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## **Technical minimum requirements for the connection of converter-based energy storage systems**

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# 1 Introduction

## 1.1 Objective, area of validity and target group

This document defines the technical and operational connection conditions for converter-based energy storage systems (CESS) that are to be connected to the transmission system (TS) in Switzerland. The aim is to provide clear, standardised and transparent requirements that ensure grid stability as well as the security and efficiency of the overall system.

The area of validity covers all CESS that are connected to grid level 1 of the Swiss transmission grid. The requirements apply to new systems and to systems that undergo significant changes with an impact on the grid connection or operating behaviour.

The target group of this document is all connection recipients, in particular project developers, operators, planners and manufacturers of CESS who are seeking a grid connection to the Swiss transmission grid. The document serves as a binding basis for the planning, design, authorisation and commissioning of such systems.

## 1.2 Need for additional requirements for CESS

The increasing expansion of converter-based energy systems (CESS) in the Swiss transmission system results in new requirements for their integration, particularly with regard to the provision of ancillary services to ensure quality of supply and grid stability. The CESS must therefore have system-supporting characteristics in order to make an economically efficient contribution to the stability of the electricity system in the course of the energy transition.

As the rapid influx of CESS brings new technical challenges, additional requirements are necessary that go beyond the existing documents. The requirements contained in this document apply in addition to the specifications set out in Swissgrid's existing contractual documents (see section 1.3.1). In case of doubt, the stricter requirement applies.

This document was prepared based on experience with existing connection conditions for CESS applied by other TSOs and with reference to the framework conditions of the underlying grid levels.

## 1.3 Document requirements

### 1.3.1 Electrical industry and Swissgrid documents

Furthermore, the applicable version of each of the following documents must also be complied with:

- Transmission Code, hereinafter referred to as TC [1];
- Grid connection contract, hereinafter referred to as NAV [2];
- General conditions for the connection to the Swiss transmission system, ABNA [3];
- Contracts for ancillary services and their requirements;
- Voltage maintenance concept [4];
- Operating agreement; [5]
- Connection operating agreement;
- Swiss Operational Handbook or operational management interface manual (SHBF);
- All other contracts with Swissgrid and the underlying electrical industry documents.

### 1.3.2 ENTSO-E specifications

The ENTSO-E requirements also play an important role with regard to international technical harmonisation. The Requirements for Generators (RfG) define the minimum requirements for the grid connection of generators, and the Demand Connection Code (DCC) defines the requirements for consumers.

### 1.3.3 Norms and standards

If no explicit standards are specified in the document, the following standardisation systems must be observed in the order given:

- Swiss laws and standards (in particular the Transmission Code);
- Cenelec standards;
- IEC standards;
- Cigré recommendations;
- Technical connection rules of European transmission system operators for extra-high-voltage systems;
- IEEE standards and technical connection rules.

## 2 General principles and conventions

### 2.1 List of abbreviations

ABBREVIATION	MEANING	DESCRIPTION/EXPLANATION
<b>ABNA</b>	General conditions for the connection to the transmission system	Part of the grid connection contract
<b>ABV</b>	Connection operating agreement	
<b>AC</b>	Alternating Current	a.c.
<b>AIS</b>	Air-Insulated Switchgear	
<b>AVR</b>	Automatic Voltage Regulator	Automatic voltage controller
<b>AWE</b>	Automatic reclosure	Protective function for system restoration after short-term disturbances
<b>BESS</b>	Battery Energy Storage System	
<b>BV</b>	Operating agreement	Governs operational cooperation between Swissgrid and the connection recipient
<b>CSV</b>	Comma-Separated Values	File format
<b>DC</b>	Direct Current	d.c.
<b>DEKWE</b>	Direct intervention in the deployment of power plants	
<b>EMT</b>	Electromagnetic Transients	Transient processes
<b>EMTP</b>	Electromagnetic Transients Program	Program for analysing electromagnetic transients
<b>FCR</b>	Frequency Containment Reserve	Primary control energy
<b>FDNE</b>	Frequency Dependent Network Equivalent	
<b>FFR</b>	Fast Frequency Response	
<b>FRT</b>	Fault Ride Through	Ability to remain connected to the grid in the event of system faults and actively contribute to grid support
<b>FSM</b>	Frequency Sensitive Mode	Frequency-dependent active power control
<b>KAS</b>	Power plant control centre	Direct partner of Swissgrid for grid restoration
<b>CESS</b>	Converter-based Energy Storage System	Energy storage system connected to the grid via power electronic converters

<b>NAV</b>	Grid connection contract	Grid connection contract for connection to the transmission system
<b>P<sub>MAX,P</sub></b>	Maximum active power in feed-in mode	Highest active power that a storage system can supply
<b>P<sub>N</sub></b>	Rated power	Nominal electrical output (in MW or MVA) that a system or component is designed for
<b>PSSE</b>	Power System Simulator for Engineering	Software for the simulation of energy systems
<b>ROCOF</b>	Rate of Change of Frequency	Frequency change rate, important for protection systems
<b>RMS</b>	Root Mean Square	Mean square value to compare fluctuating values with a single number
<b>RV</b>	Restructured Version	
<b>AS</b>	Ancillary Services	
<b>SHBF</b>	Operational management interface manual	Describes processes relevant to operations between Swissgrid and the connection recipient, part of the BV
<b>SOA</b>	Safe Operating Area	Voltage and current conditions under which the CESS can probably be operated without damage
<b>SSCI</b>	Subsynchronous Control Interactions	
<b>SSO</b>	Subsynchronous Oscillation Studies	
<b>SSR</b>	Subsynchronous Resonances	Unwanted oscillations < 50 Hz that could jeopardise grid stability or generators
<b>SSTI</b>	Subsynchronous Torsional Interactions	
<b>TC</b>	Transmission Code	Electrical industry document, key document
<b>THDI</b>	Total Harmonic Distortion Current	Measurement of harmonic distortion in current
<b>THDV</b>	Total Harmonic Distortion Voltage	Measurement of harmonic distortion in voltage
<b>TS</b>	Transmission System	
<b>TSO</b>	Transmission System Operator	
<b>VAS</b>	Distribution grid switching centre	Direct partner of Swissgrid for grid restoration
<b>VE</b>	Disposal permit	
<b>VSE</b>	Association of Swiss Electricity Companies	

Table 1: List of abbreviations

## 2.2 Definitions

For the sake of simplicity, «CESS» refers to converter-based energy storage systems such as battery energy storage systems (BESS) and alternative energy storage systems (e.g. FlyWheel, compressed air storage, supercaps, etc.) with directly attached storage. Power-to-X systems without direct storage are not covered by this document.

## 2.3 Sign convention

This document uses the consumer meter arrow system:

$Q < 0$ , negative value: supplying inductive reactive power to the transmission system leads to an increase in voltage at the feed-in node, behaviour like capacity;

$Q > 0$ , positive value: drawing inductive reactive power from the transmission system leads to a reduction in voltage at the feed-in node, behaviour like inductance.

The same signs apply to the provision of active power. An overview of the sign convention can be found in Table 2.

	<b>Overexcited (capacitive behaviour)</b>	<b>Under-excited (inductive behaviour)</b>
<b>CESS demand mode</b>	<p><math>P &gt; 0</math>, the CESS draws active power from the grid</p> <p><math>Q &lt; 0</math>, the CESS supplies reactive power to the grid</p>	<p><math>P &gt; 0</math>, the CESS draws active power from the grid</p> <p><math>Q &gt; 0</math>, the CESS draws reactive power from the grid</p>
<b>CESS generation mode</b>	<p><math>P &lt; 0</math>, the CESS supplies active power to the grid</p> <p><math>Q &lt; 0</math>, the CESS supplies reactive power to the grid</p>	<p><math>P &lt; 0</math>, the CESS supplies active power to the grid</p> <p><math>Q &gt; 0</math>, the CESS draws reactive power from the grid</p>

Table 2: Overview of the sign convention

## 2.4 Operating convention

The following terminology is used in this document:

- Demand mode: active power is drawn from the transmission system by the CESS;
- Generation mode: active power is fed into the TS by the CESS.

### 3 Requirements for CESS behaviour

#### 3.1 Active power control and operating modes

##### 3.1.1 Active power control in normal operating conditions

The active power control of the CESS must be designed in such a way that it is coordinated with the grid-forming control in section 3.5 in order to avoid undesirable interactions and instabilities. The fast grid-forming reaction takes priority, while the slower frequency control brings the active power to the specified target value. The setpoint value of the active power must be adjustable in both generation and demand mode, with a minimum resolution of 0.1 MW. The actual value of the active power must not exceed the setpoint value, measured as a ten-second mean value.

