10 February 2026

Fingrid Modelling instruction for PSCAD models

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List of abbreviations

BESS	Battery Energy Storage System
EMT	Electromagnetic Transients
FSM	Frequency Sensitivity Mode
HVDC	High Voltage Direct Current
IBR	Inverter Based Resource
LFSM	Limited Frequency Sensitivity Mode
LV	Low Voltage
MMC	Modular Multilevel Converter
MSU	Mechanically Switched Units
MV	Medium Voltage
NDA	Non-Disclosure Agreement
OLTC	On-Load Tap Changer
OVRT	Overvoltage Ride-Through
PLL	Phase-Locked Loop
Pmax	Rated power of the plant
PMR	Parallel Multiple Run
PNI	Parallel Network Interface
POC	Point of Connection – The interface between plant and public power system
POD	Power Oscillation Damping
PPM	Power Park Module
PV	Photovoltaic
SCR	Short Circuit Ratio
SMIB	Single Machine Infinite Bus
SSO	Sub-Synchronous Oscillation
UVRT	Undervoltage Ride-Through

1 Introduction

Purpose and scope

This document describes instructions for electromagnetic transient (EMT) simulation models developed in PSCAD / EMTDC, hereafter referred to as model(s), which are delivered to Fingrid as a part of the grid compliance monitoring process presented in the relevant valid Finnish Grid Codes, see [1], [2], [3] and [4].

The instructions in sections 2-6 have been developed and they apply primarily for power park module (PPM) and battery energy storage systems (BESS) models, however same instructions also apply for demand facility and High Voltage Direct Current (HVDC) models where applicable.

The document is divided into the following sections:

- Section 2 “Intended use” aims to give an understanding of how Fingrid intends to use the model and describe the areas of study for which the model must be suited.
- Section 3 “Compatibility” defines the model capabilities which allow the model to be integrated to the simulation environment used by Fingrid.
- Section 4 “Usability” defines the model capabilities which ensure that it is practical and efficient for Fingrid to configure the model, execute simulations and analyse results.
- Section 5 “Fidelity” defines the model contents and details to ensure accurate representation of the modelled real-life plant/device/etc.
- Section 6 “Documentation” lists the relevant documents, reports, datasheets, etc to be delivered with the model.

The instructions in this document have been developed in cooperation with the Nordic transmission system operators (TSOs): Fingrid Oyj (Finland), Svenska kraftnät (Sweden), Statnett SF (Norway), and Energinet (Denmark).

Confidentiality

All models and related technical information given to Fingrid will be treated as confidential. Confidentiality obligations have been specified in the Main grid contract and in relevant Finnish Grid Codes [1], [2], [3] and [4]. Project specific non-disclosure agreements (NDA) are not issued by Fingrid.

2 Intended use

2.1 The model must accurately represent the steady-state, dynamic, and transient behaviour of the plant and support the following simulation scenarios:

a) Steady-state operation and control of passive components

b) Setpoint changes in active and reactive power regulation

c) Control mode changes for regulation of active and reactive power

d) Faults in the external network with an arbitrary fault impedance and in the form of:

   i. single-phase-to-ground

   ii. two-phase fault with and without ground contact

   iii. three-phase fault with and without ground contact

e) Voltage phase angle and magnitude jumps and changes to the external network impedance following events such as:

   i. Disconnection of, and possible subsequent automatic reconnection of, any faulty network component in the external network

   ii. Manual connection or disconnection (without prior fault) of any network component in the external network

f) Voltage disturbances and tending voltage collapse with a duration within the required minimum simulation time

g) Frequency disturbances (with duration within required minimum supported simulation time)

h) Simultaneous disturbances, such as combined voltage and frequency events with active/reactive power regulation

i) Activation of a system protection scheme (via an external signal) for rapid regulation of the plant's active power production according to a predefined final value and gradient.

j) Interaction phenomena with other network devices and components, including converter-driven stability and resonance stability

k) Frequency-dependent impedance calculation as seen from the connection point towards the plant

2.2 The model shall be capable of being integrated into larger system models. If integration of the model into larger network models presents challenges, the plant owner shall be responsible for identifying and implementing solutions in collaboration with the Fingrid.

