

Modelling instruction for PSS/E and PSCAD models

12.1.2024



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Change log

| Date | Version | Changes |
|-----------|---------|----------------|
| 5.5.2022 | 1.0 | First release |
| 12.1.2024 | 2.0 | Second release |

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1 Introduction

1.1 Purpose and scope

This instruction describes the requirements for PSS/E and PSCAD simulation models to be 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/.

Delivery of a compliant model is an important precondition for demonstrating grid code compliance required to receive Interim and Final Operational Notifications for the equipment to be connected to the grid. By following this instruction, the overall quality and compatibility of the models can be ensured which will also streamline the overall compliance monitoring process.

The type of models (PSS/E, PSCAD, both or none) to be delivered and the scope of studies to be performed for a specific project (e.g., a new power plant being built) is defined by Fingrid based on the requirements presented in the relevant grid code.

The modelling requirements are applicable as such for all new build projects. For retrofit projects — such as partial renewal or modification of an existing system — the exact scope of modelling shall be agreed separately.

The latest version of this instruction shall be used as a reference to modelling requirements for a specific project at the time of the modelling studies. The version updates of this instruction shall be checked between the stages of applying for Interim and Final Operational Notification. If this modelling instruction has been updated in between the stages, the latest version shall be followed for Final Operational Notification stage. As per request Fingrid will confirm the version of the modelling instruction to be used for a specific project and project stage.

1.2 Confidentiality

All models and related technical information given to Fingrid will be treated as confidential. Confidentiality obligations have been specified in the relevant Finnish Grid Codes.

Project specific NDAs (non-disclosure agreement) are not issued by Fingrid.

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2 General requirements

This chapter describes the general requirements for both PSS/E and PSCAD models.

2.1 Structure and aggregation

The power plant model shall include all physical equipment that essentially affect the operation of the power plant, such as the generators, transmission lines and cables, transformers, capacitor banks etc.

If the modelled power plant includes multiple similar generating units, such as wind turbines, these shall be represented as aggregated units. All generating units of the same type (identical design) shall be combined into a single aggregate. The electrical network between the power plant connection point and the main transformers shall be modelled. All main transformers shall be modelled separately. The internal electrical network, including the transmission lines, cabling, step-up transformers, capacitor banks, filters and loads behind each main transformer shall be modelled as aggregated components. Three-winding MV/LV transformer (e.g. BESS inverter transformers) can be modelled as two-winding equivalent.

Example topologies for power plants with one and two main transformers are presented in Figure 1 and Figure 2. This topology principle shall be used in the simulation models. Dummy bus and zero-impedance branch shall be included only if required by the plant controller.