The CESS must enable a smooth transition between generation and demand (bidirectional operation). It must be possible to limit the rate of change of the active power (ramp rate) both for setpoint adjustments and for frequency-related adjustments. The adjustable range for ramps extends from at least 10% to 100% of the rated power per minute. The BV [5] and its annexes specify the maximum change in active power. The change must be linear and without jumps. Further requirements may apply to the ancillary services market.

##### 3.1.2 Changes in control modes

It must be possible to switch between operating modes and setpoint values locally and remotely at any time, and this must not cause any abrupt variations in power output in the grid.

#### 3.2 Reactive power control

##### 3.2.1 Voltage-reactive power control

The CESS must be able to control voltage and reactive power automatically, continuously and smoothly; details are given in the current voltage maintenance concept [4]. Changes to the reactive power at the connection point must be made as set out in section 3.1.1. The control system must not be affected by frequency and voltage variations or short-term disturbances.

The control range must correspond to the actual reactive power capacity of the CESS and must not be artificially limited. Any limitations that are necessary for technical reasons must be documented and justified.

The control system must react stably to gradual, sudden and continuous changes and must not cause any oscillations. It must be coordinated with the grid-forming control, whereby the fast grid-forming control reacts first, and the reactive power control guides the reactive power to the target value (cascade control).

The control concepts must be agreed with Swissgrid prior to commissioning. Voltage control must be provided from the time of first commissioning onwards. If necessary, the control settings must be adjusted during operation in order to comply with the applicable regulations.

##### 3.2.2 Reactive power capacity

Active voltage maintenance according to TC section 4.4.3 applies to CESS. The CESS must be able to feed in and draw reactive power (Q) from the grid.

The CESS is regarded as a single unit together with the energy storage system and inverter and must provide reactive power resources taking into account the Safe Operating Area (SOA) in accordance with **Fehler! Verweisquelle konnte nicht gefunden werden..**

At rated power, reactive power of at least  $\cos(\Phi) = 0.925$  must be available in both positive and negative directions. A reactive power capacity diagram similar to the one shown in Figure 2 and Figure 3 is required. Higher reactive power provision is permitted and desired.

In all operational states, including an active power exchange of zero, the unit must be able to feed in or draw reactive power from the grid in accordance with the SOA and the reactive power capacity diagram in Figure 1

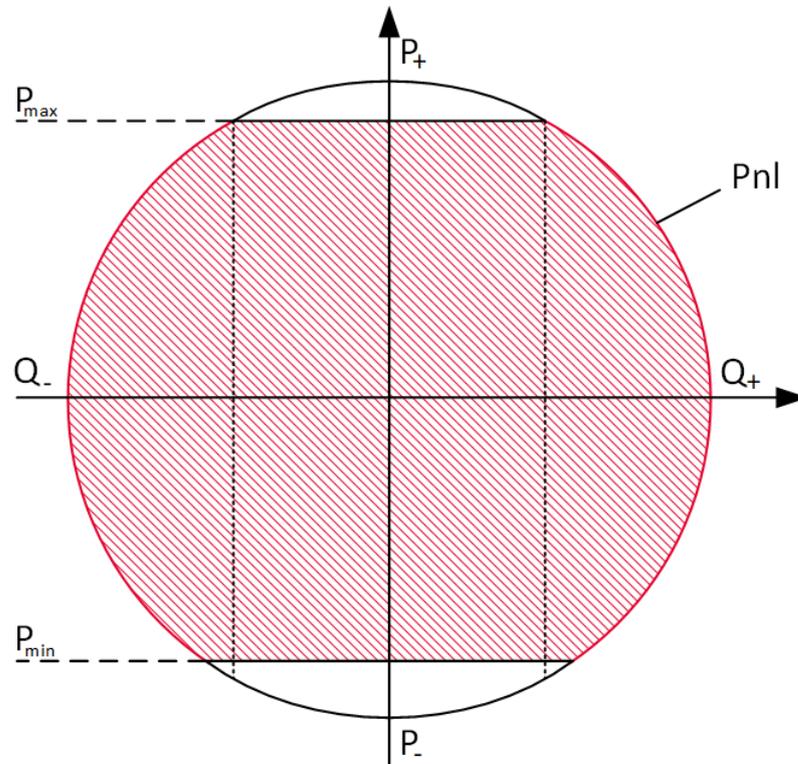


Figure 1: Reactive power must be provided taking into account the Safe Operating Area

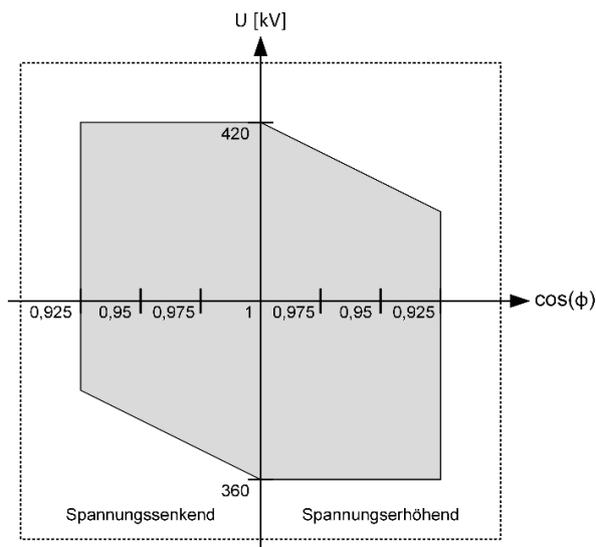


Figure 2: Reactive power capacity diagram 380 kV

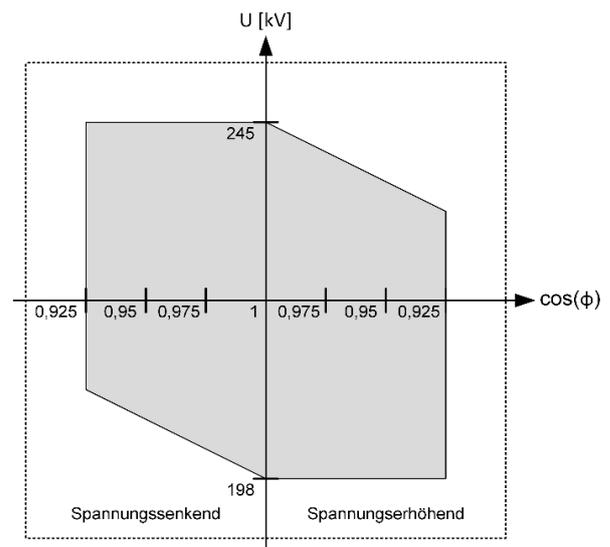


Figure 3: Reactive power capacity diagram 220 kV

### 3.2.3 Reactive power supply

A CESS is subject to active voltage maintenance in accordance with the voltage maintenance concept [4] and must therefore be successfully prequalified for active voltage maintenance.

Participants in active voltage maintenance must provide Swissgrid with operational information on their systems (including an active power vs. reactive power graph).

A CESS must feed in capacitive reactive current in the event of undervoltage (i.e. below the lower limit for continuous operation in accordance with the operational management interface manual (SHBF)) and inductive reactive current in the event of overvoltage (i.e. above the upper limit for continuous operation in accordance with SHBF). In these cases, the supply of reactive current ( $I_q$ ) must take priority over active current ( $I_p$ ). When operating within the normal voltage range, the feed-in of active current ( $I_p$ ) takes priority.

### 3.2.4 Resistance to short-term undervoltages and overvoltages

The CESS must be able to continue working at the connection point in accordance with sections 4.1 and **Fehler! Verweisquelle konnte nicht gefunden werden.** during and after a brief undervoltage or overvoltage, which may contain other frequency components, without disconnecting from the grid. The requirement for undervoltage and overvoltage resistance applies to all operational states, faults and switching operations. The dielectric strength requirement is defined by the following conditions:

- Before the undervoltage or overvoltage, the voltage at the connection point of the CESS is within the normal range;
- Prior to the voltage disturbance, the CESS does not feed in any reactive power at the connection point and does not draw any reactive power from the connection point;
- Prior to the voltage disturbance, the automatic voltage controller (AVR) of the CESS is in operation;
- It is assumed that the short-circuit power of the connection point before and after rectification of the disturbance is at the lower end of the possible range.

