FINGRID

Fingrid modelling instruction for PSCAD models –

Data Centers

13.3.2026

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Change log

Date	Version	Changes
13.3.2026	1.0	First release

List of abbreviations

AVM	Average-value model
BESS	Battery Energy Storage System
EMT	Electromagnetic Transients
ESS	Energy Storage System
LV	Low Voltage
MSU	Mechanically Switched Units
MV	Medium Voltage
NDA	Non-Disclosure Agreement
OLTC	On-Load Tap Changer
OVRT	Overvoltage Ride-Through
PLL	Phase-Locked Loop
PMR	Parallel Multiple Run
PNI	Parallel Network Interface
POC	Point of Connection
POD	Power Oscillation Damping
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 data center 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 Code, see [1].

This document applies only for data centers as *demand facilities*. In case the data center is part of hybrid facility with production or grid energy storage systems that run parallel to the grid, the scope of modelling shall be discussed separately with Fingrid.

In this document, the term *demand unit* is used to describe any individual or aggregated load entity that is interfaced with the grid. This entity could for example consist of power supply and the load it supplies, or it could be a simple static component representing passive site support load, etc.

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 facility/device/etc.
- Section 6 “Documentation” lists the relevant documents, reports, datasheets, etc to be delivered with the model.

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 Code [1].

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 demand facility and support the following simulation scenarios:

a) Steady-state operation and control of passive components

b) Setpoint changes in active power regulation (and reactive power regulation, if applicable)

c) Control mode changes for regulation of active power (and reactive power, if applicable)

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) Interaction phenomena with other network devices and components, including converter-driven stability and resonance stability (e.g. power oscillations)

j) Frequency-dependent impedance calculation as seen from the connection point towards the facility

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 facility 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 (up to at least 50) 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 demand units.

3.9 The real hardware code must be embedded in the model following the IEEE/CIGRE DLL standard [2].

3.10 The model delivery shall not include any EXE files.

Simulation time step and duration

3.11 The model must accurately represent the demand facility when being used with a time step of 10 microseconds. It is highly recommended that the model implements, supports and uses the interpolation features of PSCAD to achieve sufficient model accuracy also at larger simulation time steps.

3.12 The model must accurately represent the demand facility for simulation times up to 1 minute.

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 demand facility model must be encapsulated in a single main PSCAD module, with the POC (Point of Connection) as the external electrical interface, and signal interfaces limited to control and setpoint references as specified in point 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, facility 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 The model must provide access to relevant parameters/settings necessary for EMT analysis of the demand facility. The relevant parameters/settings shall be accessible from each individual demand unit model, control unit or facility controller etc. when applicable. These parameters/settings include for example:

a) Active power (and reactive power, if applicable) control modes, setpoints and ramp rates

b) Protection activation levels and time settings

c) Activation levels, deactivation levels and other relevant settings of different operation modes (e.g. ride-through modes, current limiting/blocking modes)

4.10 The use of configuration files is allowed except for external reference variables described in point 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 to the active power of the load (and reactive power if applicable) through an external variable signal. This signal shall be available for each demand unit included in the model. The model must accept these external variable signals for initialisation and support updates mid-simulation. It shall also be possible to select, adjust and create the demand facility load profiles as described in point 5.19 .

Signal accessibility

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

a) Protection signals (which can identify why a model has tripped during simulation)

b) Activation and deactivation of operation modes (e.g. ride-through modes, current limiting/blocking modes)

c) PLL outputs for systems using phase-locked loop synchronization

Initialization

4.13 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

4.14 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

4.15 The model must support scaling the capacity of aggregated individual demand units and demand facility controllers. This must be achieved either using an internal function or through an external scaling component.

Diagnostics

4.16 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 demand facility.

Frequency range

5.1 The model must be able to represent accurately the steady-state, dynamic and transient properties of the facility in the frequency range from 0.2 Hz to 2.5 kHz, considering the intended use of the model (point 2.1). For the converter models, limitations to accuracy in this frequency range is acceptable if caused by the average representation of the switching dynamics (i.e. use of average-value models). However, these limitations shall be clearly described and justified in the documentation.

Facility level control and protection systems

5.2 The model must include full representation of facility level control. The facility level control must accurately represent the real demand facility operation 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, switchover to high voltage back-up supply, settable control parameters or options, and any other specific implementation details which may substantially impact demand facility behaviour. All intentional or inherent latencies (e.g. signal transmission delays between different control and protection layers) must be modelled.

5.3 If multiple demand facilities are controlled by a common controller, or if the demand facility includes multiple types of active units (e.g. production or energy storage units such as PV or ESS), this functionality must be included in the demand facility control model. If supplementary or multiple voltage control devices (e.g. STATCOM) are included in the demand facility, the coordinated control of these must be included in the model.