3 Compatibility

This section defines requirements which mitigate compatibility issues and improve study efficiency.

Simulation environment

3.1 The model must be developed and delivered in PSCAD / EMTDC and be compatible with the PSCAD version and compiler settings (version and compatible version range of Intel Fortran and MS Visual Studio) as specified by Fingrid. The model must be compatible with 32-bit and 64-bit compilers.

The full model must be implemented to PSCAD, co-simulation setup is not allowed. The version information can be inquired from models@fingrid.fi.

PSCAD functionality

3.2 The model must support the use of the PSCAD 'snapshot' function. The model must display the same response with and without the snapshot function.

3.3 The model must support the use of the PSCAD 'multiple run' function and 'parallel multiple run' (PMR) function. The model must display the same response with and without the multiple run functions.

3.4 The model must not use Parallel Network Interface (PNI) functions to divide the model into multiple projects but must support use of PNI for integration into larger system models.

3.5 The model must support multiple instances of its own definitions in the same PSCAD project, each with possibility for independent parameterisation, and without requiring manual changes to be made. If the model contains an alternative to using several definitions or instances, this must be described in the user manual.

3.6 The model must be portable across different PSCAD projects using standard 'copy' or 'copy transfer' features.

3.7 The model shall not make use of the following features in the PSCAD environment:

a) global substitutions

b) radio links

c) multiple layers, including 'disabled' layers

Encryption and precompiled parts

3.8 The model may contain precompiled and encrypted parts ("black-boxed") in DLL format, limited to control and protection systems and individual active units (e.g. PV inverter, wind turbine, STATCOM).

3.9 The real hardware code must be embedded in the model for all control and protection functions including signal processing following the IEEE/CIGRE DLL standard [5].

3.10 The model delivery shall not include any EXE files.

Simulation time step and duration

3.11 The model must accurately represent the plant when being used with a time step of 10 microseconds. The model must not be restricted to operating at a single time step but shall support and be accurate for a range of simulation time steps. It is highly recommended that the model implements, supports and uses the interpolation features of PSCAD to achieve sufficient model accuracy at larger simulation time steps.

3.12 The model must accurately represent the plant for simulation times up to 5 minutes.

4 Usability

This section defines requirements which ensure it is practical and efficient for users to configure the model, execute simulations and analyse results.

File and model structure

4.1 The model delivery must be self-contained: all files must be organised in a single main folder, and all external dependencies must be in a single sub-folder. No unnecessary or obsolete files shall be included.

4.2 The model must be delivered with a complete PSCAD workspace that has all required files correctly loaded and configured.

4.3 The full plant model must be encapsulated in a single main PSCAD module, with the POC as the external electrical interface, and signal interfaces limited to control and setpoint references as specified in req. 4.11 . The main module must include all electrical components, control systems, measurements, and supporting logic.

4.4 The canvas inside the main module must be organised to be easily manageable. It is recommended to use framers, borders, and clear headings to divide the canvas into logical areas such as: electrical network, power plant control, tap changer control, monitoring, results/plots, case setup, initialisation logic, and protections.

4.5 The model must not contain any unnecessary or duplicate definitions or obsolete objects/components.

Model test case

4.6 A sample test case must be delivered with the model, configured according to the site-specific real equipment configuration up to the POC.

4.7 The test case must use a Single Machine Infinite Bus (SMIB) representation of AC power system(s) with a representative SCR.