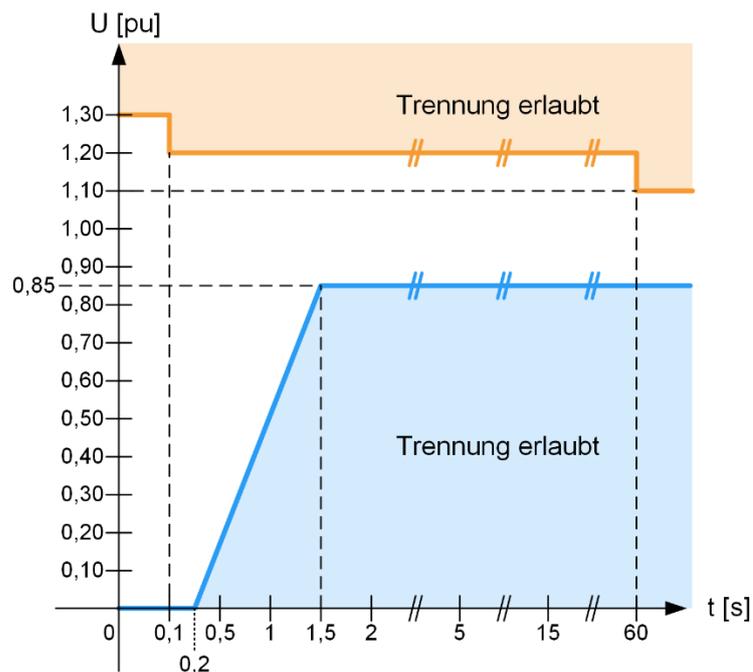


Figure 4: Behaviour for fault bridging in the event of brief overvoltages or undervoltages

### 3.2.5 Restoration of active power after a voltage disturbance

After a brief voltage disturbance, the CESS must restore the active power fed in or drawn from the grid before the fault within three seconds. The active power is considered to have been restored when it reaches the previous level at the grid connection point with a tolerance of  $\pm 5\%$  of the setpoint value. Permanent deviations or variations in power output as a result of the disturbance are not permitted.

If the restoration of active power is voltage-dependent, this dependency, including a technical description of the effects on restoration, must be transparently documented and transmitted to Swissgrid.

### 3.2.6 Voltage control

It must be possible to operate the CESS in such a way that Swissgrid's voltage plan can be followed precisely.

The setpoint value for voltage control must be adjustable within the permissible voltage limits of the connection point in steps of no more than 0.1 kV. Changes to the setpoint value, either locally or remotely, must be made via a ramping function that limits the average voltage change rate to a maximum of 0.1 kV/s

In the event of voltage jumps at the connection point of less than  $\pm 0.02$  p.u., the CESS must react as follows:

1. The grid-forming control in accordance with section 3.5 Grid-forming characteristics controls the fast initial reaction of the reactive power;
2. The rise time of the reactive power response from 0% to 80% of the total change must not exceed 1 s;
3. The overshoot must not exceed 15% of the total change;
4. The reactive power response must stabilise at the target value within 5 s;
5. The deviation in the steady state must not exceed  $\pm 5\%$  of the change;
6. The start time for the time specifications is the time of the change in the setpoint value.

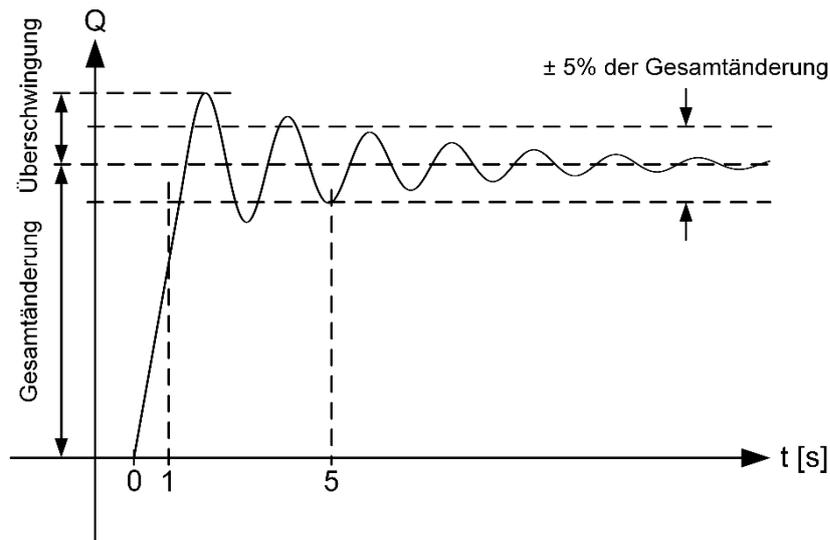


Figure 5: Reactive power control for voltage jumps

If modifications are made to existing systems that affect voltage control, Swissgrid determines the requirements on a case-by-case basis.

### 3.3 Requirements for commissioning/system restoration

The active power of the CESS may only be drawn from the transmission system or produced again after the absence of a transmission grid voltage for at least five minutes if this has been verbally authorised by Swissgrid, a power plant control centre (KAS) or a distribution grid switching centre (VAS).

If there is a permanent vector shift (phase jump) in the mains voltage of up to  $\pm 30$  degrees during a voltage disturbance, the CESS must not disconnect. The same applies if there are several consecutive voltage disturbances.

### 3.4 Resonances and controller interactions

In any operational state, the converter must not cause harmonic oscillations that exceed the permissible threshold – IEC 61000-3-6 [6] in the Swissgrid grid. The converter must not actively excite electrical resonances in the Swissgrid grid, i.e. it must not use feedback control.

### 3.5 Grid-forming characteristics

The CESS must use converters that are capable of operating in grid-forming mode. The following section specifies the general requirements to be met by the CESS in grid-forming mode.

The grid-forming control of a CESS must meet the following requirements:

- The CESS must be active and ready for operation at all times as soon as the CESS is connected to the grid. Changes or disturbances in the grid must not affect the operating mode;
- Switching between grid-forming and grid-following mode and back must take place without interrupting operation;
- The control system must also be ready for operation if the CESS is operated within the limits of its nominal capacity at any time – both in generation and demand mode – including the required reactive power capacity;
- Operational readiness must be guaranteed regardless of the current charge status of the CESS;

- The control system must function without restriction in all active power control operating modes (e.g. constant power control, frequency control);
- The reactive power control must also be ready for operation in accordance with section 3.2.
- Coordination with current limits: the grid-forming control of the CESS must be designed in such a way that it operates reliably and stably even when the current limiters are activated. Any necessary limitation of the current must neither interrupt the function of the grid-forming control nor jeopardise the secure operation of the CESS. The specified current limits must correspond to the actual efficiency of the system and take into account the short-term overload capacity of the components used. It must be ensured that the control system operates within these limits in coordination with other control systems in order to guarantee the continuous provision of grid-forming characteristics – the CESS must also operate in a coordinated manner at the current limits of the converters in the event of grid disturbances or dynamic load changes. Current limitation must not lead to an interruption of the grid-forming controller function. The current limits set for the control system must correspond to the actual power of the system and utilise the short-term overload capacity of the devices;
- The grid-forming control system must be coordinated with other control systems, both locally and at system level, in order to ensure stable operation and avoid undesirable interactions.

It is not necessary to oversize the capacity of the CESS due to the grid-forming control functions. Any resulting limitations must be reported to Swissgrid.

The following functional requirements apply to grid-forming control systems:

**1) Autonomous, fast frequency and voltage support:**

The CESS must provide autonomous, virtually delay-free frequency and voltage support in the grid:

- a) In the event of a gradual vector shift (phase jump) in the mains voltage, the CESS must counteract this shift by providing active and reactive power;
- b) If the amplitude of the mains voltage changes, the CESS must increase the voltage stability locally by feeding in reactive power, see section 3.2.3;
- c) The reaction to the two requirements a) and b) must take place within 10 ms after a change in the grid (the current must adapt according to the control system). The aim is to keep the voltage pointer of the internal voltage source constant in the subtransient time frame with the entire available current capacity.

**2) Damping of grid oscillations and ensuring small signal stability:**

According to section 6.5.6 of the TC, the reaction of the CESS to frequency and voltage variations in the grid must not amplify them, but should dampen them:

- a) The CESS must operate with small signal stability;
- b) The damping of vibrations in the following basic frequency ranges is particularly important:
  - i) 0.1–1 Hz: power oscillations (inter-area oscillations);
  - ii) 1–2 Hz: local oscillations;
  - iii) 2–15 Hz: voltage oscillations and control interactions;
  - iv) 15–45 Hz: subsynchronous and resonance oscillations.
- c) If the CESS does not meet these requirements by nature, suitable damping control must be implemented.

### 3.5.1 Stability

The CESS and its control system must be designed in such a way that stable operation is guaranteed even in a grid with a high proportion of CESS systems. In this context, stable means that the CESS remains permanently synchronised with the grid within the voltage and frequency limits specified in section 4.1 Operating voltage and basic frequency range and operates steadily and without oscillations at every permissible operating point.

In the event of grid disturbances such as voltage oscillations or phase jumps, the CESS must actively counteract these effects in order to dampen the deviations and support grid stability. If the permissible voltage at the connection point is permanently exceeded, the CESS may disconnect automatically, see Figure 6 in section 4.1. The CESS must remain connected to the grid even in the event of single-phase or three-phase self-disconnections on meshed lines, provided that its own grid section is not disconnected. In the event of sudden phase jumps in the mains voltage of up to  $\pm 30$  degrees and in a wide short-circuit power range defined individually by Swissgrid for each connection, the CESS must continue to operate stably and remain synchronised, see **Fehler! Verweisquelle konnte nicht gefunden werden.** in section 3.2.4.

