4** on synchronous power generating modules | |
| | | Water time constant of hydroelectric power plants ($T_w$) | |
| **2.3** | Documentation and data sheets of transformers | | |
| | | Power [MVA], current [A], transformation ratio [primary, secondary], short-circuit impedance [%], short-circuit resistance [%], vector group and earthing details, control range and step of on- or off-load tap-changer [%, %], number of steps of on- or off-load tap-changer and selected step [quantity, step] | |
| **2.4** | Documentation and data sheets of other components | | |
| | | Where applicable, the same data as on power generating units (section 2.2) and transformers (section 2.3) as well as all data that is relevant in terms of the Specifications (e.g. structure, filter tuning frequency) | |
| 3 | Operating voltage and frequency range | | |
| **3.1** | Data on the power generating facility's ability to operate at undervoltage and overvoltage (section **10.2.1 or 10.5.1**) | | |
| **3.2** | Data on the power generating facility's ability to operate at underfrequency and overfrequency (section **10.2.1 or 10.5.1**) | | |
| **3.3** | Data on the power generating facility's rate of change of frequency withstand capability (section **10.2.2**) | | |
| 4 | Fault-ride-through capability | | |
| **4.1** | Calculation of the operation of the power generating facility during voltage disturbance, and potential reports on factory testing (section **10.3.2 or 10.5.3**) | | |
| **4.2** | Data on capability to operate during short-time overvoltage (luku **10.3.3**) | | |
| **4.3** | Data on fault current injection of a power park module (section **18.1.2**) | | |
| **4.4** | Data on active power recovery after a voltage disturbance (section **10.3.4**) | | |
| 5 | Active power control and frequency control | | |
| **5.1** | Documentation and description of active power control and frequency control (chapter **11 or 16**) | | |
| | | Documentation on the control system's implementation and technical characteristics. | |
| | | Functional block diagram on the implementation of control described as transfer curves. (E.g. according to IEEE PES-TR1). | |
| **5.2** | Parameters and operating delays set for controllers | | |
| 6 | House load and changes in production power | | |
| **6.1** | Data on the operation of the power generating facility in house load operation (section **11.3.5**) | | |
| | | Magnitude of house load of the power generating facility, operating time in house load operation, potential delays in terms of transition to house load operation and synchronisation with the grid, and restrictions in terms of transition to house load operation | |
| **6.2** | Changes in production power | | |
| | | Changes in production power in conjunction with frequency and voltage fluctuations | |
| | | Dependence of production power on operating conditions (e.g. temperature, wind velocity) | |
| | | Operating conditions leading to the shutdown of production power (e.g. limit value of maximum wind velocity) | |
| | | Rate of change of production power, functionality and constraints of limiters of rate of change | |

**Table 7.2 continues.**

| | | |
|---|---|---|
| 7 | Reactive power capacity of the power generating facility | |
| 7.1 | Reactive power capacity calculation (section **12.2.4** or **17.2.4**) | |
| 7.2 | PQ diagrams | |
| | PQ diagrams of power generating units or generators and data on their voltage-frequency dependence. The setpoints used in the reactive power limiters shall be specified in the PQ diagrams. | |
| 7.3 | Other components influencing reactive power | |
| | Components that generate (e.g. capacitor or STATCOM) and consume reactive power, and their operation as a function of the variables (e.g. voltage, active power) influencing the components | |
| 8 | Voltage control and reactive power control | |
| 8.1 | Documentation and description of voltage control and reactive power control (chapter **13** or **18**) | |
| | Documentation on the control system's implementation and technical characteristics. | |
| | Functional block diagram on the implementation of control described as transfer curves. (e.g. according to IEEE 421.5). | |
| 8.2 | Parameters and operating delays set for controllers | |
| 8.3 | Voltage control performance calculation (section **13.2.3** or **18.2.2.1**) | |
| 9 | Protection setpoints of the power generating facility and impact on power quality | |
| 9.1 | Protection setpoints (section **10.3.5**) | |
| | Data on the relay protection diagram of the generators and at the facility level as well as on the setpoints of the described protection. Related data shall be submitted on protection which leads to the disconnection of the generator/facility from the grid and on protection whose activation leads to a restriction or automatic change in the generator's/power generating facility's active power, reactive power or voltage. | |
| 9.2 | The power generating facility's impact on power quality (section **10.4.4**). | |
| | Description of the change in power quality caused by the connection of the power generating facility to the grid, and potential reports of factory testing (e.g. according to IEC 61400-21). | |
| 10 | Data required for dynamic modelling | |
| | Project-specific data or simulation models required by the modelling of dynamic operation in accordance with the Specifications (Chapter **15** or **20**) | |
| 11 | Real-time measurement data and instrumentation | |
| 11.1 | Method of delivery and verification of real-time measurement data (section **9.3**) | |
| 11.2 | Technical data on and the setpoints of disturbance and swing recorders | |
| 12 | Specific study requirements | |
| | Required specific studies related to the Specifications (chapter **5**) | |
| 13 | Power generating facility project's schedule and commissioning | |
| | Schedule of the power generating facility project and the planned timing of the commissioning tests relating to the Specifications. Possible options for expanding the project and known future expansion plans shall also be reported. | |
| | Statement of compliance | |
| | The power generating facility owner's representative confirms with a signature that the documents referred to in this table's reference details prove that the power generating facility meets the Specifications set for it.<br>Place, date, signature and printed name: | |

**Table 7.3. Data to be delivered for type C and D power-generating facilities. The data in the table for type D power-generating facilities must be delivered in Stage 2 of the compliance monitoring process.**

| | Stage 2 (Commissioning and compliance) | Reference |
|---|---|---|
| 1 | Changes and further specifications | |
| | Further specifications to the data delivered in stage 1 of the compliance verification process | |
| 2 | Data related to commissioning tests | |
| 2.1 | Commissioning test plan (section **14.3.1** or **19.3.1**) | |
| | The detailed commissioning testing plan, commissioning instructions provided by the power generating facility supplier and a description of the practical arrangements of the tests for verifying compliance with the Specifications shall be submitted to the relevant network operator **at the latest two months before the tests are started**. | |
| 2.2 | Commissioning schedule (section **14.3.1** or **19.3.1**) | |
| | Commissioning schedule; subsequent changes to the commissioning schedule shall be co-ordinated with the relevant network operator and Fingrid. | |
| 2.3 | Measurement arrangements (section **14.3.1** or **19.3.1**) | |
| | Plan of the execution of measurements for the tests related to the Specifications. Data on both fixed measuring equipment and measuring equipment only used during the commissioning tests. | |
| 3 | Results of commissioning tests | |
| 3.1 | Commissioning report on tests related to the Specifications (section **14.3.3** or **19.3.3**) | |
| 3.2 | Key results of commissioning tests in numerical format (Table **15.2** or **20.2**) | |
| 4 | Verified modelling data | |
| | Validated data required for the modelling of dynamic operation, or simulation models (chapter **15** or **20**) | |
| 5 | Final controller setpoint values | |
| | Final setpoint values of the controllers of active power and frequency as well as of the controllers of voltage and reactive power of the power generating facility/generators. | |
| 6 | Final protection setpoint values | |
| | Final protection setpoint values of the power generating facility/generators and the power generating facility connection. | |
| | Statement of compliance | |
| | The power generating facility owner's representative confirms with a signature that the documents referred to in this table's reference details prove that the power generating facility meets the Specifications set for it.<br>Place, date, signature and printed name: | |

**Table 7.4. Data to be delivered on the generators of synchronous power-generating modules.**

| | | | |
|---|---|---|---|
| 1 | Rated values | | |
| 1.1 | Rated voltage $U_r$ | | [kV] |
| 1.2 | Voltage range | | [pu] |
| 1.3 | Apparent power $S_r$ | | [MVA] |
| 1.4 | Rated capacity $P_{max}$ | | [MW] |
| 1.5 | Rated current $I_r$ | | [A] |
| 1.6 | Rated power factor $cos\ \phi_r$ | | |
| 1.7 | Rated speed of rotation n | | [1/min] |
| 1.8 | Rated excitation voltage $U_e$ | | [V] |
| 1.9 | Rated excitation current $I_f$ | | [A] |
| 2 | Impedances | | |
| 2.1 | Stator resistance R | | [pu] |
| 2.2 | Direct-axis synchronous reactance $X_d$ | | [pu] |
| 2.3 | Direct-axis synchronous reactance $X_d$ (saturated) | | [pu] |
| 2.4 | Quadrature-axis synchronous reactance $X_q$ | | [pu] |
| 2.5 | Direct-axis transient reactance $X_d'$ | | [pu] |
| 2.6 | Direct-axis transient reactance $X_d'$ (saturated) | | [pu] |
| 2.7 | Quadrature-axis transient reactance $X_q'$ | | [pu] |
| 2.8 | Direct-axis subtransient reactance $X_d''$ | | [pu] |
| 2.9 | Quadrature-axis subtransient reactance $X_q''$ | | [pu] |
| 2.10 | Stator stray reactance $X_l$ | | [pu] |
| 2.11 | Zero phase-sequence reactance $X_0$ | | [pu] |
| 2.12 | Negative phase-sequence reactance $X_2$ | | [pu] |
| 3 | Time constants | | |
| 3.1 | DC short-circuit time constant $T_a$ | | [s] |
| 3.2 | Direct-axis transient open circuit time constant $T_{do}'$ | | [s] |
| 3.3 | Quadrature-axis transient open circuit time constant $T_{qo}'$ | | [s] |
| 3.4 | Direct-axis subtransient open circuit time constant $T_{do}''$ | | [s] |
| 3.5 | Quadrature-axis subtransient open circuit time constant $T_{qo}''$ | | [s] |
| 3.6 | Direct-axis transient short-circuit time constant $T_d'$ | | [s] |
| 3.7 | Quadrature-axis transient short-circuit time constant $T_q'$ | | [s] |
| 3.8 | Direct-axis subtransient short-circuit time constant $T_d''$ | | [s] |
| 3.9 | Quadrature-axis subtransient short-circuit time constant $T_q''$ | | [s] |
| 4 | Mechanical parameters | | |
| 4.1 | Inertia constant (turbine, generator and other rotating components) H | | [s] |
| 4.2 | Moment of inertia of generator $J_g$ | | [kgm²] |
| 4.3 | Moment of inertia of each turbine $J_{t1}$, $J_{t2}$, $J_{t3}$, .... | | [kgm²] |
| 4.4 | Moment of inertia of exciter (if available) $J_{exc}$ | | [kgm²] |
| 4.5 | Spring constants between the above-mentioned turbine generator parts $K_{t1\_t2}$ , $K_{t2\_t3}$ , ..., $K_{tx\_g}$ , $K_{g\_exc}$ | | [Nm/Rad] |

## 7.5 Type and factory test data

If specific type or factory tests must be conducted to demonstrate the compliance of a type B, C, or D power-generating facility, the content, method, and timing of the tests shall be agreed upon with Fingrid and the relevant network operator. Fingrid and the relevant network operator shall be allowed the opportunity to participate in tests related to the compliance monitoring process at their own discretion and expense.

The results of completed or necessary type and factory tests relevant to the compliance monitoring of individual devices or installations in a type B, C, or D power-generating facility must be included in the data submitted to Fingrid or the relevant network operator upon request.

## 8 Derogations

The derogation procedure has been laid down explicitly in European Commission Regulation 2016/631, Article 60. The described procedure is applied on a national level to these Specifications.

Pursuant to Regulation 2016/631, Article 62 (5), Fingrid must assess any derogations concerning a type C and D power generating facility. Fingrid shall assess the request for a derogation based on the following criteria:

1) the derogation does not compromise the system security of the power system;
2) the derogation does not restrict the transmission capacity of the power system;
3) the power generating facility does not cause disturbance to the other parties connected to the power system;
4) the power generating facility supports the operation of the power system during disturbance situations, and operates reliably during and after such situations;
5) the derogation is technically and commercially justified; and
6) the derogation may be granted in the future in a similar situation impartially and without discriminating against any future power generating facility projects.

# 9 Real-time measurements, data exchange and instrumentation

## 9.1 Real-time measurements and data exchange for type A power-generating facilities

Real-time measurements are not required for type A power generating facilities. The relevant network operator determines the notification procedure before the power generating facility is connected.

## 9.2 Real-time measurements and data exchange for type B power-generating facilities

The power generating facility owner shall deliver to the relevant network operator the real-time active power and reactive power measurement data, as well as status information on the switchgear.

The relevant network operator shall deliver or oblige the power generating facility owner to deliver to Fingrid the real-time measurement data on the power generating facilities connected to the electricity network of the relevant network operator.

The update cycle of the real-time data may be no more than 60 s. The measurement data shall be available to Fingrid before the power-generating facility begins to supply active power to the power system.

The measurement data shall primarily be delivered as a net measurement[1)]. Upon separate agreement, the data can be delivered as a producer-specific sum if specific power-generating facility data cannot be delivered. In this case, wind and solar power production shall be delivered separately from other production.

Before the power-generating facility begins to supply active power to the power system, the power-generating facility owner shall inform the relevant network operator of this.

Section 10.3.1 presents the requirements for information exchange related to the operation and remote control of the power-generating facility.

The implementation of information exchange is described in more detail in Fingrid's application instruction on real-time information exchange.

## 9.3 Real-time measurements and data exchange for type C and D power-generating facilities

The power generating facility owner shall deliver to the relevant network operator the real-time active power and reactive power measurement data, as well as status information on the switchgear. The measurement data shall primarily be delivered as a net measurement[1]. In addition, the power-generating facility owner must deliver voltage measurement data on the voltage according to which the power-generating facility controls the voltage when operating on constant voltage control.

[1] A power-generating facility's net production is the figure that is achieved when a power-generating facility's house load is deducted from its gross production.

The relevant network operator shall deliver or oblige the power generating facility owner to deliver to Fingrid the real-time measurement data on the power generating facilities connected to the electricity network of the relevant network operator.

The update cycle of the real-time data may be no more than 60 s. The measurement data shall be available to Fingrid before the power-generating facility begins to supply active power to the power system.

Before the power generating facility begins to supply active power to the power system, the power generating facility owner shall inform both the relevant network operator and Fingrid's Main Grid Control Centre of this.

Section 10.4.1 presents the requirements for information exchange related to the control and remote operation of the power-generating facility.

The implementation of information exchange is described in more detail in Fingrid's application instructions on real-time information exchange.

## 9.4 Instrumentation for type C power-generating facilities

Disturbance and swing recorders must be installed in type C power-generating facilities. This recording system consisting of disturbance and swing recorders allows the recording of the power generating facility functionality and its controllers during disturbance and change situations in the power system. The recording system can also be implemented with disturbance recorders integrated in relays. A separate swing recorder is not necessary if the disturbance recorder's recording time covers the requirements set for the swing recorder.

The recording system shall meet the following requirements:

1. The disturbance recorder must measure and record the momentary values of the voltages and currents in each phase at the connection point or a different measurement point agreed upon with Fingrid. The disturbance recorder must be triggered when:

    - a protective relay operates (trip)
    - the voltage is lower than 0.95 or higher than 1.05 pu

2. The swing recorder must measure and record the voltages and currents at the connection point or another measurement point agreed upon with Fingrid as RMS values in stages, as well as record the phase angle of the voltages and currents. If the phase angles are not recorded, the generator's active and reactive power must be recorded. The frequency must also be recorded. The swing recorder must be triggered when:

    - A protective relay operates (pick-up)
    - the voltage is lower than 0.95 or higher than 1.05 pu

- the frequency is lower than 49.80 Hz or higher than 50.20 Hz

3. In addition to the variables cited in items 1 and 2 above, recording the controlling devices' operating points and the SCADA system logs is recommended
4. The measurements in items 1 and 2 above can be taken from the generator terminal values in synchronous power-generating modules.
5. The sampling and recording frequency of the disturbance recorder shall be high (1 kHz or greater). The recording period shall be a few seconds.
6. The sampling frequency of the swing recorder shall be high (1 kHz) and the recording frequency can be low (50 Hz or higher). The recording period shall be a few dozen seconds.
7. Both recorders must record a sample before the trigger point. When the recorder is triggered at 0 s, the recorders must record a set pre-fault time and post-fault time. These pre- and post-fault times are as follows:
    - The disturbance recorder shall record 0.5 to 1 s pre-fault and more than 2 s post-fault
    - The swing recorder shall record 1 to 5 s pre-fault after more than 15 s post-fault
8. The recording systems shall be implemented in such a way that Fingrid has access to the system records no later than 24 hours from Fingrid's request to the power-generating facility owner.
9. The recorder system shall have enough memory to ensure that disturbance recordings remain available for at least seven days after a recorded event. This requirement is considered to be met when at least the last 20 recorded incidents are stored.

## 9.5 Instrumentation for type D power-generating facilities

Type D power-generating facilities must be equipped with a continuous recording system, and the RO must be able to access the measurements quickly. The recording system shall enable the operation of the power-generating facility and its controllers to be recorded continuously whenever the facility is connected to the grid. The equipment must accurately record power system disturbances and changes.

The recording system shall meet the following requirements:

1. The recorder must measure and record the momentary values of the voltages and currents in each phase at the connection point or a different measurement point agreed upon with Fingrid.
2. The recorder must measure and record the active and reactive power and frequency at the connecting point or another measurement point agreed upon with

Fingrid. The recording frequency for power and frequency measurements must be at least 50 Hz.

3. In addition to the variables cited in items 1 and 2 above, recording the controlling devices' operating points and the SCADA system logs is recommended
4. The sampling and recording frequency for current and voltage measurements shall be high (4 kHz or more).
5. The recorder's time shall be synchronised with an external time server (such as the power-generating facility's automation system or the GNSS system).
6. The recording system must be implemented so that the RO can access the recorder's measurements in under an hour, and the relevant network operator and Fingrid receive the recordings no later than eight hours after requesting them.
7. The recording system must have enough storage capacity for 30 days of recordings. Recording can be implemented with a software solution that transfers the measurement data to a repository outside the power-generating facility. However, the continuity of recording must be assured in situations such as telecommunications disruptions.

For synchronous power-generating modules rated at less than 100 MW, interference and oscillation recorders in accordance with chapter 9.4 may be used instead of a continuous recording system.

Although the continuous recording system is the power-generating facility's primary disturbance recorder, Fingrid recommends using the disturbance recorder features of the power-generating facility's protection relays and making the recordings available to the RO.

# 10 General requirements

## 10.1 Power system voltages and frequencies

The normal operating voltage (voltage corresponding to the 100% value) at the connection point is case dependent, and the power generating facility owner must always find out what the voltage is from the relevant network operator. The relevant network operator determines the voltage fluctuation range in its electricity network in normal, disturbance and exceptional situations. In a normal situation, the voltage fluctuation range must be at least 0.90–1.05 pu of the normal operating voltage.

The nominal voltage levels in Finland's main grid are 110 kV, 220 kV and 400 kV. The normal operating voltages of the main grid's connection point on which the design of the connection are based are, correspondingly, 118 kV, 233 kV and 410 kV.

In Fingrid's grid, the voltage fluctuation ranges in normal, disturbance and exceptional situations are as follows: The normal fluctuation range of voltage in a grid with a nominal voltage of 400 kV is 395–420 kV, and in exceptional and disturbance situations the voltage range is 360–420 kV. The normal fluctuation range of voltage in a grid with a nominal voltage of 220 kV is 215–245 kV, and in exceptional and disturbance situations, the voltage range is 210–245 kV. The normal fluctuation range of voltage in a grid with a nominal voltage of 110 kV is 105–123 kV, and in exceptional and disturbance situations, the voltage range is
100–123 kV.

The Nordic Power System's nominal frequency is 50 Hz and the frequency is normally 49.9–50.1 Hz. The frequency of the grid during normal use may vary between 49.0–51.0 Hz and exceptionally even between 47.5–51.5 Hz.

## 10.2 General requirements for a type A power-generating facility

### 10.2.1 Operating voltage and frequency range of the power-generating facility

The power generating facility shall be able to operate continuously and normally in the voltage range defined by the relevant network operator.

The power generating facility shall be able to operate continuously and normally when the electricity system's frequency is 49.0–51.0 Hz. The power generating facility must be able to operate for a period of 30 minutes when the electricity system's frequency is 51.0–51.5 or 49.0–47.5.

The power-generating facility's performance in the frequency and voltage ranges that are technically possible must not be limited without a technically justified reason. This shall be taken into account especially in protection configurations.

The disconnection of an individual plant section of a hybrid power-generating facility as a result of an operating procedure or disruption must not cause the unplanned disconnection of other plant sections.

### 10.2.2 Rate of change of frequency withstand capability

The power generating facility shall be capable of continuing to operate normally when the rate of change of frequency is less than 2.0 Hz/s.

The measurement of the rate of change of frequency shall not react to the sudden changes in the waveform of voltage caused by disturbances in the system.

### 10.2.3 Limited frequency-sensitive mode – over-frequency (LFSM-O)

The power generating facility must be capable of reducing its active power production as a linear function of frequency when the electricity system's frequency exceeds 50.5 Hz (see Figure 10.1), if the availability of primary energy does not impose restrictions.

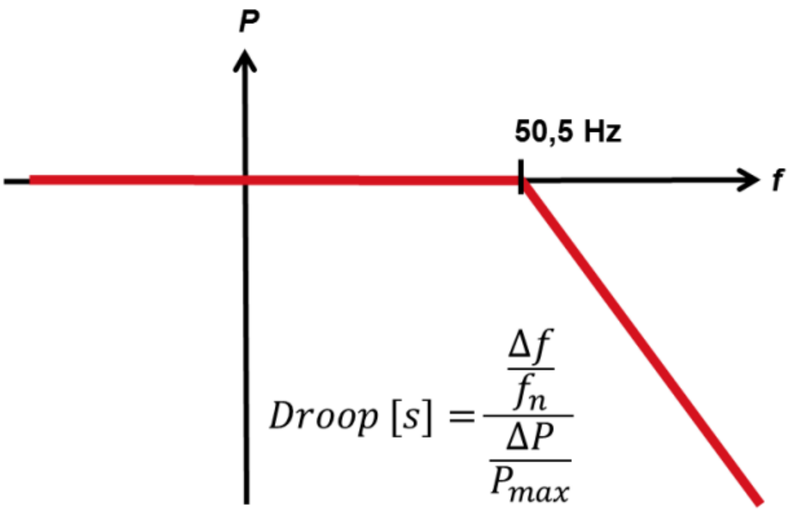
It shall be possible to adjust the droop of LFSM-O between 2 and 12 per cent. The recommended setpoint is 4%.

A frequency response shall be activated with an initial delay that is as short as possible, within two seconds at the most, when the electricity system's frequency exceeds 50.5 Hz. Active power must be reduced at the maximum rate permitted by the power-generating facility's technology.

When a power generating facility achieves the lowest possible regulating level, it must be able to continue its operations at that level. The minimum regulating level is the minimum power output if the availability of primary energy does not impose restrictions. The down-regulation of active power must not result in the disconnection of the power park facility or its individual modules.

The power generating facility shall be capable of operating stably during LFSM-O operation, and when LFSM-O is active, its setpoint will prevail over any other active power setpoints.

Limited frequency sensitive mode – overfrequency status must always be enabled.




$$Droop\ [s] = \frac{\frac{\Delta f}{f_n}}{\frac{\Delta P}{P_{max}}}$$

**Figure 10.1. In LFSM-O operation, the power-generating facility must be capable of reducing its active power production as a linear function of frequency when the electricity system's frequency exceeds 50.5 Hz. It shall be possible to adjust the droop to between 2 and 12 per cent. In the figure, $f$ is the frequency, $f_n$ is the nominal frequency (50 Hz), $P$ is the power-generating facility's active power, and $P_{max}$ is the power-generating facility's rated capacity.**

### 10.2.4 Active power control

The power generating facility must be capable of maintaining active power according to the target value, regardless of changes in the frequency, except when any frequency control mode is active. If the facility's primary energy production decreases rapidly (e.g. when wind velocity decreases), there is no need to maintain active power with a separate energy reserve.

### 10.2.5 Admissible reduction in active power production

When the electricity system's frequency falls below 49 Hz, the power generating facility is allowed to reduce its active power generation linearly by 10% per 1 Hz frequency drop.

The reduction in active power is assumed to take place in environmental conditions where the power generating facility is capable of reaching its rated capacity.

### 10.2.6 Remote control capability

The power generating facility shall be equipped with a logic interface (input port) in order to cease active power output within five seconds following an instruction being received at the input port. The relevant network operator shall decide on the commissioning of a bus interface and define the data transfer protocol used in the bus interface.

### 10.2.7 Autonomous connection

Autonomous connection means that a power-generating facility independently follows an automated sequence of actions to connect to the grid and begin transmitting power.

Autonomous connection is always agreed upon separately with the relevant network operator.

The power-generating facility may autonomously connect to the electricity system if the following conditions are met:

- the electricity system's frequency is 49.0–51.0 Hz
- the connection point's voltage is in the normal range
- the maximum allowed rate of change of the power-generating facility's active power is 100% of the rated capacity in one minute if the relevant operator has not defined a smaller value.
- the relevant network operator permits the installation of an autonomous reconnection system and automatic connection 1–10 minutes after a disturbance

### 10.2.8 Protection

The relevant network operator shall specify the schemes and systems necessary for protecting the network, taking into account the characteristics of the power generating facility. The protection schemes needed for the power generating facility and the network as well as the settings relevant to the power generating facility shall be coordinated and agreed between the relevant network operator and the power generating facility owner.

The power generating facility owner is responsible for specifying the protection settings of the power generating facility and power generating facility connection in order to guarantee personal and equipment safety and to prevent equipment damage.

Fingrid recommends not to use of protection systems that identify the rate of change of frequency (RoCoF) or vector shift (phase jump) as the risk of this kind of protection system malfunctioning is high, and unexpected disconnection may occur in the normal operating voltage and frequency range. If a protection system that detects the RoCoF is used it may disconnect the power-generating facility from the network only if the rate of change of frequency exceeds 4Hz/s for at least 250ms.

A protection system that detects vector shift may only be used to protect power-generating facilities with a rated capacity of less than 50 kW and the protection operates at voltage angle changes greater than 15 degrees.

### 10.2.9 Recovery from loss of external network connection

The loss of the external network connections to the power-generating facility due to a disturbance or planned outage must not cause changes to the facility's compliant operation after the network connections have been restored (such as resetting the configurations of devices to the factory settings).

## 10.3 General requirements for a type B power-generating facility

The same general requirements (section 10.2) apply to type B power-generating facilities as those that apply to type A power-generating facilities, with the exception of remote control capability (section 10.2.6). A type B power generating facility must also fulfil the requirements set out in this section.

### 10.3.1 Operation and remote control of the power-generating facility

The power-generating facility owner must designate a relevant operator (RO) of the power-generating facility. At all times, the RO must know the operating state of the power-generating facility and have the right and possibility to control the power-generating facility and change its operating point and regulation status, and authorise or limit any controls issued outside the power-generating facility. The RO may control the power-generating facility remotely or locally.

If necessary, the relevant network operator is entitled to specify the required remote control commands and status information for the management and monitoring of power-generating facilities connected to its network. The power-generating facility owner is responsible for implementing the information exchange needed for the controls and status information between the power-generating facility and the relevant network operator's systems.

In terms of the relevant network operator’s control capability, the minimum requirement is to equip the power-generating facility with a bus interface (input port), so that a setpoint can be given to the production of active power in order to reduce the active power according to the setpoint. The relevant network operator shall decide on the commissioning of a bus interface and define the data transfer protocol used in the bus interface.

### 10.3.2 Fault ride-through capability

The power-generating facility shall be able to continue operating during and after power system disturbances caused by deep voltage dips:

- *A synchronous power-generating module*, with its house load operation, shall be designed in such a way that it can withstand a momentary voltage fluctuation, as shown in Figure 10.2, occurring at the connection point without being disconnected from the grid and without losing its synchronous operation. Momentary pole slipping of a synchronous power generating module is not allowed.

- *A power park module*, with its house load operation, shall be designed in such a way that it can withstand a momentary voltage fluctuation, as shown in Figure 10.3, occurring at the connection point, without being disconnected from the grid.

After a disturbance, the power generating facility shall be able to operate without being disconnected from the grid during momentary variations in voltage amplitude and phase angle caused by potential local or inter-area electromechanical oscillations following a voltage disturbance.

The fault ride-through requirement is applicable to symmetrical faults (3-phase short circuits) and asymmetrical faults (2-phase short circuits and earth short circuits, 1-phase earth short circuits).

The fault ride-through requirement has been specified for the following conditions:

- Before the voltage disturbance, the voltage of the connection point of the power generating facility is 1.0 pu.
- Before the voltage disturbance, the power generating facility does not supply reactive power to the connection point or take reactive power from the connection point.
- Before the voltage disturbance, the automatic voltage regulator of the power-generating facility is in operation.
- The connection point's short-circuit power is assumed to be at the lower end of the normal variation range indicated by the relevant network operator before and after a fault ride-through.

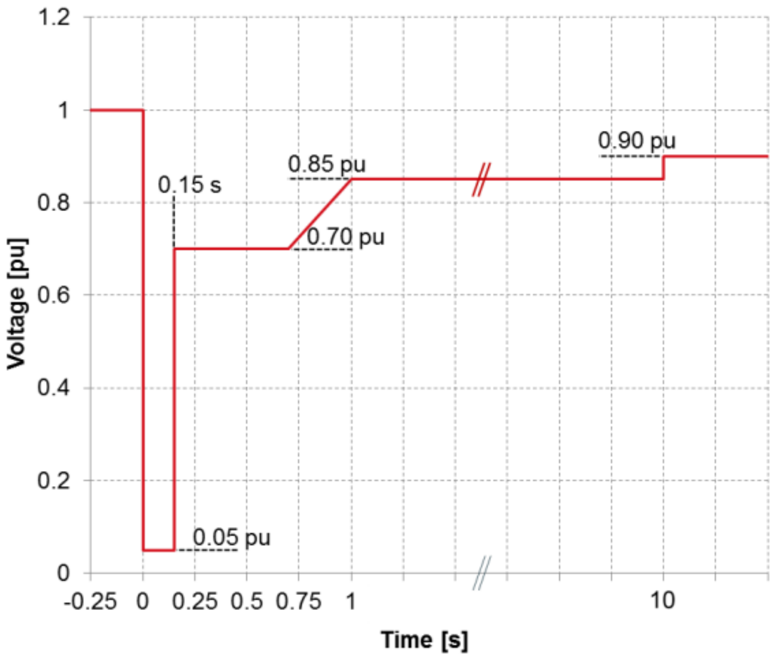



**Figure 10.2. The voltage of a connection point corresponding to a momentary voltage disturbance, during and after which type B and C synchronous power-generating modules shall continue to operate normally. The per unit value 1.0 pu of voltage is the voltage before the disturbance. The voltage is 0.05 pu for 150 milliseconds.**

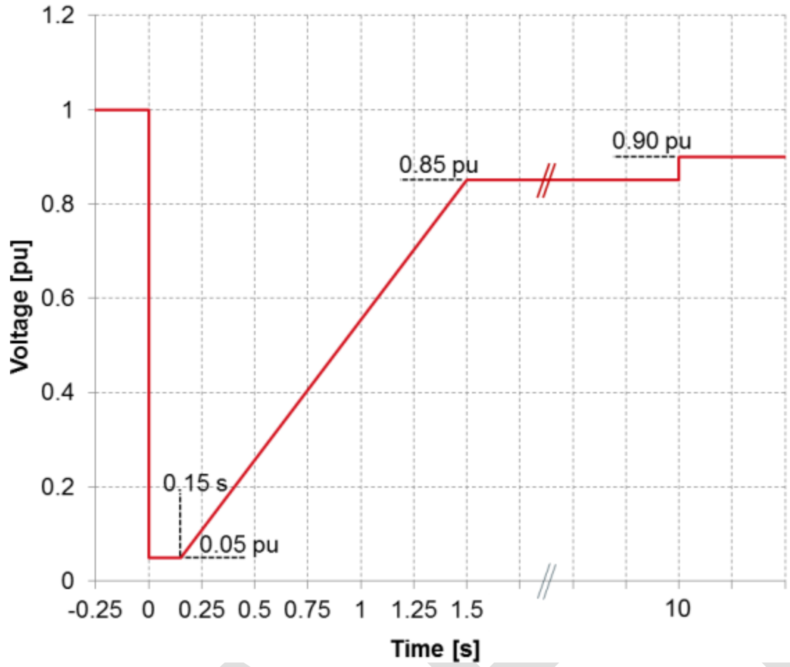



**Figure 10.3. The voltage of a connection point corresponding to a momentary voltage disturbance, during and after which type B and C power park modules shall continue to operate normally. The per unit value 1.0 pu of voltage is the voltage before the disturbance. The voltage is 0.05 pu for 150 milliseconds.**

The power generating facility may not automatically disconnect as a result of several consecutive voltage disturbances. Disconnection in such cases is only allowed when the transient angle stability of the power generating facility is jeopardised or the duration of braking energy exceeds the rated value.