5.4 The model shall include all facility level voltage, current and frequency protection functions that can trip the demand facility or parts of the demand facility (e.g. UFLS, Under-frequency load shedding) due to external events. This generally includes all protections located at the connection point voltage level, including ground current protection. Other facility level protections, such as SSO protection, shall also be included. The model shall allow protections to be disabled and enabled by the user.

Demand units and other equipment

5.5 All demand units must be modelled with sufficient detail for EMT-analysis considering the requirements for simulation scenarios (see 2.1) and valid frequency range (see 5.1). This also applies to all relevant physical, electrical and mechanical components such as filters, transformers, shunt components, etc.

5.6 Centralized and rack-level UPS (Uninterruptible Power Supply) systems, any dynamic reactive power compensation devices such as STATCOMs and SCVs, and all utility-scale ESS (Energy Storage System) and E-STATCOMs etc. shall be modelled with manufacturer specific models. These models shall comply with the following points:

a) Actual hardware code must be implemented in the modelling of control and protection. The hardware code must be interfaced as specified in 3.9 .

b) The model must include complete representation of inner and outer control loops, including e.g. phase-locked loop, fault ride-through logic, limiter functions, specific measurement methods and filtering.

c) The model 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:

   i. Over-voltage and under-voltage protections (both instantaneous and RMS)

   ii. Overcurrent protections (both instantaneous and RMS)

   iii. Frequency protections

   iv. DC bus voltage and current protections

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

   vi. Any other converter-specific or unit-specific protections

d) All control and protection parameters included in the model 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 (see point 6.11). Default values are not acceptable unless they match the actual site configuration.

e) The model shall 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 demand facility must not be compromised.

f) The actual storage elements of ESS (UPS/BESS battery) can be modelled with simple DC voltage source, if the state-of-charge does not significantly change and affect the EMT simulations (see point 2.1) in the minimum required simulation timeframe (1 minute). CESS capacitors shall be modelled explicitly.

5.7 The ITE load itself and its power supply can be modelled as single resistive load, if 1) those are fully behind a centralized three-phase UPS with no direct network connection, and 2) there are no rack-level UPS systems. Otherwise, the power supply shall have the rectifier (including the DC bus capacitor) and its relevant control loops modelled, and the inverter and ITE load itself can be modelled as simple passive resistive load on the DC side.

5.8 The variable frequency drives (VFD), supplying the cooling loads (motors of pumps, fans, etc.), shall have the rectifier (including the DC bus capacitor) and its relevant control loops modelled, and the inverter side and motor load itself can be modelled as simple passive resistive load on the DC side.

5.9 The models of ITE load power supplies and cooling load power supplies shall also include the dynamics of load disconnection, reconnection and shedding (e.g. protection functions, reconnection logic and ride-through features) with correct ramp-rates and other relevant settings. If the reconnection happens after the minimum required simulation timeframe (1 minute), the reconnection logic can be omitted.

5.10 The equipment and components which are not normally connected to the facility and connect only in cases where the facility has no network connection (e.g. backup generation) shall not be modelled. Exception to this is if the reconnection to network happens before the minimum required simulation duration (1 minute), in which case the modelling of this equipment shall be defined project specifically.

5.11 Other non-critical support loads (lighting, etc.) can be modelled as simple static loads.

5.12 All voltage source inverter models shall use an average representation of the switching dynamics, i.e. be modelled as average-value models (AVM).

Electrical components

5.13 The model must include all network components and other equipment which affect the operation of the facility. This includes transmission lines (incl. high voltage back-up supply connections), cables, transformers (incl. tap changers), filters/capacitors, SVCs and STATCOMs etc.

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

Aggregation

The goal of aggregation is to minimize the model size and improve the simulation performance efficiency, while maintaining a necessary level of accuracy required for the EMT analysis of the facility in scope of studies conducted by Fingrid (see point 2.1).

5.15 The aggregation shall comply with the following points:

a) The electrical network between the POC (Point of Connection) and main transformers shall be modelled in full detail.

If demand facility has high voltage back-up supply connections, these must be included in the aggregated model

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

c) All passive component types such as LV cables, MV cables MV/LV transformers, capacitors, filters etc. shall be aggregated per type behind each main transformer.

d) All individual demand units ‘of the same type’ (incl. design and settings) shall be aggregated into as few instances as possible behind each main transformer.

5.16 One of the main difficulties in demand facility modelling is aggregation of potentially numerous different types of demand units, for example loads with varying settings, technical capabilities, characteristics, complexities or manufacturers. Simply aggregating only the loads of the same design and settings could lead to excessive number of aggregated model instances, leading to decreased model performance while providing little additional accuracy. Therefore, certain simplifications can be made in defining which loads are ‘of the same type’ and can be aggregated to single instance. All loads which have similar or close to similar behaviour in the following characteristics can be aggregated to same instance:

a) UVRT and OVRT (or current blocking / current limiting, etc.) activation thresholds and other logic

b) Load characteristics, i.e. response to smaller voltage and frequency changes (which are not activating any special operation mode, protection function, etc.)

c) protection functions, settings, disconnection and reconnection logics, etc.