### 3.5.2 Synthetic inertia (virtual inertia)

The CESS must be able to provide synthetic inertia to support the frequency stability of the TS immediately after sudden power imbalances. Since CESS, unlike synchronous machines, have no physical inertia, this function must be simulated using suitable control strategies such as virtual inertia, Fast Frequency Response (FFR) or a Virtual Synchronous Machine (VSM).

The provision of synthetic inertia must begin within a maximum of 10 ms after a frequency disturbance and have a stabilising effect on the grid. The reaction is achieved by means of targeted feed-in or feed-out of active power proportional to the rate of change of frequency (RoCoF).

This function must be active regardless of the operating mode (generation or demand), be coordinated with other controls (e.g. frequency and active power control) and take into account the current limits of the converters. This control system is modelled and verified in simulation models (RMS and EMT) in accordance with section 6.2.

## **3.6 Grid perturbations**

### **3.6.1 General**

The CESS is to be planned, constructed and operated in such a way that impacts on the TS and the systems of other customers are limited to a permissible level.

The maximum permissible amplitudes for harmonic currents of the CESS are determined by Swissgrid for each specific project and depend on the location of the CESS and the nature of the surrounding grid.

In particular, the bases are:

- The DACHCZ technical rules for the assessment of grid perturbations [7];
- The planning levels according to IEC/TR 61000-3-6 [6] and SN EN 50160 [8].

Swissgrid is responsible for the coordination of magnitudes of disturbance across all grid levels. The permissible disturbance input of a CESS into the TS therefore only represents part of the compatibility level.

If Swissgrid uses more detailed project-specific procedures to determine the applicable limits, their application is to be given priority. If any strengthening is necessary, Swissgrid shares the technical evidence (e.g. grid data, calculations) with the customer. Deviations must be agreed upon in writing.

### **3.6.2 Evaluation of grid perturbations**

Swissgrid carries out a grid quality measurement at the planned connection node of the CESS system to determine the background level. The measurement is repeated under comparable conditions (in particular in terms of the short-circuit power at the connection point) during operation of the CESS system. The operational states of the CESS during the measurement must be agreed upon with Swissgrid. The measurement results are used as the basis for evaluating grid perturbations.

In principle, the measurement methods in accordance with SN EN 61000-4-30 (Class A) [6] must always be applied for measurements.

### **3.6.3 Measures**

If impermissible perturbations occur, the connection recipient is obliged to take suitable measures to limit them. These measures must be coordinated with Swissgrid.

All measures to reduce grid perturbations are subject to review and approval by Swissgrid.

After implementing measures to reduce grid perturbations, a grid quality measurement is carried out to evaluate the effectiveness of the measures.

## 4 Operating behaviour

### 4.1 Operating borders

The basic conditions for connection to the TS are set out in section 6 of the TC [1]. As in section 6.5 of the TC, this section describes more precise additional requirements for the owners of CESS connected to the TS which are not described in the TC. Otherwise, the TC applies.

It must be possible to operate the CESS within the mains voltage and system frequency values specified in Figure 6, i.e. in these ranges, they must not be automatically disconnected from the grid by voltage or frequency-dependent tripping devices. Furthermore, no CESS may disconnect from the grid in the area shown as «permanent», and the CESS must remain connected to the grid for the relevant time in the areas labelled with times, insofar as this is technically possible, e.g. with a transformer with an automatic tap changer. If the voltage or frequency deviation is even larger (grey area), immediate grid disconnection is permitted. The voltage values apply to the connection point. The CESS must be able to connect to the TS at between 49 Hz and 51 Hz.

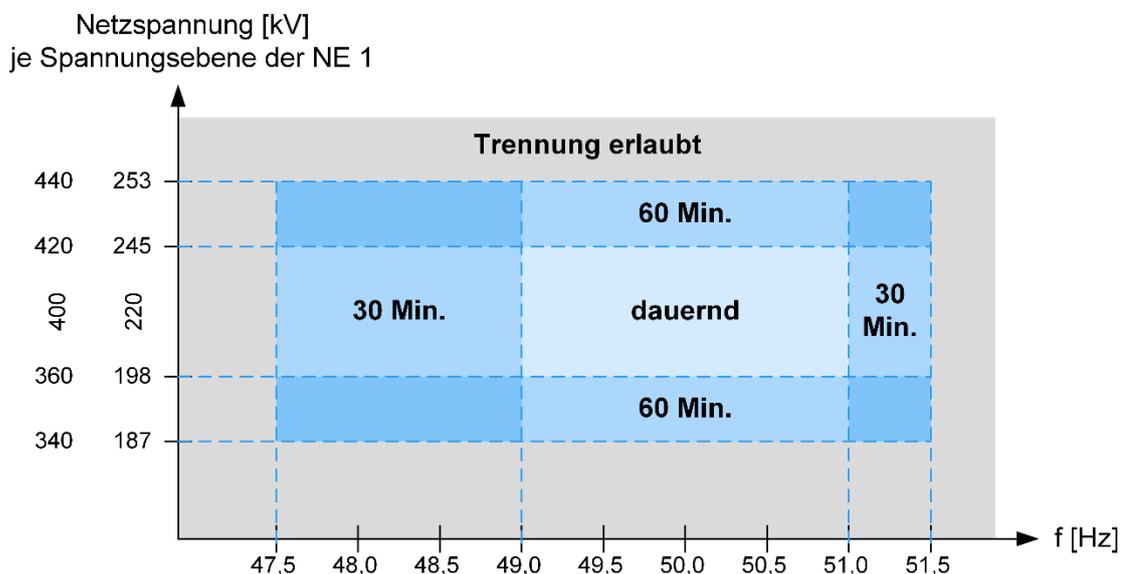


Figure 6: Frequency and voltage range at which the CESS must not disconnect

### 4.2 Operating voltage and basic frequency range

In normal operating conditions, the CESS must be able to operate continuously within the voltage and basic frequency range specified in section 4.1.

### 4.3 Rate of change of frequency (RoCoF)

The CESS must be able to continue normal operation as long as the average rate of change of frequency of  $\pm 2.0$  Hz/s, determined over a sliding time window of 500 ms, is not exceeded.

The measurement of the rate of change of frequency must not react to sudden changes in the voltage waveform due to disturbances in the system. In order to obtain a robust result, a frequency measurement must be carried out every fifth voltage period (100 ms) for the rate of change of frequency calculation.

#### 4.4 Reclosure after grid disconnection

Grid disconnection of the CESS due to a disturbance or a planned outage must not result in changes being made to the intended operation of the CESS after the grid connections have been restored (e.g. resetting the configurations of the devices to the factory settings). In addition, reconnection after disconnection from the grid and the set operating mode must be carried out in accordance with section 3.3.

#### 4.5 Contact office of the CESS operator

The operator of the CESS must have a power plant control centre (KAS) in accordance with the BV [5] which is informed at all times (24/7 every day of the year) about the status of the CESS and can control its operation in real time – on site or remotely.

The KAS must:

- Be able to change the operational state and control mode;
- Authorise or limit external control commands;
- Be able to react without delay in the event of direct intervention in the deployment of power plants (DEKWE);
- Have the relevant measurement data and suitable control technology for remote control.

At the request of Swissgrid, the KAS operational management must be able to change the operational state or setpoint values of the CESS. The request can be made electronically or by telephone.

#### 4.6 Frequency control

The frequency control system must be able to function continuously during the transitions between the basic frequency ranges and between production mode and grid-withdrawal mode. It should be noted that the droop is defined as follows:

$$Statik = \frac{\frac{\Delta f}{f_n}}{\frac{\Delta P}{P_N}} = - \frac{\frac{f - f_0}{f_n}}{\frac{P_{e,b} - P_0}{P_N}}$$

- $f$ : frequency [Hz]
- $f_n$ : rated frequency [50 Hz]
- $f_0$ : setpoint frequency [Hz]
- $P_e$ : active power of the CESS in generation mode
- $P_b$ : active power of the CESS in demand mode
- $P_{e,b}$ :  $P_e$  or  $P_b$ , depending on whether the formula for the generation or demand mode is applied
- $P_0$ : active power setpoint value of the CESS
- $P_N$ : rated power of the CESS in generation mode

##### 4.6.1 Over-frequency

The over-frequency control must always be activated. For system frequencies above 50.2 Hz, the CESS must:

- Reduce its active power linearly in generation mode;

- Increase its active power consumption linearly in demand mode.

All CESS connected to the TS must reduce the active power linearly from a frequency of 50.2 Hz with a droop of between 2% and 12%. The default value should be set to 5%.

