TRANSPOWER

Modelling Requirements for Synchronous Assets

GL-EA-0716

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TRANSPOWER

Version	Date	Change
0.1	Nov 2018	First Draft
0.2	Mar 2019	Removed comments, revised and accepted changes, removed unwanted appendices.
1.0	May 2020	Added Appendix C and D and references to these appendices
2.0	June 2022	Updated section 3.3, added sections 6.6 & 6.7, updated Appendix C, general updates
3.0	September 2022	Minor updates to sections 3.2, 5.2 and 6.7
4.0	15 May 2023	Minor updates
4.1	15 Jan 2024	Appendix D reinstated
5.0	7 May 2025	Requirements for IBR models updated
6.0	29 June 2026	Split modelling requirements between this document (synchronous) and GL-EA-1311 (IBR); guidance aligned with CACTIS requirements

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Introduction

This document guides you, the asset owner, to understand the System Operator's requirements for developing mathematical models of your asset. Following our guidance will mean your models are appropriately validated and fit-for-purpose. The System Operator requires that you submit these, alongside with supporting information so that we can plan to meet, and meet, our principal performance obligations (PPOs).

This guide focuses on **synchronous assets**: synchronous generating units and synchronous condensers.

If you want to model an inverter-based resource and DFIG, refer to our *GL-EA-1311* guideline.

If you are commissioning an asset, this guide forms part of a suite of documents that support you in that process. Refer to the document suite on the next page for hyperlinks to the other documents and for an idea of when you should consult them. In particular, we expect you to read this document alongside the following:

- the *Electricity Industry Participation Code 2010* (the Code), especially Part 8, which includes the most up-to-date performance requirements
- the *Connected Asset Commissioning, Testing, and Information Standard* (CACTIS), especially Chapter 4
- *GL-EA-953* Connection Study Requirements
- *GL-EA-010* Generator Testing Requirements

Providing mathematical models is a requirement of the *Code*. This document expands on the requirements stipulated in Part 8 of the Code and Chapter 4 of the *CACTIS*. The information provided seeks to answer common questions about, model quality, modelling software, supporting documentation, and model validation. We recommend you familiarise yourself with both your requirements and our guidance to avoid costly and time-consuming rework and potential delays.

Note: Model validation remains the responsibility of asset owners, as does compliance with all your obligations as stipulated in the Code (and any incorporated documents, such as the CACTIS). You therefore need to read, understand, and comply with asset owner obligations outlined within the Code. If there is a conflict between this document and the Code, the Code takes precedence. If you engage a consultant for testing and model validation purposes, you should share all relevant documentation with them so they are aware of our requirements.