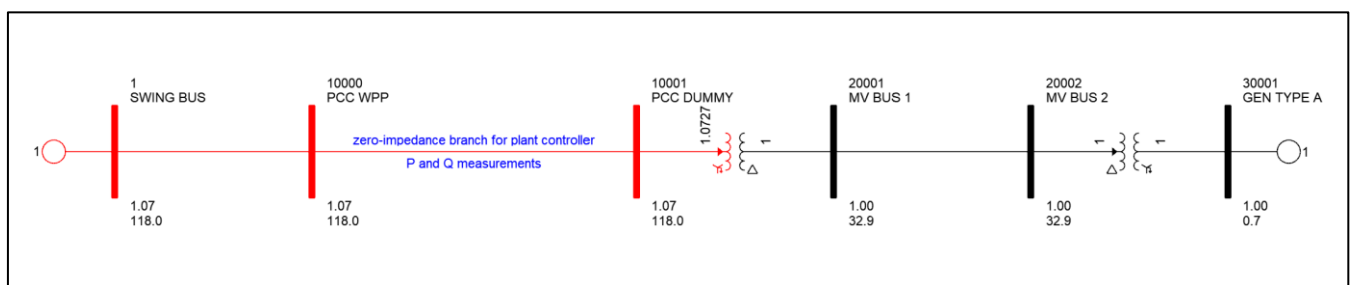


FIGURE 1. EXAMPLE TOPOLOGY OF AN AGGREGATED MODEL WITH ONE MAIN TRANSFORMER

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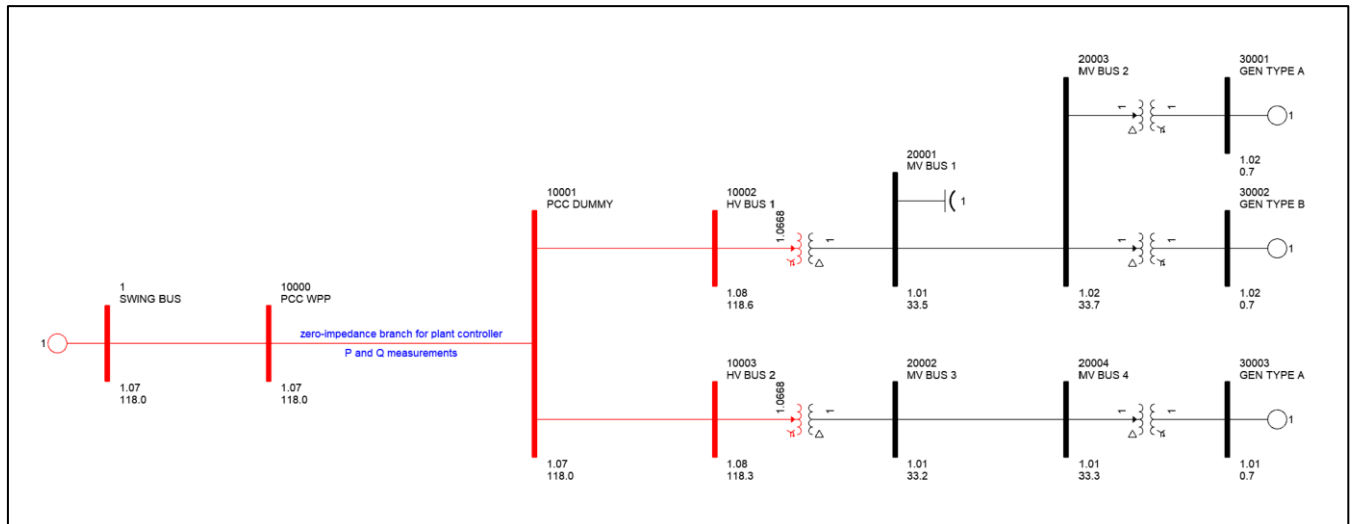


FIGURE 2. EXAMPLE TOPOLOGY OF AN AGGREGATED MODEL WITH TWO MAIN TRANSFORMERS AND TWO TYPES OF GENERATORS

2.2 Functionalities

Models shall be delivered with control modes and setpoints that will be primarily used in the normal operation. The model operating range shall reflect the actual power plant operating range, and the model shall include all limiters that restrict the operation of the power plant. The limiters shall represent the actual power plant response.

The model shall have the capability to change the control mode to any control mode possible in the actual power plant, such as voltage droop control, reactive power control and power factor control. The setpoints of these control modes, such as active power, reactive power, and voltage setpoints shall also be changeable during the simulation. The modification of the essential control parameters (e.g., voltage regulator settings, fault current infeed, power ramp rates) must be available for the user.

At least following parameters must be adjustable during simulation:

- active power setpoint
- available active power and/or wind speed etc.
 - if wind speed etc. is used to adjust the power, also wind speed vs. active power curve shall be provided.
- reactive power setpoint
- voltage setpoint
- power factor setpoint

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- reactive power control mode
- active power control mode
- active power ramp rates

The model shall include all generator protection functionalities relevant from the power system perspective. Plant level frequency and voltage protection functions shall be included in the model. Protection settings used in the model shall correspond to the ones to be used on site. The model shall announce the type of protection in case of tripping. Protection functions shall be modelled within the limits of simulation program capabilities.

The model shall include limited frequency sensitive mode for overfrequency and underfrequency (LFSM-O and LFSM-U) and those shall be enabled by default. In addition to limited frequency sensitive mode the frequency sensitive mode (FSM) shall be available to be enabled by the user. The model shall be built so that all frequency control modes can be enabled at the same time with different slope values i.e., the slope depends on the function currently in use.

2.3 Usability

The project specific model is expected to be fully compatible and operable as part of large system models. To ensure this, the external dependencies such as library files etc. shall either have unique version numbering, or there shall be a capability to rename the dependencies. If the model does not operate in large system models, the issues must be identified and resolved together with Fingrid. The number of model dependencies are recommended to be kept at minimum.

Any unstable operation of the model shall not result in crashing of the simulation, and any mechanism (protection etc.) that ceases the unstable operation shall reflect the actual power plant response.

