Simulation Studies and Modelling Requirements for Compliance Demonstration

11th October 2021

The document includes references to the relevant EU Network Connection Codes in various sections in the form of "(Art 15-2)". These are intended for the reviewers during the drafting stage of this document and will be deleted in the final published version.

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Introduction

Simulation studies are an integral part of power system design, analysis and operation as they provide an easy to follow analytical process in establishing various system parameters during for example the connection of a new facility to grid. As such, provision of up-to-date and accurate models is an imperative part of this process.

In general, simulation studies can be utilised to model and analyse power networks' dynamic behaviour in terms of voltage and frequency stability as well as other transient phenomena.

The detail and specifics of the model required is normally dictated by the type of study intended to be used. For generation facilities, this usually implies analysis of behaviour in steady-state and quasi-steady-state and as such static and RMS models to be used for various studies are required. The following table provides a summary of the different model requirements for simulation purposes.

For non-synchronous generation, more detailed modelling is required in order to capture detailed control system behaviour. This is because voltage source technologies can exhibit control instabilities due to the use of technologies that is system voltage dependent. In addition, control interaction in close proximity is a distinct possibility and the ability to model and predict these has become paramount. Electromagnetic transient time domain modelling is the industry norm for such studies and hence generator models (an in most cases the inverter/converter model) in EMT domain are required.

Generation type	**Model requirement**	**Load flow**	**Short Circuit**	**Transient Stability**	**HF Transients**	**SSCI**	**Power Quality**
Synchronous Power Generating Module	Static simulation model	✓	✓				
	RMS simulation model			✓		✓	
Power Park Module	Static simulation model	✓	✓				
	RMS simulation model			✓			
	EMT simulation model			✓	✓	✓	
	Harmonic simulation model						✓
Demand Facilities, Distribution Facilities, Closed Distribution Systems	Static simulation model	✓	✓				
	RMS simulation model			✓			
	Harmonic simulation model						✓
HVDC Systems	Static simulation model	✓	✓				
	RMS simulation model			✓			
	EMT simulation model			✓	✓	✓	
	Harmonic simulation model						✓