The supply of active power to the grid during and after voltage disturbances must not be unduly restricted.

### 10.3.3 Overvoltage withstand capability

The power-generating facility must be able to continue operating without disconnecting from the grid during and after a momentary overvoltage at the operating frequency, possibly containing other frequency components, at the connection point as shown in Figure 10.4.

The overvoltage withstand requirement applies to symmetrical faults (3-phase short circuits), asymmetrical faults (2-phase short circuits and earth short circuits, 1-phase earth short circuits), and switching.

The overvoltage withstand requirement is defined under the following conditions:

- Prior to overvoltage, the voltage at the power-generating facility’s connection point is the normal operating voltage, i.e., 1.0 pu.

- Before the overvoltage, the power-generating facility does not supply reactive power to the connection point or take reactive power from the connection point.
- Before the overvoltage, the automatic voltage regulator of the power-generating facility is in operation.
- The connection point's short-circuit power is assumed to be at the lower end of the normal variation range indicated by the relevant network operator before and after a fault.
- The relevant network operator defines the voltage outside of the time scale shown in Figure 10.4.

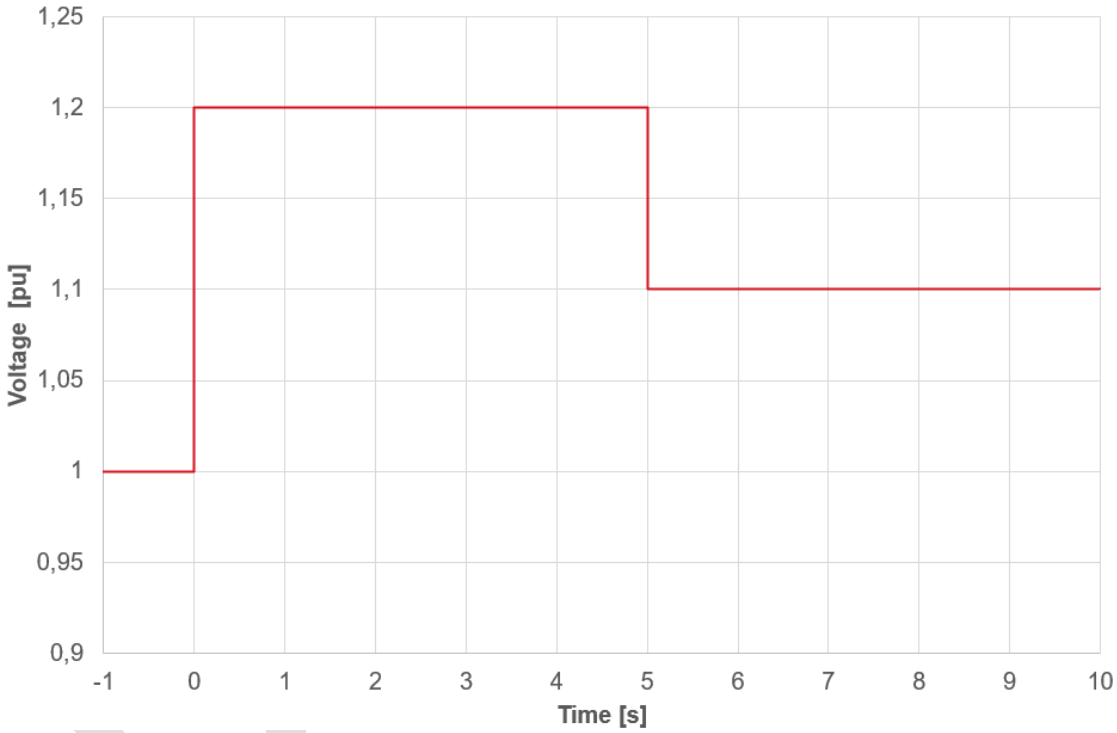



**Figure 10.4. The main voltage of a connection point corresponding to a momentary overvoltage, during and after which type B, C, and D power-generating facilities must continue to operate normally. The relative voltage value of 1.0 pu is the normal operating voltage at the connection point before the disturbance.**

### 10.3.4 Recovery of active power after a voltage disturbance

After a momentary voltage disturbance (see section 10.3.2 or 10.5.2), the power-generating facility shall restore the active power which preceded the disturbance within three seconds of the start of the disturbance. Active power is considered restored when the active power measured at the connection point is at the pre-fault level (tolerance ±5%

of the setpoint. No permanent power changes are accepted as a result of a voltage disturbance.

If the restoration of active power depends on the level of voltage at the connection point, said dependence and a description of its potential impact on power restoration shall be delivered to Fingrid and to the relevant network operator.

### 10.3.5 Protection

The protection settings shall be set in such a way that the power-generating facility remains connected to the grid during disturbances in the power system for as long as this is possible within the scope of the technology and operational safety of the power-generating facility.

The power generating facility owner is responsible for ensuring that the planning of the protection of the power generating facility takes into account the intense short-term changes in the voltages, currents and frequency of the power system caused by disturbances and faults, and the high-speed automatic reconnection and delayed automatic reconnection commonly used in restoring the operation of transmission lines. The configurations shall be based on the capability of the equipment to withstand severe fluctuations in system frequency and in the voltage at the connection point. The protection of the power generating facility must not conflict with the Specifications.

Electrical protection of the power generating facility shall take precedence over operational controls, taking into account the system security and the health and safety of staff and of the public, as well as mitigating any damage to the power generating facility. The power generating facility owner shall organise its protection and control devices in accordance with the following priority ranking (from highest to lowest):

1. the protection of the electricity network and the power generating facility,
2. synthetic inertia (if required),
3. active power control and frequency control,
4. power restriction,
5. power gradient constraint

### 10.3.6 Telecommunications and information security

The power-generating facility owner is responsible for considering information security threats that may affect the operation of the power-generating facility or its connecting network when planning the power-generating facility’s telecommunication connections and information security. Unauthorised access to the power-generating facility’s control system, including any remote access connections, must be prevented. The power-generating facility owner is obliged to ensure that the requirement is also fulfilled for all external service providers that have access to the power-generating facility's systems (such as equipment suppliers or the RO).

The power-generating facility owner must provide Fingrid with a report on the power-generating facility's information security and telecommunications connections as part of the required information. The information shall be submitted to Fingrid in a separately agreed manner.

## 10.4 General requirements for a type C power-generating facility

The same general requirements as for type A and B power-generating facilities (sections 10.2 and 10.3) are applicable to type C power-generating facilities, with the exception of remote control capability (sections 10.2.6 and 10.3.1) and autonomous connection (section 10.2.7). A type C power generating facility must also fulfil the requirements set out in this section.

### 10.4.1 Control and remote operation of the power-generating facility

The power-generating facility owner must designate a relevant operator (RO) of the power-generating facility. At all times, the RO must know the operating state of the power-generating facility and have the right and possibility to control the power-generating facility and change its operating point and regulation status, and authorise or limit any controls issued outside the power-generating facility. The RO may control the power-generating facility remotely or locally. If the primary control method is remote operation, the RO must have the controls and measurements needed to remotely control and monitor the power-generating facility at their control location.

The RO shall change the mode or setpoint of the power-generating facility's active power control or reactive power control within the constraints of the power-generating facility technology if Fingrid's Main Grid Control Centre or the relevant network operator so requests. A control request may be issued using an electronic control connection or by phone.

Figure 10.5 shows the control principle and the parties.

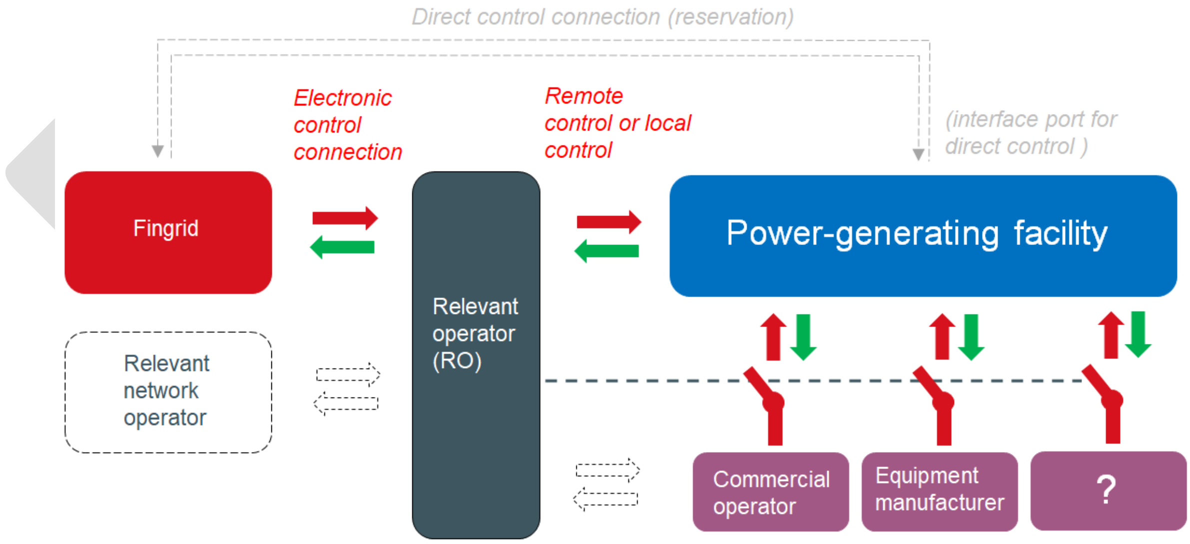



**Figure 10.5. Control and remote operation of the power-generating facility. The RO operates the power-generating facility. Fingrid can issue control requests (the red arrows) to the RO and receive status information (the green arrows) over an electronic control connection. The implementation of a separate direct connection between Fingrid and the power-generating facility is decided upon separately. In addition, the RO may have an electronic control connection (the dashed line arrows on the left) or another form of information exchange with the relevant network operator (such as the distribution system operator) or other operators who can control the power-generating facility subject**

**to certain conditions (the dashed line arrows on the right). The RO has the possibility to authorise and restrict the control capabilities of other parties.**

#### 10.4.1.1 Fingrid's electronic control connection

Fingrid's electronic control connection (see Figure 10.5) refers to the exchange of information between Fingrid and RO's supervisory control and data acquisition systems (SCADA). The power-generating facility owner is responsible for implementing the control connection. The purpose of the electronic control connection is to support the system security of the electricity system by enabling Fingrid, as the party with system responsibility, to coordinate the operations of power-generating facilities in exceptional circumstances.

The RO must be able to use an electrical control connection to:

- receive and implement the control requests sent by Fingrid in accordance with Table 10.1; and
- collect and send to Fingrid status information in accordance with Table 10.2.

A change in the operating mode or setpoint requested via the electronic control connection must be implemented within one minute of receiving the control request from Fingrid. The new operating point (P, Q) corresponding to the requested setpoint must be reached no later than 15 minutes after receiving the control request from Fingrid. The final state of a change requested by phone must be reached no later than 15 minutes after the request is made.

The electronic control connection is used to convey Fingrid's request to adjust the power-generating facility's operation to the RO. The responsibility for the operation of the power-generating facility shall not transfer to Fingrid when control requests are sent. The implementation of control requests in the power-generating facility's systems can be automated, but the RO is always responsible for assessing whether any factors, such as personal or plant safety or fulfilment of specific permit conditions, limit the implementation of the control request. For this reason, the implementation of the control request may be longer than the one-minute response time stated in the requirements.

The implementation of information exchange for the electronic control connection is described in more detail in Fingrid's application instruction on real-time information exchange.

**Table 10.1. Control requests (X) received by the RO from Fingrid. Several separate signals may be required to implement a single control request.**

| No. | Control request | Information received | Synchronous power-generating module | Power park module |
|---|---|---|---|---|
| 1 | Maximum active power value | $P_{min}$–$P_{max}$ | X | X |
| 2 | Active power setpoint | $P_{min}$–$P_{max}$ | X | X |
| 3 | Power requested according to the active power setpoint | Yes/No<br><br>(activates the above active power setpoint request) | X | X |
| 4 | Maximum active power rate of change for setpoint changes | 0.1×$P_{max}$ /min–unlimited, see section 16.3.5 | | X |
| 5 | Rapid down-regulation of active power 100→20% / 5 s | On/Off<br><br>See section 16.3.6 | | X |
| 6 | Voltage and reactive power control mode | Voltage regulation/constant reactive power control/constant power factor control | | X |
| 7 | Constant reactive power control setpoint | $Q_{min}$–$Q_{max}$ (maximum inductive reactive power - maximum capacitive reactive power). | X | X |
| 8 | Voltage setpoint | 105–123 kV / 215–245 kV / 395–420 kV. Setpoints beyond the setpoint range must be prevented.<br><br>For synchronous machines, setpoints corresponding to terminal voltage control must be agreed upon. | X | X |
| 9 | Constant power factor control setpoint | 0.95cap to 0.95ind, see section 18.2.4 | | X |
| 10 | Voltage control setting group* | Switching the configuration between two predefined parametrisations (group | | X |

| | | | | |
|---|---|---|---|---|
| | | 1/group 2), see section 18.2.2 | | |
| 11 | Voltage control droop (slope) setpoint* | 2–7%, see section 18.2.2 | | X |
| 12 | Frequency control by frequency range | On/Off | X | X |
| 13 | Frequency control droop by frequency range | Explained in section 16.3.3.3 | | X |
| 14 | Frequency control power range | Explained in section 16.3.3.3 | | X |
| 15 | State of the electricity system | Normal state/alert state/emergency state state/blackout state/restoration state.<br><br>The status information is informative and can be used to implement controls agreed upon separately with the power-generating facility owner or relevant network operator. | X | X |

*) The necessity of controls affecting the voltage control configuration (no. 10) and the droop setting (no. 11) is assessed based on the technical implementation and performance of voltage control.

**Table 10.2. Status information to be sent from the power-generating facility by the RO to Fingrid**

| No. | Status information | Information to be sent | Synchronous power-generating module | Power park module |
|---|---|---|---|---|
| 1 | Acknowledgement of receipt of controls in Table 10.1 | | X | X |
| 2 | Status information/numerical value corresponding to controls in Table 10.1 | | X | X |
| 3 | Available active power capacity at the power-generating facility | MW | X | X |
| 4 | Available reactive power capacity at the power-generating facility* | Mvar, with the inductive and capacitive capacities separately. | X | X |

| | | | | |
|---|---|---|---|---|
| 5 | Availability of the remote operation connection between the power-generating facility and the RO | Yes/No | X | X |

*) The reactive power capacity can be provided as a rough estimate based on the power-generating facility's active power level to an accuracy of at least ±15% x Qn.

#### 10.4.1.2 Fingrid's direct control connection

The power-generating facility must be equipped with a bus interface (input port) that Fingrid can use to control the power-generating facility directly. The bus connection must enable the exchange of signals shown in Tables 10.1 and 10.2.

Fingrid shall decide on the implementation of a direct control connection and the commissioning of a bus interface for each power-generating facility project separately. Fingrid shall also specify the data transfer protocol used for the bus interface.

#### 10.4.1.3 Relevant network operator's control connections

If necessary, the relevant network operator is entitled to specify the required remote control commands and status information for the management and monitoring of power-generating facilities connected to its network. The power-generating facility owner is responsible for implementing the information exchange needed for the controls and status information between the power-generating facility and the relevant network operator's systems.

#### 10.4.1.4 Other requirements related to the remote control of power-generating facilities

As a prerequisite for starting the supply of active power to the Finnish electricity system, the power-generating facility owner must implement and test the remote operation controls and information exchange described above and provide the contact details of the power-generating facility and the RO to Fingrid and the relevant network operator. The power-generating facility owner is responsible for ensuring that the RO is available 24 hours a day, 7 days a week.

Continuous monitor shall be used to ensure the controllability of the power-generating facility and the functionality of the telecommunication connections used for remote operation. The monitoring solution shall provide the RO with the following information without delay:

- An outage in the remote operation connection between the power-generating facility and the RO's control location; and
- An outage related to the controllability of individual production modules in the power-generating facility.

If control over the production modules in the power-generating facility is lost, the production module must continue operating in accordance with the setpoints in force before the loss of the control, unless a deviating procedure, such as the automatic stop of production, has been agreed upon separately with the relevant network operator. If control cannot be restored within two hours of the loss of control, the power-generating facility must be manned without delay or partially or completely disconnected from the grid, if demanded by the relevant network operator or Fingrid.

The RO must notify Fingrid and the relevant network operator of deviations observed in the operation, controllability, and operating safety of the power-generating facility and its connection network.

The functionality of remote operation connections between the RO, the power-generating facility, Fingrid and the relevant network operator must be tested periodically. The frequency and scope of functional tests shall be agreed upon with Fingrid and the relevant network operator.

### 10.4.2 Autonomous connection

The autonomous connection of a power-generating facility shall always be agreed upon separately with the relevant network operator. If it is allowed, the power-generating facility may connect autonomously to the electricity system when the following conditions are met:

- the electricity system's frequency is 49.0–51.0 Hz
- the connection point's voltage is in the normal range
- the facility's remote control connection is operating
- the operating point after connection (P, Q, U), control mode, and other setpoints are defined or authorised by the RO
- the rate of change of active power does not exceed the value agreed upon with the relevant network operator
- if the restarting of generation by the power-generating facility after disconnection from the grid involves restrictions related to the operation and implementation of the power-generating facility, a description of the restrictions shall be delivered as part of the power-generating facility documentation.

The state of the power system may prevent autonomous connection or require it to be done with hardware settings that differ from the normal operating mode. The power-generating facility must be capable of receiving a signal to prevent autonomous connection and the pre-agreed settings that must be used. Fingrid provides information on the state of the power system as an electrical control using the signal "State of the electricity system" (see section 10.4.1).

### 10.4.3 Limited frequency sensitive mode – under-frequency (LFSM-U)

The power-generating facility must be capable of increasing its active power production as a linear function of frequency when the electricity system's frequency is below 49.5 Hz (see Figure 10.6).

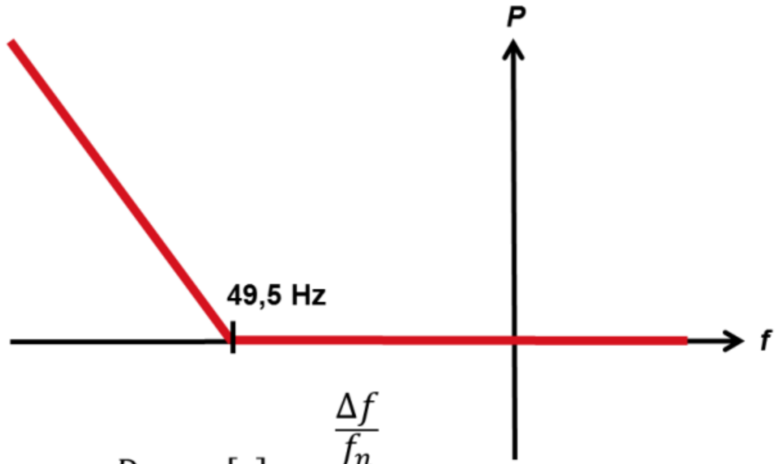
It shall be possible to adjust the droop of LFSM-U between 2 and 12 per cent. The recommended setpoint is 4%.

A frequency response shall be activated with an initial delay that is as short as possible, within two seconds at the most, when the electricity system's frequency is below 49.5 Hz.

When a power generating facility achieves the highest possible regulating level, it must be able to continue its operations at that level. The maximum regulating level is the rated capacity unless the availability of primary energy, the ambient temperature, or the network operator's power limit impose restrictions.

The power-generating facility shall operate stably in LFSM-U mode. Once the mode is activated, the setpoint (maximum regulating level) shall take precedence over any other active power setpoints except the maximum active power value requested by the relevant network operator or Fingrid (see Table 10.1).

Limited frequency sensitive mode – underfrequency status must always be on.




$$Droop\ [s] = \frac{\frac{\Delta f}{f_n}}{\frac{\Delta P}{P_{max}}}$$

**Figure 10.6. In LFSM-U operation, the power-generating facility must be capable of increasing its active power production as a linear function of frequency when the electricity system's frequency is below 49.5 Hz. It shall be possible to adjust the droop to between 2 and 12 per cent. In the figure, $f$ is the frequency, $f_n$ is the nominal frequency (50 Hz), $P$ is the power-generating facility's active power, and $P_{max}$ is the power-generating facility's rated capacity.**

### 10.4.4 Requirements relating to stability

With regard to voltage stability, the power-generating facility may be capable of automatic disconnection when voltage at the connection point exceeds, in continuous state, normal levels specified by the relevant network operator (see section 10.1). The relevant network operator may also specify voltage levels outside the normal levels at which the power generating facility must disconnect.

In the event of power or voltage oscillations, the power-generating facility shall retain steady-state stability when operating at any operating point of the P-Q-capability diagram.

Without prejudice to the admissible active power reduction when frequency falls below 49.0 Hz, the power-generating facility shall be capable of remaining connected to the network and operating without power reduction, as long as voltage and frequency remain within the limits defined in these Specifications (see section 10.2.5).

The power generating facility shall be capable of remaining connected to the network during single-phase or three-phase auto-reclosures on meshed network lines, if the connection point of the power generating facility is not part of a network section that is disconnected.

With regard to loss of angular stability or loss of control, the power generating facility shall be capable of disconnecting automatically from the network in order to help preserve system security or to prevent damage to the power generating facility. Angular stability has been lost when the electrical angular difference between the active power of the power generating facility and the active power of its connection point exceeds 90 degrees in steady state.

### 10.4.5 Power quality

With regard to the power quality, the design of the power-generating facility shall take into account the factors and emission limits affecting the power quality described in the report “Power quality in Fingrid’s 110 kV grid”. The report is available on Fingrid’s website.

The power generating facility owner is obliged to follow the power quality requirements imposed by the relevant network operator. The power generating facility owner shall deliver the information and reports (e.g. IEC 61400-21) requested by the relevant network operator, on the basis of which information and reports the relevant network operator can evaluate the impacts of the power generating facility on the power quality before the power generating facility is connected to the grid.

The power generating facility owner shall be prepared for the power quality specified by the relevant network operator.

### 10.4.6 Earthing of the neutral point of the main transformer

Earthing arrangement of the neutral point at the high-voltage side of the main transformer of the power generating facility owner shall comply with the specifications of the relevant network operator.

### 10.4.7 Black start capability and island operation

Black start and island operation arrangements are agreed upon separately as necessary in accordance with European Commission Regulation 2016/631, Article 15(5).

### 10.4.8 Protection

Use of protection devices based on the detection of the rate of change of frequency (RoCoF) is prohibited.

## 10.5 General requirements for a type D power-generating facility

The same general requirements as for type A, B and C power-generating facilities (sections 10.2, 10.3 and 10.4) are applicable to type D power-generating facilities, with the exception of remote control capability (sections 10.2.6 and 10.3.1), autonomous connection (section 10.2.7) and fault ride-through (section 10.3.2). A type D power generating facility must also fulfil the requirements set out in this section.

### 10.5.1 Control and remote operation of the power-generating facility

In addition to the requirements of section 10.4.1, a type D power-generating facility must be capable of receiving on/off control signal of the special regulation required of it and sending information on the operating status of each regulation. Such special controls include, for example, the power system stabiliser (PSS) in synchronous machines and POD regulation required for power park modules based on the special study requirements in chapter 5.

### 10.5.2 Operating voltage and frequency range of the power-generating facility

The power-generating facility shall be able to operate continuously and normally when the voltage at the connection point is 90–105% of the normal operating voltage and the frequency is 49.0–51.0 Hz. If the voltage, frequency or both at the connection point differ from these values, the power-generating facility shall remain connected to the network for at least the periods of time specified in Figure 10.7. When the frequency falls below 49.0 Hz, the power generating facility is allowed to reduce its active power generation linearly by 10% per 1 Hz frequency drop.

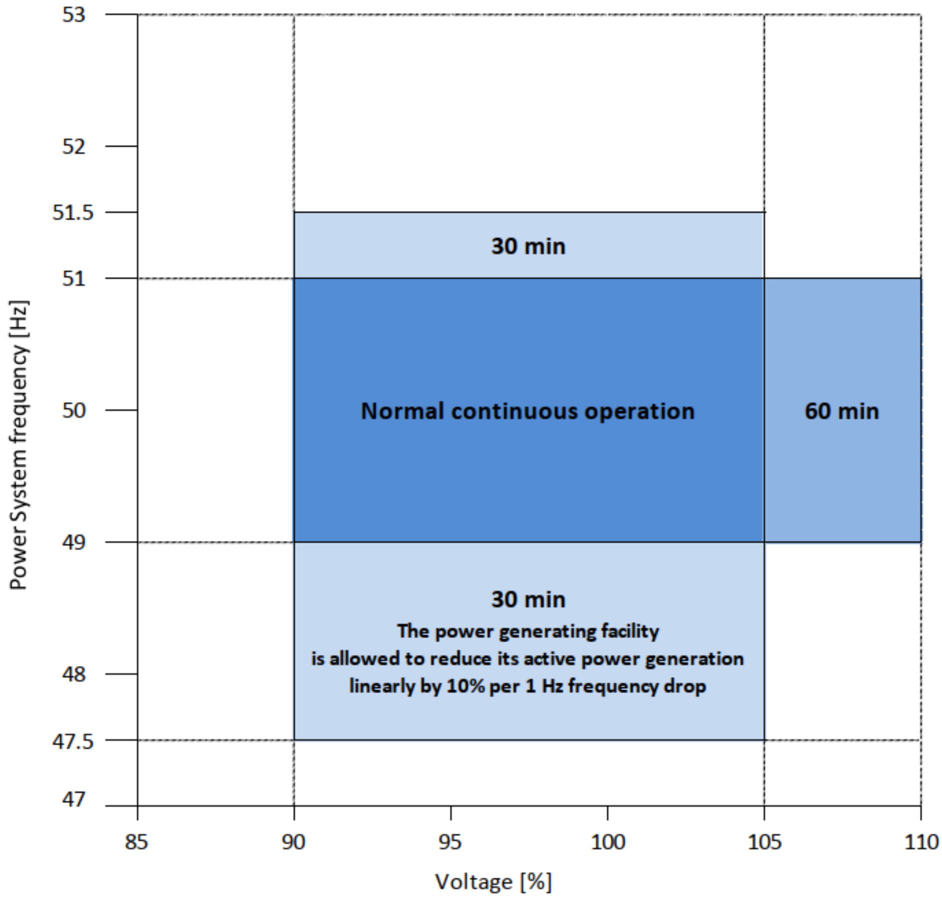



**Figure 10.7. The power-generating facility must remain connected to the network at the different frequencies and voltages at the connection point set out in the figure. The 100% voltage of the continuous operating range in the 400 kV grid is always 400 kV. At other voltages, the value of the voltage corresponding to the 100% value shall be requested from the relevant network operator.**

### 10.5.3 Fault ride-through capability

The power-generating facility shall be able to continue operating during and after power system disturbances caused by deep voltage dips:

- *A synchronous power generating module,* with its house load operation, shall be designed in such a way that it can withstand a momentary voltage fluctuation, occurring at the connection point, without being disconnected from the grid and without losing its synchronous operation. Momentary pole slipping of a synchronous power generating module is not allowed. The requirements are specified according to the voltage level of the connection point:
    - A type D synchronous power-generating module, the nominal voltage of which at the connection point is below 400 kV, must withstand voltage fluctuation as shown in Figure 10.8, occurring at the connection point.

    - A type D synchronous power-generating module, the nominal voltage of which at the connection point is at least 400 kV, must withstand voltage fluctuation as shown in Figure 10.9, occurring at the connection point.

- *A power park module*, with its house load operation, shall be designed in such a way that it can withstand a momentary voltage fluctuation as shown in Figure 10.10, occurring at the connection point, without being disconnected from the grid.

After a disturbance, the power generating facility shall be able to operate without being disconnected from the grid during momentary variations in voltage amplitude and phase angle caused by potential local or inter-area electromechanical oscillations following a voltage disturbance.

The fault ride-through requirement is applicable to symmetrical faults (3-phase short circuits) and asymmetrical faults (2-phase short circuits and earth short circuits, 1-phase earth short circuits).

The fault ride-through requirement has been specified for the following conditions:

- Before the voltage disturbance, the voltage of the connection point of the power generating facility is 1.0 pu.
- Before the voltage disturbance, the power generating facility does not supply reactive power to the connection point or take reactive power from the connection point.
- Before the voltage disturbance, the automatic voltage regulator of the power-generating facility is in operation.
- The connection point's short-circuit power is assumed to be at the lower end of the normal fluctuation range indicated by the relevant network operator before and after a fault ride-through.