2.4 Other requirements

2.4.1 Modelling of synchronous generators

If the power generating facility is identified by Fingrid as having a risk or contributing to sub-synchronous oscillation phenomena particularly subsynchronous torsional interaction and subsynchronous resonance, detailed EMT model in format usable by PSCAD simulation tools shall be delivered. The model shall include turbine-generator shaft, Power System Stabilizer (PSS), Exciter and Automatic Voltage regulator model. The shaft shall be modeled with the multi-shaft mass torsional interface. Key parameters including Inertia constant for each mass and the spring constant between adjacent masses, torque share and respective damping coefficient parameter must be included as listed in Table 1 below.

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TABLE 1. INITIAL DATA FOR MODELLING OF THE SHAFT OF A TURBINE GENERATOR.

| Parameter | Unit |
|--------------------------------|------------------|
| Inertia Constant | kgm ² |
| Shaft Spring Constant | Nm/rad |
| Turbine Torque Share | P.U. |
| Self Damping | Nms/rad |
| Mutual Damping | Nms/rad |
| Speed Variation Damping Factor | P.U. |

Project specific turbine governor model shall also be provided. The model shall cover project specific frequency control functions and functions related to island mode operation. Related documentation depicting the control block diagram, possible modes of operation, model parameters which reflect actual project specific installed settings in the field (not manufacturer default parameter) shall be delivered. The model provided shall also be able to replicate the characteristics of the turbine dynamics up to the level relevant for grid studies.

2.4.2 Control parameters

If base values used in the model require scaling of the real set values, all information and values used for scaling shall be provided.

2.4.3 Modelling of house loads

The house load of the generating facility exceeding 1% of the rated power (Pmax) shall be included in the model. The house loads shall be modelled as passive components (R, L, C) or with suitable load block. The modelling of house loads and process loads of integrated manufacturing facilities exceeding 5 MW shall be agreed separately with Fingrid.

2.4.4 The model documentation

The model documentation shall include:

- 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.

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- Compatibility, including what PSS/E and PSCAD versions the model supports. For PSCAD models, the compatible version of the Intel Fortran Compiler shall be specified.
- Requirements for the simulation environment. This includes the minimum and maximum simulation time steps and other relevant parameters.
- List of dependencies in PSCAD. The list of all dependencies, such as library files, that are required to run the model shall be listed.
- List of library files or DLLs in PSS/E. The list of all needed files that are required to run the model shall be listed.
- Limitations of the project specific model performance. Defined as the model response matching actual power plant performance. This shall include:
 - o minimum SCR at turbine level and point of common coupling.
 - o model bandwidth and observable oscillation frequencies.
- Description of protection functions and tripping signals. This includes the description of what protection signals are available to the user, and how to view these signals.
- Description of the modelled additional functionalities such as power oscillation damping, subsynchronous damping circuit, control logic of mechanically switched capacitor banks and on-load tap changers of transformers.
- Transfer functions and bode diagram of the possible power system stabilizer and/or power oscillation damping functionality.

The following model usage instructions:

- For PSS/E and PSCAD models, how to change the control mode and the setpoints of each available control mode.
- For PSCAD models, how to transfer the power plant model to another simulation project (for example to large network model), including for example how to set up the required dependencies, settings etc.
- For PSS/E models, how to parametrize the dynamic model in case of bus number changes.
- For PSS/E models, a full list of ICONs, CONs, STATEs and VARs and other relevant parameters with descriptions.

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3 Simulation program specific requirements

3.1 PSCAD models

3.1.1 Version requirements

The model shall be compatible with the PSCAD, Fortran compiler and Visual Studio versions currently in use in Fingrid. Version information can be inquired from mallinnus@fingrid.fi.

3.1.2 Model initialization

The model shall initialize to any user defined and valid operating point in less than 3 seconds. During this time the mechanically switched compensation units and on-load tap changers of the transformers shall find the correct position. To achieve this, smaller delays in the control logic of the mechanically switched compensation units and on-load tap changers of the transformers are acceptable during the initialization. The initial state of mechanically switched compensation units and on-load tap changers of transformers shall be user-adjustable.