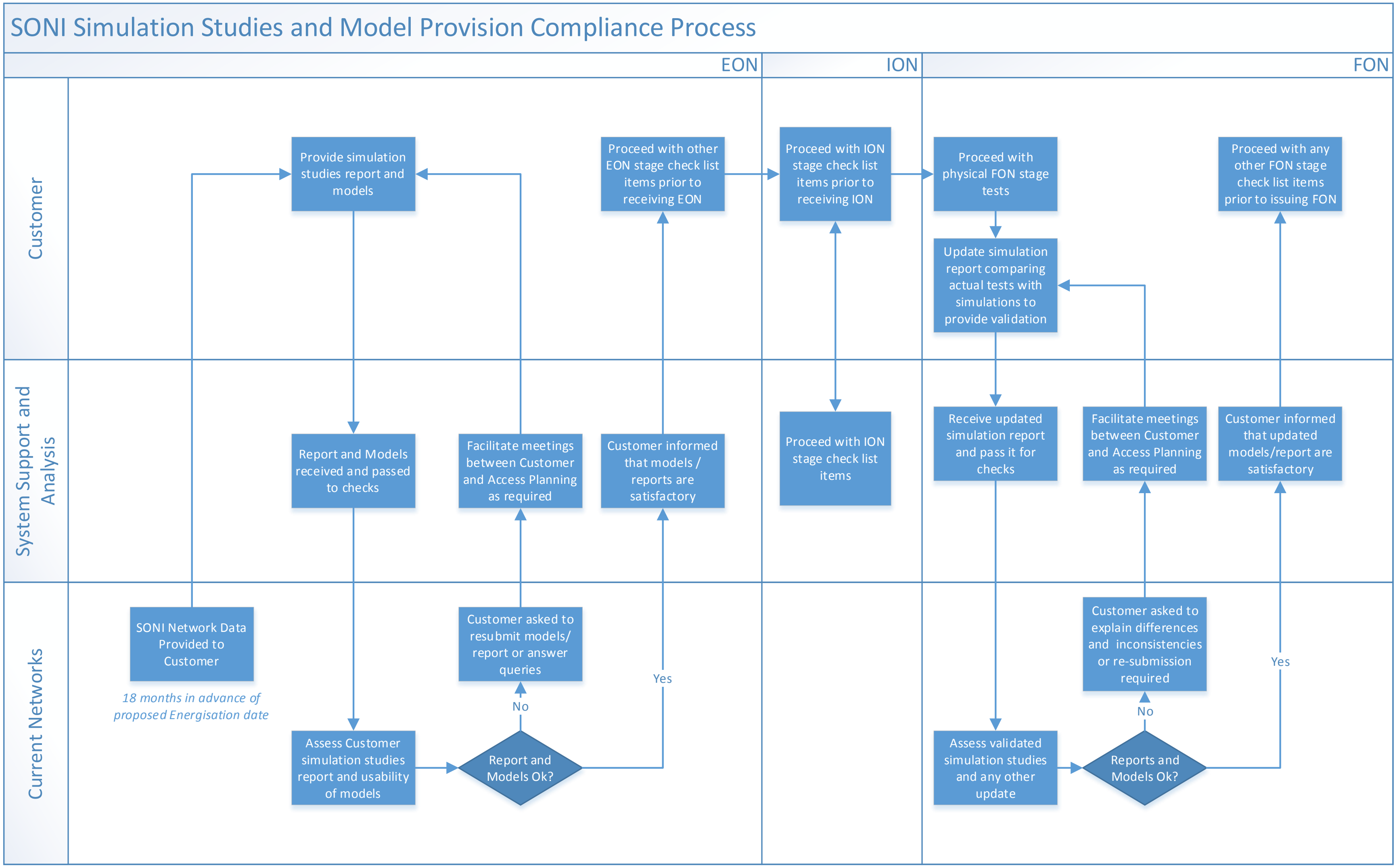
Compliance Process

Simulation studies and model provision is part of a larger compliance process that involves other items as per the check list for the connection of a given category.

The process with regards to the provision of simulation studies and model, their check and provisional acceptance and later update and final acceptance is summarised in the next flow chart.

The process as indicated in the flow chart should be followed by all connections (or modifications) irrespective of technology.

In exceptional circumstances due to system security requirements, it may be necessary to energise a connection in the absence of a simulation study report or model with the express permission of senior level SONI management. In such cases, a temporary Grid Code derogation would still be required.



SONI Simulation Studies and Model Provision Compliance Process
EON
ION
FON
Customer
System Support and Analysis
Current Networks
Provide simulation studies report and models
Proceed with other EON stage check list items prior to receiving EON
Proceed with ION stage check list items prior to receiving ION
Proceed with physical FON stage tests
Proceed with any other FON stage check list items prior to issuing FON
Update simulation report comparing actual tests with simulations to provide validation
Report and Models received and passed to checks
Facilitate meetings between Customer and Access Planning as required
Customer informed that models / reports are satisfactory
Proceed with ION stage check list items
Receive updated simulation report and pass it for checks
Facilitate meetings between Customer and Access Planning as required
Customer informed that updated models/report are satisfactory
SONI Network Data Provided to Customer
18 months in advance of proposed Energisation date
Customer asked to resubmit models/ report or answer queries
No
Yes
Assess Customer simulation studies report and usability of models
Report and Models Ok?
Customer asked to explain differences and inconsistencies or re-submission required
No
Yes
Assess validated simulation studies and any other update
Reports and Models Ok?

PART 1. SYNCHRONOUS POWER GENERATING MODULES

1.1. General Provisions

Simulation studies are aimed at demonstrating the performance requirements of individual power-generating modules and the following general provisions apply: (Art 43-1)

- Generating facility shall provide technical data and documentation as part of the simulation studies compliance procedures (Art 41-3-a and b). All data requirements are detailed in the Planning Code Appendix of the Grid Code;
- Generating facility shall provide an appropriate model as part of the simulation studies compliance procedures (Art 41-3-c and d) The timeline of the model provision is covered by the phases of Operational Notification Procedure;
- SONI shall not accept an alternative set of simulations to those given as part of this compliance procedure (Art 43-2-a);
- SONI may require additional or alternative sets of simulations to those given in this procedure when deemed insufficient to demonstrate compliance (Art 43-2-b);
- Generation facility shall provide a report that includes modelling and results of all the simulation studies detailed in this procedure (Art 41-3-e & Art 43-3);
- Generation facility shall provide a validated simulation model as detailed in this procedure (Art 43-3);
- SONI may perform its own simulation studies based on the simulation model, simulation reports and compliance test measurements (Art 43-4);
- SONI shall provide the generation facility owner system data in order to carry out the simulation studies detailed in this procedure (Art 43-5); and
- SONI shall not accept provision of equipment certificates submitted as part of demonstrating compliance with relevant simulation study requirement (Art 52-1, 53-1, 55-1 and 56-2).

1.2. Simulation Model Requirements

1.2.1. Static Model

The static simulation model for synchronous power generating modules should represent the steady state characteristics of the generating facility at the point of connection suitable to be used in network wide load flow and short circuit calculation studies. More specifically the static model shall be capable of:

- covering a range of frequencies (47 to 52 Hz) and voltages (0 to 1.4 pu);
- representing the characteristics of the generation facility's operating ranges for active and reactive power;

- providing calculated RMS values of all phases for all types of system faults (balanced and unbalanced); and
- providing control functionality with reference points for the following modes
  - reactive power control mode
  - voltage control mode including parameters for droop setting
  - power factor control mode

1.2.2. RMS Model

The RMS model is aimed to be used for dynamic studies and as such the simulation model shall include information or be capable of:

- representing the dynamic properties of the generation facility;
- representing the characteristics of the generation facility's operating ranges for active and reactive power;
- covering a range of frequencies (47 to 52 Hz) and voltages (0 to 1.4 pu);
- handling control functionality (with input/output signals) with indication of reference point
  - power factor control,
  - reactive power control,
  - voltage control including parameters for droop setting
  - frequency control including droop and deadband,
  - activation of protection functionality (if present)
- activating an internal protection functionality in the event of external network faults;
- utilising an internal excitations system that includes relevant voltage, frequency, stator current, over and under excitation limiters;
- providing a numerically stable simulation for a minimum of 60 seconds following any set point changes or system incidents/faults;
- running under with a user defined integration time step in the range of 1 to 10 ms;
- initialising in a stable operating point;
- not requiring any special settings to be implemented into a larger network model;
- simulating the dynamic behaviour of the generators (or generating facility) under system faults, voltage disturbances and frequency disturbances; and
- not containing any encrypted or compiled parts.