4.8 User guidance on how to load and run the test case must be provided.

Parameter accessibility

4.9 All relevant control and hardware options/settings that are available either locally or remotely on the real plant must be accessible to the user. This includes but is not limited to:

a) Active power control modes, setpoints and ramp rates

b) Reactive power control modes, setpoints and settings including voltage regulator (droop and deadband)

c) Frequency control (droop, deadband and frequency reference)

d) Fault current infeed settings

e) Fault ride-through activation levels for both undervoltage (UVRT) and overvoltage (OVRT)

f) Protection activation levels and time settings

g) If relevant, settings for special functions (POD, synthetic inertia control etc.)

4.10 The use of configuration files is allowed except for external reference variables required according to req. 4.11 . If configuration files are used, they must not result in conflicting or duplicated parameter definitions. The adjustment of any given setting must not require changes in more than one location.

External references

4.11 The model must support changes in setpoint and control mode for regulation of active and reactive power through an external reference variable/signal. The model must accept these references for initialisation and support updates in references mid-simulation, i.e. dynamic signal references. This includes changing:

a) All control modes for active power including activation/deactivation of FSM/LFSM

b) All control modes for reactive power

c) Available active power (for plants with varying primary energy source)

d) Active power reference value (for active power control mode)

e) Reactive power reference value (for Q control mode).

f) Voltage reference value (for V control mode).

g) Power factor reference value (for PF control mode).

4.12 Setpoint references for active power, reactive power and voltage must be specified in per unit according to the nominal active power and voltage of the plant at the connection point. Setpoint for power factor control must be specified as $\cos(\varphi)$.

Positive active and reactive power direction is defined from the plant towards the grid.

4.13 For generation facilities with varying primary energy source, the reference for available active power must be specified in per unit either based on rating of individual active units or nominal power at connection point.

Signal accessibility

4.14 The model must provide access to all electrical, mechanical, control and protection signals necessary for EMT analysis of the plant. Relevant signals should be accessible for each individual active unit, protection unit and plant controllers. At a minimum, the following categories of signals must be accessible (when applicable):

a) Reference signals from the plant controllers to individual units

b) Reference signals from within the control of individual units with regards to output current/voltage (active current, reactive current in positive/negative sequence etc.)

c) Controller input measurements for plant controllers (AC voltage, currents, power, frequency etc.)

d) Controller input measurements for individual units (AC voltage and DC voltage, frequency, currents etc.) This includes voltage and current measurements as used for input to the internal control, for example the direct and quadrature axis currents (Id/Iq) signals used for comparison to the Id and Iq references).

e) PLL outputs for systems using phase-locked loop synchronization.

f) Activation and deactivation of operation modes and special regulation functions (e.g. FSM, LFSM, UVRT, OVRT)

g) Activation and deactivation of fault current contribution

h) Activation signals of protection functions (which can identify why a model has tripped during simulation)

i) Activation signals of limiters

j) Status signal of converter blocking/de-blocking

k) Generator mechanical speed (RPM)

l) Outputs from damping or oscillation control functions (e.g. sub-synchronous damping controllers)

Initialization

4.15 The model must be capable of self-initialisation to any user-defined terminal conditions and must reach steady-state conditions within 3 seconds of simulation time. It must tolerate non-nominal system conditions during the first few seconds (e.g., due to other devices initialising).

Initialization speed is evaluated in SMIB with ‘SCR Normal’ background network impedance

4.16 During initialisation, mechanically switched compensation units (MSUs) and on-load tap changers (OLTCs) must be able to find their correct operating positions. To facilitate this, fast adjustments without physical constraints (e.g., instantaneous switching or tap changes) are acceptable during the initialisation phase. The initial state of MSUs and OLTCs must be user-adjustable, allowing to define their starting positions explicitly.

Scaling

4.17 The model must support scaling the capacity of aggregated individual units (turbines, PV-inverters etc.) and power plant controllers. This must be achieved either using an internal function or through an external scaling component.

Diagnostics

4.18 The model must provide meaningful messages in the PSCAD output window if preconfigured network conditions or model parameters are beyond valid operational limits. Models shall not produce repeated or excessive messages to the PSCAD output window during simulation.