3.1.3 Functional requirements

For the PSCAD models following requirements must be fulfilled:

- The model shall work accurately with simulation time step of 10 microseconds or greater. If the model requires smaller time step, justification and evidence as to why 10 microseconds or higher time step cannot achieve the same level of accuracy shall be provided.
- The model shall include overvoltage protection devices (e.g. Surge Arresters) and filters.
- The model shall include the saturation and the on-load tap changer of the transformers.
- The model shall include the control logic of the relevant auxiliary equipment, such as mechanically switched capacitor banks and on-load tap changers of transformers.
- The model shall work with the 'snapshot' and 'multiple run' features of the PSCAD.
- The positive and negative sequence fault current injection during the balanced and unbalanced faults (FRT mode) shall be modelled.

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- The models of the inverter-based resources shall have a full power transistor representation or use an average representation that maintains the accuracy of the inner controls and DC side protection schemes. It is highly recommended to embed the hardware code used in the real equipment into the PSCAD model.
- The model shall be able to simulate the power plant accurately for simulation times up to 5 minutes.

Base values of the controller parameters, such as the PPC base voltage, in the model shall correspond to the real-life implementation.

The model shall have the following output signals available for plotting:

- Active power, reactive power and frequency at power plant level and at the generating unit level.
- Voltage and current (both RMS and 3-phase instantaneous values) at power plant level and at the generating unit level.
- All protection signals that can cause tripping
- Activation of the FRT modes
- Output of possible active damping functions such as subsynchronous damping controllers

3.1.4 Model structure

The model shall not use Parallel Network Interface etc. to divide the model into multiple projects. The model shall not use global variables or multiple layers.

3.2 PSS/E models

3.2.1 Version requirements

The model shall be compatible with the PSS/E version currently in use in Fingrid. Version information can be inquired from mallinnus@fingrid.fi.

3.2.2 Model initialization

If the model is initialized with partial power, the model will assume that it is the maximum available active power. The user must be able to change available active power during the simulation. For example, LFSM-U shall not be able to raise active power in case it is operating already within the limits of the available active power. In case available power is increased also the active power shall rise in LFSM-U situation.

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3.2.3 Powerflow model

The base MVA of the simulation model shall be 100 MVA. The base voltage for the buses must be set as defined in Table 2. Note that the base voltages defined in Table 2 are only for modelling purposes and e.g. reference value for voltage control is based on local conditions and relevant grid code requirements acc. to /1/, /2/, /3/, /4/.

TABLE 2. SELECTING THE BASE VOLTAGE OF THE BUSES

| Normal operating voltage | Base voltage for buses |
|--------------------------|--------------------------|
| 395–420 kV | 400 kV |
| 215–245 kV | 220 kV |
| 105–123 kV | 110 kV |
| <105 kV | Normal operating voltage |

The generator shall have Q_{\min} and Q_{\max} set as the limits during $P=\max$ and $U_{LV}=1.0$ pu operation. Possible compensation devices must be modelled separately.

In case the dynamic model measures power flow from the power plant, a dummy bus must be included before the point of common coupling. There shall not be any measurements over the branch representing the background network i.e. from swing bus to study network.

Bus numbering can be selected freely, however small bus numbers below 100 shall be avoided.

3.2.4 Dynamic model

3.2.4.1 Type requirements

Dynamic models which include calls into CONEC and CONET subroutines are not allowed. Only table-driven models shall be used.

To make sure the models work in large network model, version and sub-version numbering shall be included in the dynamic model's name.

3.2.4.2 Functional requirements

For the dynamic models following requirements must be fulfilled:

- The models shall be able to work with time step from 1 to 5 ms.
- Models shall be able to run multiple disturbances in the same simulation.

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- Model flat-run simulation shall not present any changes from steady state.
- Models shall have stable operation for simulation times up to 5 minutes.
- The initializing of the models shall not cause initial condition suspects.
- Linearized models that are accurate only for a single operating point are not acceptable.
- The model shall include the control logic of the relevant auxiliary equipment, such as mechanical switched capacitor banks and on-load tap changer of the transformers.
- Tap changer dynamic model shall be parametrized with same setpoints and delays as in the physical device.

4 Reporting and model review by Fingrid

Fingrid tests the models to ensure that model fulfills requirements set in the grid code and complies with this modelling instruction. Template explaining the test set currently used by Fingrid for PSS/E and PSCAD are provided as appendix. The templates are also available on Fingrid's website in word (.doc) format. When delivering the model package, template shall be included with last column filled in showing that the model provider ensures that model complies with the requirements presented in this instruction. A separate report including e.g. visualization of each test is not required.