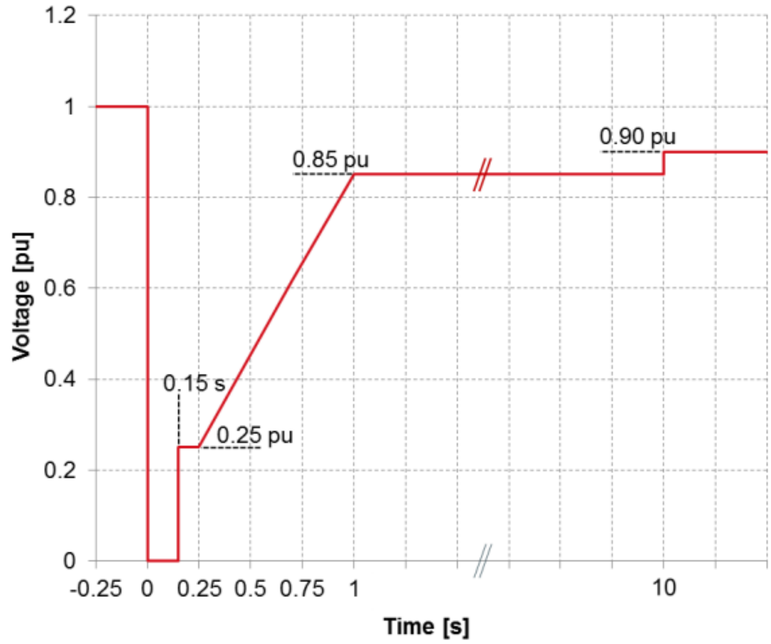



**Figure 10.8. The voltage of a connection point corresponding to a momentary voltage disturbance, during and after which type D synchronous power-generating modules with a nominal voltage under 400 kV at the connection point shall continue to operate normally. The per unit value 1.0 pu of voltage is the voltage before the disturbance. The voltage is 0.00 pu for 150 milliseconds.**

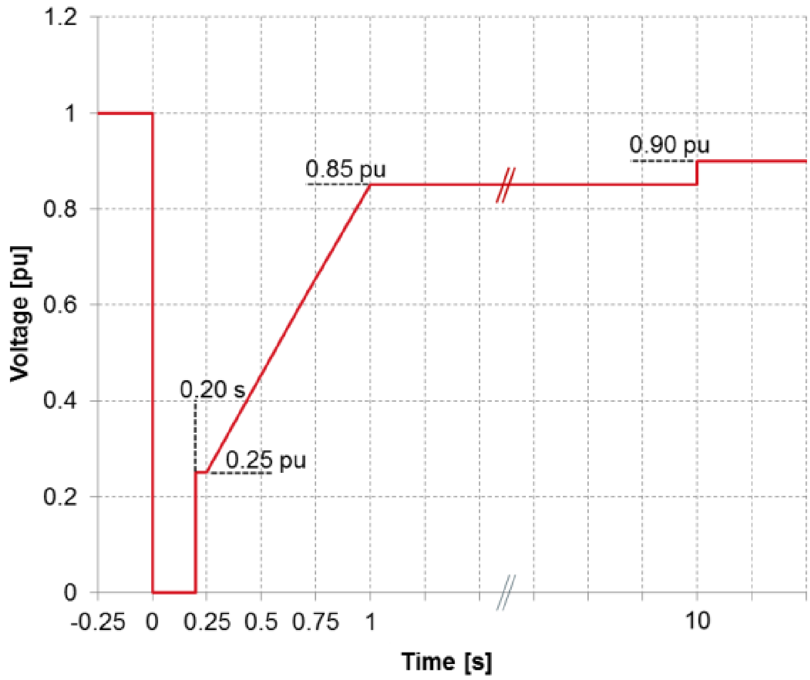



**Figure 10.9. The voltage of a connection point corresponding to a momentary voltage disturbance, during and after which type D synchronous power-generating modules with a nominal voltage of at least 400 kV at the connection point shall continue to operate normally. The per unit value 1.0 pu of voltage is the voltage before the disturbance. The voltage is 0.00 pu for 200 milliseconds.**

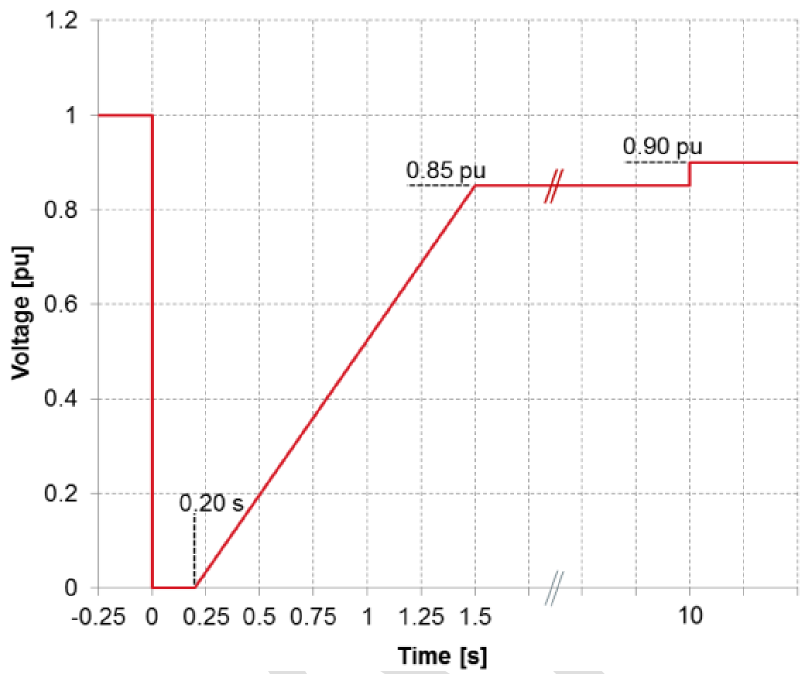



**Figure 10.10. The voltage of a connection point corresponding to a momentary voltage disturbance, during and after which type D power park modules shall continue to operate normally. The per unit value 1.0 pu of voltage is the voltage before the disturbance. The voltage is 0.00 pu for 200 milliseconds.**

The power generating facility may not automatically disconnect as a result of several consecutive voltage disturbances. Disconnection in such cases is only allowed when the transient angle stability of the power generating facility is jeopardised or the duration of braking energy exceeds the rated value.

The supply of active power to the grid during and after voltage disturbances must not be unduly restricted.

### 10.5.4 Calculation of the operation of the power-generating facility during voltage disturbance

A calculation of the fault ride-through capability of the power-generating facility shall be delivered to the relevant network operator in stage 1 of the compliance monitoring process of the specifications of the power-generating facility. The calculation does not need to describe the entire power generation process, but the restrictions set by the power generation process on electricity generation shall be taken into account in the calculation. The calculation shall describe the dynamic operation of the power generating facility during voltage disturbances, the calculation criteria are shown in the tables according to connection point nominal voltage:

- connection point nominal voltage less than 400 kV (Table 10.3)

- connection point nominal voltage at least 400 kV (Table 10.4)

The voltage disturbance calculation shall be performed with the following assumptions:

- Before the voltage disturbance, the voltage of the connection point of the power generating facility is 1.0 pu.
- Before a voltage disturbance, the power-generating facility supplies active power corresponding to its rated capacity to its connection point
- Before the voltage disturbance, the power generating facility does not supply reactive power to the connection point or take reactive power from the connection point.
- Before the voltage disturbance, the automatic voltage regulator of the power-generating facility is in operation.
- When viewed from the power generating facility, an equivalent circuit is made of the power system beyond the connection point. The equivalent circuit contains impedance describing the short circuit power of the power system and ideal voltage source connected in series. If the connection point of the power generating facility is at the 400 kV voltage level or electrically close to a 400 kV transmission grid, the modelling of the power system shall be agreed upon with Fingrid.
- The connection point's short-circuit power is assumed to be at the lower end of the normal fluctuation range indicated by the relevant network operator before the disturbance. The relevant network operator shall inform the power-generating facility owner of the short circuit powers to be used in the calculation and presented in Table 10.3 or 10.4. In the tables, the "Normal" short-circuit power level is the lower limit of the range during the normal operating state. "Minimum" is the short-circuit power level after a disturbance, when the strongest supply connection closest to the connection point is disconnected.
- For synchronous power-generating modules, the fault used in the calculation is a 3-phase short circuit with no fault resistance at the connection point.
- For power park modules, the faults used in the calculation are a 3-phase short circuit with no fault resistance at the connection point, a 2-phase short circuit with no fault resistance, a 2-phase short circuit with earth contact and no fault resistance, and a 1-phase earth fault with no fault resistance.
- A description of the model used in the calculation, including the parameters used in the calculation and the block diagram presentations of the control systems, shall be delivered as part of the calculation to the relevant network operator.
- The results of the calculation shall be compared with the protection settings for the power-generating facility to demonstrate that the protection will not malfunction during a voltage disturbance.

**Table 10.3. Input data used in the voltage disturbance calculation, when the connection point voltage is less than 400 kV.**

| Input data | Fault 1 | Fault 2 |
|---|---|---|
| Fault time | 150 ms | 250 ms |
| Connection point's voltage during the fault | 0.0 pu | 0.25 pu |
| Connection point's short circuit current before the | Normal | Normal |
| Connection point's short circuit current after the fa | Minimum | Normal |

**Table 10.3. Input data used in the voltage disturbance calculation, when connection point voltage is at least 400 kV.**

| Input data | Fault 1 | Fault 2 |
|---|---|---|
| Fault time | 200 ms | 250 ms |
| Connection point's voltage during the fault | 0.0 pu | 0.25 pu |
| Connection point's short circuit current before the | Normal | Normal |
| Connection point's short circuit current after the fa | Minimum | Normal |

### 10.5.5 Overvoltage withstand capability

The voltage outside the time scale shown in Figure 10.4 is determined according to Figure 10.7. In other words, the voltage can remain at 1.10 pu for 60 minutes, including the 10-second period shown in Figure 10.4.

### 10.5.6 Requirements relating to synchronisation

Requirements relating to synchronisation of a power generating facility are as follows:

- The power generating facility shall be equipped with the necessary synchronisation devices.
- The power generating facility owner may synchronise the power generating facility with the grid only after the relevant network operator has given permission to do so.
- Synchronisation of the power-generating facility with the grid shall be possible at the normal continuous operation frequencies and voltages set out in section 10.5.1.
- The power generating facility owner shall agree on the setting of the synchronisation conditions of a synchronous power generating module with the relevant network operator, if the conditions deviate from what is set out below:
  - Frequency 49.0–51.0 Hz
  - Voltage 0.90–1.05 pu.

- Phase angle difference < 10°
- Frequency deviation < 0.2 Hz
- Voltage deviation < 0.05 pu
- Phase sequence shall be the same on both sides of the circuit breaker to be synchronised

## Requirements applicable to synchronous power-generating modules

## 11 Active power control and frequency control of synchronous power-generating modules

### 11.1 Active power control and frequency control of type A synchronous power-generating modules

Type A synchronous power-generating modules shall have the functionalities required by active power control and frequency control and for maintaining power output as described in section 10.2. If the power-generating facility characteristics include other functionalities related to active power control and frequency control, Fingrid has the right, if necessary, to utilise these functionalities as described in section 11.3.1.

### 11.2 Active power control and frequency control of type B synchronous power-generating modules

Type B synchronous power-generating modules shall have the functionalities required by active power control and frequency control and for maintaining power output as described in section 10.3. If the power-generating facility characteristics include other functionalities related to active power control and frequency control, Fingrid has the right, if necessary, to utilise these functionalities as described in section 11.3.1.

### 11.3 Active power control and frequency control of type C and D synchronous power-generating modules

In addition to what is set out in this section, type C synchronous power-generating modules shall have the functionalities required by active power control and frequency control and for maintaining power output as described in section 10.4.

In addition to what is set out in this section, type D synchronous power-generating modules shall have the functionalities required by active power control and frequency control and for maintaining power output as described in section 10.5.

#### 11.3.1 Fingrid's rights during a disturbance in the power system

Fingrid has the right to demand power generating facilities to adjust themselves within the power control features presented in this document, if the power system cannot be restored to the normal state after a disturbance.

#### 11.3.2 Active power and start-up time of a power-generating facility

##### 11.3.2.1 Minimum output

The minimum output of the power generating facility shall be as small as possible. The following minimum outputs shall be used as the design basis for the power generating facility:

- Hydropower, gas turbine and motor power-generating facilities: 10% of rated capacity; and

- Combined heat and power plants and other power-generating facilities: 40% of rated capacity.

The minimum output of the power generating facility and its capability to operate momentarily below its minimum output limit shall be reported as part of the data to be delivered.

If the power generating facility consists of several generators and the minimum output is not evenly distributed between the generators, the minimum outputs of individual generators shall also be reported alongside the minimum outputs of the entire power generating facility.

#### 11.3.2.2 Rated capacity and short-term overloadability

The short-term overload capacity and the dependence of the rated capacity and the short-term overloadability of the power generating facility on external factors, such as the temperature of outdoor air or sea water, shall be reported as part of the data to be delivered.

#### 11.3.2.3 Start-up time

Hydropower, gas turbine and motor power-generating facilities shall have the ability to start up and achieve rated capacity output in 15 minutes. Estimates of typical starting times to minimum output power and rated power shall be reported as part of the data to be delivered.

With combined heat and power plants and other power-generating facilities, there are no requirements concerning the start-up time, except for the requirements presented in section 11.3.5 concerning the restoration from house load operation. An estimate of start-up times in the various ready-to-start states of the power generating facility shall be reported as part of the data to be delivered.

### 11.3.3 Implementation of active power control and frequency control

#### 11.3.3.1 General controller requirements

The power-generating facilities shall be equipped with a turbine controller and associated rotation speed control, with which the active power output and the rate of change of active power can be adjusted.

The active power control of the power-generating facility shall allow the setting of the active power output manually and the adjustment of the power output on the basis of frequency measurement (frequency control) using the turbine controller and potential power plant controller.

Frequency control shall be implemented in such a way that the power generating facility can automatically contribute to supporting the frequency of the power system in disturbance situations. Transition to disturbance power control state is executed by a frequency relay or other frequency-sensing equipment. The frequency measurement of frequency control shall be carried out in such a way that frequency control follows the frequency of the power system.

If functions or actuators, which filter and average the frequency measurement or functions or actuators which otherwise slow down the measurement or alter its nature, are used in conjunction with the frequency measurement, a description of their impact on the accuracy and delay of the frequency measurement shall be provided as part of the data to be delivered.

The active power control system of the power generating facility shall be executed in such a way that the inherent deadband of the control is as small as possible.

#### 11.3.3.2 Functionalities of frequency control

It shall be possible to set a deadband and linear droop for frequency control. The control shall be implemented so that the control has at least two modes of operation: normal state and disturbance state.

If other modes of operation have been specified for active power control and frequency control alongside the normal state and disturbance state, Fingrid shall be informed of them and their setting principles.

#### 11.3.3.3 Control parameters to be set

The setpoint of frequency control shall correspond to the nominal frequency of 50 Hz of the power system.

It shall be possible to adjust the droop of frequency control between 2 and 12 per cent in steps of a maximum of one percentage point. The default value for the droop to be configuredto the regulator during commissioning is 4%.

It shall be possible to adjust the deadband of frequency control between 0.0 and 0.5 Hz in steps of a maximum of 0.01 Hz.

It shall be possible to set the setting limits of the criteria which define the automatic transition in the modes of operation (normal state, disturbance state) based on the frequency measurement in at least the following limits:

- frequency limits leading to a transition in the modes of operation: ±2 Hz in steps of a maximum of 0.1 Hz,
- delay after which the status change is implemented: 0 to 60 s in steps of a maximum of 1 second,
- delay after which the restoration from a status change is implemented: 0 to 600 s in steps of a maximum of 1 second,
- off-period following recovery from a status change, when a new status change from exceeding the frequency limit in the same direction as the previous status change is prevented: 0–15 min in steps of a maximum of 1 minute.

For frequency control, it must be possible to set a power level, above the minimum power level, at which down-regulation stops. Frequency control must not cause the power-generating facility to disconnect from the grid (e.g. from reverse power).

A separate agreement with Fingrid shall be reached if the automatic transition in the modes of operation of the control is carried out in a manner other than based on the frequency deviation.

#### 11.3.3.4 Accuracy and sensitivity of control

The accuracy of active power control must be at least ±0.05 × $P_{max}$, and at most 10 MW in the range between the minimum power and rated capacity. The required accuracy is defined as the one-minute time average and takes into account the constant fluctuation in active power of the primary power source.

The sensitivity of frequency control shall be at least 10 mHz. The frequency control start delay when making stepwise changes to the frequency must not exceed 2 s (the frequency control response time is 1 s for a stepwise frequency change, and the response to the control shall become visible no more than 2 s after the stepwise frequency change).

The accuracy and sensitivity of the active power generating facility's power and frequency control shall be verified as part of commissioning testing. A description of these and of the factors affecting them shall be delivered as part of the power generating facility documentation.

#### 11.3.3.5 Transitions between modes of operation

It shall be possible to change, prevent, and allow the modes of operation and setpoints of the active power control and frequency control of the power-generating facility. It must be possible to change the operating mode from the power-generating facility's control room. The control of the modes of operation and setpoints shall work in the same way regardless of whether the power-generating facility is controlled locally or remotely.

A description of the functionalities which carry out the automatic transitions in the modes of operation of the power control and frequency control of the power generating facility shall be delivered as part of the power generating facility documentation.

### 11.3.4 Rate of change and adjustment range of active power

#### 11.3.4.1 Rate of change and adjustment range of active power in normal state

The requirements for the rate of change of active power have been specified as the highest rate of change of power that shall be achieved in response to a change in the setpoint of the active power of the generator or the power generating facility.

In a normal operation situation, the rate of change of the power of hydro, gas turbine and motor power-generating facilities shall be at least ±40% of the rated capacity per minute. It shall be possible to carry out the rate of change of power when the power of the facility is 40–100% of the rated capacity. The rate of change of power can be limited to the maximum permitted rate of change of power restricted by the characteristics of the power generating facility in question when the power of the facility is below 40% of the rated capacity.

The rate of change of the power of combined heat and power plants and power-generating facilities other than hydro, gas turbine, or motor power-generating facilities shall be at least ±5% of the rated capacity per minute. It shall be possible to carry out the rate of change of power when the power of the facility is 60–90% of the rated capacity. In this case, the change of power to take place at a time shall be no more than 20% of the rated capacity. The rate of change of power can be limited to the maximum permitted rate of change of power restricted by the characteristics of the power generating facility in question when the power of the facility is below 60% or above 90% of the rated capacity.

#### 11.3.4.2 Rate of change and adjustment range of active power in disturbance state

The requirements for the rate of change of active power in disturbance state have been specified as response times to a minimum step-like change of 0.5 Hz taking place in the frequency measurement. The total required change must be achieved within 30 seconds of the disturbance (maximum time allowed for full activation).

The power change of hydropower, gas turbine and motor power-generating facilities shall be at least ±10% of the rated capacity in disturbance situations. It shall be possible to carry out the power change when the power output of the plant is 50–100% of the rated capacity. The power change can be limited to the maximum permitted power change conforming to the characteristics of the power generating facility when the power output of the facility is below 50%, but in this case the determining factors that limit the power change shall be reported as part of the data to be delivered.

The immediate power change of combined heat and power plants as well as power-generating facilities other than hydro, gas turbine or motor power-generating facilities shall be at least ±5% of the rated capacity. It shall be possible to carry out the power change when the power output of the facility is 50–90% of the rated capacity. The power change can be limited to the maximum permitted power change restricted by the characteristics of the power generating facility in question when the power output of the facility is below 50%, but in this case the determining factors that limit the power change shall be reported as part of the data to be delivered.

### 11.3.5 House load operation

The power-generating facility shall be designed in such a way that it can safely trip to house load operation when the voltages or frequencies of the connection point are such that the power-generating facility can shift to house load operation by virtue of section 10. The power generating facility shall be able to trip to house load at any power level between the minimum capacity and rated capacity.

Hydropower and reserve gas turbine power-generating facilities shall be able to operate on house load for at least eight hours. Power-generating facilities other than hydro and nuclear power-generating facilities shall be able to operate on house load for at least an hour and be able to be restarted and resynchronised to the power system after this as soon as possible, taking the technical conditions into account; however, within a maximum of four hours during the next 12 hours. Nuclear power-generating facilities shall operate on house load and be available for start-up as prescribed in their technical specifications for safety and the Radiation and Nuclear Safety Authority regulations.

The following descriptions shall be provided as part of the data to be delivered:

1) A description of the house load of the power generating facility. If the house load depends on the mode of operation of the power generating facility, the dependence of the house load on the mode of operation shall be described as part of the documentation to be delivered.

2) A description of how long the facility can operate in house load operation.

3) Information on the delay between remaining in house load operation and synchronisation with the power system, and on the factors affecting the delay.

# 12 Reactive power capacity of synchronous power-generating modules

## 12.1 Reactive power capacity of type B synchronous power-generating modules

The relevant network operator sets the reactive power capacity requirement for type B power generating facilities. However, the requirement shall not exceed the reactive power capacity requirement specified for type C and D synchronous power generating modules.

## 12.2 Reactive power capacity of type C and D synchronous power-generating modules

### 12.2.1 Reactive power capacity required from generators

The generator(s) of the power-generating facility shall be able to operate continuously at their rated capacity $P_{max}$ when the power factor measured from the generator terminals is 0.95cap–0.90ind. Figure 12.1 illustrates this.

When the generator is operating at a power output below the rated capacity, it shall be able to generate or consume reactive power with the design voltage and frequency of the generator in accordance with the PQ diagram drawn up.

The power generating facility shall be able to limit the rise in the voltage of the connection point by consuming reactive power, when the voltage of the connection point is higher than the normal operating voltage specified by the relevant network operator. The power generating facility shall be able to limit the decrease in the voltage of the connection point by producing reactive power, when the voltage of the connection point is lower than the normal operating voltage specified by the relevant network operator.

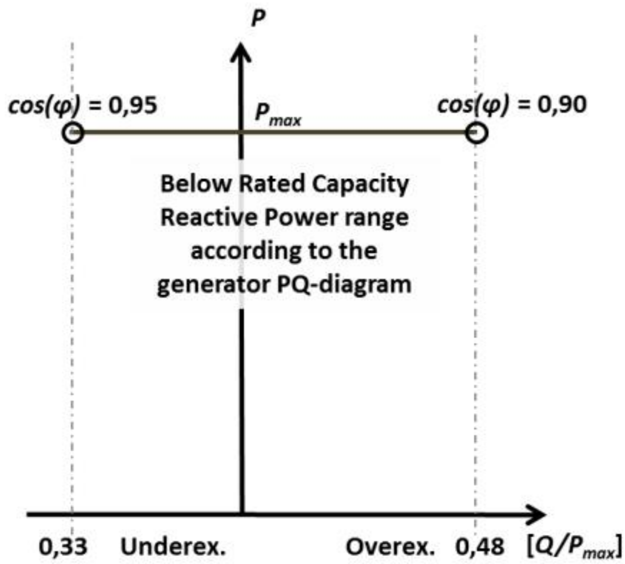



Figure 12.1. Reactive power capacity required from synchronous power-generating modules.

### 12.2.2 Reactive power capacity required from synchronous power-generating modules

The power generating facility shall be able to generate and consume reactive power (*Q*), within the operating range limited by its minimum output and rated capacity, when overexcited or underexcited at a reactive power capacity corresponding to the facility's operating point at a power factor of 0.95 of rated power. The reactive power capacity range is shown in Figure 12.2a).

As illustrated in Figure 12.2b), the reactive power measured at the connection point shall be:

- 0–0.33 [$Q/P_{max}$] overexcited, when the voltage at the connection point is 0.90–1.00 pu.
- 0–0.33 [$Q/P_{max}$] underexcited, when the voltage at the connection point is 1.00–1.05 pu.

The power generating facility shall not be required to generate reactive power below the minimum output.

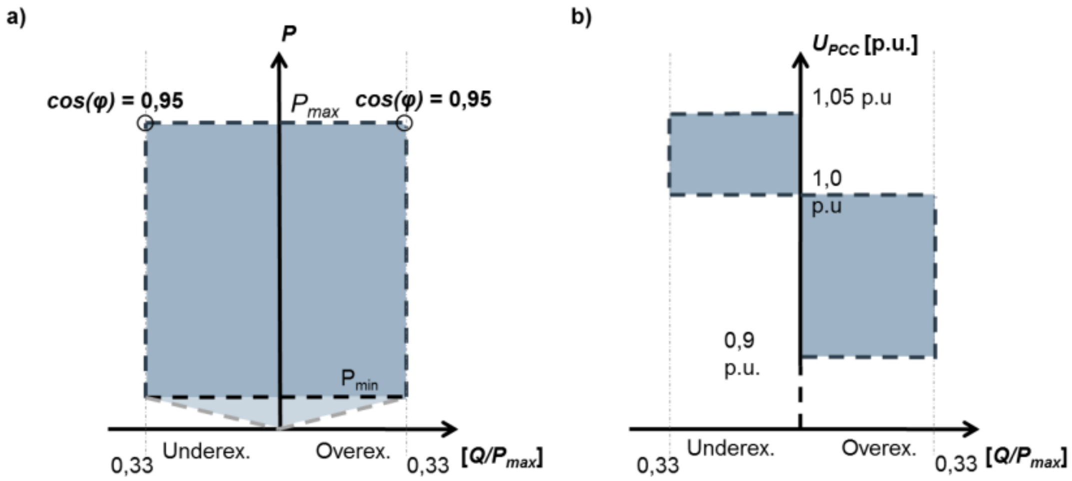



**Figure 12.2. Reactive power capacity requirements for type C and D synchronous power-generating modules as the function of active power and the voltage at the connection point. In the figure, a voltage of 1.0 pu corresponds to the normal operating voltage specified by the relevant network operator.**

If the power-generating facility cannot meet its reactive power capacity requirement temporarily—for example, due to the unavailability of the generator or compensation devices—the facility's active power production must be limited to the power level at which the reactive power capacity requirement is met.

### 12.2.3 Supplementary reactive power capacity

With regard to reactive power capability, the relevant network operator may specify supplementary reactive power to be provided if the connection point of a synchronous power generating module is neither located at the high-voltage terminals of the generator transformer to the voltage level of the connection point nor at the alternator terminals, if no generator transformer exists.

This supplementary reactive power shall compensate the reactive power demand of the high-voltage line or cable and shall automatically adapt so that the reactive power available at the connection point is as specified in section 12.2.2.

### 12.2.4 Reactive power capacity calculation

The power generating facility owner shall deliver a calculation of the reactive power capacity of the power generating facility at the connection point to the relevant network operator. The calculation shall be delivered at stage 1 of the compliance process. The calculation shall demonstrate the capability of the power generating facility to generate and consume reactive power at the voltage levels specified for the connection point and at the active power output levels specified for power generating facilities in Table 12.1.

If the generator transformer of the power generating facility is equipped with an on-load tap-changer, the calculation shall be provided for not only the middle position of the on-load tap-changer but also for the automatic settings of the on-load tap-changer of the generator transformer.

In addition to the reactive power capacity specified for the power generating facility in the calculation, the reactive power capacity calculation shall present the input data used in the calculation, such as the voltage ranges and PQ diagrams of the generators. The setpoint values used in the reactive power limiters shall be specified in the reactive power capacity calculation document.

The reactive power capacity calculation shall take into account, where necessary, the generator and any other power generating facility components that generate and consume reactive power. The frequency value used in the calculation shall be 50 Hz.

Operating point 0.85 pu is momentary at the voltage levels of the connection point, and at this operating point the power generating facility shall be able to operate for a minimum of 10 seconds.

**Table 12.1. Operating points used in the reactive power capacity calculation.**

| Connection point's voltage [pu] | 0.85* | 0.90 | 1.00 | 1.05 | 1.10 |
|---|---|---|---|---|---|
| Power level 1 | Minimum Output | | | | |
| Power level 2 | P=0.50×Pmax | | | | |
| Power level 3 | Rated Capacity | | | | |
| * The 0.85 pu operation point is momentary. The facility must be capable of producing the reactive power available at this point for at least 10 seconds | | | | | |

If the actual components of the power generating facility are different from those planned, the reactive power capacity calculation shall be updated correspondingly and delivered to the relevant network operator.

The reactive power capacity of the power-generating facility at the connection point, specified in the calculation, shall be verified during commissioning tests in accordance with the principles described in chapter 14.

### 12.2.5 Restriction of reactive power capacity

The limiters of voltage control of the generator and the power generating facility shall be designed and set so that their operation restricts the capability of the power generating facility to generate and consume reactive power as little as possible.

The additional adjustments and limiters of excitation system used for restricting the reactive power capacity and the protection related to the operation of excitation shall be co-ordinated so that the reactive power capacity of the generator can be utilised efficiently without the risk of the generator being disconnected from the grid.

# 13 Restriction of reactive power capacity

## 13.1 Voltage control of type B synchronous power-generating modules

With regard to the voltage control system, a synchronous power-generating module shall be equipped with a permanent automatic excitation control system that provides constant alternator terminal voltage at a selectable setpoint without instability over the entire operating range of the synchronous power-generating module.

## 13.2 Voltage control of type C synchronous power-generating modules

### 13.2.1 Operation and method of voltage control

The generators of the power generating facility shall have constant voltage control for the terminal voltage of the generator. The control shall be carried out so that the control operates continuously and so that the changes in reactive power at the connection point as a result of the control take place steplessly.

The control shall enable the utilisation of the reactive power capacity of the power-generating facility specified in chapter 12 when the power-generating facility generates active power to the power system. The functioning of the control shall not be disturbed by changes in the voltage and frequency of the grid or by momentary voltage disturbances.

The primary method of generator voltage control is the constant voltage control of the terminal voltage of the generator. If, for the needs of regional or local voltage control or for other corresponding reasons related to the operation of the power system, it is justified to use another control method or higher facility-level control, the control shall be able to respond, wherever necessary, to voltage changes in the same manner as the constant voltage control of the terminal voltage of the generator. The use of a method other than constant voltage control as the primary voltage control method of the power-generating facility shall be agreed separately with the relevant network operator and Fingrid. The principles of voltage control setpoint configuration for power-generating facilities are set out in Appendix B.

### 13.2.2 Performance of the automatic voltage regulator of generator

The following must be considered when implementing voltage control to ensure the system security of the electricity system:

- The voltage controller must be implemented in two channels. The channel must change automatically if the control channel in use fails.
- Both control channels shall have automatic constant voltage control of the terminal voltage of the generator, and constant current control of the excitation current as its back-up system (manual control of the excitation current).
- The magnitude of the change phenomenon caused by changing the control channel or control mode must be minimised and it must not cause any harm to the power-generating facility’s operation or a power quality deviation in the connection point's network.

- The automatic voltage regulator shall be designed so that its ceiling voltage is at least twice the excitation voltage corresponding to the design load of the generator[1)] with static excitation and at least 1.6 times that with brushless excitation, while taking into account all the other requirements set on voltage control. It shall be possible to maintain the ceiling voltage for at least 10 seconds. The ceiling excitation shall be taken into account in the power-generating facility's protection, the excitation limiter settings, and the generator's dimensioning.

When the setpoint of the automatic voltage regulator of a generator which is in no-load operation and disconnected from the grid is changed in steps upwards from 95 per cent to 105 per cent, the step response shall be as follows:

1) With static excitation, the rise time of the step response from zero to 90 per cent of the total change in the Terminal Voltage shall be 0.2–0.3 seconds,

2) With brushless excitation, the rise time of the step response from zero to 90 per cent of the total change in the terminal voltage shall be 0.2–0.5 seconds.

When the setpoint of the automatic voltage regulator of a generator which is in no-load operation and disconnected from the grid is changed in steps downwards from 105 per cent to 95 per cent, the step response shall be as follows:

1) With static excitation, the negative rise time of the step response from zero to 90 per cent of the total change in the terminal voltage shall be 0.2–0.3 seconds,

2) With brushless excitation, the negative rise time of the step response from zero to 90 per cent of the total change in the terminal voltage shall be 0.2–1.5 seconds.

The automatic voltage regulator shall be set so that the step response does not oscillate. The excess in the step responses specified above shall not be greater than 15 per cent of the measured total change in the terminal voltage.

The performance requirement for the generator's automatic voltage regulator shall be met at lower-than-normal or no higher than normal generator operating temperature, at which the uninterrupted test run during the generator's commissioning is carried out.

### 13.2.3 Performance calculation of the generator's automatic voltage regulator

The power generating facility owner shall provide the relevant network operator with a calculation of the performance of the automatic voltage regulator of the power generating facility. The calculation shall be delivered at stage 1 of the compliance process. The calculation shall demonstrate the performance of the automatic voltage regulator of the power-generating facility when the setpoint of the automatic voltage regulator of a generator which is in no-load operation and disconnected from the grid is changed as set out in section 13.2.2:

- in steps upwards from 95 per cent to 105 per cent,
- in steps downwards from 95 per cent to 105 per cent.