For newly built synchronous power generating modules and for those installed but going through a modification involving any part of the drive train, in addition to the standard RMS model, information relating to mechanical mass model for each drive train element is also required. Specific information required are:

- inertia constants;
- spring and damping constants;
- torque shear stress; and
- natural oscillation frequencies.

1.2.3. Model Submission

The provision of simulation model shall be supported and include:

- description of each individual model components and their related parameters;
    - saturation, dead bands, non-linearity, time delays, any interpolation assumptions and any look-up tables utilised within the parameters utilised
- description of initialisation of the model for simulations,
- Laplace domain transfer functions, sequence diagrams and any arithmetic or logical sequence modules within the model description
- description of input and output signal
- explanation of set-up and initialisation of the model
- limitations of the model provided
- list of protection functionality that can be triggered by external events
- diagrams of excitation system, AVR, PSS and any other equipment implemented within the excitation system in the form of standardised block diagrams
- information on excitation system constraint functions such as current limiter, overexcitation and underexcitation limiter

For a generation facility that comprises more than one generator unit, the submitted simulation model must be such that the characteristics of the generation facility is represented at the point of connection. Submitted model parameters must contain all data sets for each unit.

The RMS simulation model to SONI must be compatible with PSSE 33 and later version. Information relating to the mechanical mass model can be submitted in written data form rather than in a model. No special settings other than standard software setting should be required for the submitted model to be implemented.

Model validation against test measurements is a requirement and the specific simulation that needs to be validated are indicated.

The submitted simulation model and studies shall have the following accuracy requirements:

- For a linear response over a frequency range of 0.1 to 5Hz, deviations between simulated and measured waveforms of the control system must be less than 10% for amplitude and less than 5 degrees for the phase angle. Discrete waveform changes (amplitude spikes) on the simulated waveform should be less than 10% in relation to measured quantity and in the case of where this level is exceeded due to numerical integration issues, this should be documented in the report.
- For dynamic time domain simulations where non-linear response is included to replicate set point changes or response to disturbances on the wider network, the following requirements apply for deviations between simulated and measured response:

- for rapid slopes within 10% for 95% of the samples recorded within a defined event window[1], and time offset of the gradient start or end time must be less than 20 milliseconds;
- for events (e.g. switching) resulting in positive and negative spikes, the amplitude must be less than 10% from the corresponding measured value for 95% of the samples recorded;
- oscillation in active power, reactive power, voltage and frequency in the 0.1-5Hz range must have damping and the deviation in the frequency of oscillation must be less than 10% for 95% of the recorded samples;
- considering possible difference in the voltage at the point of connection, deviation in active and reactive power response must be less than 10% for 95% of the samples;
- considering possible difference in the final settled value of voltage at the point of connection, the final value of active and reactive power must settle to within 2% of the plants rated capacity.

[1] An event window is defined as the instant a reference value changes or a disturbance is initiated and lasts until the response returns to within 5% of the maximum induced or reference quantity change.

1.3. Simulation Studies

This section details simulation studies required for synchronous power generating modules (SPGM). In most of the simulation studies, a model as given in Figure 1 is sufficient for study purposes and when this is the case each simulation study directs the user to use the given model arrangement.

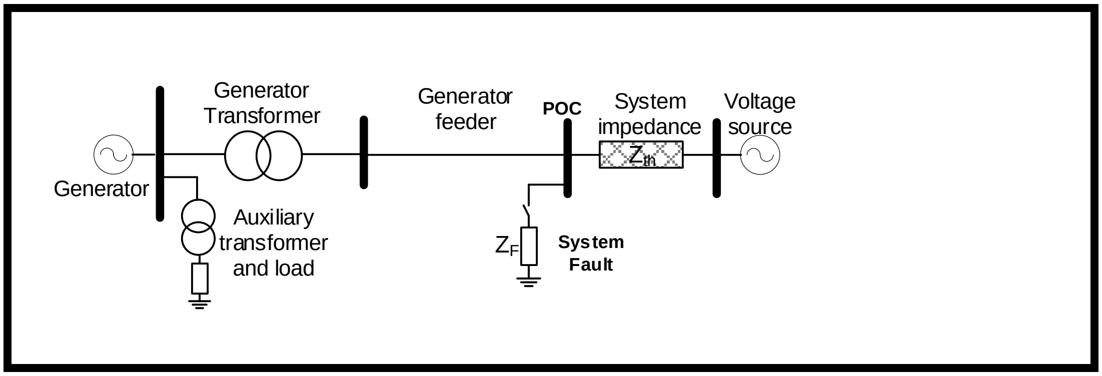


Figure 1

System impedance to be requested from SONI prior to the commencement of studies.