In addition to the test set provided in the template, Fingrid will test that model can be integrated as part of the larger network model. Fingrid will also evaluate the similarity of the PSCAD and PSS/E models. Differences due to model program characteristics in transient state are evaluated separately in each case.

5 Appendices

- Appendix 1 PSS/E test template
- Appendix 2 PSCAD test template

6 References

- /1/ Grid Code Specifications for Demand Connections, KJV
- /2/ Grid Code Specifications for Power Generating Facilities, VJV
- /3/ Grid Code Specifications for Grid Energy Storage Systems, SJV
- /4/ Grid Code Specifications for High Voltage Direct Current Systems, HVDC

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Appendix 1 PSS/E test template

1 Documentation

| | Requirement | Acceptance |
|---------------|---|------------|
| Documentation | PSS/E version compatibility | |
| | Usable time step | |
| | List of needed files | |
| | Minimum SCR | |
| | Model bandwidth and observable oscillation frequencies | |
| | Description of protection functions and signals | |
| | Description of possible POD or MSU | |
| | Instructions to change mode and setpoint | |
| | Instructions to bus number change | |
| | Full list of ICONs, CONs, STATEs, VARs and other parameters | |

2 Used SCR values

| | | R (Ohm) | X (Ohm) |
|-----------------|-------------|---------|---------|
| Used SCR values | SCR Normal | | |
| | SCR Minimum | | |
| | VCSCR | | |

3 Functionalities

| | Number | Active power | Test | Description | Background network | Acceptance criteria | Model complies (Yes/No) | Comments |
|-----------------|--------|--------------|---|---|--------------------|-----------------------------------|-------------------------|----------|
| Functionalities | 1.1 | 1.0 pu | Setpoint change - voltage droop control | Setpoint change 1.0 pu -> 0.98 pu -> 1.0 pu -> 1.02 -> 1.0 pu | SCR Normal | Reactive power to PCC is expected | | |

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| | 1.2 | 1.0 pu | Setpoint change - Q-control | Setpoint change 0.0 pu -> -0.1 pu - > 0.0 pu -> 0.1 pu | SCR Normal | Reactive power to PCC is expected | | |
| | 1.3 | P ramp | Setpoint change - pf-control | Setpoint change 1.0 -> 0.98. After setpoint change P change 1.0 pu -> 0.8 pu -> 1.0 pu. | SCR Normal | Reactive power to PCC is expected | | |
| | 1.4 | P ramp | Setpoint change - Active power max | Setpoint change 1.0 pu -> 0.5 pu -> 1.0 pu | SCR Normal | Active power is expected | | |
| | 1.5 | P ramp | Setpoint change - Active power min | Setpoint change Pmin -> 0.5 pu -> Pmin | SCR Normal | Active power is expected | | |
| | 2.1 | 0.5 pu | FSM | Frequency 50 Hz - > 49.5 Hz -> 50 Hz -> 50.5 Hz -> 50 Hz | SCR Normal | Active power follows frequency setpoints. Droop 2- 12 %. | | |
| | 2.2 | 0.5 pu | LFSM-O | Frequency 50 Hz - > 49 Hz -> 50 Hz - > 51 Hz -> 50 Hz | SCR Normal | Active power regulates as expected. Droop 2- 12 %. | | |
| Capabilities | 3.1 | 1.0 pu | Operating limits - Voltage - Full power | PCC voltage 1.0 pu -> 0.9 pu -> 1.0 pu -> 1.1 pu -> 1.0 pu. | Infinite bus - Forced voltage to PCC | Stable operation | | |
| | 3.2 | 0.5 pu | Operating limits - Voltage - Partial power | PCC voltage 1.0 pu -> 0.9 pu -> 1.0 pu -> 1.1 pu -> 1.0 pu. | Infinite bus - Forced voltage to PCC | Stable operation | | |
| | 3.3 | 1.0 pu | Operating limits - Frequency - Full power | Frequency 50 Hz - > 47.5 Hz -> 50 Hz -> 51.5 Hz -> 50 Hz | SCR Normal | Stable operation. Active power reduction is not more than 10 % per 1 Hz when frequency is below 49.0 Hz | | |
| | 3.4 | 0.5 pu | Operating limits - Frequency - Partial power | Frequency 50 Hz - > 47.5 Hz -> 50 Hz -> 51.5 Hz -> 50 Hz | SCR Normal | Stable operation. Active power reduction is not more than 10 % per 1 Hz when frequency is below 49.0 Hz | | |
| | 4.1 | P ramp | Compensation equipment logic disconnect | Active power ramp 0.81 pu -> 0.19 pu | SCR normal | Compensation devices shall be connected at the beginning and shall be disconnected during the active power ramp | | |