A description of the model used in the calculation, including the parameters used in the calculation and the block diagram presentations of the control systems, shall be delivered as part of the calculation to the relevant network operator.

### 13.2.4 Modes and functionalities of the generator's voltage regulator

The automatic voltage regulator shall operate with the constant voltage control of the terminal voltage of the generator. Moreover, the automatic voltage regulator may have other modes such as constant reactive power control or constant power factor control.

The control system shall include, in addition to the automatic voltage regulator and potential additional stabiliser, also functionalities which protect the generator from overloading.

It shall be possible to set the setpoint of constant voltage control in maximum steps of 0.01 pu in accordance with the limit values specified for the voltage of the generator (continuous operation).

The slope of voltage control shall be linear, and it shall be possible to set the slope within a range of 0–7 per cent in steps no greater than 0.5 percentage points. The setpoint can be set as positive or negative.

If the power generating facility has constant reactive power control, it shall be possible to set the setpoint in maximum steps of 1 Mvar.

If the power-generating facility has constant reactive power control, it shall be possible to set the setpoint in maximum steps of 0.005.

### 13.2.5 Changes in the modes of the voltage regulator

The regulator must be capable of changing the mode of operation while the generator is online.

Any transitions in the mode and operating point of the control shall take place without sudden and significant changes or repeated and significant oscillations in the active power or reactive power generated by the power generating facility.

The control of the modes of operation and setpoints of the automatic voltage regulator shall work in the same way regardless of whether the power-generating facility is controlled locally or remotely.

It must be possible to change the operating mode from the power-generating facility's control room.

### 13.2.6 Limiters and protection related to the functioning of voltage control

The current limiters of the generator shall have inverse time characteristics so that the overload range of the automatic voltage regulator of the generator can be utilised in various operation situations.

The functioning of the limiters shall control, as directly and delay-free as possible, the functioning of the automatic voltage regulator in order to avoid potential intense overvoltages or undervoltages at the connection point of the power generating facility.

The functioning of the limiter of underexcitation shall be co-ordinated with the current limiters (stator, rotor, excitation) as well as with the loss of excitation (LOE) and potential power system stabiliser (PSS).

The functioning of the limiter of overexcitation shall be co-ordinated with the current limiters as well as with overvoltage protection (stator, rotor, excitation) and the potential power system stabiliser (PSS).

### 13.2.7 Other components contributing to the voltage control and reactive power control of the power-generating facility

If separate compensation devices implemented as part of the power generating facility are utilised in order to achieve the reactive power capacity requirement, the functioning of such devices shall be co-ordinated with the functioning of the controllers of the generators of the power generating facility.

## 13.3 Voltage control of type D synchronous power-generating modules

The voltage control requirements for type D synchronous power-generating modules are the same as for type C power-generating modules (section 13.2) with the following additions.

The power converter of the generator's excitation system shall be implemented so that the failure of one power semiconductor bridge does not reduce the excitation system's performance as set out in the Specifications. The requirement is considered fulfilled if the power converter is implemented on the 2×100% or 3×50% principle, for example.

The voltage control of the power-generating facility's generators shall be equipped with a power system stabiliser (PSS) if:

- the rated capacit|y of the power-generating facility's generator is more than 20 MW
- the facility is a hydroelectric power-generating facility that consists of several independent power-generating modules, where the facility's total rated capacity exceeds 40 MW, the rated capacity of an individual generator is less than 20 MW, and the connection points of the generators are electrically close to each other (for example, sharing switchgear).
- the generator is connected to the network of Lapland

The structure of the PSS shall be such that the stabiliser can be tuned to damp the oscillations between the generator and the power system at frequencies of 0.2–2.0 Hz.

The power system stabiliser shall be tuned to improve the damping of the local oscillation frequency between the power generating facility and the power system. The PSS shall not amplify inter-area oscillations of 0.2–2.0 Hz. The tuning of the PSS must take into account operation during frequency disturbances of the Nordic power system, which also have frequency components below 0.2 Hz.

Fingrid recommends using dual-input power system stabilisers of the type PSS2A, PSS2B, or PSS2C that conform to standard IEEE 421.5. The tuning of the power system stabiliser for the damping of system-frequency oscillations shall be agreed upon separately with Fingrid.

It must be possible to switch the PSS on and off from the power-generating facility's control room, locally from controllers, and remotely at unmanned facilities. The magnitude of the stabilisation signal shall be restricted using limiters with adjustable settings.

The compliance of the power system stabiliser's functioning shall be verified during commissioning testing. Appendix B to this document provides instructions on tuning the power system stabiliser.

# 14 Commissioning testing of synchronous power-generating modules

## 14.1 Shared requirements for the commissioning testing of all synchronous power-generating modules

It is the responsibility of the power generating facility owner to verify that the operation of the power generating facility meets the specified requirements. The power generating facility owner is responsible for the costs related to the compliance process. Compliance with requirements shall primarily be verified through tests conducted during the commissioning of the power-generating facility using the facility's normal primary energy source.

The relevant network operator and/or a representative of Fingrid may participate in the compliance testing either on site or using a suitable remote connection, such as the connection from the network operator's control centre. For that purpose, the power generating facility owner shall provide the monitoring equipment necessary to record all relevant test signals and measurements as well as ensure that the necessary representatives of the power generating facility owner are available on site for the entire testing period. Signals specified by the relevant network operator or Fingrid shall be provided if, for selected tests, the network operator or Fingrid wishes to use its own equipment to record performance. The relevant network operator and Fingrid shall decide on their participation at their discretion.

## 14.2 Commissioning testing of type B synchronous power-generating modules

The power generating facility owner shall deliver minutes of commissioning testing to the relevant network operator. The minutes shall comprise the documentation of the variables validated by means of measurements and the time of the measurements.

It is the responsibility of the power generating facility owner to verify by commissioning testing that the following characteristics of a type B synchronous power generating facility conform to the specifications:

1) Impact of the starting and stopping of the power generating facility on the voltage level at the connection point
    - The test shall verify that starting or stopping the power generating facility does not cause quality deviations in the network of the relevant network operator.
2) Rated capacity of the power generating facility
    - The test shall verify that the power generating facility has the rated capacity specified in the connection agreement.
3) Reactive power capacity of the power generating facility

- The test shall verify the reactive power capacity of the power generating facility by running the facility at its rated capacity and at the highest possible inductive and capacitive reactive power.

4) Functioning of voltage control

- The test shall verify that the constant voltage control of the facility functions appropriately. If necessary, the relevant network operator shall provide additional instructions for the test.

5) Limited frequency sensitive mode — overfrequency – (LFSM-O)

- The power generating facility's technical capability to continuously modulate active power to contribute to frequency control in case of any large increase of frequency in the system shall be demonstrated. The steady-state parameters of regulations, such as droop, and dynamic parameters, including frequency step change response shall be verified,
- The test shall be carried out by simulating frequency steps and ramps big enough to trigger at least 10% per cent of rated capacity change in active power, taking into account the droop settings.
  The test can be performed by introducing an interfering signal of +0.7 Hz in the frequency measurement and using a droop of 4%.
- The test shall be deemed successful if the requirements set out in section 10.2.3 are fulfilled and no undamped power oscillations occur after the step change response.

Instead of the relevant test, the power generating facility owner may use equipment certificates issued by an authorised certifier to demonstrate compliance with the relevant requirement. In such a case, the equipment certificates shall be provided to the relevant network operator. As a rule, equipment certificates cannot be relied upon to demonstrate the cooperation of the power generating facility as a whole and of all of its auxiliary equipment. Consequently, equipment certificates shall not be accepted as a primary means of verifying compliance, and their use must be agreed on separately with the relevant network operator and Fingrid.

## 14.3 Commissioning testing of type C synchronous power-generating modules

### 14.3.1 Commissioning test plans, measurements and data exchange

The commissioning testing shall be carried out in co-operation between the power generating facility owner, the relevant network operator, and Fingrid. Fingrid’s representatives have the right to participate in all commissioning testing.

The power generating facility owner shall draw up a commissioning testing plan for the specific power generating facility. The plan shall cover the testing of the operation specified in the Specifications at least in the scope described in this section. The power generating facility owner shall deliver the commissioning test plan, preliminary commissioning instructions and a description of the practical arrangements of the tests.

The description of the practical arrangements shall cover at least the measurement arrangements, responsible persons, and preliminary schedule. The documents shall be delivered to the relevant network operator no later than 2 months before the planned start of the commissioning testing.

In conjunction with the drawing up and delivery of the commissioning test plans, the power generating facility owner shall arrange a meeting between the power generating facility owner, the relevant network operator, and Fingrid. The meeting shall take place no later than two months before the commissioning testing. In the meeting, the power generating facility owner shall agree on the final commissioning test plan and on the schedule and practical arrangements of the commissioning testing with the relevant network operator and Fingrid. If the above-mentioned parties agree that a meeting will not be held, the data exchange concerning the issues to be agreed shall be arranged in some other way. Each of the above-mentioned parties shall appoint at least one contact person for the commissioning testing.

As the transmission system operator, Fingrid has the right to cancel or change the schedule of the commissioning testing if the execution of the tests at the planned time is not possible due to the operation situation of the power system. The relevant network operator has a corresponding right with regard to the operation situation of its own electricity network. The cancellation or schedule change may be caused by factors such as circumstances related to the operation of power generating facilities or the operation situation of the local electricity network and power system. If the timing of the commissioning testing needs to be changed, the power generating facility owner shall agree on a new schedule with the relevant network operator and Fingrid.

At least the variables below shall be measured at a sampling rate of at least 1 kHz and recorded at a minimum recording frequency of 50 Hz in all commissioning testing:

- terminal voltage of the generator,
- excitation voltage of the generator or its excitation system,
- frequency of the generator,
- excitation current of the generator or its excitation system,
- active power of the generator, and
- reactive power of the generator

Moreover, the setpoint of the variable adjusted in the commissioning testing and the changes of the setpoint shall be recorded.

The permamently installed measurement devices in the power-generating facility may be used for measuring if they meet the above requirements.

The commissioning testing shall be planned so that the correspondence of the actual operation of the power generating facility and the dynamic modelling data can be demonstrated by means of calculations.

### 14.3.2 Substituting the commissioning testing

Instead of the relevant test, the power generating facility owner may use equipment certificates issued by an authorised certifier to demonstrate compliance with the relevant requirement. In such a case, the equipment certificates shall be provided to the relevant network operator. As a rule, equipment certificates cannot be relied upon to demonstrate the cooperation of the power generating facility as a whole and of all of its auxiliary equipment. Consequently, equipment certificates shall not be accepted as a primary means of verifying compliance, and their use must be agreed on separately with Fingrid and the relevant network operator.

If the commissioning testing cannot be performed, for example, due to the operational situation of the power system, the power generating facility owner shall agree separately with Fingrid and the relevant network operator on substituting the commissioning testing. Fingrid shall determine whether any commissioning testing can be substituted with one of the following methods:

1) equipment certificates issued by an authorised certifier, certificates issued by accredited laboratories, or equivalent detailed test reports of the turbine generators,
2) continuous monitoring,
3) simulation examinations carried out by utilising verified calculation models.

### 14.3.3 Documentation and acceptance of commissioning testing

The power-generating facility owner is responsible for documenting the commissioning tests and compiling the results into a commissioning report that demonstrates the grid code compliance of the characteristics identified in the commissioning tests. The power-generating facility owner shall deliver the commissioning report as an electronic document and the results of the commissioning testing in numerical format to the relevant network operator in the scope specified in section 15.2.2. The power-generating facility owner shall agree separately with the relevant network operator on the timing of tests of power-generating facility projects which proceed in stages, described in section 6.3.

It is the responsibility of the relevant network operator to confirm the fulfilment of the compliance obligation related to the requirements in terms of the commissioning testing based on the following four sectors:

1) The preparation, planning and data exchange of the tests have been carried out in accordance with the Specifications.
2) The tests have been carried out in accordance with the scope of the Specifications.
3) The operation of the power generating facility verified by the tests is in accordance with the Specifications and with the data provided on the power generating facility.
4) A commissioning report and measurement data in numerical format have been delivered of the tests related to the Specifications (section 15.1.2).

The graphs and tables in the commissioning report must show the variables measured in the commissioning tests and the changes in setpoints for a time frame and resolution that enables the grid code compliance of the results to be evaluated for each test. If a numerical target is set as the criterion for evaluating the outcome of the test, the report must clearly state the value and its connection to the power-generating facility's design criteria.

### 14.3.4 Functions to be verified in commissioning testing

Before starting the commissioning tests, the hardware settings of the power-generating facility's controls, limiters, and protections shall be checked to ensure they correspond to the supplied information. In particular, the equivalence of the parameters used in the provided simulation models must be verified. Differences in the configurations shall be studied before starting the commissioning tests. The configuration review and any changes to the settings during the commissioning tests shall be documented and included in the commissioning report.

The commissioning testing shall verify the following functions:

1) Limited frequency sensitive mode — overfrequency – (LFSM-O)

   - The power generating facility's technical capability to continuously modulate active power to contribute to frequency control in case of any large increase of frequency in the system shall be demonstrated. The steady-state parameters of regulations, such as droop, and dynamic parameters, including frequency step change response shall be verified,

   - The test shall be carried out by simulating frequency steps and ramps big enough to trigger at least 10% per cent of rated capacity change in active power, taking into account the droop settings.

   - The test can be performed by demonstrating the activation of the control by introducing an interfering signal of +0.7 Hz in the frequency measurement and using a droop of 4%. It is also necessary to demonstrate that the control is not activated by an over-frequency of less than 0.5 Hz.

   - The test shall be deemed successful if the requirements set out in section 10.2.3 are fulfilled and no undamped power oscillations occur after the step change response.

2) Limited frequency sensitive mode — underfrequency – (LFSM-U)

   - The test shall demonstrate that the power generating facility is technically capable of continuously modulating active power at operating points below rated capacity to contribute to frequency control in case of a large frequency drop in the system.

   - The test shall be carried out by simulating appropriate active power load points, with low frequency steps and ramps big enough to trigger active power change of at least 10% of rated capacity, taking into account the droop settings.

- The test can be performed by demonstrating the activation of the control by introducing an interfering signal of -0.7 Hz in the frequency measurement and using a droop of 4%. It is also necessary to demonstrate that the control is not activated by an under-frequency of less than 0.5 Hz.

- The test shall be deemed successful if the requirements set out in section 10.4.2 are fulfilled and no undamped power oscillations occur after the step change response.

3) Frequency sensitive mode and rate of change of active power in disturbance state

- The power generating facility's technical capability to continuously modulate active power over the full operating range between rated capacity and minimum regulating level to contribute to frequency control shall be demonstrated in the test. The steady-state parameters of regulations, such as droop and deadband and dynamic parameters, including robustness through frequency step change response and large, fast frequency deviations shall be verified. The controller's automatic change of mode between normal and disturbance operation mode must be verified.
  At the start of the tests, the active power generation of the power generating facility shall be at least 30% of the rated capacity of the power generating facility, and the control range of frequency control shall be at least ±10% of the rated capacity of the power generating facility.

- The test must be performed based on the measurement of grid frequency and by simulating frequency steps and ramps that are large enough to activate the entire frequency response range for active power. The test must take into account the droop settings, deadband, and the ability to actually increase or decrease the production of active power relative to the operating point in question.
  When performing the test, all interfering signals shall be reset to zero before introducing a new interfering signal. The test can be performed using the following procedures:

  a) The response of frequency control shall be measured for no less than 10 minutes on the basis of normal network frequency measurement.

  b) Using two different droop values, such as 4% and 6%, an interfering signal of +0.1 Hz shall be introduced by means of both steps and ramps.

  c) Using two different droop values, such as 4% and 6%, an interfering signal of +0.5 Hz shall be introduced by means of both steps and ramps.

  d) Using two different droop values, such as 4% and 6%, an interfering signal of -0.1 Hz shall be introduced by means of both steps and ramps.

  e) Using two different droop values, such as 4% and 6%, an interfering signal of -0.5 Hz shall be introduced by means of both steps and ramps.

  f) Inject into the frequency measurement a change 10 mHz below the frequency limit for changing to the disturbance mode, resulting in no change of mode. After that, inject into the frequency measurement a change 10 mHz above the frequency limit for changing to the disturbance mode, resulting in a change of mode and allowing the activation time to be determined. Restore the frequency to 50.0 Hz and wait for the controller to return to normal mode. Then verify the off-period after recovering from the change of mode by exceeding the frequency limit in the same direction and the opposite direction.

g) The deadband shall be set to ±10 mHz and the response of frequency control shall be measured for no less than 5 minutes on the basis of normal network frequency measurement.

h) The deadband shall be set to ±100 mHz. An interfering signal of +50 mHz and –50 mHz shall be introduced, followed by an interfering signal of +150 mHz and –150 mHz.

i) The droop shall be set to the minimum and maximum value of the droop setpoint range. The deadband shall be set to the minimum and maximum value of the deadband setpoint range.

- The test shall be deemed successful if the requirements set out in section 11.3.3 and section 11.3.4.2 are fulfilled and no undamped power oscillations occur after the step change response.

4) Rate of change of active power

- The test shall demonstrate the technical capability of the power-generating facility to modulate active power within the operating range and at the rate of change defined in section 11.3.4.1.
  The test can be performed by lowering the active power of the power generating facility to the minimum level, where the required rate of change of active power change is possible, and afterwards, gradually increasing the active power of the power generating facility to the maximum level, where the required rate of change of active power is possible. Once complete, the test shall be repeated in the opposite order.

- The test shall be deemed successful if the requirements set out in section 11.3.4.1 are fulfilled and no undamped power oscillations occur during or after the power change.

5) Transition to house load operation

- The test shall demonstrate the power generating facility’s technical capability to trip to and stably operate on house load.

- The test shall be carried out at the power generating facility’s rated capacity and reactive power under normal operating conditions before disconnecting from the power system. Following the disconnection, stable house load operation must be demonstrated for a minimum period of one hour before re-synchronisation to the power system.

- The test shall be deemed successful if tripping to house load is successful, stable house load operation has been demonstrated for a minimum period of one hour and re-synchronisation to the power system has been performed successfully.

6) Voltage control step response test at no load

- The test shall demonstrate the power-generating facility's voltage step change performance in accordance with the requirements set out in section 13.2.2 with the generator operating at no load while disconnected from the network.
- The test shall be deemed successful if the requirements set out in section 13.2.2 are fulfilled and, following the step change response tests, the power-generating facility is able to reach a stable operating point free of poorly damped reactive or active power oscillations.

7) Testing the change of channel

- The test shall demonstrate that the voltage controller changes the channel as required in section 13.2.2 in the event of a fault in one of the controller's channels.
- The test can be performed while the generator is connected to the grid by simulating a controller fault separately for both control channels.
- The test shall be deemed successful if the requirements of section 13.2.2 are met without the channel change leading to change phenomena in the generator's active or reactive power that could cause a deviation in the power quality.

8) Voltage control tests while connected to the network

- The test shall demonstrate the technical capability of the power-generating facility to regulate voltage and to function in accordance with the requirements set out in sections 13.2.4 and 13.2.5 when the generator is connected to the network.
- The test shall consist of voltage control step response tests with the generator connected to the network. The tests shall demonstrate the ability to set the voltage control setpoint and slope.
  The test can be performed using the following procedures:
  a) Set the voltage controller's slope to 2% and change the generator's voltage control setpoint as follows: 1.00 pu, 1.01 pu, 1.00 pu, 0.99 pu, 1.00 pu, 1.02 pu, 1.00 pu, 0.98 pu, 1.00 pu.
  b) Set the voltage controller's slope to 4% and change the generator's voltage control setpoint as follows: 1.00 pu, 1.01 pu, 1.00 pu, 0.99 pu, 1.00 pu, 1.02 pu, 1.00 pu, 0.98 pu, 1.00 pu.
- The test shall be deemed successful if the requirements set out in sections 13.2.4 and 13.2.5 are fulfilled and, following the step change response tests, the power-

generating facility is able to reach a stable operating point free of poorly damped reactive or active power oscillations.

- If the voltage controller has other operating modes in addition to constant voltage control, such as constant reactive power control or constant power factor control, their functionality shall be tested and reported.

9) Limiters and protection related to the functioning of voltage control

- The test shall demonstrate the limiters' capability to limit the generator's reactive power in accordance with the principles set out in sections 12.2.5 and 13.2.6 before protection activates.
  The test can be performed by making gradual changes in the voltage control setpoint of the generator, until both the inductive and capacitive limit is reached, at which point the limiter stops the change at the limit value. The test can also be performed in conjunction with the reactive power capacity test.

- The test shall be deemed successful if the limiters allow extensive use of the generator's reactive power capacity in accordance with the principles set out in sections 12.2.5 and 13.2.6.

10) Reactive power capacity test and restriction of active power

- The test shall demonstrate the capability of the power-generating facility to generate and consume reactive power in accordance with the requirements set out in section 12.2, and the test shall verify the results of the reactive power calculation. Additionally, the test shall verify the functioning of the facility's active power restriction and the accuracy of its active power control.

- Before conducting the test, the power generating facility owner and the relevant network operator shall agree on the permissible voltage and reactive power ranges. The reactive power capacity test shall be restricted to within the range permitted by normal operating voltage range of the network.

- The test shall be performed at the maximum inductive and maximum capacitive reactive power of the power generating facility, with the power generating facility generating active power at three different operating points for the required operating time:

  a) at rated power, no less than 60 minutes

  b) at 50% of rated power, no less than 60* minutes

  c) at minimum power, no less than 60* minutes

  *) The duration of the test at minimum power and at 50% power can be reduced to 15 minutes if an authorised certifier has issued a certificate (type or factory test report) indicating the reactive power capacity of the generator and the excitation equipment in a test lasting at least 60 minutes. The certificate must be presented as part of the test programme before the test is conducted.

- The test can be performed by making gradual changes in the voltage control setpoint of the generator until both the inductive and capacitive limit is reached, at each active power level.
- The test shall be deemed successful if the operating time at the required operating point is verified and the requirements set out in sections 11.3.3.4 and 12.2 are fulfilled.

11) Fault ride-through capability

- The test shall demonstrate the fault ride-through capability of the power-generating facility in accordance with the requirements set out in section 10.3.2 (type C) or 10.5.2 (type D). The procedure for the fault ride-through test shall be determined by Fingrid on a case-by-case basis. If a fault ride-through test is not conducted, the functioning of the power-generating facility in case of a local fault shall be demonstrated through simulation calculations and continuous monitoring when the facility is in operation.

12) Remote control

- The test must demonstrate that the remote control and other information exchange (measurements, status information) required for the power-generating facility function as required in sections 9.3, 10.4.1 and 10.5.1 (Type D). The test shall cover all control locations, including Fingrid's electronic control connection and, if applicable, the relevant network operator's control connection. The test shall also demonstrate prioritisation of control rights between the control locations.
- The test shall be conducted by issuing an electronic control signal to the power-generating facility from the control location. Control tests shall be performed for all control signals to verify that the control signal issued by the party with primary control authority is prioritised. The control tests shall be conducted in conjunction with other commissioning tests using the RO's primary user interface. The functionality controls at other control locations—including the electronic control connection between Fingrid and the RO—can be verified separately.
- The test shall be deemed successful when the requirements of sections 10.4.1 and 10.5.1 are met.

## 14.4 Commissioning testing of type D synchronous power-generating modules

The commissioning testing requirements for type D synchronous power-generating modules are the same as for type C synchronous power-generating modules (section 14.3). In addition, the commissioning testing of type D power-generating facilities shall verify the compliance and characteristics of the power system stabiliser (PSS) of the voltage control of the generator (section 13.3). The commissioning testing of the power system stabiliser shall verify the response of the controller to electromechanical oscillations, because they have an impact on the transmission capacity of the grid and on the assessment of the transmission capacity.

The detailed content and scope of the commissioning testing of the power system stabiliser shall be agreed separately with Fingrid and with the relevant network operator. The commissioning testing shall cover at least the following issues:

1) The tests shall be carried out at the rated capacity and at least at one active power level which is different from it.

2) The response of the controllers of the power generating facility within the frequency range of system-frequency oscillations shall be verified in the commissioning testing. This can be done by changing the system switching situation or by feeding a separate signal, which imitates the oscillation, to the power generating facility controllers (test signal injection).

3) The functioning of the power generating facility and its controller shall be recorded extensively in numerical format using measurement equipment with a sufficient sampling frequency for the analysis of the response of the controller.

Appendix B to this document provides instructions on tuning the power system stabiliser and the related reporting.

# 15 Modelling requirements applicable to synchronous power-generating modules

## 15.1 Modelling requirements of type C and D synchronous power-generating modules

### 15.1.1 Functional requirements of dynamics modelling data

The data to be delivered for the dynamics modelling shall enable the modelling of the interaction between the turbine generator of the power-generating facility and the power system, taking into account the response of the power-generating facility's turbine and its impact on the following issues:

1) changes in the voltage amplitude and in its phase angle in conjunction with electromechanical transients,

2) electromechanical oscillations related to angle stability at frequencies 0.2–2 Hz following small and large signal disturbances,

3) high-speed (10 ms – 10 s) transients related to voltage stability. These shall take into account the operation of the facility in conjunction with momentary voltage disturbances, and the dependence of the recovery of active power and the reactive power capacity on voltage, taking into account the limiters of the voltage controller

The data delivered for the dynamic modelling shall enable the construction of models corresponding to the true operation of the power-generating facility in the PSS®E and PSCAD™ software used by Fingrid, utilising the ready-made block diagrams available in the software's libraries (IEEE 421.5).

If the modelling data provided is not standardised and unambiguous, the models shall be provided as self-created open ("white box") or closed ("black box") manufacturers' models compatible with Fingrid's specified simulation software.

### 15.1.2 Requirements concerning the verification and documentation of the modelling data

The data to be delivered for the dynamics modelling shall be verified by comparing the modelling data, using the modelling results obtained, to the results of the commissioning testing of the power-generating facility. The verification requirement of modelling data applies to power generating facilities in the scope presented in Tables 15.1 and 15.2.

The data to be delivered for dynamics modelling shall be documented. The power generating facility owner shall deliver the data as electronic documents to the relevant network operator. The documents to be submitted shall be clear and unambiguous in terms of their layout and structure. The documentation shall cover the following main issues:

1) Alternator and prime mover, and the related mechanical rotating components

2) A block diagram of speed control and active power control and the associated parameters (including limiters)
3) A block diagram of voltage control and reactive power control and the associated parameters (including limiters)
4) a block diagram of the power system stabiliser and the associated parameters (only for type D)
5) Results of verification of modelling data:
    a) report of the verification of modelling data,
    b) comparison of the modelling results and the results of the commissioning testing in the scope presented in Table 15.1,
    c) measurement results of the commissioning testing in numerical format in the scope presented in Table 15.2 in so far as Table 15.1 obliges verification,
    d) account of potential differences between the modelling results and the results of the commissioning testing.

**Table 15.1. Verification obligation (X) of modelling data on synchronous power-generating modules by type.**

| Item to be verified | Type C | Type D |
|---|---|---|
| Step response of voltage control at no load (both the increase and decrease of voltage) | X | X |
| Reactive power capacity of the power generating facility and the functioning of limiters that restrict the capacity | X | X |
| Functioning of power system stabiliser (PSS) | | X |
| Fault ride-through test[1] | | X |

[1] To be agreed on a case-by-case basis. If a fault ride-through test for the power-generating facility is not carried out, the functioning of the power-generating facility in a local fault shall be demonstrated by means of simulation calculations.

**Table 15.2. Measurement data on commissioning testing to be delivered in numerical format, to which measurement data the results calculated using the modelling data is compared.**

| Item to be verified | $U_{gen}$ | $U_f$ or $U_{ef}$ | $f_{gen}$ | $I_f$ or $I_{ef}$ | $P_{gen}$ | $Q_{gen}$ | Signals |
|---|---|---|---|---|---|---|---|
| Step response of generator voltage control (both the increase and decrease in voltage) | X | X | X | X | | | Voltage setpoint |
| Reactive power capacity of the power generating facility | X | X | X | X | X | X | Voltage setpoint |
| Functioning of power system stabiliser (PSS), see Appendix B | X | X | X | X | X | X | PSS output signals |
| Fault-ride-through test | To be agreed on a case-by-case basis. If a fault-ride-through test for the power generating facility is not carried out, the functioning of the power generating facility in a local fault shall be demonstrated by means of simulation calculations. | | | | | | |

- $U_{gen}$ Terminal voltage of the generator
- $U_{ef}$ Excitation voltage of the excitation system
- $U_f$ Excitation voltage of the generator
- $f_{gen}$ Frequency of the generator
- $I_{ef}$ Excitation current of the excitation system
- $I_f$ Excitation current of the generator
- $P_{gen}$ Active power of the generator
- $Q_{gen}$ Reactive power of the generator

### 15.1.3 Specific study requirements

If calculation programs applicable to electromagnetic transients are used in conducting the specific studies (chapter 5), the simulation models of the power-generating facility used in the simulation shall be delivered to Fingrid as part of the final report of the specific study. The said simulation models shall be updated after the commissioning testing and delivered to Fingrid as part of the final documentation of the power-generating facility.

### 15.1.4 Requirements for the simulation models of compensation devices

Data for passive compensation devices, such as a capacitor bank, is attached to the modelling data. The simulation models for active compensation devices related to the power generating facility project shall be agreed upon separately with Fingrid.

## Requirements for power park modules

### 16 Active power control and frequency control of power park modules

#### 16.1 Active power control and frequency control of a type A power park module

Type A power park modules shall have the functionalities required by active power control and frequency control, and maintaining of power output as described in section 10.2. If the power-generating facility characteristics include other functionalities related to active power control and frequency control, Fingrid has the right, if necessary, to utilise these functionalities as described in section 16.3.1.

#### 16.2 Active power control and frequency control of a type B power park module

Type B power park modules shall have the functionalities required by active power control and frequency control, and maintaining of power output as described in section 10.3. If the power-generating facility characteristics include other functionalities related to active power control and frequency control, Fingrid has the right, if necessary, to utilise these functionalities as described in section 16.3.1.

#### 16.2.1 Active power

#### 16.2.1.1 Minimum output

The minimum output of the power generating facility and its capability to operate momentarily below its minimum output limit shall be reported as part of the data to be delivered. The minimum output of the power-generating facility shall be no more than 10 per cent of the rated capacity of the power-generating facility.

If the power-generating facility consists of several units and the minimum output is not evenly distributed between the power park units, the minimum outputs of individual units shall also be reported as part of the data to be delivered alongside the minimum output of the entire power-generating facility.

#### 16.2.1.2 Rated Capacity

The dependence of the active power output of the power-generating facility on external factors, such as wind speed and the temperature of outdoor air, shall be reported as part of the data to be delivered.

If the power generating facility consists of several units and the rated capacity is not evenly distributed between the power park units, the rated capacities of individual units shall also be reported as part of the data to be delivered alongside the rated capacity of the entire power generating facility.

For hybrid power-generating facilities, the rated capacities of the facility's plant sections and information on their capability to operate as independent power-generating facilities shall also be reported.

Information on the power-generating facility's overload capacity (for example, the duration and dependence on external factors such as temperature) shall be provided as part of the required information.

The rated capacity can be limited by software to below the nominal rated capacity specified for the installed production capacity of the power-generating facility owner's electricity production installations. If the rated capacity of the power-generating facility is limited by software, a description of the reasons for the limitation, implementation, and monitoring must be included in the required information.