5 Fidelity

This section defines the model details and contents to ensure accurate representation of the real plant.

Frequency range

5.1 The model must be able to represent accurately the steady-state, dynamic and transient properties of the plant in the frequency range from 0.2 Hz to 2.5 kHz, considering the intended use of the model (req. 2.1).

Control and protection systems

5.2 Actual hardware code must be implemented in the modelling of control and protection of individual active units and for modelling of plant controllers. The hardware code must be interfaced as specified in 3.9 .

5.3 The model must include full representation of plant-level regulation. The plant level regulation must accurately represent the real plant with all relevant control and monitoring functions implemented as in real equipment, including specific measurement methods, communication and processing time delays, transitions into and out of fault-ride-through modes, settable control parameters or options, and any other specific implementation details which may impact plant behaviour. All intentional or inherent latencies (e.g. signal transmission delays between different control and protection layers) must be modelled. Generic plant controller representations are not acceptable.

5.4 If multiple plants are controlled by a common controller, or if the plant includes multiple types of converter-based units (e.g. hybrid BESS/PV) this functionality must be included in the plant control model. If supplementary or multiple voltage control devices (e.g. STATCOM) are included in the plant, the coordinated control of these must be included in the model.

5.5 The model shall include all plant-level voltage, current and frequency protection functions that can trip the plant due to external events. This generally includes all protections located at the connection point voltage level, including ground current protection. Other plant level protections, such as SSO protection, shall also be included. The model shall allow protections to be disabled and enabled by the user.

5.6 Individual active unit models must include complete representation of inner and outer control loops, including e.g. voltage control, phase-locked loop, fault ride-through logic, damping controllers, limiter functions, specific measurement methods and filtering.

5.7 Individual active unit models must include in detail all unit-level protection systems that are relevant from a power system perspective. The model shall allow protections to be disabled and enabled by the user. Any protection that can influence dynamic behaviour or fault ride-through during the simulation period shall be included. This typically includes:

a) Over-voltage and under-voltage protections (both instantaneous and RMS)

b) Overcurrent protections (both instantaneous and RMS)

c) Frequency protections

d) DC bus voltage and current protections

e) Mechanical protections (e.g. thermal limits on wind turbine crowbar logic)

f) Any other converter-specific or unit-specific protections

5.8 All control and protection parameters must reflect the settings of the installed equipment. The model must include all tuneable parameters, control and protection settings, delay values, and thresholds. Mapping between model parameters and real equipment settings must be clearly documented (req. 6.12). Default values are not acceptable unless they match the actual site configuration.

Converter units

5.9 Active units must be modelled with sufficient detail for EMT-analysis considering the requirements for simulation scenarios (req. 2.1) and valid frequency range (req. 5.1). This also applies to all relevant physical, electrical and mechanical components such as filters, transformers, shunt components, gearbox, pitch controller, generators, DC-link chopper etc.

5.10 The model shall as default use an average representation of the switching dynamics, implemented using a controlled voltage source approximation. The average model must preserve the accuracy of the inner control loops, DC-side dynamics and protection schemes, with only switching and modulation being omitted. The model's ability to accurately represent the dynamics that exist between the DC side and the AC side of the plant must not be compromised.

5.11 If the average model is not sufficiently accurate within the required frequency range (req. 5.1), if the converter is of modular multilevel converter (MMC) type, or if the plant is connected to HVDC or offshore AC networks, a detailed switching model must also be provided in addition to the average model.

5.12 For active units with mechanical drive trains, the model must include a mechanical oscillation mass model representing the rotor, gearbox, and blades. Key parameters such as inertia constants, natural frequencies, spring and damping constants must be included in the model and documented.

5.13 For active units with varying primary energy source, it must be possible to adjust the available power, also during simulation.

Electrical components

5.14 The model must include all network components and other equipment which affect the operation of the plant. This includes transmission lines, cables, transformers (incl. tap changers), filters/capacitors, SVCs and STATCOMs etc.