The power reaction must start within 1 second of exceeding 50.2 Hz in order to prevent the critical frequency of 51.5 Hz from being exceeded. The measures described above are applied in particular if the TS is in a critical situation in accordance with section 2 of the TC. In this case, the above instructions must be followed in addition to the measures in accordance with TC section 5.3, and apply in addition to the control energy already provided.

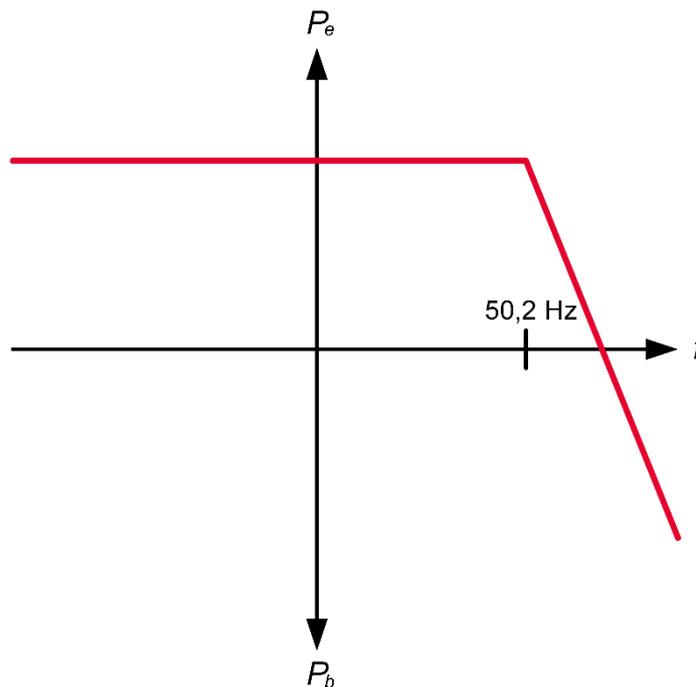


Figure 7: Frequency dependence in exceptional situations – over-frequency

#### 4.6.2 Underfrequency

At frequencies of less than 49.8 Hz, the CESS in demand mode must:

- Reduce the active power consumption linearly to 0 MW;
- If technically possible, increase the active power output to stabilise the grid;
- Retain operational readiness at 0 MW in order to be able to feed reactive power into the grid.

All CESS connected to the TS must reduce the active power consumption linearly from a frequency of 49.8 Hz with a droop of between 0.2% and 5%. The default value must be set to 1.6%.

The power reaction must start within 1 second of falling below 49.8 Hz in order to prevent the critical frequency of 48.5 Hz from being undercut. The measures described above are applied in particular if the TS is in a critical situation in accordance with section 2 of the TC. In this case, the above instructions must be followed in addition to the measures in accordance with TC section 5.3, and apply in addition to the control energy already provided.

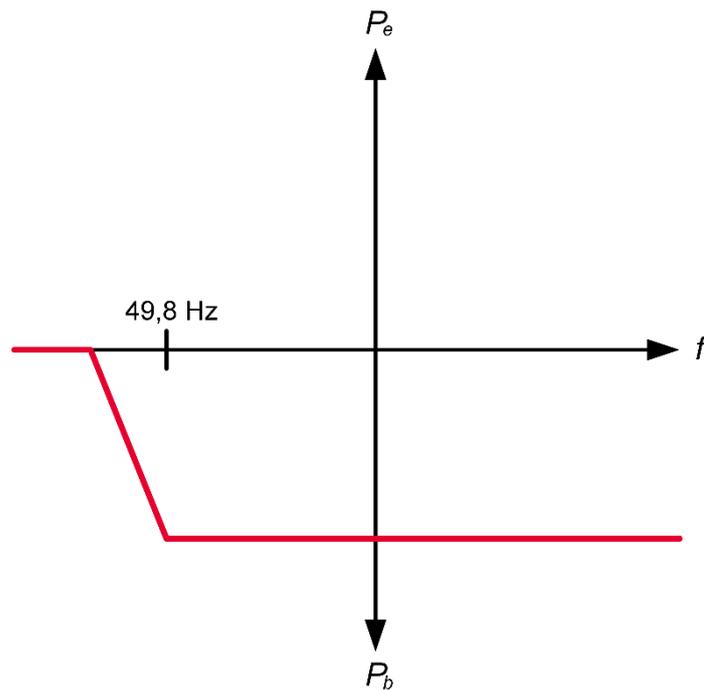


Figure 8: Frequency dependence in exceptional situations – underfrequency

#### 4.7 Behaviour during grid restoration

After a grid outage, the CESS must not carry out any charging or feed-in processes when the voltage returns. Active and reactive power withdrawal and delivery must be coordinated with Swissgrid under all circumstances. Controlled and stable grid restoration of the upstream grid must always be prioritised. CESS which are in island operation during or after the grid outage must report proactively to Swissgrid.

## 5 Design of the grid connection

### 5.1 Primary equipment at the connection point

The Swissgrid standards apply to all primary equipment and components. This section also describes specific requirements and special characteristics when connecting a CESS.

#### 5.1.1 General

Swissgrid specifies the characteristic values required for the dimensioning of the CESS at the grid connection point. These values include:

- Maximum connectable apparent power;
- Rated voltage;
- Measured voltage for operating facilities;
- Voltage operating range;
- Frequency operating range;
- Maximum operating current;
- Maximum earth and short-circuit currents;
- Insulation level.

Furthermore, Swissgrid provides the CESS with the following data for determining the sizes of the connection recipient's own protection devices and for analysing grid perturbations:

- Expected minimum initial symmetrical short-circuit current and the impedance angle from the Swissgrid grid at the grid connection point;
- Total fault switch-off time of the main protection from the Swissgrid grid at the grid connection point.

Short-circuit currents from both the Swissgrid grid and the CESS must be taken into account when dimensioning the operating facilities.

The connection recipient must design the electrical systems it owns for short-circuit currents at least within the short-circuit withstand capability of Swissgrid's systems at the grid connection point. In the event of anticipated increases in the relevant short-circuit currents, Swissgrid specifies the required short-circuit withstand capability of the CESS to the connection recipient. If an increase in the short-circuit power beyond the previous short-circuit withstand capability of the grid operator's systems at the grid connection point makes it necessary to increase the short-circuit withstand capability of the existing CESS, the measure will be agreed upon with Swissgrid.

#### 5.1.2 CESS connection system

The CESS is connected in the Swissgrid switchgear via a connection feeder in accordance with Figure 9 or if, for example, the installed load or specific availability requirements make it necessary, via several connection feeders or a separate switchgear.

The CESS is connected via a connection system on the customer side at the connection point.

The entire connection system must be installed in accordance with the applicable standards and recognised technical regulations. It must be possible to check that sections that can be subdivided using disconnection devices are de-energised and earthed (fixed earth points or earthing switches with manual drive for larger connection distances; for a transformer connection in an AIS, see Figure 9).

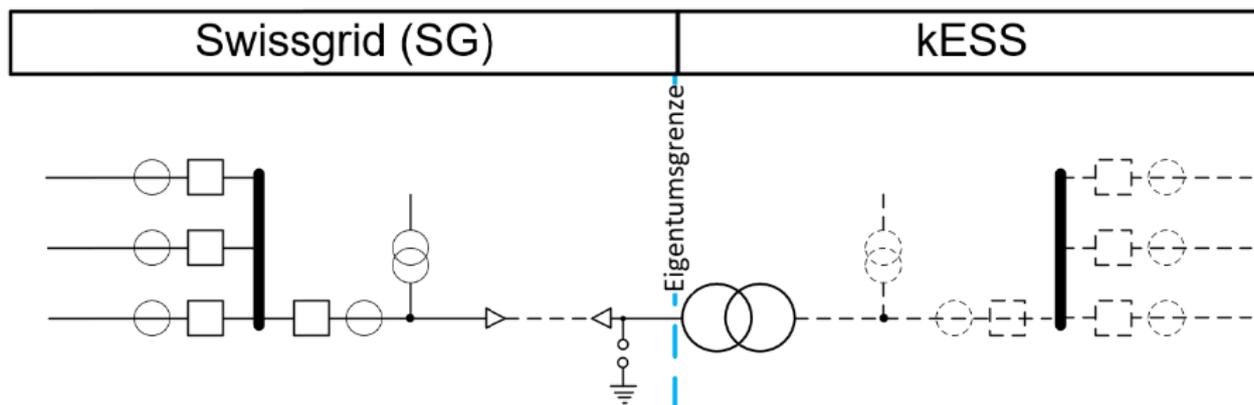


Figure 9: Schematic CESS connection diagram

### 5.1.3 Neutral-point configuration

The neutral point configuration for the TS is determined by Swissgrid. Swissgrid also specifies the type of neutral-point configuration for all the connection recipient's operating facilities that are galvanically connected to Swissgrid's TS.