If the active power simultaneously available from the power-generating facility's power park modules without controller limitations could exceed the rated capacity, the power-generating facility must be equipped with a protective device to ensure that the rated capacity is not exceeded (for example, in the event of a controller fault). The protective device shall measure the power-generating facility's active power and disconnect the volume of production required to achieve the allowable rated capacity if the power exceeds 105% x $P_{max}$ for 20 seconds or 120% x $P_{max}$ for 1 second. The relevant network operator may require a lower setting for protection.

### 16.2.2 Curtailment of active power

It shall be possible to curtail the upper limit of active power generation so that it shall be possible to specify a value smaller than the rated capacity for the highest permitted level of active power of the power generating facility.

The functioning of the upper limit set shall ensure that the active power generation, which is measured as 10 second averages, does not exceed the specified level. It shall be possible to set the upper limit setpoint at a minimum accuracy of 0.1 MW within the range limited by the minimum output and rated capacity of the power park module.

It shall be possible to limit the speed of power change when limiting active power.

## 16.3 Active power control and frequency control of type C and D power park modules

In addition to what is set out in this section, type C power park modules shall have the functionalities required by active power control and frequency control, and maintaining of power output as described in section 10.4.

In addition to what is set out in this section, type D power park modules shall have the functionalities required by active power control and frequency control, and maintaining of power output as described in section 10.5.

### 16.3.1 Fingrid's rights during a disturbance in the power system

Fingrid has the right to demand power generating facilities to adjust themselves within the power control characteristics presented in this document, if the power system cannot be restored to the normal state after a disturbance.

### 16.3.2 Start-up and house load of the power-generating facility

#### 16.3.2.1 Start-up of power-generating facility

The connection of the power generating facility to the power system shall not cause a change in excess of 3 per cent in the voltage of the connection point of the power generating facility.

The need to limit the gradient of increase in active power output during the start-up of the power generating facility shall be agreed separately with the relevant network operator.

#### 16.3.2.2 House load

The house load power of the power generating facility shall be reported as part of the data to be delivered. The house load shall be reported when the power-generating facility is connected to the grid and ready for production but not producing active power and when it is operating at its rated capacity (transfer of reactive power to the grid is minimised).

### 16.3.3 Implementation of active power control and frequency control

#### 16.3.3.1 General controller requirements

The power generating facility shall be equipped with devices with which the active power and the rate of change of active power can be adjusted.

The active power control of the power generating facility shall allow the setting of the reference of active power manually and the adjustment of the active power on the basis of frequency measurement (frequency control).

#### 16.3.3.2 Functionalities of frequency control

Frequency control must operate in proportion to the frequency deviation. In other words, the control system must have a configurable linear droop for frequency control, and it must be possible to specify the linear droop for each frequency range, taking into the account normal and disturbance control ranges, and the limited frequency sensitive modes for over- and under-frequency (LFSM-O/-U), see Figure 16.1.

Frequency control shall be continuous when moving between frequency ranges.

It must be possible to turn frequency control on and off for each frequency range.

It shall be possible to control the active power of the power generating facility so that as a result of the functioning of frequency control, the power generating facility can increase or decrease its active power generation based on the frequency variation. Restriction shall be possible for both the constant active power and in proportion to the maximum power available from the primary energy.

It shall be possible to specify a power range for frequency control in each frequency range, within which the active power generated by the power-generating facility can be adjusted.

The down-regulation of active power must not result in the disconnection of the power park facility or its individual modules.

It shall be possible to set a deadband for frequency control. If a deadband is used, the frequency control curve starts at the deadband boundary.

A separate commercial agreement shall be signed on the use and settings of the frequency control operating mode.

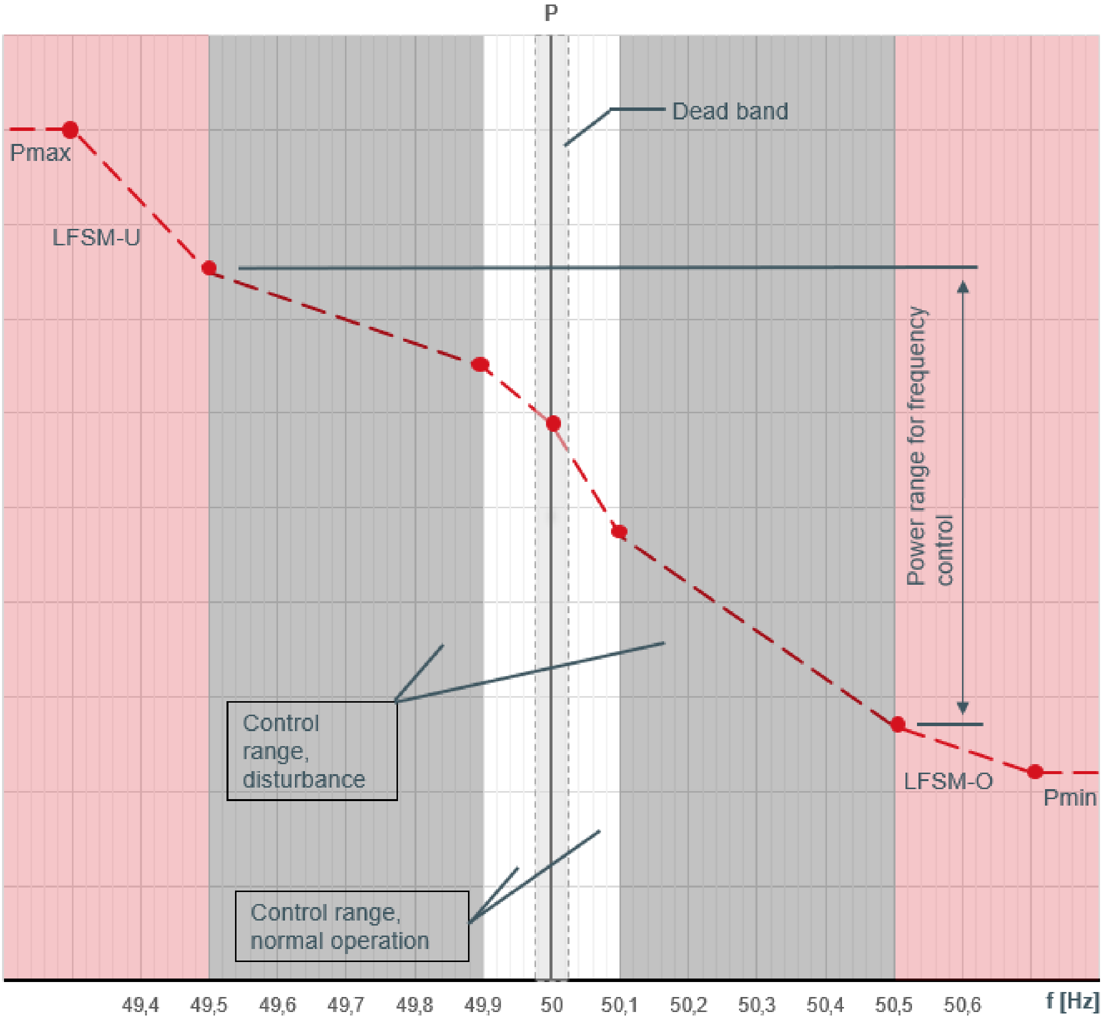



**Figure 16.1. Continuous operation of frequency control in different frequency ranges. Each frequency range has separate droop and power limit settings. The deadband around 50 Hz can be configured separately. The frequency values, droop settings, and power ranges shown in the diagram are examples. The power levels $P_{max}$ and $P_{min}$ represent the maximum and minimum control levels.**

#### 16.3.3.3 Control parameters to be set

The setpoint of frequency control shall correspond to the nominal frequency of 50 Hz of the power system.

It must be possible to set the droop for frequency control in each frequency range separately

- between 2% and 12% in steps of up to one percentage point.
- for at least four frequency ranges (excluding LFSM-O and -U, which are separate functions) with widths that can be set between 0.05 Hz and 1.0 Hz

The default value for droop set on the regulator during commissioning is 4% in all frequency ranges.

It shall be possible to adjust the deadband of frequency control between 0.0 and 0.5 Hz in steps of a maximum of 0.01 Hz.

The power range to be specified for frequency control shall correspond to the rated capacity (($P_{min}$ –100 %) × $P_{max}$) of the power-generating facility, and it shall be possible to adjust it in steps of 0.1 MW.

It shall be possible to limit the rate of change of active power used for frequency control in the range between the lowest and highest control level defined for frequency control.

It shall be possible to specify the power range for frequency control in each frequency range separately into a direction increasing the power output and to a direction decreasing the power output. In other words, it shall be possible to specify the range as asymmetrical.

### 16.3.4 Rate of change of active power

The requirement for the rate of change of active power is specified as the highest rate of change of power that shall be achieved in response to a change in the power-generating facility’s active power setpoint.

Assuming that the availability of primary energy does not limit the production of active power, the power-generating facility's rate of change of power must be at least 100% of its rated capacity per minute for up- and down-regulation.

The requirements for the rate of change of active power and the maximum time allowed for full activation while the power-generating facility operates under frequency control are determined according to the technical requirements set by the marketplace (e.g., FCR-N and FCR-D).

### 16.3.5 Restriction of rate of change of active power

It shall be possible to restrict the rate at which the active power generation of the power generating facility and its power park modules is changed.

It shall be possible to restrict the rate of change during an increase in active power in cases where there is a change in the active power limiter setpoint or an increase in the active power generation of the power generating facility due to an increase in primary energy production (e.g. when there is an increase in wind velocity).

If primary energy production decreases rapidly (e.g. when wind velocity decreases), there is no need to restrict the rate of change of active power. It shall be possible to restrict the rate of change of power if the setpoint of the active power limiter is decreased.

A description of the implementation method of the functionality shall be delivered as part of the power generating facility documentation.

It shall be possible to specify the setpoint of the rate of change of active power, at least within a range where the minimum value is 10% of the rated capacity per minute ($0.1 \times P_{max}$ / minute) and the maximum value is the maximum possible rate of change for the power-generating facility, which must be at least 100% of its rated capacity per minute ($1.0 \times P_{max}$ / minute) The smallest change in the setpoint shall be at least one megawatt per minute (1 MW/minute). By default, the rate of change of active power can be 100% of the rated capacity per minute. The change in power shall occur linearly, with no stepwise changes greater than 5%.

If the operating situation of the electricity network so requires, Fingrid may limit (see Chapter 10.4.1 and Table 10.1) the rate of change of the active power. This limitation applies to setpoint changes and changes due to the availability of primary energy.

It shall be possible to specify the rate of change setpoints, which restrict the increase and decrease of active power, separately.

### 16.3.6 Rapid down-regulation of active power

It shall be possible to control the active power generation of the power generating facility down from 100 per cent to 20 per cent of the rated capacity in less than five seconds.

It shall be possible to restore the active power within a short period of time after downward control.

It is not necessary to implement the rapid downward control as a function of its own if it can be implemented by utilising the other functionalities of the power control system of the power generating facility.

### 16.3.7 Changes between the modes of active power control and frequency control

A change in the mode of active power control and frequency control shall not cause a major sudden variation in the active power or reactive power generated by the power generating facility.

It shall be possible to change, prevent and allow the modes of operation and setpoints of the active power control and frequency control of the power generating facility. The control of the modes of operation and setpoints shall work in the same way regardless of whether the power-generating facility is controlled locally or remotely.

### 16.3.8 Accuracy and sensitivity of control

The accuracy of active power control must be at least ±0.05 × $P_{max}$, and at most 10 MW in the range between the minimum power and rated capacity. The required accuracy is defined as the one-minute time average and takes into account the constant fluctuation in active power of the primary power source.

The sensitivity of frequency control shall be at least 10 mHz. For a step change in frequency, the frequency control start delay must be no more than 2 s.

The accuracy and sensitivity of the active power generating facility's power and frequency control shall be verified as part of commissioning testing. A description of these and of the factors affecting them shall be delivered as part of the power generating facility documentation.

### 16.3.9 Interrupting the generation of active power due to high wind

The wind turbine generators of the wind power park module shall not stop simultaneously due to high wind velocity. The stopping shall be graded, and the grading shall be based on the capability of the wind turbine generators to operate safely in high wind.

The implementation of the gradation of the automatic stopping of a wind turbine generator in terms of wind velocities which are critical in order to ensure functional safety and in terms of related delays shall be documented and delivered as part of the power-generating facility documentation. The documentation shall also contain a description of the principles relating to continued generation after an interruption due to high wind velocities.

# 17 Reactive power capacity of power park modules

## 17.1 Reactive power capacity of type B power park modules

The relevant network operator sets the reactive power capacity requirement for type B power generating facilities. However, the requirement shall not exceed the reactive power capacity requirement specified for type C and D power park modules.

The relevant network operator sets the reactive power capacity requirement for type B hybrid power-generating facilities. However, the requirement shall not exceed the reactive power capacity requirement specified for type C and D hybrid power-generating facilities.

## 17.2 Reactive power capacity of type C and D power park modules

### 17.2.1 Reactive power capacity requirement

The power generating facility shall be able to generate and consume reactive power (*Q*), within the operating range limited by its minimum output and rated capacity, when overexcited or underexcited at a reactive power capacity corresponding to the facility's operating point at a power factor of 0.95 of rated power. Figure 17.1a) shows this reactive power capacity range.

The reactive power capacity requirement for the power-generating facility must primarily be met at the facility’s connection point. Alternatively, the rated capacity ($P_{max}$) used to determine the required reactive power capacity can be the maximum active power measured on the high-voltage side of the power-generating facility’s main transformer. In this case, the reactive power capacity requirement must be met at this point, and the connecting network between the main transformer and the connection point and the associated losses shall not be taken into account in the power-generating facility’s rated capacity and the determination of the reactive power capacity.

The reactive power measured at the point where the reactive power capacity requirement is determined must be as shown in Figure 17.1b):

- 0–0.33 [$Q/P_{max}$] overexcited, when the voltage at the connection point is 0.90–1.00 pu.
- 0–0,33 [$Q/P_{max}$] underexcited, when the voltage at the connection point is 1.00–1.05 pu.

The power generating facility shall not be required to generate reactive power below the minimum output.

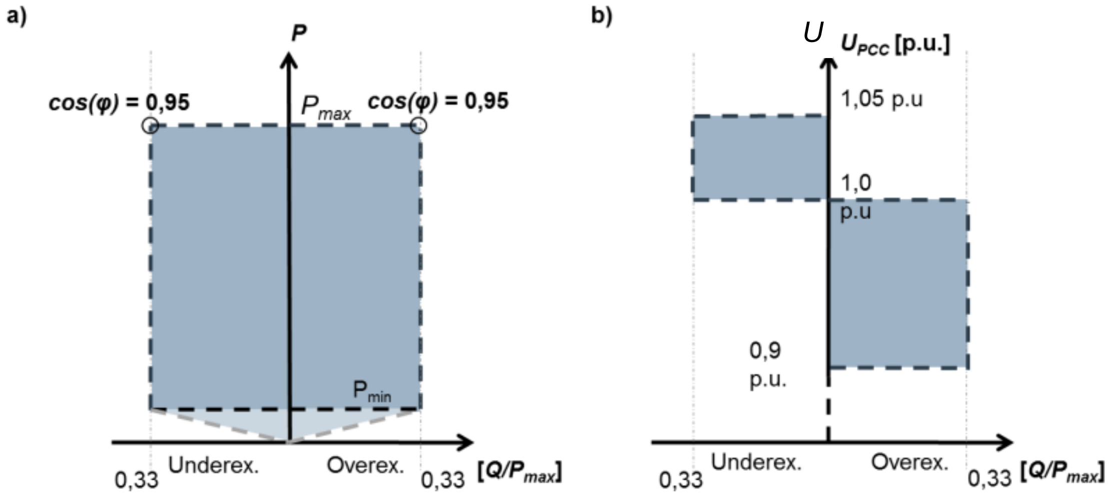



**Figure 17.1. Reactive power capacity requirements for type C and D power park modules as the function of active power and the voltage at the point where the reactive power capacity requirement is determined. In the figure, a voltage of 1.0 pu corresponds to the normal operating voltage specified by the relevant network operator.**

If the power-generating facility cannot meet its reactive power capacity requirement temporarily—for example, due to the unavailability of inverters or compensation devices—the facility's active power production must be limited to the power level at which the reactive power capacity requirement is met.

### 17.2.2 Supplementary reactive power capacity

With regard to reactive power capability, the relevant network operator may specify supplementary reactive power to be provided if the connection point of a power park module is neither located at the high-voltage terminals of the step-up transformer to the voltage level of the connection point nor at the alternator terminals, if no step-up transformer exists.

This supplementary reactive power shall compensate the reactive power demand of the high-voltage line or cable and shall automatically adapt so that the reactive power available at the connection point is as specified in section 17.2.1.

### 17.2.3 Components utilised to achieve the reactive power capacity requirement

Reactive power capacity does not need to be reserved in power park units only; it can be reserved in one or more separate adjustable reactive power compensation devices, which have been connected to the power system to the connection point of the power-generating facility or beyond it to be part of the other power-generating facility equipment.

The functioning of components utilised so as to achieve the reactive power capacity requirement shall be co-ordinated with the functioning of the other power-generating facility components that control voltage, in such a manner that the voltage control requirements and reactive power control requirements laid down for the power-generating facility in chapter 18 are fulfilled.

The power-generating facility's reactive power capacity can be supplemented by switchable compensation devices (such as capacitor banks) if the inverters of the power park modules have insufficient capacity to meet the reactive power capacity requirement. The switchable compensation devices can constitute no more than 20% of the total reactive power capacity required for the power park module. In addition, the power-generating facility must be capable of meeting the reactive power capacity requirement in its entirety without additional compensation when the power-generating facility produces active power at less than 85% of its rated capacity ($P_{max}$).

The compensation devices shall be detuned filter capacitor banks or other filter devices. Requirements for switchable compensation devices:

- The recommended tuning frequency is 189 Hz unless the relevant network operator indicates a different rating.
- Connection must not cause a voltage change of more than 3% in Fingrid's network.
- Control must be based on the amount of active power and reactive power produced at the power-generating facility unless the compensation device is continuously connected.
- Controls must be configured with time delays to prevent the unnecessary connection and disconnection of the compensation device in the event of transient changes in the network.
- There shall be a hysteresis between connection and disconnection to prevent the unnecessary connection and disconnection of the compensation device.

The testing, documentation and simulation requirements of devices used so as to fulfil the reactive power capacity requirement of the power generating facility shall be agreed upon separately with the relevant network operator in Stage 1 of the compliance process of the Specifications.

### 17.2.4 Reactive power capacity calculation

The power generating facility owner shall deliver a calculation of the reactive power capacity of the power generating facility at the connection point to the relevant network operator. The calculation shall be delivered at stage 1 of the compliance process. The calculation shall demonstrate the capability of the power-generating facility to generate and consume reactive power at the voltage levels specified for the connection point and at the active power output levels specified for power-generating facilities in Table 17.1. The setpoint values used in the reactive power limiters shall be specified in the reactive power capacity calculation document.

If the step-up transformer of the power generating facility is equipped with an on-load tap-changer, the calculation shall be provided for not only the middle position of the on-load tap-changer but also for the automatic settings of the on-load tap-changer of the step-up transformer.

In addition to the reactive power capacity specified for the power-generating facility in the calculation, the reactive power capacity calculation shall present the input data used in the calculation, such as the power park modules' voltage ranges, reactive power capacities, and any other components or functional requirements that could limit the reactive power capacity.

The reactive power capacity calculation shall take into account, where necessary, the power park units and any other power generating facility components that generate and consume reactive power. The frequency value used in the calculation shall be 50 Hz.

Operating point 0.85 pu is momentary at the voltage levels of the connection point, and at this operating point the power generating facility shall be able to operate for a minimum of 10 seconds.

**Table 17.1. Operating points used in the reactive power capacity calculation.**

| Connection point voltage [pu] | 0.85* | 0.90 | 1.00 | 1.05 | 1.10 |
|---|---|---|---|---|---|
| Power level 1 | Minimum Output | | | | |
| Power level 2 | P=0.50×Pmax | | | | |
| Power level 3 | Rated Capacity | | | | |
| * The 0.85 pu operation point is momentary. The facility must be capable of producing the reactive power available at this point for at least 10 seconds | | | | | |

If the actual components of the power generating facility are different from those planned, the reactive power capacity calculation shall be updated correspondingly and delivered to the relevant network operator.

The reactive power capacity of the power-generating facility at the connection point, specified in the calculation, shall be verified during commissioning in accordance with the principles described in chapter 19.

### 17.2.5 Restriction of reactive power capacity

When operating outside the limit values specified in section 17.2.1, the reactive power generation capacity of the power-generating facility and its power generating units shall be in accordance with that indicated in the reactive power capacity calculation, and it must not be limited by software, unless otherwise agreed with Fingrid.

The protection related to the operation of current limiters (or equivalent equipment) used in the power-generating facility shall be co-ordinated so that the available reactive power capacity can be utilised efficiently without the risk of the power-generating facility disconnecting from the power system.

### 17.2.6 Reactive power capacity of a hybrid power-generating facility

Hybrid power-generating facilities must meet the requirements of sections 17.2.1 to 17.2.5 and the supplementary requirements of this section.

The reactive power capacity requirement for the hybrid power-generating facility is determined according to its rated capacity as shown in Figure 17.1 and is in full when the largest section of the hybrid facility operates above its minimum output. The reactive power capacity of other production-ready and voltage-controlled plant sections below this minimum output must not be limited by software to below the actual technical performance of the installation.

If individual plant sections can also operate independently (for example, when other plant sections are not in use), they must then meet the reactive power capacity requirement according to the rated capacity of the specific plant section at the point where the hybrid power-generating facility's reactive power capacity requirement is defined.

If the hybrid power-generating facility includes a type C or D grid energy storage facility, the reactive power capacity requirement shall also be valid for the reactive power capacity required for the particular plant section in consumption mode according to the grid code specifications for grid energy storage systems.

The reactive power capacity requirement of the hybrid power-generating facility and the independently operating plant sections can be met using a combination of the reactive power capacities of the plant sections included in voltage control.

# 18 Voltage control and reactive power control of power park modules

## 18.1 Voltage control and reactive power control of a type B power park module

### 18.1.1 Functionalities of voltage control and reactive power control

The power generating facility shall be able to operate at a power factor of 1.0 measured at the connection point, or alternatively the power generating facility shall be able to support the voltage of the connection point by means of its reactive power capacity, as follows:

- The power generating facility generates reactive power to the power system when the voltage of the connection point decreases.
- The power generating facility consumes reactive power from the power system when the voltage of the connection point increases.

If necessary, the relevant network operator may impose additional requirements for the voltage and reactive power control of the power-generating facility.

### 18.1.2 Reactive current supply by a power park module

A power park module must supply capacitive reactive current during undervoltage and inductive reactive current during overvoltage. The supply of reactive current ($I_q$) shall be prioritised over active current ($I_p$) during undervoltage and overvoltage.

The power park module shall be capable of activating the supply of fast reactive current (fault current supply) either by:

- ensuring the supply of the fast reactive current at the connection point, or
- measuring voltage deviations at the terminals of the individual units of the power-generating facility and providing a fast reactive current at the terminals of these units.

The reactive current supply mode during undervoltage must be activated when the phase voltage at the terminals of the connection point or the individual module is less than 0.85 pu and deactivated when the phase voltage returns to above 0.90 pu.

The reactive current supply mode during overvoltage must be activated when the phase voltage at the terminals of the connection point or the individual module is more than 1.10 pu and deactivated when the phase voltage returns to under 1.05 pu.

When operating at a voltage where the reactive current supply mode is not active, supply of active current (Ip) shall be prioritised.

The time taken for the reactive current to rise to 90% of the target value shall be between 30 and 50 ms, and the reactive current shall reach the target value (tolerance +20% to -10%) within 80 ms. The delay shall be determined from the start of the stepwise change in voltage. Required additional reactive current is defined at the point where the voltage measurement used to activate the reactive current supply is measured.

The power-generating facility’s voltage or reactive power control must return to the operating mode prior to the voltage change as soon as possible after the voltage returns to between 0.90 pu and 1.05 pu.

It must be possible to set the *k*-factor of the reactive current supplied by a power-generating facility equipped with a full converter (FC) separately for capacitive and inductive reactive current between 2 and 6. The default k-factor of reactive current injection is 2.5, and in asymmetrical faults, the positive and negative sequence component must be supplied in the ratio defined by the k-factor.

It must be possible to set the k-factor of the reactive current supplied by a power-generating facility equipped with a double-fed induction generator (DFIG) separately for capacitive reactive current between 2 and 6 and inductive reactive current between 2 and 4. In asymmetrical faults, the negative sequence component that is naturally produced by the machine shall be supplied in accordance with EN 50549-1/-2.

Figure 18.5 presents the reactive current supply function. When reactive current supply is activated, the required additional reactive current $\Delta I_q$ sums up to the reactive current prior to activation. The maximum reactive current supplied is determined by the inverter’s current-carrying capacity.

If the inverters in a power park module are grid-forming inverters, the reactive power supply characteristics may differ from those required in this chapter. In this case, Fingrid will assess the compliance of the implementation separately.

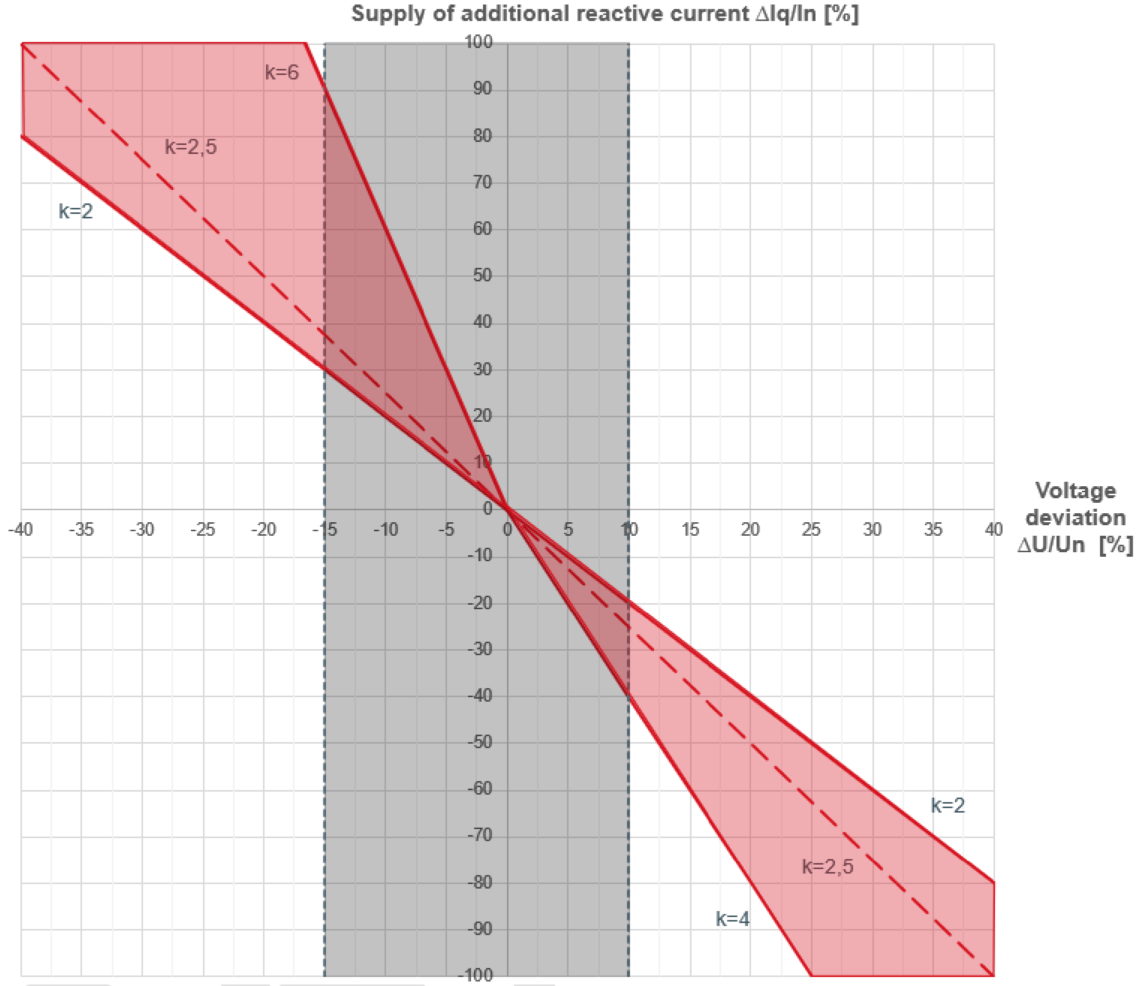



**Figure 18.5. The reactive current activation limits based on voltage and determination of the k-factor. The reactive power supply is activated outside of the grey area. The red area shows the k-factor setting range for a DFIG power-generating facility. The dashed line represents the slope of a full converter facility *k* = 2.5.**



## 18.2 Voltage control and reactive power control of a type C power park module

### 18.2.1 Functionalities of voltage control and reactive power control

The power generating facilities shall have automatic reactive power control and voltage control. The control shall be carried out so that the control operates continuously and so that the changes in reactive power at the connection point as a result of the control take place steplessly.

Voltage control and reactive power control shall enable the utilisation of the reactive power capacity of the power generating facility in the manner described in chapter 17. The functioning of the control shall not be disturbed by changes in the voltage and frequency of the power system or by momentary voltage disturbances.

The voltage control and reactive power control of the power generating facility shall have the following operating modes:

1) constant voltage control
2) constant reactive power control, and
3) constant power factor control

The control range of voltage control and reactive power control shall correspond to the actual reactive power capacity of the power generating facility. The reactive power capacity shall not be artificially limited. The basic operation of limiters implemented in order to guarantee the electrical strength of the power generating facility components shall be described as part of the power generating facility documentation to be delivered.

The voltage control functions and reactive power control functions shall be able to keep the reactive power generation of the power generating facility within the reference value of the control function. The accuracy of the voltage control functions and reactive power control functions shall be verified during the commissioning testing. The response of the control functions to stepwise changes and to continuous variation in the voltage of the power system shall be stable, and the control functions to be carried out as a result of the changes shall not lead to repeated or poorly damping oscillations in the reactive power or active power of the facility.

The power-generating facility, including its its plant- and equipment-level controls, must be designed to operate stably as part of a power system in which power park modules and converter-connected demand connections are the dominant facilities over synchronous power-generating facilities. To ensure stable operation, the relevant network operator or Fingrid may impose additional requirements for the technical implementation of controls, the related studies, simulation models to be prepared for the power-generating facility, and commissioning tests to demonstrate compliance with the requirements.

If necessary, the power-generating facility owner shall adjust the control settings over the life cycle of the power-generating facility to maintain compliance.

If the power park module is operating below its minimum output ($P_{min}$), the power park module does not have an obligation, from the viewpoint of the Specifications, to control the voltage or reactive power of the connection point.

Before starting the commissioning of the power-generating facility, the power-generating facility owner shall agree with the relevant network operator and Fingrid on the operating mode of the power-generating facility’s voltage and reactive power control between the moment when the supply of active power starts and the commissioning tests are conducted on the finished power-generating facility. The relevant network operator or Fingrid may require the commissioning of voltage control before the power-generating facility’s full capacity is completed.

### 18.2.2 Constant voltage control

The power-generating facility must be capable of operating with constant voltage control in such a way that a common control signal for the power park modules, taking into account the slope, can be used to directly control the voltage at the connection point or another point agreed upon with the relevant network operator and Fingrid.