5.15 Transformers must be modelled with magnetisation/saturation characteristics, correct phase-shift behaviour, and grounding configuration.

5.16 For cables within the plant collector grid operating below 110 kV, aggregation using PI sections is permitted, provided it does not misrepresent the plant's frequency-dependent characteristics. For cables and lines above 110 kV, geometric models are recommended for:

a) cables longer than 5 km

b) overhead lines longer than 25 km

5.17 The main electrical circuit from the POC to the LV terminals of converter-based units must be open, i.e. accessible to user and not black-boxed.

5.18 If house load of the generating plant exceeds one percent of the rated power (Pmax), it shall be included in the model. The house loads can be modelled as simple static loads.

Aggregation

5.19 For plants with multiple identical units, the model must be aggregated. All units of the same type (incl. design and settings) shall be combined into as few equivalents as possible while also ensuring:

a) The electrical network between the POC and main transformers is modelled in full detail

b) Separate modelling of all main transformers, preserving winding configurations

c) Maintenance of the overall structure of the plant layout ensuring:

    i. impedances are placed at the correct voltage level

    ii. aggregated strings are divided appropriately with nodes/busbars, if relevant with regards to location of measurement points for control and protection

    iii. all passive component types such as LV cables, MV cables, MV/LV transformers, capacitors etc. should be aggregated per type

5.20 Whilst the collection grid and active units should generally be combined into a single aggregated string, semi-aggregated models are accepted where full aggregation would compromise accuracy, for example due to:

a) Long cables or overhead lines requiring geometric models

b) Asymmetry in plant layout (e.g. different transformer sizes, line lengths, or loading)

c) Plant consisting of multiple bays at the POC that can operate independently

d) Plant capacity exceeding 250 MW. Other motivations for semi-aggregation may be relevant for large plants, and aggregation level must be defined on a project-specific basis

Sufficient accuracy can generally be ensured by following the instructions described in Appendix B: General guideline to model aggregation

5.21 For hybrid plants or plants with different unit types (e.g. PV + BESS), each type must be aggregated separately.

6 Documentation

This section defines requirements for user guidance and other documentation that must accompany the simulation model delivery.

Ready **documentation template** for model user manual, including instructions on what information to fill and where, can be downloaded from the Fingrid website [6]. This document template **shall be used for providing the required documentation information**.

User manual

A comprehensive and project-specific user manual must be provided with the model, as one single document unless stated otherwise. The manual must include as a minimum:

6.1 Version history of the complete plant model. If any changes to the model are required after the initial delivery, these changes shall be listed in the version history.

6.2 Identification of the manufacturer's model release version and the appropriate associated firmware version of the real units (turbine/PV-converter etc.)

6.3 Model compatibility with specific PSCAD, Intel Fortran Compiler and Visual Studio versions

6.4 List of dependencies

6.5 Requirements for the simulation environment (minimum and maximum simulation time steps, etc.).

6.6 Maximum number of definitions and instances

6.7 Limitations of the plant specific model performance:

e) Minimum SCR at single production unit level

f) Minimum SCR at POC level

g) Model bandwidth (frequency range)

6.8 Simplified illustration of plant layout showing voltage levels and main components within the plant.

6.9 Plant data, such as and not limited to:

h) Rated power at POC

i) Rated voltage at POC

j) Data of the grid used for model validation and development (grid impedance / short circuit data)

k) Point of measurement and point of plant control

Should also include all relevant information about line droop compensation etc. if such is used

l) Installed capacities per unit type

6.10 Description of model aggregation which shall include as least:

a) The complete plant layout (before and after aggregation)

b) Principles used for aggregation as well as any restrictions on its application

c) A validation report demonstrating that the aggregated model accurately represents the full plant. Validation may be based on comparison with a detailed model or analytical methods.

The validation of model aggregation can be included in the project specific manual or delivered in a separate reference.