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| 4.2 | P ramp | Compensation equipment logic connect | Active power ramp 0.19 pu -> 0.81 pu | SCR normal | Compensation devices shall be disconnected at the beginning and shall be connected during the active power ramp | | |
| 5.1 | 1.0 pu | Reactive power capability - Full Power | PCC voltage 1.0 pu -> 0.9 pu -> 1.0 pu -> 1.1 pu -> 1.0 pu | Infinite bus - Forced voltage to PCC | Reactive power matches reactive power capacity calculations | | |
| 5.2 | 1.0 pu | Plant operating in momentary operating point 0.85 pu – Full power | PCC Voltage 1.0 pu -> 0.85 pu-> 1.0 pu | Infinite bus - Forced voltage to PCC | Reactive power shall be produced for a minimum of 10 seconds | | |
| 6.1 | 1.0 pu | Step response test - Full power | Background network voltage 1.0 pu -> 0.98 pu -> 1.0 pu -> 1.02 pu -> 1.0 pu. | VCSCR | Rise time for all steps 1.0±0.1 s. Reactive power to PCC matches droop setting. | | |
| 6.2 | 1.0 pu | Step response test 10 s - Full power | Background network voltage 1.0 pu -> 0.98 pu -> 1.0 pu -> 1.02 pu -> 1.0 pu. | VCSCR | Rise time for all steps 10 ± 1 s. Reactive power to PCC matches droop setting | | |
| 7.1.1 | 1.0 pu | Fault ride through test 1 - VJV | VJV table 10.1 or 10.2 test | SCR Normal, after fault SCR minimum | No tripping, expected recovery | | |
| 7.1.2 | 1.0 pu | Fault ride through test 2 - VJV | VJV table 10.1 or 10.2 test | SCR normal | No tripping, expected recovery | | |
| 7.2 | 1.0 pu | Multiple FRT | 10 consecutive 100 ms bolted three phase faults during same simulation | SCR Normal | Expected performance | | |
| 7.3 | 1.0 pu | Fault current injection | Fault sequence or separate simulations of three phase faults with following PPC residual voltages: 0.9 pu, 0.8 pu, 0.7 pu, 0.6 pu, 0.5 pu, 0.4 pu, 0.3 pu, 0.2 pu, 0.1 pu, 0.0 pu. | SCR Normal | Active and reactive current provisions calculated. Reactive power k-factor shall be as defined in VJV. Reactive current shall be prioritized. | | |
| 7.4 | 1.0 pu | LVRT | Fault sequence or separate simulations of PPC voltage drops | Infinite bus - Forced voltage to PCC/SCR Normal | LVRT activates and deactivates at expected thresholds. | | |

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|-------------|-----|--------|---------------------------|---|--------------------------------------|--|--|--|
| Protections | 8.1 | 1.0 pu | High voltage protection | Voltage raised until power plant trips | Infinite bus - Forced voltage to PCC | Power plant trips and user will be notified about the protective function. | | |
| | 8.2 | 1.0 pu | Low voltage protection | Voltage lowered until power plant trips | Infinite bus - Forced voltage to PCC | Power plant trips and user will be notified about the protective function. | | |
| | 8.3 | 1.0 pu | High frequency protection | Frequency raised until power plant trips | SCR Normal | Power plant trips and user will be notified about the protective function. | | |
| | 8.4 | 1.0 pu | Low frequency protection | Frequency lowered until power plant trips | SCR Normal | Power plant trips and user will be notified about the protective function. | | |
| PSS/E | A1 | - | Version compatibility 35 | Model run with different PSS/E 35 subversions | N/A | No errors with different subversions | | |
| | A2 | - | Unique model name | Check that dynamic models have unique names | N/A | Dynamic model version number or other identifier included in the model name. This allows running different model versions in the same simulation | | |
| | A3 | - | System decimal separator | Model run with different decimal separators | N/A | Model shall run regardless of system decimal separator | | |
| | A4 | 1.0 pu | Initialization | Model run 5 minutes | N/A | Model initializes without changes in the model output and continues flat run for 5 minutes | | |