The neutral point of the transformers on the high-voltage side between the TS and the customer's grid must be made externally accessible and designed and wired in accordance with Swissgrid's specifications (this also applies to other operating facilities forming neutral points).

The insulation coordination and the loadability of the neutral point must be agreed upon between Swissgrid and the connection recipient. The neutral point configuration on the high-voltage side must not be impaired by the CESS.

The impacts of unbalanced faults from the CESS must be minimised (in particular, no zero-sequence components may be transmitted from the connection recipient's grid). Simultaneous neutral point earthing (solid or current-limiting) on more than one side of a transformer is therefore not permitted. If the simultaneous use of several neutral points on one transformer is required, a corresponding concept must be coordinated and agreed upon with Swissgrid.

Swissgrid defines the neutral point configuration not only technically but also operationally, i.e. it determines how the neutral points are to be configured and monitored during operation.

The connection recipient must ensure that no impermissible DC currents are fed into the neutral points of the windings on the high-voltage side during operation of the CESS.

### 5.1.4 Circuit breakers

The circuit breakers on the high-voltage side must be designed to allow the secure disconnection of all possible short-circuit currents in the event of faults on both the CESS side and on the grid side.

The circuit breakers must be able to perform all the necessary switching operations without generating transient overvoltages that could damage Swissgrid system components.

Specific switching requirements must be agreed upon with Swissgrid.

### **5.1.5 Transformers**

The selection and connection of the transformers must be agreed upon between Swissgrid and the CESS operator.

### **5.1.6 Lightning arresters**

The need for lightning arresters and their specifications to protect the CESS must be agreed upon with Swissgrid.

### **5.1.7 Cable systems**

The shielding and earthing of cable systems used to connect the CESS must be agreed upon with Swissgrid.

### **5.1.8 Earthing system**

The earthing concept of the CESS must be agreed upon with Swissgrid.

The earthing system of the CESS must be dimensioned and installed in accordance with Swissgrid's grid data for the maximum short-circuit and earth-fault currents. Compliance with the permissible contact voltages must be verified using technical measuring equipment. The earthing measurement reports including the earthing plan must be submitted to Swissgrid in good time before initial energisation.

The earthing of the CESS is connected to the Swissgrid system earthing as standard. The tie-lines must be sufficiently dimensioned to securely conduct fault currents and minimise potential differences between the earthing grids of the systems.

## **5.2 Secondary equipment**

### **5.2.1 General**

The grid elements on the TS side must be monitored and, if necessary, controlled in accordance with the requirements of the Swiss Operational Handbook or the BV/ABV [5], [9]. This requires a coordinated exchange of signals between the CESS and Swissgrid.

The exchange of signals at the interface between the TSO and the CESS must always comply with the requirements set out in the VSE manual «Technical requirements for the protection interfaces of transformers to the transmission system» [10] and must be agreed upon between the partners.

If there are remote-controlled elements in the connection feeder on the CESS side (e.g. remote-controlled disconnectors if several transformers are operated in parallel on the CESS side or if systems are physically separated (guide value >300 m)), the operator of the CESS must provide separate premises for the control, measurement and protection devices. These premises must be equipped with a suitable supply of electricity, be accessible to Swissgrid at all times and be protected against unauthorised access.

### **5.2.2 Synchronisation**

The connection recipient must enable secure synchronised connection of its systems to the TS (with its own switching devices).

The operator of the CESS is responsible for the control and synchronisation apparatus of its system. The CESS must be synchronised by primary components owned by the CESS operator.

### 5.2.3 Control sovereignty

Control sovereignty at the connection point must be agreed upon between Swissgrid and the CESS operator prior to the commissioning of the CESS and must meet the requirements of the Swiss Operational Handbook and the BV/ABV.

### 5.2.4 Control interface between active and reactive power

The control system of the CESS must have a suitable interface (analogue, binary inputs or a system interface) via which Swissgrid can influence the operating point of the CESS (active and reactive power) if necessary (e.g. to prevent a blackout). This is not currently planned and will be set out in detail in the CESS operating concept. Furthermore, the requirements for reactive power control described in section 3.2 must be met.

## 5.3 Protection

### 5.3.1 General

The protection systems of the CESS are fully secured by the CESS operator and must meet the requirements at the connection point and be technically coordinated and compatible with the protection concepts defined in the Swissgrid standards. The system protection of the CESS must be ensured by the CESS operator.

The protection systems must be able to reliably detect electrical faults on the CESS side and disconnect the CESS selectively and with no impact. The requirements set out in the VSE manual «Protection Guide Switzerland» [11] and the specifications listed in section 6.3.7 of the TC must be observed. Within the permissible voltage range and basic frequency range, protection systems must not react to normal grid oscillations (see section 4).

Suitable current transformers must be provided to ensure a selective protection concept. The protection systems must not interfere with the system fault ride-through requirements and should be designed to be compatible with the requirements for the frequency-dependent control of the system and not hinder its specified response to rapid frequency changes to support system stability.

Faults at the connection point must also be recognised so that the CESS can disconnect from the grid after a defined time. The connection recipient must provide suitable protective measures for this purpose; this also applies to island operation if the CESS has island operation capability. In addition, switching failure protection must be integrated in order to take the failure of circuit breakers into account in the protection concept.

If grid disconnection of the CESS occurs due to protection triggering, reclosure may only take place after the cause of the disturbance has been clarified and after approval by Swissgrid (no AWE). The structure and design of the necessary transformers, in particular their joint use, must be agreed upon between the contractual partners.

### 5.3.2 Automatic frequency relief

The operator of the CESS is responsible for ensuring that the CESS meets the requirements in accordance with the VSE electrical industry recommendation «Technical requirements for automatic frequency relief». [12] It should be noted that the requirements vary depending on the operational state and that sections 4.6.1 and 4.6.2 must be observed and complied with.

### **5.3.3 Island grid detection and island operation**

The CESS can go into island operation without a connection to the TS to cover its own energy requirements in the event of disturbances in the upstream grid. The operator of the CESS is responsible for taking all the necessary precautions to control the island and ensure operational security during island operation.

The arrangements for (technical and organisational) synchronisation of the island with the TS must be coordinated with Swissgrid, whereby synchronisation must not take place via the primary equipment of the TS.

Black start capability is not mandatory for CESS. CESS with black start capability can participate in the AS tender for black start and island operation capability if they meet Swissgrid's requirements.

### **5.3.4 Disturbance analysis**

Swissgrid carries out systematic disturbance analysis in the TS and, based on the results, develops suitable solutions for improving the existing processes with the affected CESS operators. The necessary information (e.g. measurement data, protection reactions and records of the behaviour of the CESS during the disturbance) for fault clarification is exchanged between Swissgrid and the CESS operators connected to the TS on request. The parties must coordinate in advance regarding communication to the public about disturbance analyses.

## **5.4 Own requirements and auxiliary energy**

The CESS system to cover its own requirements must have a three-phase current system for auxiliary services supplies and at least one emergency power supply that is not dependent on the grid. Operation of the CESS without a functioning emergency power supply is not permitted.

The system operator of the CESS is responsible for monitoring and maintaining its own requirements and the auxiliary energy supply.

The function of the protection devices or the tripping of the switching devices requires two auxiliary power supplies (e.g. battery, condenser, transformer current) that are independent of the mains voltage. The same applies when using control devices for remote control of the primary components.

If the auxiliary power supply is required for an extended period of time, its capacity must be dimensioned so that the CESS can be operated with all protection, secondary and emergency operating devices in accordance with the requirements of the CESS in the absence of a mains voltage. It should be noted that any requirements from AS may extend the necessary bridging time.

## **5.5 Communication and IT security**

The operator must take appropriate technical and organisational measures to ensure the secure operation of the CESS and prevent unauthorised access, in particular via remote access connections. This obligation also applies to external service providers with access to CESS facilities or IT systems. The operator must submit regular reports on information security and the telecommunications connection to Swissgrid on request; the form and extent of these reports will be agreed upon between the parties.

In the event of a major disturbance, the operator must ensure that relevant real-time data remains available and retrievable for at least 72 hours to enable a complete analysis. The security measures must be continuously adapted to the state of the art and must ensure protection against information security threats commensurate with the operational importance of the ccess. Information security risks must be actively identified, evaluated and dealt with appropriately on an ongoing basis.

## 5.6 Access to physical infrastructure

The CESS operator and Swissgrid must make suitable areas and/or rooms available to each other by mutual agreement (e.g. for secondary equipment) for the installation and expansion of systems and operating facilities required for the establishment and maintenance of the grid connection.

The CESS operator and Swissgrid must grant each other and authorised representatives access to the areas and/or rooms used by both parties free of charge. Details of the structural design of the areas and/or rooms used by both parties are contractually agreed upon between Swissgrid and the CESS operator.