6.11 Description of model structure including high level overview of PSCAD canvas. The description must cover on high level all individual plant components both active and passive represented in the model. For passive components like transformers, cables etc. the modelling approach must be described and explained. Detailed description of the functions within individual active units can be omitted if covered in separate references as described below.

6.12 Project-specific parameter values for all model components, including:

a) Controls at both POC and unit level

b) Protections at both POC and unit level

Parameters may be listed in table format in the manual or provided in a separate spreadsheet reference.

6.13 Parameters of passive components, both for each type and the aggregated model components.

a) The relevant parameters (such as positive-, negative- and zero-sequence impedances for cables or transformers) used in the model must be stated explicitly. Submission of datasheets from which the model parameters can be derived is not sufficient.

b) The documentation must explain and describe how the component parameters have been selected whether taken directly from datasheet, calculated or derived based on any assumptions. Further datasheet references must point to the exact location (page / table etc.).

6.14 Model usage instructions covering:

a) How to change setpoints and control modes for regulation of active and reactive power, such as:

i. Reactive power control functions: Q-mode (reactive power control), U-mode (voltage droop control), PF-mode (power factor control)

ii. Active power control functions: P-mode (active power setpoint), dP-mode (delta limiter mode)

iii. Frequency control enable/disable of FSM/LFSM modes

iv. Setpoints: Q-ref, U-ref, PF-ref and P-ref

b) Setting of available power

c) Setup and initialization of the model, such as:
   i. Quick initialization of plant controllers / OLTC / MSUs etc.

d) Instructions for transferring the model to another simulation project.

e) Instructions for how to create multiple instances of the model and with separate parameterisation.

f) Instructions for scaling the power rating of active units and the plant controllers.

The **following items from 6.15 to 6.21 may be included in the project-specific manual or in generic vendor manuals** for specific components. If covered in vendor manuals, those documents shall be delivered as references to the project-specific user manual. Even if all topics are addressed in the project-specific manual, any vendor model manuals must still be submitted to Fingrid.

6.15 Description of active components and control functions included in model.

6.16 Description of automatic control of passive components, such as OLTC.

6.17 Description of protection functions and tripping signals. The descriptions are expected to vary in detail level for open and black boxed protection functions.

a) Plant level / open / generic implementations; documentation must describe how the protection functions work and how they have been modelled. Further for each function list all relevant parameters (with plant specific settings), signals and activation flags, with explanation of usage.

b) Component level / black boxed / real hardware functions; documentation must list all protection functions implemented in the model with name and short explanation of purpose. Further for each function list all relevant parameters (with plant specific settings), signals and activation flags, with explanation of usage.

If the protection parameters are described in vendor manuals with generic values, the project specific settings should be included in the project specific manual in table format or delivered in separate spreadsheet as reference.

6.18 Description of plant setpoints and functional settings available in the model and description of other model parameters including saturation characteristics, non-linearity, deadbands, time delays and limiter functions (non-wind-up / anti wind-up) as well as look-up table data and applied principles for interpolation etc. Each model parameter must be described with PSCAD component/group, parameter name, function/purpose and where relevant, unit, typical value, range, input options etc.

6.19 Description of the model input and output signals, both on park level and for each unit type model, with explanation of data type, unit of measurement, range, purpose and function.

6.20 Description of any additional functionalities such as POD, SSO damping circuit etc.

6.21 Description of the average models and approach used for implementation

Further supplementary documentation

6.22 Data for all component such that the Fingrid can structure a fully detailed plant model, including:

a) Plant single-line diagram (SLD) showing main components up to the POC

b) Lengths, electrical and geometrical data of all high voltage cables and overhead lines required for EMT simulation modelling

c) Data sheets for transformers, cables, surge arresters, harmonic filters (if applicable)

6.23 Documentation about the average model performance accuracy (either against detailed model or real equipment) up to 2.5 kHz shall be delivered.