It shall be possible to adjust the constant voltage control setpoint within the continuous operating range limit values specified for the voltage of the connection point in steps no greater than 0.1 kV. Changes to the setpoint issued from the local user interface or via a remote control connection shall be implemented using a ramp function that controls the average rate of voltage change so that it does not exceed 0.1 kV/s.

The slope of voltage control shall be linear, and it shall be possible to set the slope, at least within a range of 2–7 per cent in steps no greater than 0.5 percentage points. The reference value can be set as positive or negative depending on the implementation of the voltage control of the power generating facility.

When the power-generating facility is connected to the grid, the constant voltage control response shall be as follows when the stepwise change in the voltage at the connection point is ±0.02 pu:

1) The time taken for the reactive current ($I_q$) to rise from zero to 5 per cent of the total reactive current change measured from a single unit of the power park module must not exceed 30 ms. The fast initial response of this reactive current change shall be based on rapid regulation of the individual units of the power park module, and the direction of change of the reactive current shall be towards the final value. The magnitude or rise time of reactive current shall not be unduly limited. The response shall activate quickly and be as large as possible, taking into account the stable operation of the regulation.

2) When measured at the connection point, the rise time of the reactive power response from zero to 80 per cent of the measured total change in reactive power shall not exceed 1 second.

3) The overshoot verified in the step response shall not be more than 15 per cent of the total change in reactive power measured at the connection point.

4) The reactive power response measured at the connection point shall settle at its target level within 5 seconds of the stepwise excitation.

5) The deviation of the reactive power value in the steady state when measured at the connection point must no exceed ±5% of the target value for the reactive power change.

6) The start time for the delays referred to above is the start of the voltage step visible in the grid.

The required response must be achieved in the performance calculation performed for the connecting point network, represented by a background network specified by Fingrid.

If voltage control does not operate stably in all operating situations with the same control settings, alternative configuration based on different settings shall be defined for voltage control and taken into use at the request of Fingrid or the relevant network operator, if required. In this case, it must be possible to change the configuration remotely (see chapter 10.4.1).

In connection with changes to existing power generation facilities affecting the performance of the voltage control, Fingrid shall separately define the performance requirements for voltage control at the power-generating facility if the original technical implementation of control does not enable a fast initial response for reactive current.

#### 18.2.2.1 Constant voltage control performance calculation

The power generating facility owner shall provide the relevant network operator with a calculation of the performance of the automatic voltage regulator of the power generating facility. The calculation shall be delivered at stage 1 of the compliance process.

The calculation shall demonstrate the performance of the automatic voltage regulator of a power-generating facility connected to the grid as follows:

- Set the power-generating facility's slope to 4 per cent and change the voltage of the background network stepwise as follows: 1.00 pu, 1.01 pu, 1.00 pu, 0.99 pu, 1.00 pu, 1.02 pu, 1.00 pu, 0.98 pu, 1.00 pu, 1.04 pu, 1.00 pu, 0.96 pu, 1.00 pu.
- Set the power-generating facility's slope to 4 per cent and change the setpoint for voltage control stepwise as follows: 1.00 pu, 1.01 pu, 1.00 pu, 0.99 pu, 1.00 pu, 1.02 pu, 1.00 pu, 0.98 pu, 1.00 pu, 1.04 pu, 1.00 pu, 0.96 pu, 1.00 pu.

The background network is presented in the calculation using a model provided by Fingrid or with the values of an equivalent circuit. Fingrid checks and evaluates the functioning of the voltage control shown in the calculation and the settings used in the calculation by means of a simulation model (see Chapter 20) provided by the Connectee, which shall be integrated into Fingrid's network model. If the voltage regulation response is not stable, does not meet the performance requirements of Chapter 18.2.2 or is otherwise not appropriate for the operation of the electricity system, the Connectee, together with Fingrid and the relevant network operator, shall take the necessary measures to ensure adequate performance in terms of the system security of the electricity system.  A description of the model used in the calculation, including the parameters used in the calculation and the block diagram presentations of the control systems, shall be delivered as part of the calculation to the relevant network operator.

#### 18.2.2.2 Implementation of constant voltage control

In principle, constant voltage control shall directly control the voltage at the high-voltage terminals of the power-generating facility's step-up transformer at the connection point's voltage level. If there are several step-up transformers, voltage control shall control a common busbar voltage to the step-up transformers.

The effect of the connecting line between the power-generating facility and the connection point on the operation of the power-generating facility's voltage control and reactive power management at the connection point can be offset using line drop compensation (LDC) based on local measurements of the voltage and reactive power. In this case, the consumption of reactive power in the connecting line is offset based on a calculated estimate using the electronic values of the line.

In some cases, the reference measurement of voltage control can be taken directly from the connection point or another measuring point using an appropriate telecommunication connection to transfer the necessary voltage and reactive power measurements to the power-generating facility. In such an arrangement, there must also be a backup voltage control system based on local measurements of the power-generating facility.

If the reactive power of the connecting line is offset by voltage control at the power-generating facility, limiters must be set for voltage control at the power-generating facility to control a long-term local voltage rise at the facility. However, limiters must not prevent the full use of the power-generating facility's reactive power capacity during momentary voltage disturbances.

The relevant network operator and Fingrid shall determine the method of voltage control to be used.

### 18.2.3 Constant reactive power control

The power-generating facility shall be able to operate at constant reactive power control so that the control can be used for controlling directly the reactive power fed to the connection point and the reactive power taken from the connection point.

The reactive power measurement accuracy for constant reactive power control, measured at the connection point, shall be at least 2 per cent of the rated reactive power (tolerance: ±0.5 per cent).

When the change in the setpoint of constant reactive power control is ±30 per cent of the rated reactive power, the rise time of the reactive power response from zero to 90 per cent of the total measured reactive power change shall be 10 seconds (tolerance ±1 s).

It must be possible to define the setpoint for constant reactive power control in steps of up to 0.5 per cent of the rated reactive power, but no more than 1 Mvar. The setting range of the reference value shall correspond to the actual reactive power capacity of the power generating facility. Changes to the setpoint issued from the local user interface or via a remote control connection shall be implemented using a ramp function that controls the average rate of change of the reactive power setpoint so that it does not exceed 10 per cent of the rated reactive power per second.

### 18.2.4 Constant power factor control

The power generating facility shall be able to operate at constant power factor control so that the control can be used for controlling directly the power factor of the connection point, i.e. the reactive power fed to the connection point and the reactive power taken from the connection point as a function of the active power generated by the power generating facility.

The measurement accuracy for constant power factor control, measured at the connection point at a rated capacity of over 50 per cent, shall be at least 0.005 (tolerance: ±0.002).

When the change in the setpoint of constant power factor control is ±0.02, the rise time of the reactive power response from zero to 90 per cent of the total measured reactive power change shall be 10 seconds (tolerance ±1 s).

It shall be possible to set the reference value of constant power factor control for the power factor in maximum steps of 0.005 between 0.95ind and 0.95cap or in a broader range. Changes to the setpoint issued from the local user interface or via a remote control connection shall be implemented using a ramp function that controls the average rate of change of reactive power so that it does not exceed 10 per cent of the rated reactive power per second.

### 18.2.5 Changes in the modes and reference values of voltage control and reactive power control

Any transitions in the mode and operating point of the control shall take place without sudden significant changes (no more than 5 per cent of the rated capacity) or repeated, significant oscillations in the active power or reactive power produced by the power generating facility.

The mode transition shall take place within a predetermined period of time after the mode transition is requested from the power-generating facility (see section 10.4.1). Reactive power changes must use a ramp function when changing the operating mode, and the rate of reactive power change may not exceed 10 per cent of the rated reactive power per second.

The control of the modes of operation and setpoints of the automatic voltage regulator shall work in the same way regardless of whether the power-generating facility is controlled locally or remotely.

The control mode shall change automatically in the event of a disturbance in the control circuit in which, for example, the measurement data required for the control mode in use is lost. The change must be planned in such a way that the power-generating facility's active or reactive power production does not change or stop in a stepwise manner. The control mode shall change as follows:

1. Voltage control based on voltage measurements at the connection point or another external voltage reference (if used).
2. Voltage control based on local measurements at the power-generating facility.
3. Power factor control or reactive power control at the inverter level. The control method and setpoint shall be agreed upon with the relevant network operator.

4. If the central controller at the power-generating facility (such as a park controller) is lost, production shall be shut down at the relevant network operator's request or the power-generating facility shall be disconnected by the RO. Production may also be shut down autonomously at the component or module level based on factors such as a delay agreed upon with the relevant network operator.

The description of the operation of the change in control mode in the event of a disturbance must be included as part of the required information.

### 18.2.6 Protection and limiters related to the functioning of voltage control

When the voltage of the connection point of the power generating facility is high, the functioning of the limiters shall control, in as direct and delay-free manner as possible, the functioning of the voltage control in order to avoid intense overvoltages.

### 18.2.7 Other components contributing to voltage control and reactive power control

If separate compensation devices implemented as part of the power-generating facility are utilised in order to achieve the reactive power capacity requirement, the functioning of such devices shall be co-ordinated with the functioning of the controllers of the power park modules so as to fulfil the other requirements laid down in chapter 18. Moreover, the need to co-ordinate the functioning of the devices with the other components contributing to the control of voltage in the power system shall be agreed upon separately with the relevant network operator.

### 18.2.8 Reactive current supply by a power park module

A type C power park module must meet all the same reactive power supply requirements as a type B power park module.

### 18.2.9 Voltage control at hybrid power-generating facilities

Hybrid power-generating facilities must meet the requirements of sections 18.2.1 to 18.2.8 and the supplementary requirements of this section.

All of the plant sections in a hybrid power-generating facility that contribute to fulfilling the reactive power capacity requirement must operate with continuous voltage control. The rated reactive power used to determine the voltage control droop is based on the rated capacity of the hybrid power-generating facility. When the plant sections operate independently, the rated reactive power is determined based on the rated capacity of the plant section.

Lower level controls of specific plant components shall be coordinated with each other and with the upper facility-level control so that voltage control operates stably under normal operating conditions and in disturbances, and no interaction phenomena arise that can prevent compliant operation.

## 18.3 Voltage control and reactive power control of a type D power park module

### 18.3.1 Functionalities of voltage control and reactive power control

Type D power park modules shall meet all of the requirements concerning type C power park modules. Furthermore, type D power park modules shall be subject to additional requirements concerning the impact of voltage control and reactive power control on electromechanical oscillations and converter-driven stability.

Defining a deadband for voltage control shall not be allowed.

When tuning the setpoint for voltage control and reactive power control, the potential impact of the functioning of the relevant controller on the dynamics of the power system shall be taken into account. The analysis of the response of voltage control and reactive power control shall be carried out in close co-operation between the power generating facility owner, the relevant network operator and Fingrid in order to be able to specify the impact of the power generating facility on the transmission capacity of the power system so that it supports the functioning of the power system as well as possible.

If the response of the normal control functions of the power-generating facility to electromechanical oscillations or converter-driven stability deteriorates the transmission capacity of the power system irrespective of the implementation and set values of the controls, the impact of the response of the control of the power-generating facility on the oscillations shall be improved by means of additional control functions, such as functionalities corresponding to power system stabiliser (PSS) or power oscillation damping (POD). The need for such additional controls shall be assessed primarily as part of the specific study requirements (chapter 5).

The details related to the control settings shall be documented comprehensively and delivered as part of the data to be provided. Controls shall be accurately described as part of the simulation models provided.

The functioning of the control shall be verified during the commissioning testing.

# 19 Commissioning testing of power park modules

## 19.1 Shared requirements for the commissioning testing of all power park modules

It is the responsibility of the power generating facility owner to verify that the operation of the power generating facility meets the specified requirements. The power generating facility owner is responsible for the costs related to the compliance process. Compliance with requirements shall primarily be verified through tests conducted during the commissioning of the power-generating facility using the facility's normal primary energy source.

The relevant network operator and/or a representative of Fingrid may participate in the compliance testing either on site or using a suitable remote connection, such as the connection from the network operator's control centre. For that purpose, the power generating facility owner shall provide the monitoring equipment necessary to record all relevant test signals and measurements as well as ensure that the necessary representatives of the power generating facility owner are available on site for the entire testing period. Signals specified by the relevant network operator or Fingrid shall be provided if, for selected tests, the network operator or Fingrid wishes to use its own equipment to record performance. The relevant network operator and Fingrid shall decide on their participation at their discretion.

In commissioning tests, the operating mode of the power-generating facility's systems must correspond to the normal operating situation and at least 80 per cent of its converter units must be in use.

## 19.2 Commissioning testing for type B power park modules

The power generating facility owner shall deliver minutes of commissioning testing to the relevant network operator. The minutes shall comprise the documentation of the variables validated by means of measurements and the time of the measurements.

It is the responsibility of the power generating facility owner to verify by commissioning testing that the following characteristics of a type B power park module conform to the Specifications:

1) Impact of the starting and stopping of the power generating facility on the voltage level at the connection point
    - The test shall verify that starting or stopping the power generating facility does not cause quality deviations in the network of the relevant network operator.
2) Rated capacity of the power generating facility
    - The test shall verify that the power generating facility has the rated capacity specified in the connection agreement.
3) Reactive power capacity of the power generating facility

- The test shall verify the reactive power capacity of the power generating facility by running the facility at its rated capacity and at the highest possible inductive and capacitive reactive power.

4) Functioning of voltage control

- The test shall verify that the constant voltage control of the facility functions appropriately. If necessary, the relevant network operator shall provide additional instructions for the test.

5) Limited frequency sensitive mode — overfrequency – (LFSM-O)

- The power generating facility's technical capability to continuously modulate active power to contribute to frequency control in case of any large increase of frequency in the system shall be demonstrated. The steady-state parameters of regulations, such as droop and deadband, and dynamic parameters, including frequency step change response shall be verified,

- The test shall be carried out by simulating frequency steps and ramps big enough to trigger at least 10% per cent of rated capacity change in active power, taking into account the droop settings.
  The test can be performed by introducing an interfering signal of +0.7 Hz in the frequency measurement and using a droop of 4%.

- The test shall be deemed successful if the requirements set out in section 10.2.3 are fulfilled and no undamped power oscillations occur after the step change response.

If necessary, the relevant network operator may impose additional requirements on the scope of the commissioning tests.

Instead of the relevant test, the power generating facility owner may use equipment certificates issued by an authorised certifier to demonstrate compliance with the relevant requirement. In such a case, the equipment certificates shall be provided to the relevant network operator. As a rule, equipment certificates cannot be relied upon to demonstrate the cooperation of the power generating facility as a whole and of all of its auxiliary equipment. Consequently, equipment certificates shall not be accepted as a primary means of verifying compliance, and their use must be agreed on separately with the relevant network operator and Fingrid.

## 19.3 Commissioning testing for type C power park modules

### 19.3.1 Commissioning test plans, measurements and data exchange

The commissioning testing shall be carried out in co-operation between the power generating facility owner, the relevant network operator, and Fingrid. Fingrid’s representatives have the right to participate in all commissioning testing.

The power generating facility owner shall draw up a commissioning testing plan for the specific power generating facility. The plan shall cover the testing of the functionalities at least in the scope described in this section. The power generating facility owner shall deliver the commissioning test plan, preliminary commissioning instructions and a description of the practical arrangements of the tests. The description of the practical arrangements shall cover at least the measurement arrangements, responsible persons, and preliminary schedule. The documents shall be delivered to the relevant network operator no later than 2 months before the planned start of the commissioning testing.

In conjunction with the drawing up and delivery of the commissioning test plans, the power generating facility owner shall arrange a meeting between the power generating facility owner, the relevant network operator, and Fingrid. The meeting shall take place no later than two months before the commissioning testing. In the meeting, the power generating facility owner shall agree on the final commissioning test plan and on the schedule and practical arrangements of the commissioning testing with the relevant network operator and Fingrid. If the above-mentioned parties agree that a meeting will not be held, the data exchange concerning the issues to be agreed shall be arranged in some other way. Each of the above-mentioned parties shall appoint at least one contact person for the commissioning testing.

As the transmission system operator, Fingrid has the right to cancel or change the schedule of the commissioning testing if the execution of the tests at the planned time is not possible due to the operation situation of the power system. The relevant network operator has a corresponding right with regard to the operation situation of its own electricity network. The cancellation or schedule change may be caused by factors such as circumstances related to the operation of power generating facilities or the operation situation of the local electricity network and national power system. If the timing of the commissioning testing needs to be changed, the power generating facility owner shall agree on a new schedule with the relevant network operator and Fingrid.

At least the variables below shall be measured and recorded in all commissioning testing:

- active power of power generating facility,
- reactive power of power generating facility,
- voltage at the connection point,
- frequency at the connection point

The measurements shall be taken at a sampling frequency of at least 1 kHz, and the recording frequency shall be at least 50 Hz. Unlike other tests, the constant voltage control commissioning test (item 19.3.4 / 5c and 5d) must also include measurements of the voltage and current at the terminal of the step-up transformer of a converter module or power-generating facility with a sampling and recording frequency of at least 2 kHz.

If it is not possible to take the measurements at the connection point in accordance with the connection contract, different arrangements must be agreed upon with Fingrid.

Moreover, the setpoint of the variable adjusted in the commissioning testing and the changes of the setpoint shall be recorded. The measurements can be taken using the power-generating facility's own permanently installed measuring devices, provided that they have adequate measurement and recording capabilities.

The commissioning testing shall be planned so that the correspondence of the actual operation of the power generating facility and the dynamic modelling data can be demonstrated by means of calculations.

### 19.3.2 Substituting the commissioning testing

Instead of the relevant test, the power generating facility owner may use equipment certificates issued by an authorised certifier to demonstrate compliance with the relevant requirement. In such a case, the equipment certificates shall be provided to the relevant network operator. As a rule, equipment certificates cannot be relied upon to demonstrate the cooperation of the power generating facility as a whole and of all of its auxiliary equipment. Consequently, equipment certificates shall not be accepted as a primary means of verifying compliance, and their use must be agreed on separately with Fingrid and the relevant network operator.

If the commissioning testing cannot be performed, for example, due to the operational situation of the power system, the power generating facility owner shall agree separately with Fingrid and the relevant network operator on substituting the commissioning testing. Fingrid shall determine whether any commissioning testing can be substituted with one of the following methods:

1) equipment certificates issued by an authorised certifier, certificates issued by accredited laboratories, or equivalent detailed test reports of the turbine generators,
2) continuous monitoring,
3) simulation examinations carried out by utilising verified calculation models.

### 19.3.3 Documentation and acceptance of commissioning testing

The power-generating facility owner is responsible for documenting the commissioning tests and compiling the results into a commissioning report that demonstrates the conformity of the characteristics identified in the commissioning tests. The power-generating facility owner shall deliver the commissioning report as an electronic document and the results of the commissioning testing in numerical format to the relevant network operator in the scope specified in section 20.1.5.

The power-generating facility owner shall agree separately with the relevant network operator on the timing of tests of power-generating facility projects which proceed in stages, described in section 6.3.

It is the responsibility of the relevant network operator to confirm the fulfilment of the compliance obligation related to the requirements in terms of the commissioning testing based on the following four sectors:

1) The preparation, planning and data exchange of the tests have been carried out in accordance with the Specifications.

2) The tests have been carried out in accordance with the scope of the Specifications.

3) The operation of the power generating facility verified by the tests is in accordance with the Specifications and with the data provided on the power generating facility.

4) A commissioning report and measurement data in numerical format have been delivered of the tests related to the Specifications in accordance with the Specifications (section 20.1.5).

The graphs and tables in the commissioning report must show the variables measured in the commissioning tests and the changes in setpoints for a timeframe and resolution that enables the conformity of the results to be evaluated for each test. If a numerical target is set as the criterion for evaluating the outcome of the test, the report must clearly state the value and its connection to the power-generating facility's design criteria.

### 19.3.4 Functions to be verified in commissioning testing

Before starting the commissioning tests, the project-specific hardware settings of the power-generating facility's controls, limiters, and protections shall be checked to ensure they correspond to the supplied information. In particular, the equivalence of the parameters used in the provided simulation models must be verified. Differences in the configurations shall be clarified before starting the commissioning tests. The configuration review and any changes to the settings during the commissioning tests shall be documented and included in the commissioning report.

The commissioning testing shall verify the following functions:

1) Limited frequency sensitive mode — overfrequency – (LFSM-O)

- The power generating facility's technical capability to continuously modulate active power to contribute to frequency control in case of any large increase of frequency in the system shall be demonstrated. The steady-state parameters of controls, such as droop, activation frequency, and dynamic parameters, including the frequency step change response shall be verified,
- The test shall be carried out by simulating frequency steps and ramps big enough to trigger at least 10% per cent of rated capacity change in active power, taking into account the droop settings.
- The test can be performed by demonstrating the activation of the control by introducing an interfering signal of +0.7 Hz in the frequency measurement and using a droop of 4%. It is also necessary to demonstrate that the control is not activated by an over-frequency of less than 0.5 Hz. The test shall be deemed successful if the requirements set out in section 10.2.3 are fulfilled and no undamped power oscillations occur after the step change response.

2) Limited frequency sensitive mode — underfrequency – (LFSM-U)

- The test shall demonstrate that the power generating facility is technically capable of continuously modulating active power at operating points below rated capacity to contribute to frequency control in case of a large frequency drop in the system.
- The test shall be carried out by simulating appropriate active power load points, with low frequency steps and ramps big enough to trigger active power change of at least 10% of rated capacity with a starting point of no more than 80% on rated capacity, taking into account the droop settings.
- The test can be performed by demonstrating the activation of the control by introducing an interfering signal of -0.7 Hz in the frequency measurement and using a droop of 4%. It is also necessary to demonstrate that the control is not activated by an under-frequency of less than 0.5 Hz.
- The test shall be deemed successful if the requirements set out in section 10.4.3 are fulfilled and no undamped power oscillations occur after the step change response.

3) Frequency sensitive mode

- The power generating facility's technical capability to continuously modulate active power over the full operating range between rated capacity and minimum regulating level to contribute to frequency control shall be demonstrated in the test. The steady-state parameters of controls, such as droop, deadband, active power limits for up- and down-regulation, and dynamic parameters, including robustness through frequency step change response and large, fast frequency deviations shall be verified. The continuity of frequency control operation from one frequency range to another with different settings must be verified. At the start of the tests, the active power generation of the power generating facility shall be at least 30% of the rated capacity of the power generating facility, and the control range of frequency control shall be at least ±10% of the rated capacity of the power generating facility.
- The test must be performed based on the measurement of grid frequency and by simulating frequency steps and ramps that are large enough to activate the entire frequency response range for active power. The test shall take into account the droop settings and deadband dependent on the frequency range, as well as the capability to actually increase or decrease active power output from the respective operating point. The rate of change of the active power setpoint shall be set to the highest permissible value for the duration of the test. When performing the test, all interfering signals shall be reset to zero before introducing a new interfering signal. The RO shall carry out the frequency control setting and activate/deactivate it. The test can be performed using the following procedures:

    a) Set the power ranges for frequency control, taking into account the test conditions, so that they are achievable during the test and droop by frequency range, for example, as follows:

        i. <49.5 Hz / 4% (LFSM-U)

ii. 49.5–49.9 Hz / 6%

iii. 49.9–50.0 Hz / 5%

iv. 0 mHz is set as deadband

v. 50.0–50.1 Hz / 3%

vi. 50.1–50.5 Hz / 7%

vii. >50.5 Hz / 4% (LFSM-O)

b) Activate frequency control for all frequency ranges and measure the frequency control response for no less than 10 minutes on the basis of normal network frequency measurement.

c) Introduce an interfering signal of +0.1 Hz in the frequency measurement by means of steps.

d) Turn off frequency control in the 50.1–50.5 Hz frequency range. Inject an interfering signal of +0.4 Hz in the frequency measurement by means of steps.

e) Turn off frequency control in the 50.0–50.1 Hz frequency range. Inject an interfering signal of +0.05 Hz in the frequency measurement by means of steps.

f) Turn on frequency control in the 50.1–50.5 Hz frequency range. Inject an interfering signal of +0.5 Hz in the frequency measurement by means of steps.

g) Inject an interfering signal of −0.1 Hz in the frequency measurement by means of steps.

h) Turn off frequency control in the 49.5–49.9 Hz frequency range. Inject an interfering signal of −0.4 Hz in the frequency measurement by means of steps.

i) Turn off frequency control in the 49.9–50.0 Hz frequency range. Inject an interfering signal of −0.05 Hz in the frequency measurement by means of steps.

j) Turn on frequency control in the 49.5–49.9 Hz frequency range. Inject an interfering signal of −0.5 Hz in the frequency measurement by means of steps.

k) Turn on frequency control in all frequency ranges, and set the frequency control droop to values that differ from a) for each frequency range. Inject an interfering signal of −0.7–+0.7 Hz in the frequency measurement by means of ramps so that the power-generating facility’s power control is able to track the frequency change through the test up to the given power limit.

l) The deadband shall be set to ±10 mHz and the response of frequency control shall be measured for no less than 5 minutes on the basis of normal network frequency measurement.

m) The deadband shall be set to ±100 mHz. Inject an interfering signal of +50 mHz and −50 mHz in the frequency measurement, followed by an interfering signal of +150 mHz and −150 mHz.

- The test shall be deemed successful if the requirements set out in sections 16.3.3 and 16.3.8 are fulfilled and no undamped power oscillations occur after the step change.

4) Rate of change of active power

- The test shall demonstrate the technical capability of the power-generating facility to modulate active power within the operating range and at the rate of change defined in section 16.3.5.
  The test shall be conducted using two different values for the rate of change of active power: 0.1 × $P_{max}$ / minute and the maximum rate of change (which must be at least 1.0 × $P_{max}$ / minute).

- The test can be performed by gradually lowering the active power of the power generating facility to its minimum and, afterwards, gradually increasing the active power of the power generating facility to its maximum. Once complete, the test shall be repeated in the opposite order.

- The test shall be deemed successful if the requirements set out in section 16.3.5 are fulfilled and no undamped power oscillations occur during or after the power change.

5) Constant voltage control

- The test shall demonstrate the technical capability of the power-generating facility to regulate voltage and to function in accordance with the requirements set out in sections 18.2.2 and 18.2.5 when the power-generating facility is connected to the network.

- The test shall consist of voltage control step response tests performed with the power generating facility connected to the network. The tests shall demonstrate the performance of voltage control and the ability to set the required setpoint and slope. The test can be performed using the following procedures:

a) Set the voltage controller’s slope to 2% and change the power-generating facility’s voltage control setpoint stepwise as follows: 1.00 pu, 1.01 pu, 1.00 pu, 0.99 pu, 1.00 pu.

b) Set the voltage controller's slope to 4% and change the power-generating facility's voltage control setpoint stepwise as follows: 1.00 pu, 1.01 pu, 1.00 pu, 0.99 pu, 1.00 pu, 1.02 pu, 1.00 pu, 0.98 pu, 1.00 pu.

c) Make a voltage change in the power-generating facility's internal network by, for example, stepping the main transformer's tap-changer. The test aims to verify the rapid initial response of reactive power control in inverter modules.

d) Make a voltage change in the connection point network by, for example, stepping the main grid transformer's tap-changer or connecting a reactor. The test shall be agreed upon separately with Fingrid.

e) If an alternate configuration is specified for voltage regulation, the tests in points a–d shall be repeated with the new configuration.

f) Demonstrate that the RO can adjust the setpoint and limit the rate of change from a user interface.

- The test shall be deemed successful if the requirements set out in sections 18.2.2 and 18.2.5 are fulfilled and, following the step change response tests, the power-generating facility is able to reach a stable operating point free of poorly damped reactive or active power oscillations. As the voltage control performance calculation was prepared in a model that does not correspond to the network situation during the tests, the power-generating facility's reactive power response may differ from the results provided by the model.
- If multiple operating modes or measurement points are available for voltage control, the operation of control must also be verified for these.

6) Constant reactive power control

- The test shall demonstrate the technical capability of the power-generating facility to regulate reactive power and to function in accordance with the requirements set out in sections 18.2.3 and 18.2.5 when the power-generating facility is connected to the network.
- The test shall include stepwise changes in reactive power when the power generating facility is connected to the network. The tests shall demonstrate the performance of reactive power control and the ability to set the required setpoint.
- The test can be conducted by controlling the set value for reactive power control in the power-generating facility and making stepwise changes of 0.3 × $Q_n$ to demonstrate the rise time of the reactive power response. There should be a separate demonstration that the RO can adjust the setpoint and limit the rate of change from a user interface.
- The test shall be deemed successful if the requirements set out in sections 18.2.3 and 18.2.5 are fulfilled and, following the stepwise change in reactive power, the power-

generating facility is able to reach a stable operating point free of poorly damped reactive or active power oscillations.

7) Constant power factor control

- The test shall demonstrate the technical capability of the power-generating facility to regulate the power factor measured from the connection point in accordance with the requirements set out in sections 18.2.4 and 18.2.5 when the power-generating facility is connected to the network.
- The test shall consist of stepwise changes in reactive power, achieved by adjusting the power factor, with the power generating facility connected to the network. The tests shall demonstrate the performance of power factor control and the ability to set the required setpoint.
- The test can be conducted by controlling the set value for power factor control in the power-generating facility in steps of 0.02 to demonstrate the rise time of the reactive power response. There should be a separate demonstration that the RO can adjust the setpoint and limit the rate of change from a user interface.
- The test shall be deemed successful if the requirements set out in sections 18.2.4 and 18.2.5 are fulfilled and, following the stepwise change in reactive power, the power-generating facility is able to reach a stable operating point free of poorly damped reactive or active power oscillations.

8) Reactive power capacity test and restriction of active power

- The test shall demonstrate the capability of the power-generating facility to generate and consume reactive power in accordance with the requirements set out in section 17.2, and the test shall verify the results of the reactive power calculation. Additionally, the test shall verify the functioning of the facility's active power restriction and the accuracy of its active power control. If the power-generating facility uses separate compensation devices in accordance with section 17.2.3, their operation must also be verified.
- Before conducting the test, the power generating facility owner and the relevant network operator shall agree on the permissible voltage and reactive power ranges. The reactive power capacity test shall be restricted to within the range permitted by normal operating voltage range of the network.
- The test shall be performed at the maximum inductive and maximum capacitive reactive power of the power generating facility, with the power generating facility generating active power at three different operating points for the required operating time:

   a) At more than 60% of rated capacity: no less than 30 minutes*. The test must be conducted at the maximum available active power that can be maintained throughout the test.

b) At 30–50% of rated capacity: no less than 30 minutes*.

c) At 10–20% of rated capacity: no less than 60 minutes**.

*/**) The duration of the test at each power level can be reduced to 15 minutes if an authorised certifier has issued a certificate (factory or type test report) indicating the reactive power capacity of the installation in a test lasting at least 30*/60** minutes. The certificate must be presented as part of the test programme before the test is conducted.

- The test can be performed by making gradual changes in the voltage control setpoint of the power generating facility until both the inductive and capacitive limit is reached, at each active power level. Alternatively, the test can be conducted with constant reactive power control.
- The test shall be deemed successful if the requirements set out in sections 16.3.4, 16.3.8, and 17.2 are fulfilled.

9) Rapid downward control of active power

- The test shall demonstrate the technical capability of the power-generating facility to rapidly down-regulate active power as specified in section 16.3.6.
- The test can be performed by lowering the active power of the power generating facility from its rated capacity to an active power level of 20%.
- The test shall be deemed successful if the requirements set out in section 16.3.6 are fulfilled and no undamped power oscillations occur as a result of the power change.