A summary of the simulation studies for SPGM is given in the following table along with reference to the EU Network Code (2016/631) simulation requirement and the related SONI Grid Code capability requirement.

Capability Area	EU – NC (2016/631)	SONI GC Capability	Validate against test
Fault Ride Through	Art(53)3 & Art 51(4)	CC.S1.1.9.1 and CC.S1.1.9.2 or CC.S1.2.5.1 and CC.S1.2.5.2	
LFSM-O	Art51(2)	CC8.8.7.1	Yes
LFSM-U	Art52(2)	CC8.8.7.2	Yes
FSM	Art52(3)	CC8.8.7.3	Yes
Load Rejection	Art52(4)	CC8.8.7.5 and OC7.5.4	
Reactive Capability	Art52(5)	CC.S1.1.3.2, CC.S1.1.3.3 and CC.S1.1.3.4	Yes
Power System Stabiliser	Art53(2)	CC.S1.1.3.3.(f)	

1.3.1. FRT, Active Power Recovery

Simulate fault-ride-through and active power recovery using a model as in Figure 1 with system impedance set equal to a value representing minimum short circuit level.

Set generator operation to P=Pmax, Q=Qmin (maximum leading reactive power) for the simulations.

Simulate:

Apply four different types of faults at the POC:

- phase-to-earth fault;
- phase-to-phase-to-earth fault;
- three-phase fault.

Under each of the above faults, set the faulted phases retained voltage at the POC to the values given below for the given duration. In each case clear the fault and let steady-state condition to be reached before commencing the next study.

Faulted Phase Retained Voltage (p.u.)	**Fault Duration (milliseconds)**
0	150
0.5	300
0.9	1550

Check and report:

Voltage at generator terminals and POC

Active power at generator terminals

Reactive power at generator terminals

Rotor angle

Excitation Voltage

AVR and PSS output signal

Success Criteria:

Generator remains synchronised and stable while meeting the capability requirements in CC.S1.1.9.1 and CC.S1.1.9.2 (transmission connected) or CC.S1.2.5.1 and CC.S1.2.5.2 (distribution connected).

1.3.2. LFSM-U and LFSM-O

This simulation needs to be validated against actual compliance tests.

Simulate limited frequency response using the model as in Figure 1 with system impedance set to minimum short circuit level and the generator operated at Limited Frequency Sensitive Mode with a droop setting set to 4% with active power as indicated in the table and reactive power at zero.

Simulate:

Apply the following frequency step and ramps at the given loading. Each setpoint change is only initiated when steady state conditions are met.

Loading Level	f step or ramp
Designed Minimimum Operating Level (DMOL)	-0.5Hz (Step)
DMOL	-0.5Hz (ramp of 1Hz/sec)
DMOL	-0.5Hz (ramp of 2Hz/sec)
50%	-0.5Hz (Step)
50%	-0.5Hz (ramp of 1Hz/sec)
50%	-0.5Hz (ramp of 2Hz/sec)
50%	+0.5Hz (ramp of 1Hz/sec)
50%	+0.5Hz (ramp of 2Hz/sec)
75%	-0.5Hz (Step)
75%	-0.5Hz (ramp of 1Hz/sec)
75%	-0.5Hz (ramp of 2Hz/sec)
75%	+0.5Hz (ramp of 1Hz/sec)
75%	+0.5Hz (ramp of 2Hz/sec)
95%	-0.5Hz (Step)
100%	+0.5Hz(Step)
100%	+0.5Hz (ramp of 1Hz/sec)
100%	+0.5Hz (ramp of 2Hz/sec)

Check and report:

Voltage at generator terminals

Active power at generator terminals

Reactive power at generator terminals

Frequency

Success Criteria:

Generator remains stable while meeting the capability requirements in CC8.8.7.1 and CC8.8.7.2

1.3.3. Frequency Sensitive Mode

This simulation needs to be validated against actual compliance tests.

Simulate frequency sensitive mode using the model as in Figure 1 with system impedance set to minimum short circuit level and the generator operated in Frequency Sensitive Mode.

Generator operating at P= 0.75*Pmax, Q=0

Generator droop settings set to 4%.

Simulate:

Apply the following frequency step and ramps.

1- Start with nominal system frequency for t<0 s
2- apply a ramped reduction of 0.8 Hz over x seconds
3- run with the reduced frequency for y seconds
4- apply a ramped increase of 0.3 Hz over z seconds
5- run with this frequency for xyz seconds
6- apply a ramped increase of 0.2 Hz over x seconds

Check and report:

Voltage at generator terminals

Active power at generator terminals

Reactive power at generator terminals

Frequency

Success Criteria:

Generator remains stable while meeting the capability requirements in CC8.8.7.3.

1.3.4. Islanded Operation (Load Rejection)

Simulate load rejection using the model as in Figure 1 with system impedance set to minimum short circuit level and the generator operating at P= Pmax and Q=0

Simulate:

While the generator is at maximum active power output, island the generator from the system by opening the generator breaker such that it supplies only the house load.