## 6 Studies and supporting documents

A report on the studies carried out on the CESS and the simulation models used with Swissgrid as part of the grid connection procedure must be submitted six months before the first feed-in or the first purchase of energy.

### 6.1 Requirements for dynamic studies

The CESS connection recipient is obliged to initiate, carry out and coordinate all the necessary specific studies itself as part of the preliminary planning. Swissgrid is responsible solely for testing and monitoring the planned system in order to evaluate its conformity with the grid connection requirements.

Swissgrid advises the CESS connection recipient to await the evaluation of the requirements for a specific study before signing a binding procurement contract for the main components of the CESS. This is because specific studies can influence the selection and dimensioning of the electricity-generating equipment and the project schedule.

At least the following studies are required to adequately evaluate the impact of the CESS on the grid:

- Transient stability;
- «Subsynchronous oscillation» study;
- Study on harmonic stability.

A detailed description of the scope of the relevant studies can be found in the annex, see section 8.3.

If the specific investigations require special measures for the grid connection of the energy storage system, these measures are deemed to be binding specifications, and the CESS connection recipient is responsible for their implementation.

### 6.2 Modelling requirements

As part of the preliminary planning, the CESS connection recipient is obliged to provide Swissgrid with a complete and validated simulation model of the CESS. This model must realistically and comprehensibly depict the main functions and characteristics of the CESS, including the dynamic behaviour in the event of grid disturbances.

Swissgrid uses this model for its own grid studies to evaluate the potential impact of the CESS on grid stability, system dynamics and compliance with this document. The provision of the model is a prerequisite for carrying out these studies and must take place in good time so that the results can be incorporated into the evaluation of the grid connection.

The simulation models must integrate all the main components of the CESS, including the compensation systems and the controllers, limiters and protection devices that influence the operation of the CESS in the grid. It must be possible to set parameters for the simulation models with regard to the characteristics within

the scope of the specifications. The simulation models must have comprehensive documentation that enables the model to be used and parameters to be set for various studies of operating and disturbance situations. The models must be provided in Root Mean Square (RMS) format using the Siemens PSSE software and in Electromagnetic Transient (EMT) format using the EMTP software. Swissgrid maintains detailed modelling instructions that describe the software versions currently used and the required characteristics of the models created with them. These instructions are made available to the connection recipient as a construction aid and must be complied with.

## 6.2.1 Harmonic models

### 6.2.1.1 General

- The connection recipient must provide harmonic models representing each converter and all relevant auxiliary systems connected to the grid connection point;
- The models must be supplied in machine-readable format (e.g. text, CSV or Excel) or in another format specified by Swissgrid;
- The models must be based on measurements and/or verified calculations;
- If asymmetries exist, both positive and negative sequence models must be provided;
- Zero-system analysis is only required at the request of Swissgrid.

### 6.2.1.2 Steady-state harmonic model

The converter must be represented as a frequency-dependent Norton or Thevenin equivalent and must contain the following components:

#### 6.2.1.2.1 Harmonic emission source

- Harmonic voltage or current emissions must be specified for integer multiples of 50 Hz in the range of 100 Hz to 2,500 Hz with a frequency resolution of 50 Hz;
- Interharmonic and high-frequency emissions must be documented up to 9 kHz in 200 Hz bands;
- Both the magnitude and phase of the emissions must be provided for each operating point.

#### 6.2.1.2.2 Frequency-dependent impedance

- The converter impedance (real and imaginary part) must be specified as a function of the frequency, taking into account the control effects;
- The impedance must be specified: in 1-Hz steps from 100 Hz to 2,500 Hz and in 10-Hz steps from 2,500 Hz to 9 kHz;
- Impedance data must be provided for representative operational states (e.g. 0%, 50% and 100% active power and the associated reactive power states);
- If deviations with power, voltage or control mode are below 10% or 5  $\Omega$ , this must be justified in writing.

#### 6.2.1.2.3 Associated operating facilities

The frequency-dependent impedances of the primary components, e.g. transformers, filters, cables and converter chokes, must also be provided on the basis of manufacturer or measurement data.

### 6.2.1.3 Harmonic stability model

A harmonic stability model must be provided that uses the same structure and basic frequency range as the steady-state model.

If impedance values differ between the two models, these differences and the reasons for them must be documented.

### 6.2.1.4 Model with active damping (if available)

If the converter has an active damping function, a harmonic model with activated damping must also be provided.

The model must contain the following information:

- a) Target and range of the damping;
- b) The parameters used (e.g. virtual resistance).

### **6.2.1.5 Validation**

The accuracy of the harmonic model must be verified by validating the following points.

#### **6.2.1.5.1 Validation sources**

At least two of the following sources must be used for verification (excluding the type of model used to create the model):

- a) Electromagnetic transient simulation (EMT);
- b) Factory test;
- c) Analytical model;
- d) Commissioning or field measurement.

#### **6.2.1.5.2 Validation of impedance**

- a) The validation must be carried out over the entire basic frequency range from 100 Hz to 9 kHz;
- b) Frequency step size:  $\leq 1$  Hz to 2,500 Hz, and  $\leq 10$  Hz above 2,500 Hz;
- c) The model is considered valid if the real and imaginary parts of the impedance deviate from the validated data by less than 10% or 5  $\Omega$ .

#### **6.2.1.5.3 Validation of harmonic emissions**

- a) The harmonic emissions must be validated for all specified operating points;
- b) At least one independent validation source must be used;
- c) Deviations must not exceed 10% in magnitude and 10° in phase.

### **6.2.1.6 Documentation**

A model report and user manual must be provided with the model and must include the following contents:

- a) Model overview: description of the model structure, the equivalent circuit (Norton/Thevenin) and the software format;
- b) Data sources: indication of whether the data was measured, simulated or provided by manufacturers;
- c) Methodology: description of the methods used to determine the impedance and emission data, including any filtering or averaging;
- d) Validation summary: description of the validation methods used with comparison diagrams and quantitative deviations;
- e) Constraints: scope of application, operational states and simplifying assumptions;
- f) Measurement reports: if measurements were used, complete test reports with calibration data must be enclosed.

## 7 Conformity tests

### 7.1 Test procedure

It is the responsibility of the CESS connection recipient to check that the operation of the CESS meets the requirements of this document. The CESS connection recipient must bear the costs of the conformity CESS. Conformity with the specifications must primarily be verified by tests during the commissioning of the CESS. In order to be authorised for ancillary services, the current prequalification conditions must also be met.

#### 7.1.1 Commissioning

Commissioning is carried out in cooperation between the CESS connection recipient and Swissgrid. Swissgrid representatives have the right to participate in and accompany all commissioning tests.

The CESS connection recipient must draw up a commissioning test plan for the CESS. The documents must be submitted to Swissgrid in advance, and at least three months before commissioning. The CESS connection recipient suggests suitable test procedures to demonstrate the necessary requirements. Supporting documents may include design documents, studies, simulations, tests during commissioning or tests during operation. Wherever technically possible, supporting documents should be provided in real-time operation. Swissgrid has the right to cancel or change the schedule of the commissioning tests if it is not possible to carry out the tests at the scheduled time due to the operational situation of the grid.

According to section 6.4 of the TC, the dates for the conformity tests must be agreed upon with Swissgrid in good time. The successful completion of all conformity tests confirmed by Swissgrid is a prerequisite for the definitive connection to the TS.

At least the following variables must be measured and recorded during all commissioning tests:

- Active power of the CESS;
- Reactive power of the CESS;
- Voltage at the connection;
- Frequency at the connection point.

The following functions must be checked during the commissioning test:

- 1) Rate of change of active power:
  - a) The purpose of the test is to demonstrate the ability to model active power in accordance with the operating range defined in section 3.1 and with the rate of change specified there. The test is carried out with two active powers:  $0.1 \times P_{\max/\min}$  and the maximum rate of change in both feed-in mode and grid-withdrawal mode;
  - b) The test is considered successful if the parameters specified in section 3.1 are met and no un-damped power oscillations occur.
- 2) Control of constant voltage:
  - a) The test demonstrates the technical capability of the CESS to control the voltage and to function in accordance with the requirements specified in section 3.2;
  - b) The test consists of voltage control step response tests. The tests should demonstrate the performance of the voltage control and the ability to set the required setpoint value and slope;
  - c) The test is considered successful if the requirements defined in section 3.2 are met and the CESS can reach a stable operating point after the step response without poorly damped reactive or active power oscillations.

- 3) Constant reactive power control:
  - a) The test must demonstrate the technical capability of the CESS to control reactive power and to function in accordance with the requirements specified in section 3.2 when the CESS is connected to the grid;
  - b) The test must include a gradual change in reactive power and must check whether the specified target values can be complied with;
  - c) The test is deemed to have been passed if the requirements in accordance with section 3.2 are met and the CESS can reach a stable operating point with damped oscillations after the gradual change in reactive power.
  