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Appendix 2 PSCAD test template

1 Documentation

| | Requirement | Acceptance |
|---------------|--|------------|
| Documentation | PSCAD version compatibility | |
| | Usable time step | |
| | List of needed files | |
| | Minimum SCR | |
| | Model bandwidth and observable oscillation frequencies | |
| | Description of protection functions and signals | |
| | Description of possible POD or MSU | |
| | Instructions to change mode and setpoint | |
| | Instructions to bus number change | |
| | Instructions to transfer the model to another simulation project | |

2 Used SCR values

| | | R (Ohm) | X (Ohm) |
|-----------------|-------------|---------|---------|
| Used SCR values | SCR Normal | | |
| | SCR Minimum | | |
| | VCSCR | | |

3

Functionalities

| | Number | Active power | Test | Description | Background network | Acceptance criteria | Model complies (Yes/No) | Comments |
|-----------------|--------|--------------|---|---|--------------------|-----------------------------------|-------------------------|----------|
| Functionalities | 1.1 | 1.0 pu | Setpoint change - voltage droop control | Setpoint change 1.0 pu -> 0.98 pu -> 1.0 pu -> 1.02 -> 1.0 pu | SCR Normal | Reactive power to PCC is expected | | |
| | 1.2 | 1.0 pu | Setpoint change - Q-control | Setpoint change 0.0 pu -> -0.1 pu -> 0.0 pu -> 0.1 pu | SCR Normal | Reactive power to PCC is expected | | |

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|-----|--------------|--------|--------------------------------------|---|---|--|---|--|--|
| | 1.3 | P ramp | Setpoint change - pf-control | Setpoint change 1.0 -> 0.98. After setpoint change P change 1.0 pu -> 0.8 pu -> 1.0 pu. | SCR Normal | Reactive power to PCC is expected | | | |
| | 1.4 | P ramp | Setpoint change - Active power max | Setpoint change 1.0 pu -> 0.5 pu -> 1.0 pu | SCR Normal | Active power is expected | | | |
| | 1.5 | P ramp | Setpoint change - Active power min | Setpoint change Pmin -> 0.5 pu -> Pmin | SCR Normal | Active power is expected | | | |
| | 2.1 | 0.5 pu | FSM | Frequency 50 Hz -> 49.5 Hz -> 50 Hz -> 50.5 Hz -> 50 Hz | SCR Normal | Active power follows frequency setpoints. Droop 2-12 %. | | | |
| | 2.2 | 0.5 pu | LFSM-O | Frequency 50 Hz -> 49 Hz -> 50 Hz -> 51 Hz -> 50 Hz | SCR Normal | Active power regulates as expected. Droop 2-12 %. | | | |
| | Capabilities | 3.1 | 1.0 pu | Operating limits - Voltage - Full power | PCC voltage 1.0 pu -> 0.9 pu -> 1.0 pu -> 1.1 pu -> 1.0 pu. | Infinite bus - Forced voltage to PCC | Stable operation | | |
| | | 3.2 | 0.5 pu | Operating limits - Voltage - Partial power | PCC voltage 1.0 pu -> 0.9 pu -> 1.0 pu -> 1.1 pu -> 1.0 pu. | Infinite bus - Forced voltage to PCC | Stable operation | | |
| | | 3.3 | 1.0 pu | Operating limits - Frequency - Full power | Frequency 50 Hz -> 47.5 Hz -> 50 Hz -> 51.5 Hz -> 50 Hz | SCR Normal | Stable operation. Active power reduction is not more than 10 % per 1 Hz when frequency is below 49.0 Hz | | |
| | | 3.4 | 0.5 pu | Operating limits - Frequency - Partial power | Frequency 50 Hz -> 47.5 Hz -> 50 Hz -> 51.5 Hz -> 50 Hz | SCR Normal | Stable operation. Active power reduction is not more than 10 % per 1 Hz when frequency is below 49.0 Hz | | |
| | | 4.1 | P ramp | Compensation equipment logic disconnect | Active power ramp 0.81 pu -> 0.19 pu | SCR normal | Compensation devices shall be connected at the beginning and shall be disconnected during the active power ramp | | |
| 4.2 | | P ramp | Compensation equipment logic connect | Active power ramp 0.19 pu -> 0.81 pu | SCR normal | Compensation devices shall be disconnected at the beginning and shall be connected | | | |