Check and report:

Voltage at generator terminals

Active power at generator terminals

Reactive power at generator terminals

Frequency

Success Criteria:

Generator remains connected and in operation while meeting the capability requirements in CC8.8.6.1 and CC.S1.1.3.3.(e).

1.3.5. Reactive Power Capability

This simulation needs to be validated against actual compliance tests.

Simulate reactive power capability of the generator using the model in Figure 1 with system impedance set to minimum short circuit level. Generator operating at various points as indicated.

Simulate:

Run load flow studies with the generator at various points on the VQ/Pmax diagram.

Check and report:

Check it can supply maximum leading and lagging reactive power at Pmax at specified voltage levels in CC.S1.1.3.3.(a).

Check it can supply maximum leading and lagging reactive power at Pmin at specified voltage levels in CC.S1.1.3.3.(a).

Voltage at generator terminals

Active power at generator terminals

Reactive power at generator terminals

Success Criteria:

Simulation shows output within the boundaries of the VQ/Pmax diagrams given in CC.S1.1.3.3.(a).

1.3.6. Power System Stabiliser / AVR Control

Three separate simulations cases are expected for Power System Stabiliser:

Simulation 1:

This simulation is aimed at obtaining the response time of the AVR controls and is named idle response or open circuit test.

Set generator active and reactive power to zero and apply 10% generator terminal voltage step change to check excitation system response time.

Check and report:

Terminal voltage

AVR output signal

Success Criteria:

Compliance with respect to rise time requirements

Simulation 2:

Voltage variation test under different disturbances

Use minimum system fault level impedance as in Figure 1 and set the generator active power to maximum and reactive power to maximum leading reactive power (i.e. Qmin).

Apply 5% step to reference voltage to check PSS response to voltage disturbances. Repeat test with PSS on and off.

Apply three-phase short-circuit at generator transformer HV side. Repeat it with PSS on and off.

Check and report:

Generator terminal voltage

Active power

Reactive power

Excitation voltage

PSS output signal

AVR output signal

Success Criteria:

Improved attenuation of system power fluctuation when PSS is on compared to when PSS is off.

Simulation 3:

This simulation is aimed at obtaining frequency response of the SPGM Excitation System in the form of Bode diagrams (both gain and phase) in order to have an insight into possible stability margins. Two separate frequency responses are expected:

Open loop frequency response

Closed loop frequency response

Check and report:

Gain and phase Bode plot for open loop frequency response with PSS on and off.

Gain Bode plot for closed loop on load frequency response with PSS on and off. Generator is operating at Pmax and unity pf.

Success Criteria:

Improved contribution with PSS operation with respect to the gain and phase margin of Excitation System during open loop frequency response.

Improved active power damping with PSS during closed loop frequency response.

PART 2. POWER PARK MODULES

2.1. General Provisions

Simulation studies are aimed at demonstrating the performance requirements of individual power-generating modules and the following general provision apply: (Art 43-1)

- Generating facility shall provide technical data and documentation as part of the simulation studies compliance procedures (Art 41-3-a and b). All data requirements are detailed in the Planning Code Appendix of the Grid Code;
- Generating facility shall provide an appropriate model as part of the simulation studies compliance procedures (Art 41-3-c and d). The timeline of the model provision is covered by the phases of Operational Notification Procedure;
- SONI shall not accept an alternative set of simulations to those given as part of this compliance procedure (Art 43-2-a);
- SONI may require additional or alternative sets of simulations to those given in this procedure when deemed insufficient to demonstrate compliance (Art 43-2-b);
- Generation facility shall provide a report that includes modelling and results of all the simulation studies detailed in this procedure (Art 41-3-e & Art 43-3);
- Generation facility shall provide a validated simulation model as detailed in this procedure (Art 43-3);
- SONI may perform its own simulation studies based on the simulation model, simulation reports and compliance test measurements (Art 43-4);
- SONI shall provide the generation facility owner system data in order to carry out the simulation studies detailed in this procedure (Art 43-5); and
- SONI shall not accept provision of equipment certificates submitted as part of demonstrating compliance with relevant simulation study requirement (Art 52-1, 53-1, 55-1 and 56-2).

2.2. Simulation model requirements

2.2.1. Static Model

The static simulation model for power park modules should represent the steady state characteristics of the generating facility at the point of connection suitable to be used in network wide load flow and short circuit calculation studies. More specifically the static model shall information or be capable of:

- covering a range of frequencies (47 to 52 Hz) and voltages (0 to 1.4 pu),
- representing the characteristics of the generation facility's operating ranges for active and reactive power,
- providing calculated RMS values of all phases for all types of system faults (balanced and unbalanced),
- providing control functionality with reference points

  - reactive power control mode
  - voltage control mode including parameters for droop setting
  - power factor control mode

2.2.2. RMS Model

The RMS model used for dynamic simulation studies shall include information or be capable of:

- representing the static and dynamic properties of the generation facility
- covering a range of frequencies (47 to 52 Hz) and voltages (0 to 1.4 pu)
- representing the characteristics of the generation facility's operating ranges for active and reactive power,
- handling control functionality (with input/output signals) with indication of reference point
  - power factor control,
  - reactive power control, and
  - voltage control including parameters for droop setting
  - frequency control including droop and deadband
  - activation of protection functionality
  - control signal(s) to external plants such as FACTS devices
- providing calculated RMS values of all types of system faults (balanced and unbalanced),
- activating an internal protection functionality in the event of external network faults,
- utilising an internal excitations system that includes relevant voltage, frequency, stator current, over and under excitation limiters,
- providing a numerically stable simulation for a minimum of 60 seconds following any set point changes or system incidents/faults
- running under with a user defined integration time step in the range of 1 to 10 ms
- initialising in a stable operating point
- not requiring any special settings to be implemented into a larger network model
- simulating the dynamic behaviour of the generators (or generating facility) under system faults, voltage disturbances and frequency disturbances

If an aggregated model instead of individual units is used, then the aggregated model must be able to represent the characteristics of the whole facility at the point of connection. Descriptive information on the aggregation approach and assumptions should be provided.

The provision of simulation model should be supported and include:

- description of each individual model components and their related parameters,
- description of input and output signal
- explanation of set-up and initialisation of the model
- limitations of the model provided
- list of protection functionality that can be triggered by external events

The model should not contain any compiled parts in order to be embedded within a larger network model without any restrictions.

2.2.3. EMT Model Requirements

In addition to static and RMS simulation models, PPMs are required to provide an EMT model.

The EMT model should be capable of recreating all the requirements of the static and RMS models and in addition shall:

- Represent all components, control and protection systems relevant for time domain analysis
- Initialise at a fraction of the simulation time. Conditions under which the model can be assumed initialised shall be documented.
- Give the user the ability to set various activation schemes within the model (for example activation of protection functions or apparent power dispatch)
- Allow the user to set all parameters relevant to the analysis
- Be repeatable, i.e. can be used multiple times within the same model without numerical issues
- Be able to capture high frequency transients
- Be capable of representing possible signal delays between various elements (for example park controller to individual wind turbine generators)
- Include any relevant non-linearities, deadbands, saturation, limits or mathematical functions.
- Primarily be based on the use of standard components that are within the given software environment
- In the case of compiled or encrypted part, not create any complications or incompatibility with respect to its integration to a wider network model.
- Be capable of using it in later versions of the given software.

2.2.4. Harmonic Model Requirements

Harmonic model to represent the power park generating facilities harmonic emissions as well as the effect of its passive network on the transmission system harmonics is required.

The model shall be capable of or include:

- Representing integer harmonic emissions at a single unit level from 2^{nd} to 100^{th} harmonic
- Being defined either as Thevenin or Norton equivalent
- Passive response of the units (lumped impedance) within 50-5000 Hz range at a resolution of 1 Hz for all sequence networks.
- Specify a summation process from multiple units either using correct phase angles for injections or utilising a summation law
- Dependency on the power park generating facilities level of generation or operating point – model valid for at least three different operating regimes (minimum, average and maximum) shall be submitted
- Details of power park generating facility infrastructure equipment such as cables, transformers, shunt compensation etc as frequency dependent components.

If the power park generating facility has more than one unit, an aggregated harmonic simulation model can be submitted instead. The aggregated model shall be such that it represents the total emissions and include the total passive harmonic impedance at the point of connection within the 5-2500 Hz frequency range.

2.2.5. Model Submission

The provision of simulation model shall be supported and include:

- instruction of integrating the provided model into a wider network model so as to be used as part of wider system studies.
- guidance on the interpretation of error messages and troubleshooting.
- a comprehensive list of parameters, default and range of values applicable, block diagrams and transfer functions.
- model single line diagram showing main electrical components and connectivity to the network interface point.
- description of each individual model components and their related parameters,
- description of initialisation of the model for simulations,
- Laplace domain transfer functions, sequence diagrams and any arithmetic or logical sequence modules within the model description
- saturation, dead bands, non-linearity, time delays, any interpolation assumptions and any look-up tables utilised within the parameters utilised
- description of the electrical input and output signals, explanation on the measurement point used, signal units and base values.
- explanation on any restrictions on its use, limits applicable such as the maximum integration step size, and accuracy of the model.
- list of protection functionality that can be triggered by external events
- diagrams of control system and any other equipment implemented within the control system in the form of standardised block diagrams
- information on applicable software version, compiler version if any and simulation model unique version control.

For a power park that comprises more than one generator unit, the submitted simulation model must be such that the characteristics of the power park is represented at the point of connection. Submitted model parameters must contain all data sets for each unit.

The static and RMS simulation models submitted to SONI must be implemented in (or compatible with) PSSE33 and later versions. No special settings other than standard software setting should be required for the submitted model to be implemented.

The EMT model must be developed and delivered in PSCAD version 4.6.3 or later.

The harmonic simulation model shall be delivered in PowerFactory version 2020.