- 4) Control of the constant power factor:
  - a) The test must demonstrate the technical capability of the CESS to control the power factor measured at the connection point in accordance with the requirements set out in section 3.2.2;
  - b) The test consists of a gradual change in reactive power using the power factor. The tests should demonstrate the performance of the power factor control and the ability to set the required setpoint value;
  - c) The test is considered successful if the CESS can reach a stable operating point with damped oscillations after a gradual change in the power factor.
  
- 5) Testing reactive power capability and limiting the active power:
  - a) The test must demonstrate that the CESS is capable of feeding in and drawing reactive power from the grid. It must also check whether the active power limitation is working;
  - b) The test must be carried out at the maximum inductive and maximum capacitive reactive power of the CESS and at five different operating points.
  
- 6) Testing the frequency at the connection point:
  - a) The measurements must be carried out with a sampling frequency of at least 1 kHz, and the recording frequency must be at least 50 Hz.
  - b) This does not apply to the commissioning test of the constant voltage control or the measurements of voltage and current on a converter module, which must be recorded with a sampling and recording frequency of at least 2 kHz.
  
- 7) Starting and stopping:
  - The test must prove that connecting and disconnecting the CESS does not cause any quality deviations in the voltage and frequency of the grid.
  
- 8) Behaviour in the event of a voltage control disturbance:
  - The test must demonstrate that the voltage control of the CESS changes its mode correctly in the event of a disturbance.
  
- 9) Remote control:
  - a) The test must show that the remote control required for operation of the CESS is functioning properly;
  - b) The test must cover all control points, including Swissgrid's electronic control connection. It must also check whether the prioritisation of control rights between the control points is working properly;
  - c) It must also check whether the control signal issued by the party with primary control authority has priority.
  
- 10) Resynchronisation after an electric system loss:
  - The CESS operator must ensure that its internal processes for resynchronisation after an electric system loss are set up in accordance with section 3.3.

11) Small signal stability and damping:

The CESS must demonstrate that it and its control system do not cause any undamped oscillations in the event of minor grid disturbances and actively contribute to their damping

12) Mandatory documentation:

General mandatory documentation is governed by sections 7 & 9 of the grid connection contract [2] and the ABNA [3].

The records of the commissioning tests serve as proof of the correctness and validity of the simulation results specified in section 6. The CESS connection recipient is obliged to summarise the supporting documents in a formal validation report that:

- confirms that the measured commissioning data corresponds to the simulations carried out in section 6,
- proves compliance with all the requirements set out in section 6 and in this document,
- must be given to Swissgrid for review and approval prior to the final connection authorisation.

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### 8.3 Studies

This annex describes the studies required for the connection of CESS to the Swissgrid grid. These requirements are to be understood as guiding principles. Swissgrid reserves the right to adapt the necessary studies or to impose additional requirements depending on the specific case.

#### 8.3.1 Transient stability

The aim of the stability study is to check the interoperability of the CESS with the TS under transient conditions. This is done using RMS simulations. In addition, the conformity of the grid support functions with Swissgrid's contractual landscape is to be demonstrated and the corresponding design validated.

The connection recipient must create a test matrix that lists all the simulation cases to be considered in the stability study. The test matrix is developed jointly by the connection recipient and Swissgrid and must be approved by Swissgrid before the start of the study. If additional critical or relevant scenarios or error cases are identified during the study or when analysing the results, the connection recipient must investigate them and add them to the original test matrix.

##### 8.3.1.1 Short-circuit study

The connection recipient must simulate various short-circuit locations in the reduced AC grid model, taking the following parameters into account:

- Short circuit at the grid connection point;
- Short circuits on all AC lines emanating from the battery storage system, including the outage of the affected lines (single and double lines);
- Other fault locations in the AC grid, including lines and busbars.

Symmetrical three-phase short circuits with different residual voltages and fault durations must be simulated.

At the grid connection point, at least the following operating points and operating conditions must be taken into account:

- Active power: 100%, 50%, 0% of  $P_{\max}$  – both feed-in and consumption;
- Reactive power: maximum capacitive, maximum inductive, zero;
- Different voltage levels in the AC grid at the grid connection point;
- Different short-circuit powers at the grid connection point.

### 8.3.1.2 Investigation of reactive power control modes

The connection recipient must provide evidence of the dynamics of reactive power control.

The connection recipient should demonstrate the behaviour of the CESS when the reactive power limits are reached for all control modes using a simplified model of the AC system. The scope and extension of the simplified AC model are determined by mutual agreement between the connection recipient and Swissgrid. In addition, a transition from maximum inductive to maximum capacitive in the «Q = constant» control mode is to be simulated, also using the simplified AC model.

The connection recipient should demonstrate how reactive power control contributes to stabilising the voltage level in the AC grid. This involves analysing how the control modes and their controller settings influence behaviour in the event of grid disturbances (FRT) and voltage stability during and after such events.

In addition, it involves investigating how the voltage control mode with reactive power droop contributes to the stabilisation of the voltage after FRT. It is also necessary to analyse how this control mode supports voltage stability during grid events that lead to changes in voltage.

## 8.3.2 Study on harmonic stability

### 8.3.2.1 General

- The study on harmonic stability is designed to prove that the CESS exhibits stable behaviour in the intended basic frequency range under all operating and grid conditions;
- The aim is to identify and avoid undesirable interactions between inverter controls, grid resonances and other grid-connected systems;
- The study is divided into a screening study in the frequency domain and a detailed EMT study in the time domain. The study must be carried out in positive and negative sequences; a zero-system analysis is only required at the request of Swissgrid;
- The relevant basic frequency range extends from 100 Hz to 2,500 Hz;
- Swissgrid provides the connection recipient with the data required to carry out the studies; the exact scope of this data is determined in bilateral agreements.

### 8.3.2.2 Screening study

- The screening study is a frequency domain-based investigation to assess the stability reserves (phase and amplitude reserve) at the grid connection point;
- The method is based on the impedance criterion according to J. Sun: «Impedance-Based Stability Criterion for Grid-Connected Inverters» [13]);
- The study must be carried out if the system does not show demonstrably positively damped behaviour for all internal switching statuses;
- Frequency responses of the system based on the harmonic model must be provided to justify positive damping behaviour. The connection recipient must take into account all system frequency responses (switching statuses) provided by Swissgrid;

- The phase and amplitude reserve at the grid connection point must be calculated and documented. Values below 15° phase reserve or 15 dB amplitude reserve are considered critical;
- The study must be carried out for all relevant operational states (active and reactive power variations, voltage levels, control modes, switching configurations, ageing states, states of charge) if the output impedance changes by more than 10% or 5  $\Omega$  in the real or imaginary part;
- The relevant switching configurations of the system must be specified in the study concept and agreed upon with Swissgrid.

### 8.3.2.3 Detailed EMT study

- For all scenarios with a phase reserve < 15° or amplitude reserve < 15 dB, a detailed EMT study must be carried out in the time domain;
- The frequency-dependent system impedances that cause the stability reserves to be undercut must be integrated into the EMT model (e.g. as an EMTP-RV FDNE or wideband model);
- The stability of the overall system must be checked without any external disturbance. If the system remains stable, its robustness in the event of small and large signal excitations (e.g. voltage jumps) must be tested;
- A single frequency injection at the critical frequencies identified in the screening must be carried out in order to check the damping behaviour in the event of forced oscillations;
- If countermeasures are required, all calculations with implemented countermeasures must be repeated and the results compared with the original calculations;
- The connection recipient must prove that the suggested countermeasures ensure stable operation;
- All countermeasures must be coordinated with Swissgrid.

### 8.3.2.4 Evaluation criteria

- Swissgrid evaluates the frequency responses given provided that positive damped behaviour is assumed;
- The results of the screening study are checked against the defined stability reserves;
- If necessary, the modelling approach and simulation results of the detailed EMT study are evaluated;
- If necessary, suggested countermeasures are assessed for effectiveness and feasibility.

### 8.3.2.5 Documentation

- A study concept must be submitted and approved by Swissgrid before the start of the study;
- The concept must describe the method, assumptions, operating points under consideration and grid scenarios;
- After completion of the screening study, a report with all the frequency responses (operational states and switching configurations) must be provided;
- All impedance curves must be supplied in machine-readable form (e.g. CSV);
- The reports of the screening and EMT studies must consist of the following content at the very least:
  - 1) Overview of the model and the method;
  - 2) Description of the simulation parameters and operating cases;
  - 3) Illustration of the stability reserves (phase and amplitude reserve);
  - 4) Description of the countermeasures applied (if any);
  - 5) Evaluation of the stability results and conclusions.
- The simulation model must be provided with each study revision.

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