In other words, the models from different manufacturers can be aggregated to single manufacturer specific model, provided that the behaviours of the actual devices are similar or close to similar.

5.17 Additionally, the aggregation shall maintain any dependencies between the different loads. In other words, if disconnection of certain loads (e.g. cooling system) leads to disconnection of another system (e.g. the servers on datacenters) or the whole facility, this must be modelled in sufficient detail.

5.18 Considering the points 5.15 - 5.17 , the facility owner must make a proposal for the aggregation and have it approved by Fingrid in the beginning of the modelling process. The proposal shall include at least the following:

a) Simplified illustrations of facility layout (with different loads, load types, voltage levels, passive components and other equipment clearly indicated) before and after aggregation.

b) Description of principles used for aggregation as well as any restrictions on its application. This includes listing the characteristics of all loads and which of these have been combined into single aggregated instances.

c) The choice of models used for aggregated instances shall also be justified, i.e. why the model is accurate enough for studies conducted by Fingrid (see point 2.1). If there were multiple choices for the aggregated instance, why was the used model chosen. If the used model is based on any generic or publicly available model, the source of the model must be clearly stated and the use of such model shall be justified (including any modifications to the original model etc.).

Load profiles

5.19 The demand facility short-term load profile (i.e. active and/or reactive power consumption characteristics in time frame of 1 minute) must be included in the model. For example, uneven load profiles (e.g. AI training), and the relationship between ITE load and cooling load must be modelled with sufficient accuracy. If the demand facility has multiple regular load profiles, the user must have possibility to select between these profiles. The user must have possibility to adjust/create these profiles, for example with modification of the external variable signals of each demand unit (see point 4.11) or by modification of external file(s), depending on how the modelling of the load profile is implemented.

6 Documentation

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

Ready **documentation template** for project specific model user manual, including instructions on what information to fill and where, can be downloaded from the Fingrid website [3]. 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 facility 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 models listed in point 5.6

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 demand facility specific model performance:

a) Model bandwidth (frequency range)

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

6.9 Demand facility data, such as and not limited to:

a) Rated power at POC

b) Rated voltage at POC

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

6.10 Description of model structure including high level overview of PSCAD canvas. The description must cover on high level all individual demand facility 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.

6.11 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.

6.12 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.).

6.13 Model usage instructions covering:

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

   i. Active power of the demand facility, including the adjustment of individual demand units

b) How to select and adjust the load profiles of the demand facility, if applicable

c) Setup and initialization of the model, such as:

   i. Quick initialization of facility 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 demand units and the facility controllers.

6.14 Description of the load profiles

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) Demand facility 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 demand facility specific settings), signals and activation flags, with explanation of usage.

b) 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 demand facility 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 demand facility 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 facility level and for each demand unit 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 demand facility model, including:

a) Demand facility 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 A **functional description** of how the demand facility operates within a time frame of 1 minute. The documentation shall describe at least:

a) The logics and functionalities affecting the operation during and after voltage and frequency disturbances of different magnitudes and durations in the point of connection, such as tripping, load shedding or post-fault recovery sequences.

b) The logics and functionalities affecting the operation during and after voltage and frequency variations within the normal operating voltage and frequency range.

c) The logics and functionalities implemented in the simulation model, including the scope of implementation. If some logics or functionalities are omitted from the simulation model, or the scope of the implementation differs, a justification shall be provided

The functional description shall be delivered in the beginning of the modelling process (along with the model aggregation proposal described in point 5.18)

Note that the functional description document is essential for understanding the operation of the demand facility, evaluating the model and consequently grid code compliance. Well-structured and non-controversial single document is expected instead of compilation of equipment data sheets lacking synthesis of relevant technical principles.

6.24 Description of the model aggregation, as described in point 5.18 (i.e. the final and accepted aggregation proposal).

6.25 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 Specifications for Demand Connections, KJV.

[2] 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].

[3] “PSCAD model documentation template for data centers,” [Online].

Appendix A: Guideline to model accuracy validation and documentation

The model validation is comparison of type test results (and/or field measurements) of the actual equipment with the results from the corresponding simulation model under identical or similar test conditions.

If any individual active unit (UPS system, VFD, STATCOM, BESS, etc.) model has existing certificate or documentation of model validation, these shall be provided as part of the model documentation. If necessary, Fingrid can require the demand facility owner to perform the model validation of specific equipment/devices/systems/etc. If required, the scope of testing, model validation and documentation are provided separately by Fingrid.