RMS and EMT models require verification and validation which shall be included in the submitted simulation report. The EMT model must be validated for simulations at different simulation time steps and should also include comparison of the static and RMS dynamic model response. Model validation against test measurements is a requirement and the specific simulation that needs to be validated against actual tests are indicated.

In general accuracy requirement for PPM models and simulation follow a similar line to SPGM as in the previous section and repeated below. For EMT model and simulation accuracy, identical approach to RMS is used. However, the comparison is evaluated using RMS quantities with an appropriate filtering for power frequency component of measured and simulated parameters. The method of filtering must be agreed between SONI and the facility owner prior to any measurements and simulations.

The submitted simulation model and studies shall have the following accuracy requirements:

- For a linear response over a frequency range of 0.1 to 5Hz, deviations between simulated and measured waveforms of the control system must be less than 10% for amplitude and less than 5 degrees for the phase angle. Discrete waveform changes (amplitude spikes) on the simulated waveform should be less than 10% in relation to measured quantity and in the case of where this level is exceeded due to numerical integration issues, this should be documented in the report.
- For dynamic time domain simulations where non-linear response is included to replicate set point changes or response to disturbances on the wider network, the following requirements apply for deviations between simulated and measured response:
    - for rapid slopes within 10% for 95% of the samples recorded within a defined event window[2], and time offset of the gradient start or end time must be less than 20 milliseconds;
    - for events (e.g. switching) resulting in positive and negative spikes, the amplitude must be less than 10% from the corresponding measured value for 95% of the samples recorded;
    - oscillation in active power, reactive power, voltage and frequency in the 0.1-5Hz range must have damping and the deviation in the frequency of oscillation must be less than 10% for 95% of the recorded samples;
    - considering possible difference in the voltage at the point of connection, deviation in active and reactive power response must be less than 10% for 95% of the samples;
    - considering possible difference in the final settled value of voltage at the point of connection, the final value of active and reactive power must settle to within 2% of the plants rated capacity.

[2] An event window is defined as the instant a reference value changes or a disturbance is initiated and lasts until the response returns to within 5% of the maximum induced or reference quantity change.

2.3. PPM Simulation Studies

This section details simulation studies required for power park modules generating modules (PPM). In most of the simulation studies, a model as given in Figure 2 is sufficient for study purposes and when this is the case each simulation study directs the user to use the given model arrangement.

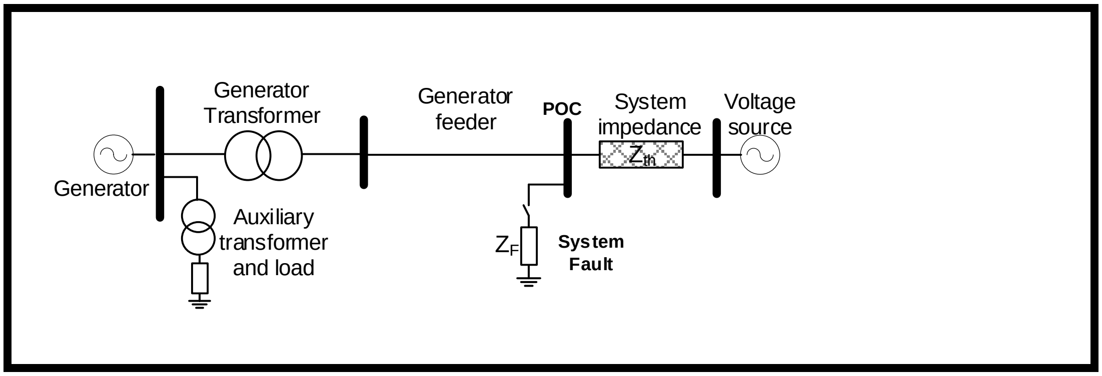


Figure 2

System impedance shown in the figure needs to be taken from Minimum System Strength Report.

A summary of the simulation studies for PPM is given in the following table along with reference to the EU Network Code (2016/631) simulation requirement and the related SONI Grid Code capability requirement.

Capability Area	EU – NC (2016/631)	SONI GC Capability	Validate against test
Fast Fault Current Active Power Recovery Fault Ride Through	Art54(3), Art54(5) & Art56(3)	CC.S2.1.4 & CC.S2.2.3.4, CC.S2.2.3.5, CC.S2.2.3.7, CC.S2.2.3.8 and CC.S2.2.3.9	
LFSM-O	Art54(2)	CC8.8.7.1	Yes
LFSM-U	Art55(2)	CC8.8.7.2	Yes
FSM	Art55(3)	CC8.8.7.3	Yes
Load Rejection	Art55(4)	CC8.8.7.5 and OC7.5.4	
Reactive Capability	Art55(6)	CC.S2.1.3.2	Yes
Power Oscillation Damping	Art55(7)	CC.S1.1.3.3(f)ii & CC.S2.1.3.3(f)	

2.3.1. FRT, Active Power Recovery and Fast Fault Current

Simulate fault-ride-through and active power recovery using a model as in Figure 2 with system impedance set equal to a value representing minimum short circuit level.

Set generator operation to P=Pmax, Q=0 for the simulations.

Simulation 1:

Apply four different types of faults at the POC:

- phase-to-earth fault;
- phase-to-phase-to-earth fault;
- three-phase fault.