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|--------------------|--------------|-------------------------|---|--|--|---|--|--|
| Protections | | | | | | during the active power ramp | | |
| | 5.1 | 1.0 pu | Reactive power capability - Full Power | PCC voltage 1.0 pu -> 0.9 pu -> 1.0 pu -> 1.1 pu -> 1.0 pu | Infinite bus - Forced voltage to PCC | Reactive power matches reactive power capacity calculations | | |
| | 5.2 | 1.0 pu | Plant operating in momentary operating point 0.85 pu – Full power | PCC Voltage 1.0 pu -> 0.85 pu-> 1.0 pu | Infinite bus - Forced voltage to PCC | Reactive power shall be produced for a minimum of 10 seconds | | |
| | 6.1 | 1.0 pu | Step response test - Full power | Background network voltage 1.0 pu -> 0.98 pu -> 1.0 pu -> 1.02 pu -> 1.0 pu. | VCSCR | Rise time for all steps 1.0±0.1 s. Reactive power to PCC matches droop setting. | | |
| | 6.2 | 1.0 pu | Step response test 10 s - Full power | Background network voltage 1.0 pu -> 0.98 pu -> 1.0 pu -> 1.02 pu -> 1.0 pu. | VCSCR | Rise time for all steps 10 ± 1 s. Reactive power to PCC matches droop setting | | |
| | 7.1.1 | 1.0 pu | Fault ride through test 1 - VJV | VJV table 10.1 or 10.2 test | SCR Normal, after fault SCR minimum | No tripping, expected recovery | | |
| | 7.1.2 | 1.0 pu | Fault ride through test 2 - VJV | VJV table 10.1 or 10.2 test | SCR normal | No tripping, expected recovery | | |
| | 7.2 | 1.0 pu | Multiple FRT | 10 consecutive 100 ms bolted three phase faults during same simulation | SCR Normal | Expected performance | | |
| | 7.3 | 1.0 pu | Fault current injection | Fault sequence or separate simulations of three phase faults with following PPC residual voltages: 0.9 pu, 0.8 pu, 0.7 pu, 0.6 pu, 0.5 pu, 0.4 pu, 0.3 pu, 0.2 pu, 0.1 pu, 0.0 pu. | SCR Normal | Active and reactive current provisions calculated. Reactive power k-factor shall be as defined in VJV. Reactive current shall be prioritized. | | |
| | 7.4 | 1.0 pu | LVRT | Fault sequence or separate simulations of PPC voltage drops | Infinite bus - Forced voltage to PCC/SCR Normal | LVRT activates and deactivates at expected thresholds | | |
| 8.1 | 1.0 pu | High voltage protection | Voltage raised until power plant trips | Infinite bus - Forced voltage to PCC | Power plant trips and user will be notified about the protective function. | | | |

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|-------|-----|--------|--|---|--------------------------------------|---|--|--|
| | 8.2 | 1.0 pu | Low voltage protection | Voltage lowered until power plant trips | Infinite bus - Forced voltage to PCC | Power plant trips and user will be notified about the protective function. | | |
| | 8.3 | 1.0 pu | High frequency protection | Frequency raised until power plant trips | SCR Normal | Power plant trips and user will be notified about the protective function. | | |
| | 8.4 | 1.0 pu | Low frequency protection | Frequency lowered until power plant trips | SCR Normal | Power plant trips and user will be notified about the protective function. | | |
| PSCAD | A1 | - | Version compatibility v5.0.1 / Fortran Compiler | Model runs with PSCAD 5.0.1 version Model supports Intel oneAPI compiler | N/A | No errors with different versions or compilers | | |
| | A2 | - | Compatibility with other models and multiple instances | Model is compatible with other models, multiple instances, and separate parametrization | N/A | Model runs with other turbine models with no issues. No errors with multiple instances or separate parametrization of different instances | | |
| | A3 | - | Model aggregation, equipment, signals, and control modes | Model is aggregated according to instructions and includes required equipment, signals, and control modes | N/A | No errors with aggregation or included equipment. Model includes required signals and control modes | | |
| | A4 | - | Multiple run and snapshot features | Model supports multiple run and snapshot features | N/A | No errors with multiple run or snapshot features | | |

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