10) Starting and stopping

- The test shall demonstrate that starting and stopping the power generating facility does not cause quality deviations in the network of the relevant network operator.
- The test shall be deemed successful if the requirements set out in section 16.3.2.3 as well as the requirements for electricity quality specified by the relevant network operator are fulfilled.

11) Voltage control disturbance

  - The test must demonstrate that the power-generating facility's voltage control changes its mode as planned in the event of a disturbance in which, for example, measurements from a controllable busbar are lost. All planned mode changes must be verified.
  - The test can be conducted by simulating a measurement disturbance in the measurement circuit.
  - The test shall be deemed successful if the requirements set out in section 18.2.5 are fulfilled.

12) Remote control

- The test must demonstrate that the remote control required for the power-generating facility operate correctly. The test shall cover all control locations, including Fingrid's electronic control connection and, if applicable, the relevant network operator's control connection. The test shall also demonstrate prioritisation of control rights between the control locations. In addition, the planned operation of any automated functions used if remote control is unavailable must be demonstrated (such as a suspending production with a delay).

- The test shall be conducted by issuing an electronic control signal to the power-generating facility from the control location. Control tests shall be performed for all control signals to verify that the control signal issued by the party with primary control authority is prioritised. The control tests shall be conducted in conjunction with other commissioning tests using the RO's primary user interface. The functionality controls at other control locations—including the electronic control connection between Fingrid and the RO—can be verified separately.

- The test shall be deemed successful when the requirements of sections 10.4.1 and 10.5.1 are met.

13) Autonomous connection after losing external network connections

- The test must demonstrate that, following the loss of external power supply and telecommunication connections, a power-generating facility designed for autonomous connection returns to local control and remote operation as planned, the planned production readiness, and, ultimately, into production when authorised by the RO. The test should also demonstrate that even a long loss of external network connections does not cause unintended changes to the device configurations, such as resetting the controllers to their factory settings.

- The test can be conducted by opening the circuit breaker at the power-generating facility's connection point or an equivalent circuit-breaker while the facility is operating at a active power level of at least 10 per cent. The power-generating facility's telecommunication connections for remote operation should be disconnected at the same time. The supply from the network at the connection point and the remote operation connection are restored after, for example, 30 minutes.

- The test shall be deemed successful if the requirements set out in sections 10.2.9, 10.4.1, 10.4.2 and 10.5.1 are fulfilled.

14) Stable operation of the power-generating facility with other power park modules

- The test must demonstrate the capability of power-generating facility's control systems to operate stably with other power park modules in the area in accordance with the requirements of section 18.2.1. The test procedure shall be determined by Fingrid on a case-by-case basis. If the test is not conducted, the stable operation of the power-generating facility shall be demonstrated through simulation calculations and continuous monitoring when the facility is in operation.

- The test can be conducted by changing the switching state of the background network when the power-generating facility is supplying active power to the network, either alone or in combination with other power-generating facilities, so that when the switching changes, the short-circuit power of the background network changes.

- The test shall be deemed successful when the power-generating facility continues to operate stably. The power-generating facility's operation must comply with the modelling data provided. Fingrid shall evaluate compliance.

15) Fault ride-through capability

- The test shall demonstrate the fault ride-through capability of the power-generating facility in accordance with the requirements set out in section 10.3.2 (type C) or 10.5.2 (type D). The procedure for the fault ride-through test shall be determined by Fingrid on a case-by-case basis. The test may use a test network with a different topology than the power-generating facility's normal network connection in terms of the network's switching and short-circuit power. If a fault ride-through test is not conducted, the functioning of the power-generating facility in case of a local fault shall be demonstrated through simulation calculations and continuous monitoring when the facility is in operation.

### 19.3.5 Commissioning tests for hybrid power-generating facilities

The tests to be performed on hybrid power-generating facilities supplement the tests for individual plant sections described in section 19.3.4. The purpose of the tests is to demonstrate the planned joint operation of the plant sections when controlled by the hybrid power-generating facility's central controller.

1) Reactive power capacity test

   - The test shall demonstrate the capability of the power-generating facility to generate and consume reactive power in accordance with the requirements set out in section 17.2.6, and the test shall verify the results of the reactive power calculation. The test shall also demonstrate the potential substitution of the reactive power capacity of the plant sections with other plant sections in accordance with the design criteria for the facility. It shall also demonstrate the curtailment of active power when the reactive power capacity is insufficient.

   - The test can be conducted by simultaneously running active and reactive power in all the plant sections at a minimum of 20 per cent of the rated capacity. The substitution of reactive power capacity by another plant section can be demonstrated by a separate test in which the operation of a single plant section is prevented, either in whole or in part, and the missing reactive power capacity is substituted by another plant section. The curtailment of active power due to insufficient reactive power capacity can be demonstrated by limiting the production capacity of one or more plant sections to a level where the active power limit takes effect.

- The test is deemed to be successful when the hybrid power-generating facility produces the amount of inductive and capacitive reactive power specified in the reactive power capacity calculation for at least 15 minutes. The substitution of reactive power capacity and the active power curtailment function must work as designed.

2) Disconnection of a plant section

- The test shall demonstrate the power-generating facility's technical capability to continue operating despite the disconnection of an individual plant section in accordance with the requirements of chapter 10.2.1.
- The test can be conducted by unexpectedly disconnecting a plant section or part thereof while the power-generating facility is supplying active power to the electricity network equivalent to at least 20% of the rated capacity and capacitive reactive power at its rated reactive power.
- The test is deemed successful if the power-generating facility continues to operate without other plant sections malfunctioning and the substitution of reactive power capacity operates as designed.

3) Monitoring period

- The test shall demonstrate that the hybrid power generation facility's central controller operates as designed and fulfils the Specifications.
- The test must be conducted by arranging a monitoring period of at least 30 days. Monitoring can be carried out using the power-generating facility's recorders if their characteristics are suitable for continuous measurement.
- The largest network disturbance/incident used to validate the simulation models during the monitoring period will be selected. The voltage and frequency recoding of the incident at the connection point shall be repeated in the simulation model, and the responses of different plant sections in different power-generating facilities shall be compared to measurements of a corresponding situation. A representative network incident shall be agreed upon with Fingrid at the end of the monitoring period, and the validation results shall be included in the report on the monitoring period.
- If deficiencies in the hybrid power-generating facility's operations are detected during the monitoring period, the deficiencies must be corrected promptly, and the necessary tests shall be arranged to verify the effect of the corrections.
- The test shall be considered successful when it demonstrates that the facility's controls operate according to the principles outlined in the information provided.

## 19.4 Commissioning testing for type D power park modules

The commissioning testing requirements for type D power park modules are the same as for type C power park modules (section 19.3). If the voltage control functions of a type D power park module influence electromechanical oscillations in a manner that reduces the transmission capacity of the power system, the power-generating facility owner and Fingrid shall separately agree on the verification of the additional control functions set out in section 18.3.

# 20 Modelling requirements applicable to power park modules

## 20.1 Modelling requirements applicable to type C power park modules

### 20.1.1 General modelling requirements

The simulation models to be supplied on power park modules shall reproduce the main functionalities and characteristics of the power park module realistically.

The simulation models shall include all the main components of the power-generating facility, including compensation equipment and the controllers, limiters, and protective devices affecting the power-generating facility's operation in the network. It must be possible to parametrise the simulation models with respect to the characteristics within the scope of the Specifications. The simulation models must be provided with comprehensive documentation that allows the model to be used and parametrised for various studies of operating and disturbance situations.

The calculation models must be provided in PSS®E format. Fingrid maintains separate modelling instruction describing the software versions currently in use and the characteristics required for the models created with them.

The power-generating facility owner must maintain the simulation models of the power-generating facility, incorporating any changes to the power-generating facility that affect the models, and submit the updated models to the relevant network operator and Fingrid.

### 20.1.2 Aggregation of power-generating facility for the simulation model

The simulation models for the power-generating facility's power distribution, fault current, and dynamics shall be submitted as a single entity describing the entire power-generating facility, where sub-systems consisting of similar converter units are described by a single equivalent generator. In addition to the equivalent generator, the model shall cover the transformers needed to connect the generator and the power-generating facility to the power system and the connection network.

The submitted model of the hybrid power-generating facility must include all the plant sections.

### 20.1.3 Requirements concerning power flow and fault current simulation

The power flow simulation model and fault current simulation model shall reproduce, within the voltage and frequency operating range conforming to the Specifications, the impact of the power generating facility on the following issues:

1) power flow of the power system, considering potential dependences, for example, between the production power and the voltage of the connection point,

2) voltage profile of the power system, considering the different modes and constraints of voltage control as well as potential compensation equipment,

3) fault currents.

### 20.1.4 Requirements concerning the dynamics simulation of power park modules

The model intended for dynamics simulation shall reproduce the operation of the power generating facility within the voltage and frequency operating range in accordance with the Specifications, taking into account the response and impact of the power generating facility on the following issues:

1) changes in the voltage amplitude and in its phase angle in conjunction with electromechanical transients,

2) electromechanical oscillations related to angle stability at frequencies 0.1–2 Hz following small and large signal disturbances,

3) high-speed (10 ms – 10 s) transients related to voltage stability. These shall take into account the operation of the facility in conjunction with momentary voltage disturbances, and the dependence of the recovery of active power and the reactive power capacity on voltage.

4) Rapid (10 ms to 10 sec) change phenomena associated with converter-driven stability. The phenomena shall be described as accurately as possible within the constraints of the PSS®E software.

### 20.1.5 Requirements concerning the verification and documentation of the modelling data

The data to be delivered for the modelling calculation shall be verified by comparing the modelling data, using the modelling results obtained, to the results of the commissioning testing of the power generating facility. The verification obligation of modelling data applies to power generating facilities in the scope presented in Tables 20.1 and 20.2. The relevant network operator and Fingrid shall provide the power-generating facility owner with information about the network and its status, as required for verification. If necessary, verification can be carried out in cooperation with Fingrid, using Fingrid's network models.

The data to be delivered for the modelling calculation shall be documented. The documentation shall be delivered as electronic documents to the relevant network operator. The documents to be submitted shall be clear and unambiguous in terms of their layout and structure. The documentation shall cover the following main issues:

1) The components of the power generating facility and the electricity network that connects the components

2) A block diagram of active power control and frequency control and the associated parameters

3) A block diagram of voltage control and reactive power control and the associated parameters

4) A block diagram of any other additional power generating facility control functions or components and their function if these are relevant in terms of the Specifications

5) Instructions for the use and maintenance of the simulation model

6) Results of verification of modelling data:

   a) report of the verification of the model,

   b) comparison of the modelling results and the results of the commissioning testing in the scope presented in Table 20.1,

   c) measurement results of the commissioning testing in numerical format in the scope presented in Table 20.2 in so far as Table 20.1 obliges verification,

   d) account of potential differences between the modelling results and the results of the commissioning testing.

**Table 20.1. Verification obligation of modelling data on power park modules by type.**

| Item to be verified | Type C | Type D |
|---|---|---|
| Stepping response of the power-generating facility's voltage control with two different values for the slope in accordance with section 19.3.4, points 5) a) and b) (voltage increase and decrease) | X | X |
| Reactive power capacity of the power generating facility and the functioning of limiters that restrict the capacity | X | X |
| Operation of additional control functions, such as POD (chapter 18.3) | | X |
| Fault ride-through test [1)] | X | X |

[1] To be agreed on a case-by-case basis. If a fault ride-through test for the power-generating facility is not carried out, the functioning of the power-generating facility in a local fault shall be demonstrated by means of simulation calculations.

**Table 20.2. Measurement data on commissioning testing to be delivered in numerical format, to which measurement data the results calculated using the modelling data is compared.**

| Item to be verified | $U_{PCC}$ | $P_{PCC}$ | $Q_{PCC}$ | Signals |
|---|---|---|---|---|
| Step response of voltage control of the power generating facility using two different slope values (both the increase and decrease in voltage) | X | X | X | Voltage setpoint |
| Reactive power capacity of the power generating facility and the functioning of limiters that restrict the capacity | X | X | X | Voltage setpoint |
| Operation of additional control functions, such as POD (type D only, see section 18.3) | X | X | X | To be agreed on a case-by-case basis. |
| Fault ride-through test | To be agreed on a case-by-case basis. If a fault ride-through test for the power-generating facility is not carried out, the functioning of the power-generating facility in a local fault shall be demonstrated by means of simulation calculations. | | | |

| | |
|---|---|
| $U_{PCC}$ | Connection point voltage |
| $P_{PCC}$ | Active power of the power-generating facility measured at the connection point |
| $Q_{PCC}$ | Reactive power of the power-generating facility measured at the connection point |

## 20.2 Modelling requirements applicable to type D power park modules

The modelling requirements for type D power park modules are the same as for type C power park modules. A type D power park module must also fulfil the requirements set out in this section.

The simulation models shall be prepared for the PSS®E and PSCAD™ software.

Due to the long duration of a power-generating facility project, the requirements for the models submitted in stage 1 of the verification process and updated in stage 2 may differ from each other. When compiling the information submitted at each stage of the verification process, the power-generating facility owner shall ask Fingrid for the current modelling requirements and take them into account in the models provided.

In addition to the requirements set out in section 20.1.4, the PSCAD™ model shall replicate the power-generating facility's operation in the voltage and frequency operating range corresponding to the Specifications and in the event of a disturbance, taking into account the power-generating facility's response and impact on the following:

1) fast phenomena (10 ms to 10 s) related to resonant stability

2) very fast change phenomena (0.4 ms to 1 s) related to converter-driven stability.

The obligation to verify the models against commissioning tests (Table 20.1) applies to all submitted models.

The power-generating facility owner shall submit information on the verification procedures for models of converter units, controllers, protection devices, and other active components included in the model of the power-generating facility, such as Hardware-In-the-Loop (HIL) tests that test the physical equipment's response to electricity network phenomena as part of a simulation model. Fingrid is entitled to require the verification of the models using HIL tests if there is no other way to verify that the operation of a device that is important for system security is equivalent to the model.

### 20.2.1 Specific study requirements

The simulation models used for the specific studies set out in chapter 5 must be submitted to Fingrid as part of the final report on the specific study. Said simulation models shall be updated after the commissioning testing and delivered to Fingrid as part of the final documentation of the power-generating facility.

# 21 Appendix A: Principles of voltage control setpoint configuration for power-generating facilities

**Table of contents**

## 21.1 Introduction

These instructions were created to harmonise the principles of voltage control setpoint configuration for power generating facilities. Primarily, the instructions apply to power generating facilities with a rating of 10 MW or more that are connected to a 110 kV network. However, the principles shall also apply at lower voltage levels. At higher voltage levels, the instructions shall apply if the parties so agree. In special cases, the power generating facility owner and the relevant network operator shall agree on whether the instructions should apply.

All power-generating facilities connected to the Finnish power system shall meet the Grid Code Specifications for power-generating facilities (VJV2024) set out by Fingrid Oyj. The Grid Code Specifications for Power Generating facilities specify a reactive power capacity for power generating facilities based on the connection method used, the rated capacity of the relevant facility and the voltage level specified for the relevant connection point.

In addition, Supply of reactive power and maintenance of reactive power reserves (an appendix to the Main grid contract, KVS2016), states the following:
"*The reactive-power-generating capacity and intake capacity of a power generating unit connected to the main grid with a rated voltage of 400 kV shall, while the power generating unit is connected to the grid, be reserved as reactive power reserve in full, with the exception of the reactive power consumed by the unit's transformer and by the unit's own consumption. With other power generating units over 10 MW or connected to a grid with rated voltage of over 110 kV, half of the reactive-power-generating capacity and intake capacity of the power generating unit, measured at the connection point, shall be reserved as reactive power reserve while the unit is connected to the grid.*"

The principles in these instructions have been defined with consideration of the requirements for available reactive power capacity and the obligation to reserve half of the reactive power capacity of the power-generating facility for power system voltage control. The values specified in these instructions are based on results obtained through calculations as well as practical experience in systems testing and operation.

## 21.2 Voltage control

### 21.2.1 Method of voltage control

The primary method for adjusting the voltage of synchronous power generating modules is to adjust the terminal voltage of the generator.

For power park modules, the primary method for adjusting voltage is to adjust the reference point voltage of the power generating facility.

### 21.2.2 Voltage control setpoint

If the 110 kV main grid is used as the reference point, the voltage control setpoint shall be set to a value of 118 kV, which is also the normal operating voltage of the main grid.

If the reference point for voltage control is at a lower voltage level, the voltage control setpoint shall be set to a value that ensures that at a grid voltage of 118 kV, the reactive power fed through and taken from the main grid by the facility is as close to zero as possible.

By following the setpoints specified above, the voltage of the power system adjusts naturally towards the defined normal operating voltage setpoint, and there is no unnecessary transfer of reactive power between the elements contributing to voltage control.

### 21.2.3 Main transformer rating

In power-generating facilities connected to the main grid, it is advisable to rate the high-voltage side of the power-generating facility's main transformer (block or step-up transformer) based on the normal operating voltage of the main grid (118 kV).

### 21.2.4 Operation of an on-load tap-changer in a main transformer

It is not mandatory to install an on-load tap-changer; however, such a device can be useful for controlling voltage in a medium voltage network. If an on-load tap-changer is installed, the following operating principles shall be observed:

- When the voltage control reference point is at the high-voltage side of the power-generating facility's main transformer, automatic voltage control by the on-load tap-changer shall be enabled.
- When the voltage control reference point is at the low-voltage side of the power-generating facility's main transformer, automatic voltage control by the on-load tap-changer shall be disabled.
- If the power-generating facility's connection point and voltage control reference point is in a distribution network that also has consumption facilities connected to it, the relevant network operator shall be responsible for coordinating the operation of its main transformer's tap-changer with the voltage control of the power-generating facility connected to the low voltage side of the transformer.

Primarily, the operation must be coordinated by selecting a high enough value for the slope of the power-generating facility's voltage control. If necessary, a deadband can be set for the power-generating facility's voltage control to allow the tap-changer to operate before the power-generating facility's voltage control at voltage changes of less than ±2 per cent.

## 21.3 Slope and setpoint

Slope allows the power generating facilities that contribute to the voltage control of the power system to jointly equalise changes in reactive power generation caused by changes in power system voltage.

### 21.3.1 Definition

Slope is expressed as the relation between the change in voltage and the change in the reactive power generated by the relevant power-generating facility. Slope shall be calculated using Equation 1 below:

$$slope = \frac{\frac{\Delta U}{U_n}}{\frac{\Delta Q}{Q_n}} \qquad (1)$$

where $\Delta U$ is change in voltage, $U_n$ is rated voltage, $\Delta Q$ is change in reactive power and $Q_n$ is rated reactive power.

Slope functions as illustrated in Figure 22.1. The reactive power generation of a power generating facility changes as a function of the voltage in accordance with the slope of the voltage droop line.

The rated reactive power $Q_n$ marked in the Figure is achieved with a voltage change corresponding to the slope. If the voltage change is larger, the power-generating facility must increase its reactive power production to the limit defined for its actual capacity ($Q_{min}$ and $Q_{max}$). Reactive power production must not be limited to the rated reactive power if the power-generating facility is capable of producing more reactive power and the characteristics of the connection point network do not prevent it.

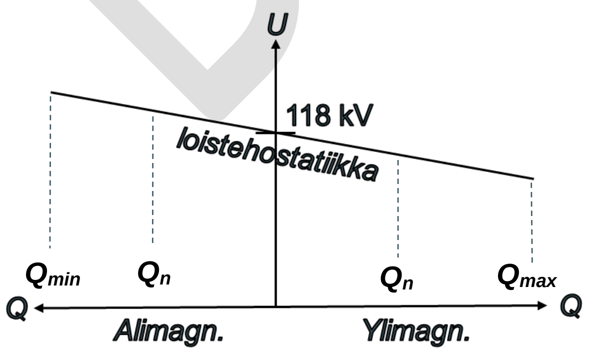



Figure 21.1. Slope

Instead of voltage droop, the slope function can be based on reactive current droop. In this case, the control method must be compliant with the principles set out in these instructions while accounting for the underlying differences between the two control principles.

#### 21.3.1.1 Definition of rated reactive power ($Q_n$)

Rated reactive power shall be determined in accordance with the VJV Specifications:

- When the voltage control reference point is at the high-voltage side of the power-generating facility's main transformer, the rated reactive power shall be $Q_n = 0.33 \times P_n$ *(rated active power)*. The rated voltage ($U_n$) is then the normal operating voltage of the controllable voltage level (e.g. 118 kV). The rated reactive power is also defined in this way when the power-generating facility's connection point and the voltage control reference point are in the distribution network on the low-voltage side of the relevant network operator's main transformer.
- When the voltage control reference point is at the low-voltage side of the power-generating facility's main transformer, the rated capacity shall be $Q_n = 0.48 \times P_n$ *(rated active power)*.In such a case, the rated voltage ($U_n$) shall be the rated voltage of the generator connected to the controllable voltage level (e.g., 10.5 kV).

### 21.3.2 Setpoint

#### 21.3.2.1 Voltage control reference point at the high-voltage side of the main transformer

When the voltage control reference point is at the high-voltage side of the main transformer, the slope setpoint shall be in the range of 4...8%. The recommended setpoint is 4%.

#### 21.3.2.2 Voltage control reference point at the low-voltage side of the main transformer

##### 21.3.2.2.1 One generator

When there is only one generator connected to the main transformer and the voltage control reference point is at the low-voltage side of the main transformer, the slope setpoint shall be in the range of 0...4%. The recommended setpoint is 0%.

If the short-circuit impedance ($u_k$) of the main transformer is greater than 12%, the setpoint value shall be 0%.

##### 21.3.2.2.2 Two or more generators

When there are two or more generators connected to the main transformer and the voltage control reference point is at the low-voltage side of the main transformer, the slope setpoint shall be in the range of 2...4%. The recommended setpoint is 4%.

If the short-circuit impedance ($u_k$) of the main transformer is greater than 12%, the setpoint value shall be 2%.

## 21.4 Intra-plant reactive power control

Intra-plant reactive power control is allowed only when the facility connected to the main grid both generates and consumes power, integrated manufacturing facilities being an example. The annual internal energy consumption of the relevant facility shall correspond to at least 1/4 of its annual energy production, otherwise the connection shall be considered a pure power generating facility connection.

The purpose of intra-plant reactive power control is to compensate for the reactive power consumed as a result of local loads and to keep the transmission of reactive power over the connection point within the bounds specified in the relevant connection agreement. No more than half of the available reactive power capacity of each generator shall be reserved for intra-plant reactive power control.

When using intra-plant reactive power control, generator voltage control shall be configured as specified in sections 21.2 and 21.3 of this document. The intra-plant reactive power control and the generator's constant voltage control make up the cascade control. Intra-plant reactive power control serves as the master controller, providing a reference input for generator voltage control or the voltage control setpoint reference summing point. Consequently, the constant voltage control of generator terminal voltage is always active, and should not be bypassed or disabled by intra-plant reactive power control.

Intra-plant reactive power control shall be enabled only when the following conditions are met:

- The connection point's voltage is 116–120 kV
- No more than 50% of the available reactive power capacity of each generator shall be used for internal compensation by intra-plant reactive power control.
- The integration time for facility-specific reactive power control shall be long, ensuring that the control function obtains a new operating point 15 minutes after the change in reactive power.

A derogation from the principles set out in this instruction may be allowed for a compelling reason subject to approval by Fingrid. Fingrid must be informed of the use of intra-plant reactive power control.

## 21.5 Example diagrams of typical setups

This section provides examples of typical setup principles illustrated through diagrams.

### 21.5.1 Power park module

Figure 21.2 provides an example of the voltage control setup used in power park modules.

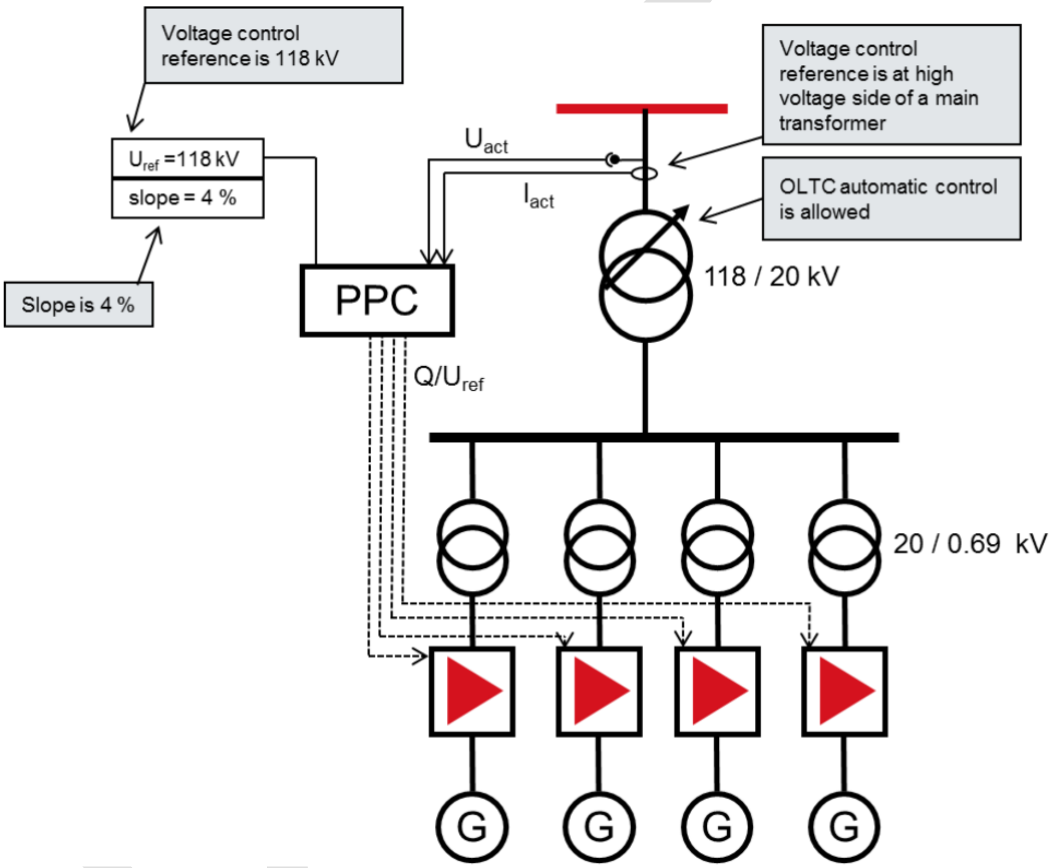



**Figure 21.2. General principle diagram of power park module voltage control. The Power Park Controller (PPC) is the facility's central controller.**

### 21.5.2 Synchronous power-generating module – one generator

Figure 21.3 provides an example of the voltage control setup used in synchronous power-generating modules that have only one generator connected to the main transformer.

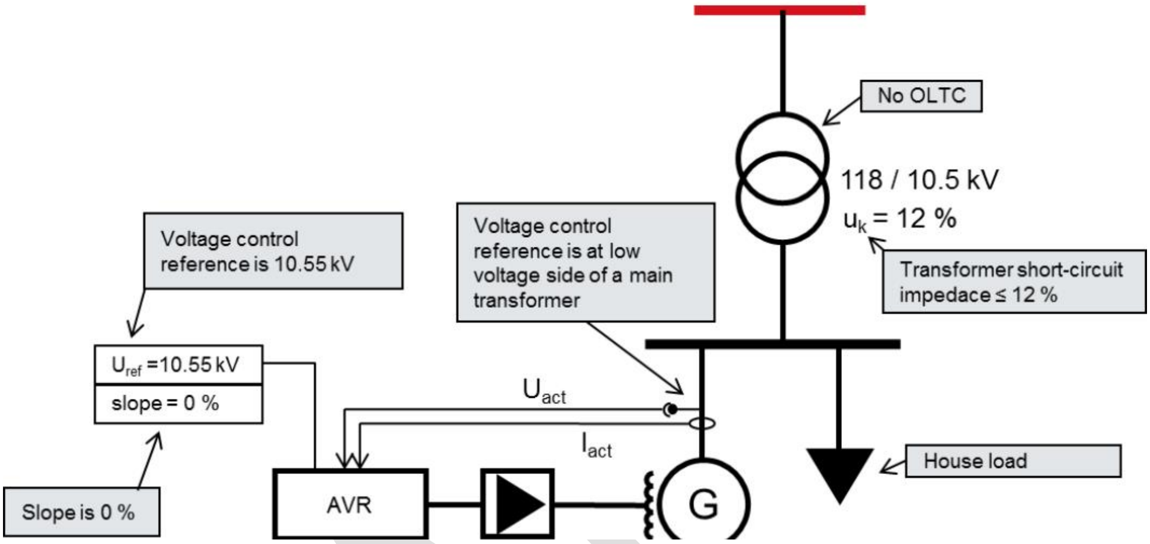



**Figure 21.3. General principle diagram of voltage control used in a one-generator synchronous power-generating module. The AVR is an Automatic Voltage Controller.**

### 21.5.3 Synchronous power-generating module – two or more generators

Figure 21.4 provides an example of the voltage control setup used in a synchronous power-generating module that has two or more generators connected to the main transformer.

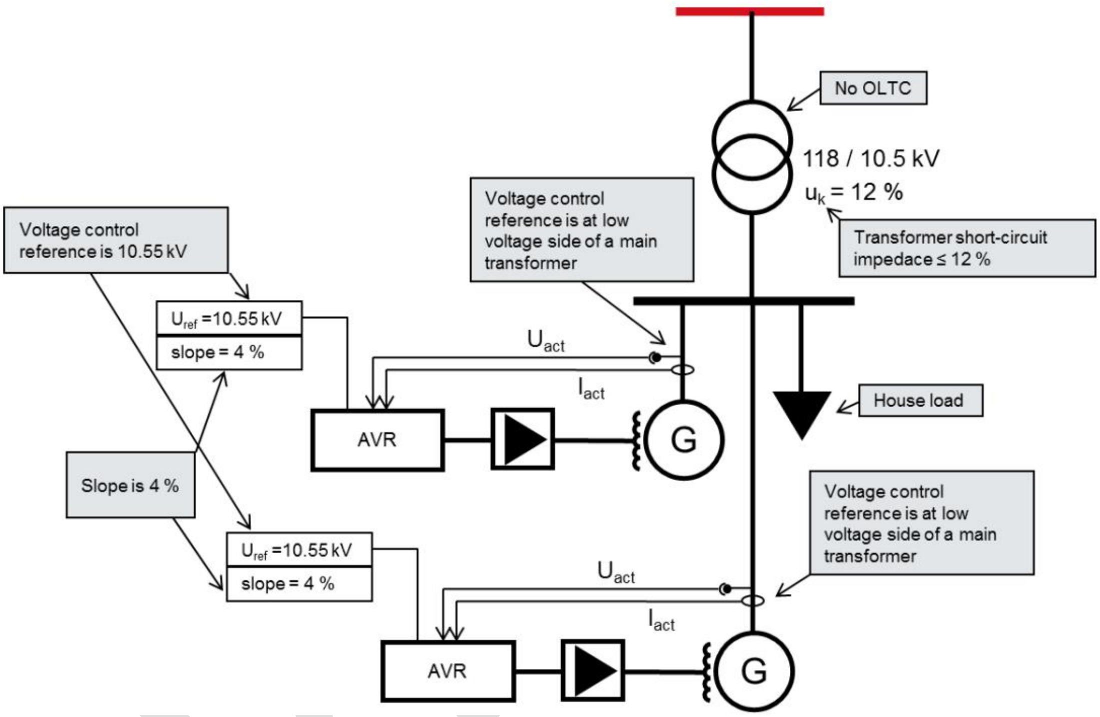



**Figure 21.4. General principle diagram of voltage control used in a synchronous power-generating module that includes two or more generators.**

# 22 Appendix B. Tuning instructions for power system stabilisers used in generators connected to the Finnish power system

**Table of contents**

## 22.1 Introduction

The purpose of this document is to describe the principles applicable to the tuning of power system stabilisers (PSS). The document does not provide specific tuning instructions for different equipment setups. The tuning principle provided in these instructions allows power generating facility owners to improve the capability of their facility's PSS to dampen both the local oscillation mode and the inter-area oscillations between their facility and the power system. The purpose of this document is to help experienced voltage control and PSS tuning professionals to create a procedure for tuning the equipment selected for the relevant equipment setup. These instructions should not be considered a stand-alone commissioning instruction document because the setup and tuning of power system stabilisers shall always be planned and implemented in a project-specific manner.