Under each of the above faults, set the faulted phases retained voltage at the POC to the values given below for the given duration. In each case clear the fault and let steady-state condition to be reached before commencing the next study.

Faulted Phase Retained Voltage (p.u.)	Fault Duration (milliseconds)
0	150
0.85	2900

Check and report:

Voltage at generator terminals and POC

Active power and active current at generator terminals and POC

Reactive power and reactive current at generator terminals and POC

Success Criteria:

Generator remains connected and stable while meeting the capability requirements in CC.S2.1.4 for transmission connected and CC.S2.2.3.4 for distribution connected PPMs.

Simulation 2:

Apply four different types of faults at the POC:

- phase-to-earth fault;
- phase-to-phase fault;
- phase-to-phase-to-earth fault;
- three-phase fault.

Under each of the above faults, set the faulted phases retained voltage at the POC to 0 p.u. and clear the fault within 140 ms.

Check and report:

Voltage at the generator terminals and POC

Active power and active current at generator terminals and POC

Reactive power and reactive current at generator terminals and POC

Success Criteria:

Show compliance against GC CC.S2.1.4.5 and CC.S2.1.4.6 for transmission connected PPM and CC.S2.2.3.8 and CC.S2.2.3.9.

2.3.2. LFSM-U and LFSM-O

This simulation needs to be validated against actual compliance tests.

Simulate Limited Frequency Sensitive Mode response using the model in Figure 2 with system impedance set to minimum short circuit level. The generator should be operated at LFSM with an active power P as indicated in the curve shown below and reactive power set to zero

Generator droop settings set to 4%.

Simulate:

Apply Test 4 in Section 6.5.1 of the PPM Setting Schedule document. Each setpoint change is only initiated when steady state conditions are met.

Apply Ramp Frequency Control Test in Section 6.5.1 of the PPM Setting Schedule document. Each setpoint change is only initiated when steady state conditions are met.

Check and report:

Voltage at generator terminals and POC

Active power at generator terminals and POC

Reactive power at generator terminals and POC

Frequency

Success Criteria:

Generator remains stable while meeting the capability requirements in CC8.8.7.1 and CC8.8.7.2

2.3.3. Frequency Sensitive Mode

This simulation needs to be validated against actual compliance tests.

Simulate Frequency Sensitive Mode response using the model in Figure 2 with system impedance set to minimum short circuit level. The generator should be operated at FSM with an active power P as indicated in the curve shown below and reactive power set to zero

Generator droop settings set to 4%.

Simulate:

Apply Injection Test 1, Test 2 and Test 3 in Section 6.5.1 of the PPM Setting Schedule document. Each setpoint change is only initiated when steady state conditions are met.

Check and report:

Voltage at generator terminals and POC

Active power at generator terminals and POC

Reactive power at generator terminals and POC

Frequency

Success Criteria:

Generator remains stable while meeting the capability requirements in CC8.8.7.3.

2.3.4. Reactive Power Capability

This simulation needs to be validated against actual compliance tests.

Demonstrate reactive power capability using the model in Figure 2 with system impedance set to minimum short circuit level and the generator operating at various points.

Simulate:

Run load flow studies with the generator at various points on the VQ/Pmax diagram.

Check and report:

Check it can supply maximum leading and lagging reactive power at Pmax at specified voltage levels in CC.S2.1.3.3.

Check it can supply maximum leading and lagging reactive power at Pmin at specified voltage levels in CC.S2.1.3.3.

Voltage at generator terminals and POC

Active power at generator terminals and POC

Reactive power at generator terminals and POC

Success Criteria:

Simulation shows output within the boundaries of the VQ/Pmax diagrams given in CC.S2.1.3.3.

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2.3.5. Islanded Operation (Load Rejection) (Only if requested by SONI)

Demonstrate islanded operation capability using the model in Figure 2 with system impedance set to minimum short circuit level and the generator operating at P= Pmax and Q=0.

Simulate:

While the generator is at maximum active power output, island the generator from the system by opening the breaker connecting the power park to the system such that it supplies only the auxiliary and any local load.

Check and report:

Voltage at generator terminals

Active power at generator terminals

Reactive power at generator terminals

Frequency

Success Criteria:

Generator remains connected and in operation while meeting the capability requirements in CC8.8.6.1 and CC.S2.1.3.5.

2.3.6. Power System Stabiliser / AVR Control (Not Applicable Presently)

If a Power System Stabiliser is specified for voltage control or if there is one already included in the voltage control system

Simulate:

Voltage variation test under different disturbances

Use minimum system fault level impedance.

P=Pmax and Q=Qmin (maximum leading reactive power)

Apply x% (5%?) step to reference voltage to check PSS response to voltage disturbances. Repeat test with PSS on and off.

Apply three-phase short-circuit at grid entry point. Repeat it with PSS on and off.

Check and report:

Generator terminal voltage

Active power

Reactive power

Excitation voltage

PSS output signal

AVR output signal

Success Criteria:

Improved attenuation of system power fluctuation when PSS is on compared to when PSS is off.