6.24 A model validation report(s) must be delivered in accordance with the guidance provided in Appendix A: Guideline to model accuracy validation and documentation.

7 References

[1] Grid Code Specification for Power Generating Facilities, VJV.

[2] Grid Code Specifications for Grid Energy Storage Systems, SJV.

[3] Grid Code Specifications for Demand Connections, KJV.

[4] Grid Code Specification for High Voltage Direct Current Systems, HVDC.

[5] Cigre Technical Brocure 958, “Guidelines for use of real-code in EMT models for HVDC, FACTs and inverter based generators in power systems analysis,” February 2025. [Online].

[6] “PSCAD model documentation template,” [Online]. Available: https://www.fingrid.fi/en/grid/grid-connection-agreement-phases/grid-code-specifications/modelling-instructions/.

Appendix A: Guideline to model accuracy validation and documentation

The model delivery must include model validation reports, which shall demonstrate that the model has sufficient accuracy when compared to the actual plant/device/etc which the model is representing. The following sections will describe in more detail what is expected to be included in the validation reports.

Unit model validation

The unit model validation is comparison of type test results of individual active units (e.g. PV inverter, wind turbine, STATCOM) with the results from the corresponding simulation model under identical or similar test conditions.

Currently Fingrid does not have specific instructions for the unit model validation, as these are still in development. If a unit model already has certification or documentation of model validation, these shall be provided to Fingrid for assessment. If accepted, no further testing is required for the validation of that unit model.

If a unit model does not have any existing certificate or documentation of type-testing, Fingrid can require the plant owner to perform the validation of that unit model. If required, the plant owner shall first provide a testing proposal for the scope of testing, model validation and documentation. Test scope is expected to follow international standards such as IEC 61400-27-2, but any similar standards or OEM guidelines can be used if sufficient and accepted by Fingrid. After the test scope is accepted, the plant owner shall perform the unit model validation and deliver the documentation for assessment.

Plant model validation

The plant model validation is comparison of field measurements from on-site commissioning tests and/or recorded grid disturbances with the full plant model under similar network conditions.

The requirements and scope for the plant model validation are specified in the relevant grid codes (Requirements concerning the verification and documentation of the modelling data).

In voltage control step response validation, special attention should be given to how the delay (reaction time) of the reactive power response on-site compares to the delay in the model. The voltage setpoint change should be displayed in the same figure with the reactive power output, so that the reaction time is clearly visible. The figures for site tests and model performance shall be delivered and compared. See Figure 1 below for example on plotting the figure and reaction time calculation. If stepwise changes in the grid voltage are performed as part of the on-site voltage control response testing, the same figures and response time calculations as with setpoint change tests should be done for these cases as well.