## 22.2 Background information on power system stabilisers

The primary purpose of power system stabilisers (PSS) is to improve the damping of power oscillations present in the power system. Improved damping increases system security and increases transmission capacity. In the Nordic synchronous system, there are inter-area power oscillations in the range of 0.2...1.0 Hz. The most prevalent oscillation mode is approximately 0.3–0.5 Hz.

PSS functions through interaction with the voltage control of the excitation system. PSS modulates the voltage control setpoint and, consequently, the reactive power generated by the relevant generator, resulting in a change in generator shaft torque angle. Excitation properties, such as rapid response time and accurate tuning, are critical factors in PSS performance. The PSS must be tuned after the excitation system has been tuned and calibrated.

In modern excitation systems, the PSS is typically implemented as software integrated into the automatic voltage regulator (AVR). Accelerating power and synthetic speed (which is the integral of accelerating power) are calculated based on the AVR's terminal voltage and terminal current measurements.

The purpose of the PSS is to compensate for the phase shift between the generator and the excitation system. This is achieved by shifting the phase of the input signal. Phase compensation is achieved by tuning the PSS to compensate for the lag caused by the generator, the excitation system and the power system in a manner that allows the PSS to provide torque changes in phase with changes in shaft speed.

PSSs are often very inexpensive, especially if purchased with the excitation system. Certain manufacturers will supply the PSS with no additional cost as an integral part of the AVR.

Both upgrade contracts and contracts for building a new power generating facility shall include PSS tuning and the delivery of verified simulation models corresponding to those provided in the IEEE standard 421.5 model library.

## 22.3 Key considerations

Power system stabilisers must be tuned with care. To avoid equipment damage when tuning and commissioning power system stabilisers, the following issues shall be taken into consideration:

- There are both analogue and digital PSSs. Analogue and digital PSSs are usually tested using different test methods.
- If the wind turbine generator shaft has resonance frequencies below 20 Hz, a change in shaft torque modulated by the PSS may excite oscillations in the shaft. This can happen especially when speed is used as the input signal for the PSS. Usually, shaft oscillations are removed from the PSS input signal using a special hardware filter. Typically, the ramp track filter filters the PSS output to the frequencies that generate shaft vibrations.
- The PSS may cause interference in the transient response of the excitation system. Consequently, PSS systems usually include output limiters.
- Underexcitation and overexcitation limiters may restrict the PSS operation. Any such limiters should be tuned so that they function in coordination with the PSS.
- When electrical power is used as the PSS input signal and there is a rapid change in the load, the PSS response may cause major reactive power oscillations in the generator response. Type PSS2A and PSS2B power system stabilisers can be tuned to better withstand changes in load.
- The PSS system shall be tuned in operating conditions where intra-plant mode damping is at its lowest level. Additionally, it must be verified that the PSS does not cause instability within the facility’s normal operating band or during foreseeable fault conditions.

## 22.4 PSS types

There is a wide variety of power system stabiliser solutions utilising different input signals. Typical input signals include rotor speed, terminal voltage frequency, electrical power, accelerating power or some combination of the above.

Fingrid recommends the use of power system stabilisers of the PSS2A, PSS2B, or PSS2C dual-input type that conform to the IEEE 421.5 standard. The block diagram for type PSS2B power system stabilisers is presented in Figure 23.1 below.

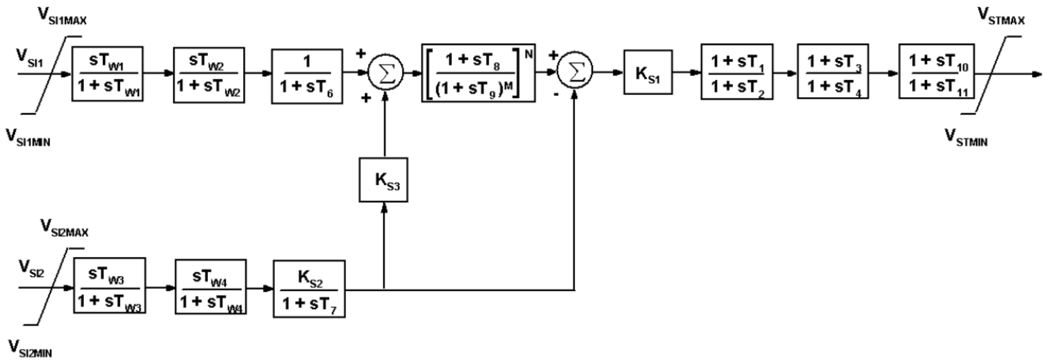


**Figure 22.1. Block diagram of a PSS2B power system stabiliser (IEE 421.5).**

## 22.5 Power system stabiliser tuning

This section provides an overview of the principles used for tuning power system stabilisers. Power system stabilisers using different input signals are tuned in a different manner; consequently, system-specific tuning instructions may vary.

### 22.5.1 Operational testing of PSS equipment

The basic functionalities of the power system stabiliser, such as phase compensation and PSS limiter operation, shall be tested. Any potentiometers installed shall function in a stable manner and provide continuous control capability within the entire operating range.

### 22.5.2 PSS output limiter

Output limits shall be configured in a manner that prevents the PSS from increasing the terminal voltage of the generator over a predetermined value.

Before the PSS is switched on for the first time, limiter setpoints should be set to a very conservative value, such as ±2% of the generator's terminal voltage.

Usually, the final setpoint values fall within the range of ±5–10% of the generator's terminal voltage. The two setpoints can be asymmetrical.

### 22.5.3 Protection and alarms

PSS output protection should be adjusted in a manner that allows it to function in co-ordination with the output limiter. The system should generate an alarm in case PSS is disabled by the protection function.

### 22.5.4 Control

It must be possible to deactivate PSS from the local controllers and the RO's control location, such as the power-generating facility's control room.

### 22.5.5 Washout filter

The washout filter is used to filter low-frequency components from the PSS input signal. PSS phase compensation can be adjusted by changing its time constant. In frequency-based PSSs, using a short time constant increases the level of phase compensation and decreases the gain.

When using type PSS2A and PSS2B power system stabilisers, a washout time constant lower than 10 seconds should be used, ensuring that low-frequency (<0.1 Hz) components are filtered rapidly from the PSS output. Using a lower time constant decreases the PSS’s effect on system voltage during extended frequency disturbances (such as dips in production), especially in cases where the PSS would have a considerable amplification.

### 22.5.6 Ramp track filter

The ramp track filter removes the high frequency components from the PSS input signal. A ramp track filter is required to prevent the PSS from amplifying its own vibration frequencies or those of nearby generator shafts. In addition, the ramp track filter ensures that the PSS does not start to amplify any voltage fluctuations that could arise in power park modules.

For example, the ramp track filter can be tuned to filter frequency components above 3 Hz.

### 22.5.7 Phase compensation tuning

Phase compensation shall be tuned in accordance with the following principles:

- The system response of the generator and the excitation system shall be tested at low generator power without the PSS engaged. The frequency response test shall be performed by feeding a sine wave signal into the voltage control input and measuring the phase shift of the signal. The frequency response test shall be performed in the range of 0.05–3.0 Hz at a minimum of ten different frequencies.

- The results of the frequency response test shall be verified for future simulation and the PSS shall be tuned to compensate for the measured phase shift.

- PSS phase shift compensation shall be tuned so that the phase shift in the 0.3–1.0 Hz inter-area oscillation frequency range is as close to 0 degrees as possible.

- Phase shift undercompensation is preferable to overcompensation. This is due to the fact that as the power system becomes weaker, the phase shift between the generator and the excitation system is also decreased.

- If intra-plant stabilisation requires the PSS to be tuned to provide a phase shift other than 0 degrees at inter-area frequencies, the response of the entire PSS/AVR/generator system shall not generate a phase shift greater than 30 degrees within the 0.2–2.0 Hz frequency range.

- When tuning phase shift, it must be verified that the gain for low-frequency signals (under 0.2 Hz) is not higher than the gain for 0.2–2.0 Hz fluctuations. In some cases, tuning phase shift and the low-frequency signal amplification requires a compromise that makes it difficult to achieve phase shift undercompensation. In such cases, the phase shift of signals in the 0.2–2.0 Hz frequency range shall be kept at or below 30 degrees.

### 22.5.8 Gain configuration

From the power system's perspective, using the highest possible gain provides the best damping. The recommended, and most reliable, way to determine the maximum safe gain is testing. To determine the gain margin, an amplification test using maximum overall gain for the system shall be performed. Consequently, the test should be performed at maximum capacity or at least at 80% of rated capacity.

Before starting to increase the PSS gain, the PSS must be in stable operation with the PSS limiters engaged and set to, for example, ±5% of the generator's terminal voltage.

The gain shall be increased until the PSS output signal or terminal voltage begins to oscillate. The oscillation in terminal voltage is caused by noise amplified by PSS gain or excitation system mode gain. This maximum gain value shall be noted down and divided by two or three, resulting in solid, stable power system stabiliser operation.

The optimal gain and the inter-area oscillation mode damping performance of the PSS shall be verified through simulation.

### 22.5.9 Commissioning testing

#### 22.5.9.1 Measured variables

At minimum, the variables listed below shall be measured and recorded during commissioning testing:

- excitation current,
- excitation voltage,
- terminal voltage,
- reactive power,
- active power,
- frequency,
- PSS output signal
- test signal (sine wave signal fed to the voltage control input to enable phase shift measurement).

The PSS can only be tuned if sine wave signals with different frequencies can be fed to the input of the voltage controller for frequency response determination.

### 22.5.9.2 Example of PSS tuning and a commissioning plan

This example illustrates the general steps that must be completed when commissioning a digital power system stabiliser. Typically, a power system stabiliser is commissioned as part of the power generating facility commissioning process. Consequently, PSS commissioning is usually incorporated into the relevant facility's commissioning schedule. The successful tuning of the PSS may require special tests to determine the machine's quantities (such as the inertia time constant).

1. Pre-tuning (simulation) calculated for voltage control and the PSS.

   Voltage control and the PSS shall be simulated and tuned using standard models (IEEE421.5) with the available initial data. At least the following simulations shall be conducted using the model:

   - Step response tests by adjusting the generator voltage ±10% in no-load operation
   - Step responses while connected to the network by adjusting the generator voltage ±2% when PSS is on and off
   - Testing the excitation limiters
   - Fault ride-through study
   - Create the following Bode plots for the 0.05–10 Hz frequency range

     i. If the phase shift of the generator-exciter-power system (GEP) was not measured in advance, compare the simulated phase shift with the phase shift created by the PSS. Demonstrate that the PSS has been tuned to compensate in accordance with the requirement in section 22.5.7. If the study is conducted with a simulated phase shift, the plot must be updated when the phase shift has been measured.

     ii. Power system stabiliser gain. Demonstrate that the PSS does not amplify low frequencies as per the requirements of section 22.5.7.

     iii. The frequency response from the AVR's summing point ($V_{inj}$) to the generator's active power ($P_g$) when the generator is operating at its rated capacity and the PSS is off and on at its rated gain. Demonstrate the PSS damping over the entire frequency range.

   - The Bode plots mentioned above shall be updated after tuning and submitted as part of the final report.

2. Voltage control step response tests (generator disconnected from the network)

The step response tests for voltage control shall be performed with the generator idling and disconnected from the network. A step response test shall be performed at 2% and 10% both upwards and downwards.

3. Voltage control step response tests (generator connected to the network, running at minimum capacity)

   The step response tests for voltage control shall be performed with the generator running at minimum and connected to the network. Conduct step response tests at 1% and 2%, upwards and downwards.

4. Frequency response measurement (generator connected to the network, running at minimum)

   The frequency response of the automatic voltage regulator shall be measured with the generator running at minimum power and connected to the network, and the power system stabiliser is not enabled. The frequency response test shall be performed by feeding a sine wave signal to the voltage control input and measuring the phase shift of the signal from terminal voltage. The frequency response test shall be performed in the range of 0.2–3.0 Hz and repeated using, for example, ten different frequencies (0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8, 1.0, 1.5, 2.0, 3.0 Hz).

5. Over- and underexcitation limiter testing (generator connected to the network, running at minimum)

   The over- and underexcitation limiters shall be tested as follows. The limit value of the overexcitation limiter shall be gradually decreased from its setpoint value to verify that the limiter functions as intended by limiting the step response of voltage control. The limit value of the underexcitation limiter is gradually increased from its setpoint value to verify that the limiter functions as intended by limiting the step response of voltage control. The setpoints of the limiters shall be reverted to their design values or adjusted as necessary. The test shall also be repeated at least once at the rated capacity of the generator.

6. Power system stabiliser tuning (simulation)

   The power system stabiliser simulation model shall be checked and tuned for step response test results. The power system stabiliser shall be tuned to compensate for the previously measured phase shift (see section 22.5.7).

7. Gain configuration (generator connected to the network, at 50% of rated capacity)

   The gain shall be configured as follows (see section 22.5.8):

   a) Before the PSS is switched on for the first time, the PSS limiter setpoints should be set to a very conservative value, such as ±2% of the generator’s terminal voltage. This allows the stepwise voltage change caused by an incorrect parameter configuration to be avoided.

b) Determine the voltage step at which the generator's active power begins to fluctuate, so that the effectiveness of the PSS's tuning can be assessed. In some cases, the voltage change must be high, requiring a step of up to 4–5%. For example, a 4% stepwise should be made by changing the setpoint by 0.98–1.02 pu.

c) The PSS gain (Ks1) shall be set to 0 and the power system stabiliser switched on for the first time, followed by an upwards and downwards step response test.

d) The PSS gain (Ks1) shall be set to 1, and the effect of the PSS during normal operation shall be monitored for approximately 5 minutes, paying attention to how the PSS reacts to the normal rapid fluctuations in the generator's active power. Conduct a step response test at 1% upwards and downwards. If voltage control provides a stable response, the power system stabiliser limiter setpoints can be increased to, for example, ±5% of the generator's terminal voltage. Then conduct a larger step response test until reaching the step size specified in item 2.

e) The gain value shall be set to 0 and increased slowly in small steps (such as 0, 1, 2, 4, 6, 8, 10, 12, 13, 14, 15). After each gain change, the output signal of the PSS, the active and reactive power of the generator, and the terminal voltage shall be monitored. Each change in gain shall be followed by an upwards and downwards step response test. When vibrations are detected in continuous mode or following a step response, the gain should no longer be increased.

f) The gain value at which oscillation is first registered shall be noted down. This maximum gain value shall be divided by 2.5–3.0 to provide a good, stable PSS. The value obtained in the manner described above is the nominal gain value. The exact divisor (2.5–3) shall be determined by considering the ratio between the short circuit power of the connection point during normal operation and during operation in a weakened network state as well as the effect thereof on the operation of the PSS.

8. Compensated frequency configuration (generator connected to the network, at 50% of rated capacity)

In most power system stabilisers, the angular difference between the terminal voltage of the generator and the internal voltage source is compensated through reactance compensation ($X_{comp}$ or $X_q$). Typically, the compensation reactance value falls between the direct-axis transient reactance and the quadrature-axis transient reactance. Based on the compensated frequency value obtained as above, the phase shift of the power system stabiliser can be tuned to compensate for the actual change in the angular velocity of the rotor. In order to obtain the correct compensation reactance value, the step response tests shall be repeated at nominal gain using alternative reactance values. The most suitable value shall be selected based on the response obtained through testing.

9. Gain configuration at maximum output (generator connected to the network, at ≥ 80% of rated capacity)

    a) The power system stabiliser shall be switched on and PSS gain (Ks1) shall be set to 0. Step response tests shall be performed at 2% both upwards and downwards. If necessary, the step shall be increased to cause the active power to swing as at 50% power.

    b) The PSS gain (Ks1) shall be set to the nominal value, and the effect of the PSS on the normal rapid fluctuations in the generator’s active power shall be monitored for approximately 5 minutes..

    c) The PSS gain (Ks1) shall be kept at the nominal value, followed by an upwards and downwards step response test, as described in item 1.

    d) The PSS gain (Ks1) shall be set to 2.0–2.5 times its nominal value, followed by an upwards and downwards step response test, as described in item 1.

    e) If the step response tests specified above provide a stable response, the PSS gain (Ks1) shall be reverted to its nominal value. This shall be the final setpoint. If the response of the PSS is unstable or there are oscillations in the response, or the results deviate significantly from the results of step response tests conducted at 50% of rated capacity, the PSS gain configuration shall be repeated from step 7 at maximum capacity.

10. Over- and underexcitation limiter testing at maximum capacity (generator connected to the network, at ≥ 80% of the rated capacity)

    The over- and underexcitation limiters shall be tested as follows. The limit value of the overexcitation limiter shall be gradually decreased from its setpoint value to verify that the limiter functions as intended by limiting the step response of voltage control. The limit value of the underexcitation limiter is gradually increased from its setpoint value to verify that the limiter functions as intended by limiting the step response of voltage control. The setpoints of the limiters shall be reverted to their design values or adjusted as necessary.

11. Raising and lowering the power

    Keep the PSS on and adjust the turbine power down and up with the power-generating facility’s normal power curve. Monitor the PSS output signal and active power. Check any activation and deactivation thresholds set for the PSS.

12. Controlling the activation and deactivation of the PSS

    Activate the PSS locally and then deactivate it.

    Activate the PSS from the control room and then deactivate it.

13. Continuous operation and final documentation

Once the power system stabiliser has been successfully tuned, it shall be left in operation. The parameters shall be saved and a power system stabiliser tuning report shall be prepared based on the results recorded during testing. The final parameters, updated modelling data, numerical test results, and tuning report shall be submitted to the relevant network operator and Fingrid as part of the power-generating facility's commissioning report.

The tuning report shall present at least the following results, with a time scale that clearly shows the relevant phenomena, such as the damping of active power fluctuations. It must be possible to determine values such as the cycle time and amplitude of a fluctuation from the active power. The follow results shall be presented:

1. Measurement of the frequency response at minimum output (phase shift as a function of frequency)
2. Step response (e.g., ±2%) while connected to the grid at minimum output when PSS is off
3. Step response (e.g., ±2%) while connected to the grid at 50% active power when PSS is off
4. Step response (e.g., ±2%) while connected to the grid at 50% active power when PSS is on and the gain is 1.0 x nominal
5. Step response (e.g., ±2%) while connected to the grid at 50% active power when PSS is on and the maximum gain is used (item 7).
6. Step response (e.g., ±2%) while connected to the grid at 50% active power when PSS is on and the nominal gain is used, but the compensation reactance (if used) is set to different values.
7. Normal network operation at 50% active power with PSS on and the nominal gain is used, time scale approximately 1 minute.
8. Step response (e.g., ±2%) while connected to the grid at 80–100% active power when PSS is off
9. Step response (e.g., ±2%) while connected to the grid at 80–100% active power when PSS is on and the nominal gain is used
10. Step response (e.g., ±2%) while connected to the grid at 80–100% active power when PSS is on and the gain is 2–3 times the nominal value
11. Normal network operation at 80–100% active power with PSS on and the nominal gain is selected, time scale approximately 1 minute.
12. Down- and up-regulation of active power when PSS is on and the nominal gain is selected
13. Activation of limiters when PSS is on.

14. The Bode plots mentioned in item 1 of section 22.5.9.2.

## 22.6 Example of a phase compensation simulation and Bode plots

Figure 22.2 below shows the compensation requirement based on calculation, the compensation requirement based on actual measurement values, and the PSS phase shift after tuning.

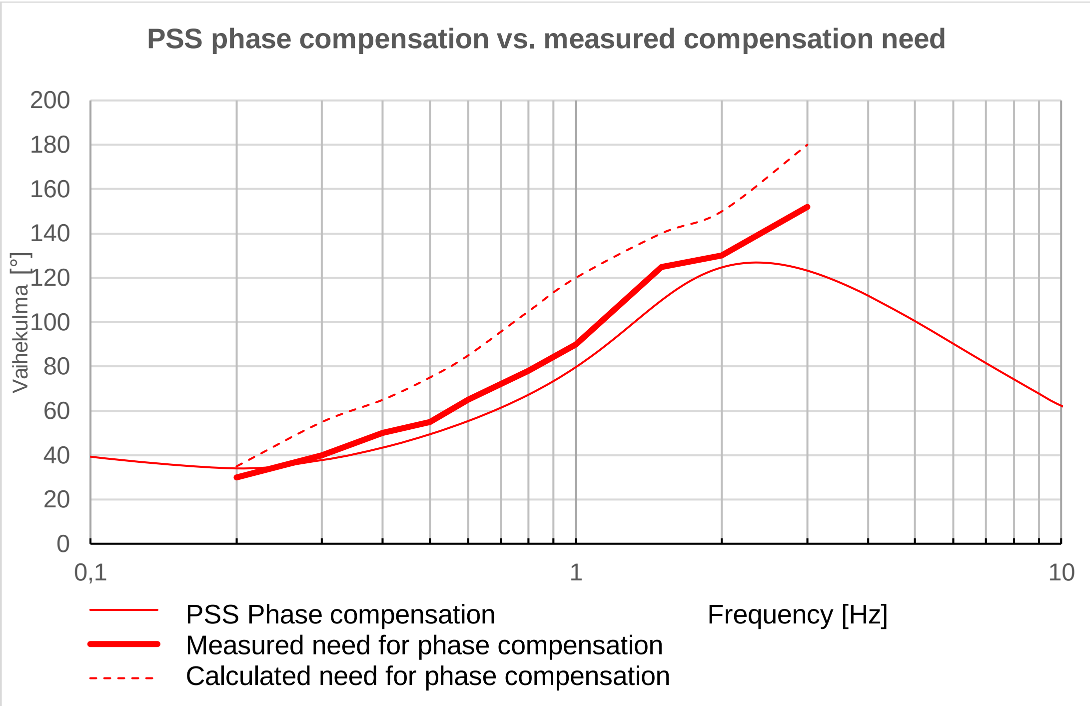



**Figure 22.2. Compensation required based on the simulation model, compensation required based on measurements and PSS phase shift after tuning.**

Figure 22.2 indicates that there is a significant difference between the predetermined (obtained using the simulation model) and the actual (measured) phase shift compensation requirement. Consequently, frequency response testing should always be performed to ensure that the power system stabiliser has been appropriately tuned.

Figure 22.3 presents a reference PSS gain where the gain remains smaller at low frequencies (< 0.2 Hz) than at higher frequencies.

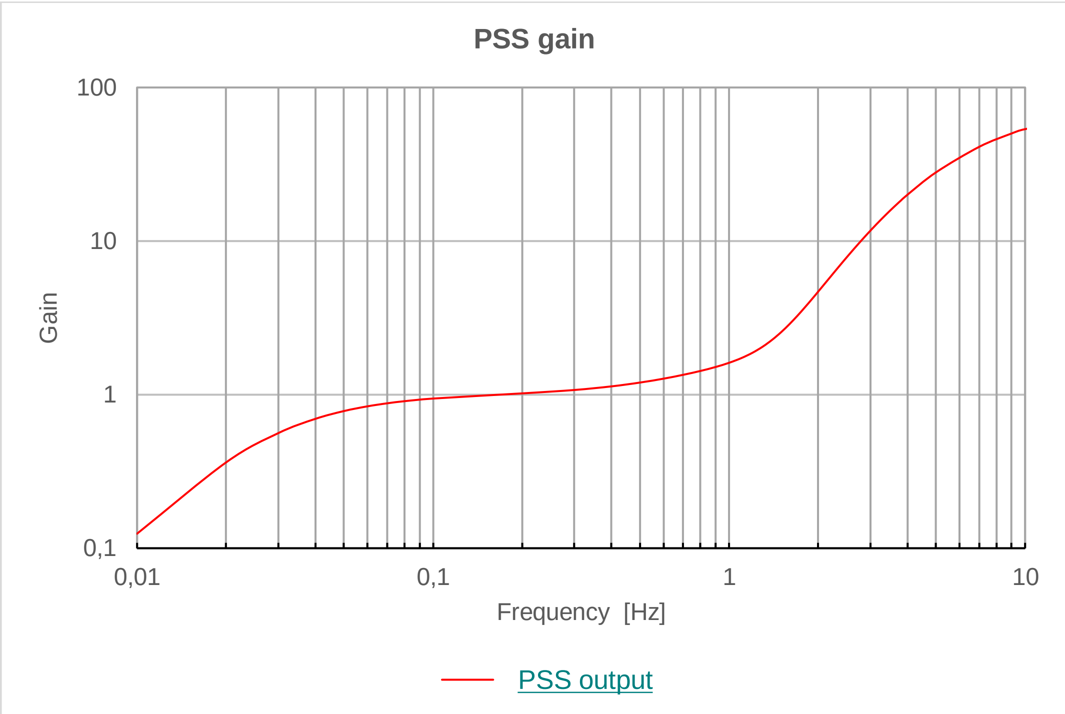



**Figure 22.3. PSS gain in a simulation model. The gain is indicative, but the result shows that the gain is lower when f < 0.2 Hz than when f > 0.2 Hz.**

Figure 22.4 shows an unacceptable tuning, as the PSS gain increases too much at low frequencies (< 0.2 Hz), and certain network phenomena could cause the PSS output to be saturated, preventing it from operating correctly in the desired frequency range.

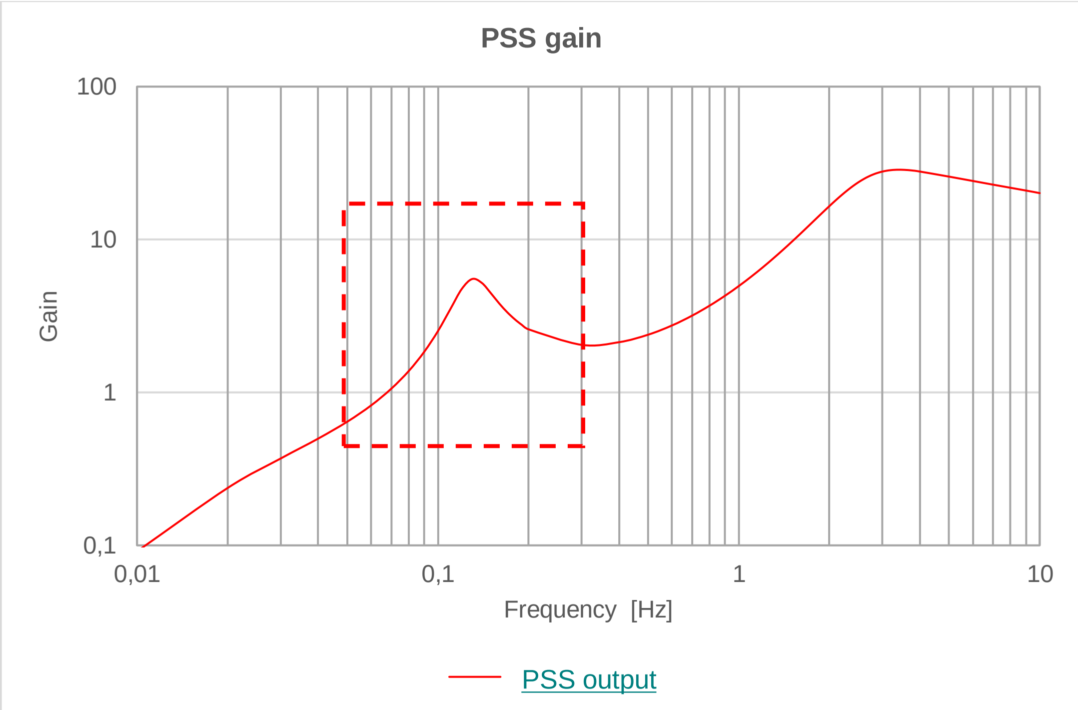



**Figure 22.4. PSS gain in a simulation model. The gain is indicative, but the result shows that the gain is higher when f < 0.2 Hz than when f > 0.2 Hz. This tuning can be problematic in certain network phenomena.**

Figure 22.5 shows a study of the PSS frequency response after final tuning. The graph shows the frequency response at the automatic voltage regulator (AVR) summing point ($V_{inj}$) on the generator's active power when the generator is operating at its rated capacity. The graph shows the frequency responses when the PSS is at its nominal gain and when the PSS is off. The study demonstrates the damping effect of the PSS throughout the frequency range, especially the damping of the local mode.

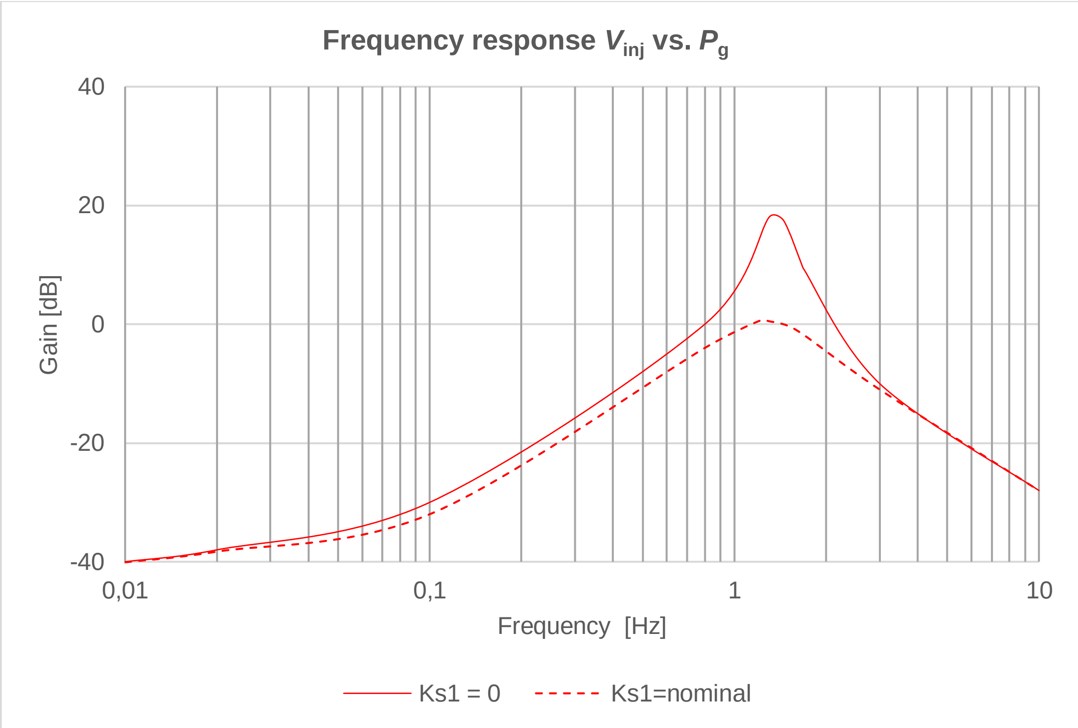



**Figure 22.5. The frequency response at the automatic voltage regulator (AVR) summing point ($V_{inj}$) on the generator's active power ($P_g$) when the generator is operating at its rated capacity.**