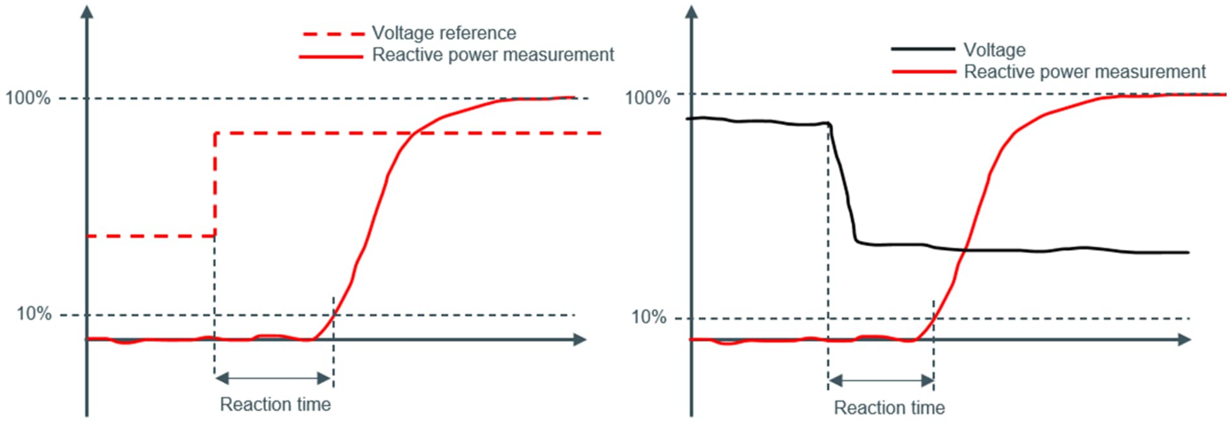

Figure 1: Guideline for signal plotting and reaction time calculation

Appendix B: General guideline to model aggregation

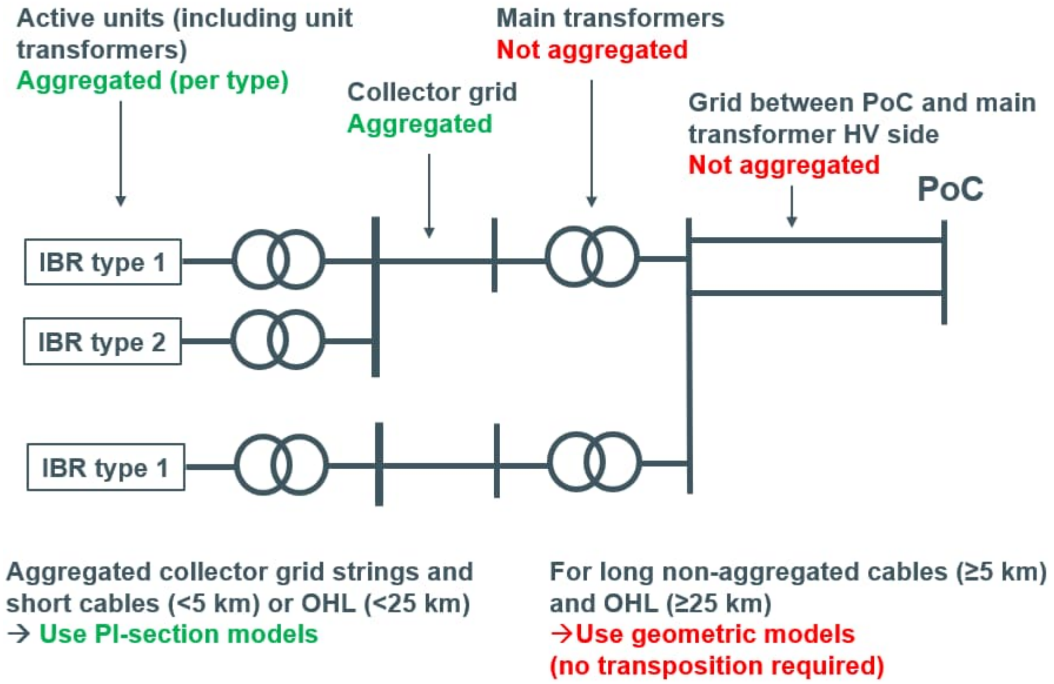

Figure 2: General guideline for IBR plant aggregation

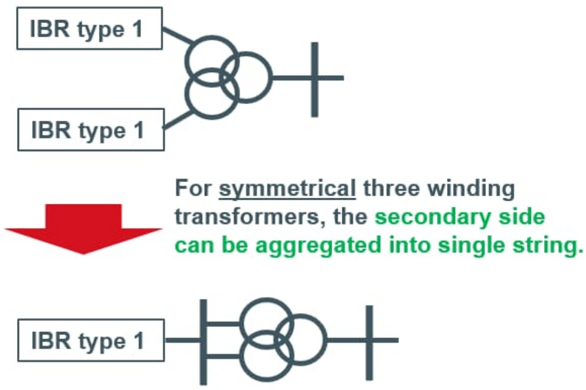

Figure 3: General guideline for aggregation of symmetrical three winding transformers