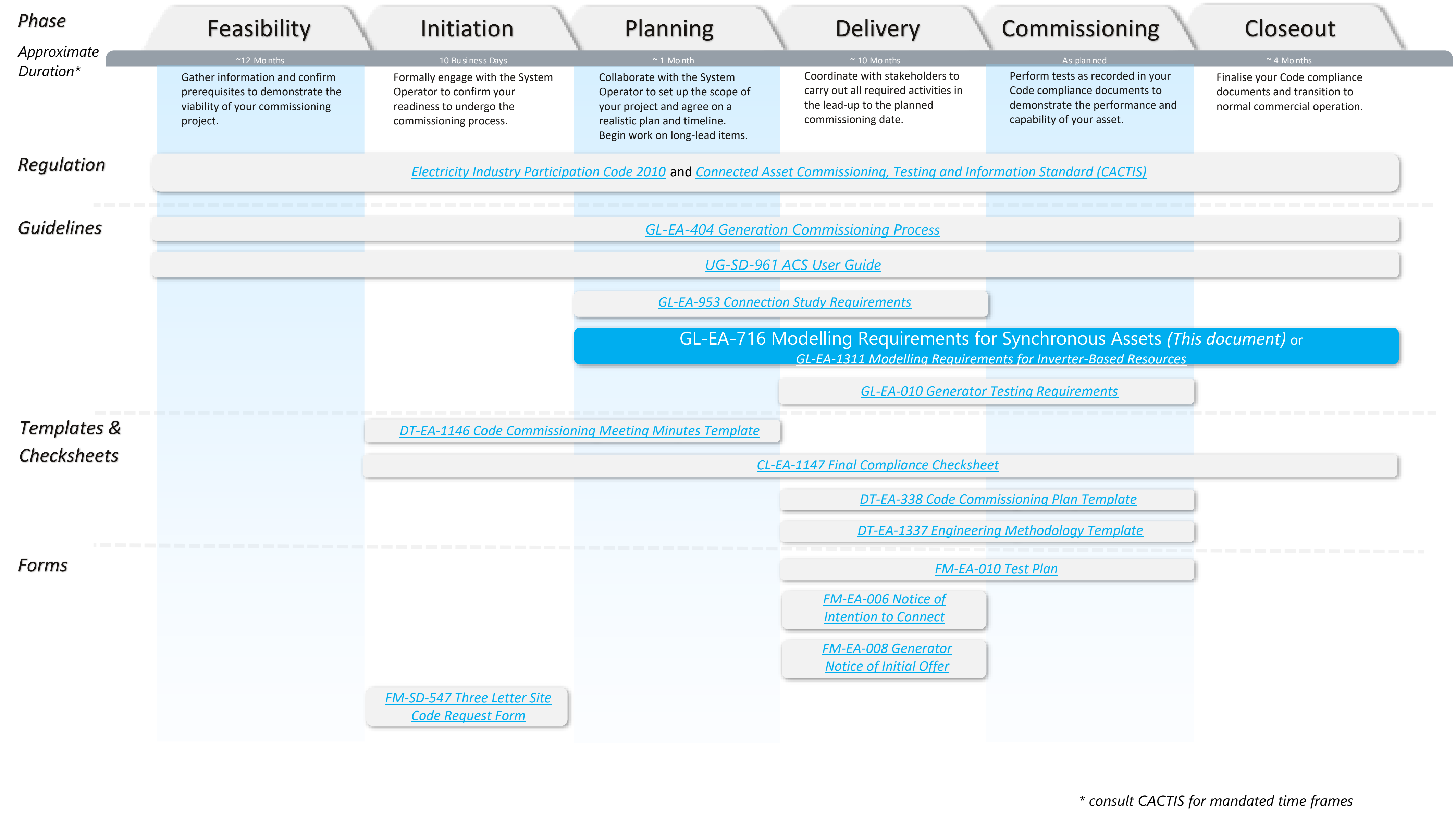


Figure 1 - Supporting Documentation Suite

1 Abbreviations

Abbreviation	Full Form/Explanation
AC	Alternating Current
AVR	Automatic Voltage Regulator
BESS	Battery Energy Storage System
CACTIS	Connected Asset Commissioning, Testing, and Information Standard
DC	Direct Current
DSL	Dynamic Simulation Language (PowerFactory software)
EMT	Electromagnetic Transient
ESCR	Effective Short Circuit Ratio
IBR	Inverter Based Resource (generation)
IEEE	The Institute of Electrical and Electronics Engineers
IP	Intellectual Property
NERC	North American Electric Reliability Corporation
NREL	National Renewable Energy Laboratory (USA)
OEM	Original Equipment Manufacturer
PID	Proportional-Integral-Derivative
PSS	Power System Stabilizer
PSS/E	Power System Simulator for Engineering Software package used to conduct RMS type studies
RMS	Root Mean Square
The Code	Electricity Industry Participation Code 2010
UDM	User Defined Model
WECC	The Western Electricity Coordinating Council

2 Scope

The purpose of this guideline is to support asset owners to accurately represent the performance of their synchronous assets, including those components within synchronous generating units and synchronous condensers.

Refer to chapter 4 of the *CACTIS* for mandated requirements. The guidance in this document to the creation of M1 and M2 models, as defined in the CACTIS. Where a requirement outlined in this guideline cannot reasonably be demonstrated prior to commissioning, it shall apply only to the M2 model unless otherwise stated.

2.1 Requirements at a Glance

Asset owners can use this section to familiarise themselves with the high-level modelling requirements.

2.1.1 M1 Model (Connection Study Model)

- An M1 model must be provided to support connection studies.
- The M1 model must represent the synchronous asset with all site specific electrical and control parameters, and must reflect the intended operating configuration at the time of connection.
- The M1 model must include, as a minimum:
  - a synchronous machine model representing the generator electrical characteristics;
  - a representation of the voltage control system, including any supplementary limiters or controls relevant to voltage control performance;
  - a representation of the frequency control system, configured to reflect the intended frequency control mode(s) (e.g. droop, load control);
  - where fitted, a representation of the Power System Stabiliser (PSS) consistent with the intended in-service configuration; and
  - representation of the protection system with appropriate preliminary settings.
- The M1 model is intended to demonstrate the expected dynamic behaviour of the synchronous asset for the purposes of connection assessment and system studies.
- The M1 model needs to be submitted in accordance with the applicable CACTIS timeframes.

2.1.2 M2 Model (Final Validated Model)

- An M2 model shall be provided as the final validated model for the synchronous asset following commissioning and testing.
- The M2 model shall include:
  - the synchronous machine model with final electrical parameters.
  - a detailed representation of the vontage control system including all limiters, supplementary controls, and as-left parameter settings.
  - a detailed representation of thefrequency control system configured with as-left settings, including all intended frequency control modes.
  - a representation of the Power System Stabiliser (PSS), where installed, with validated parameters.
  - a representation of the protection system with final settings.

- The M2 model must be validated against commissioning test results and be suitable for use in operational, planning, and dynamic stability studies undertaken by the System Operator.
- The M2 model need be submitted in accordance with the applicable CACTIS timeframes following completion of commissioning and validation activities.

2.2 Intended Use of Models

The System Operator uses models to conduct accurate load-flow analysis, dynamic stability assessments and other system studies. Models are used at appropriate stages of the commissioning process and throughout the operational life of a the asset.

The accuracy of these assessments helps us to:

- demonstrate Code compliance for power system conditions that cannot be readily replicated during on-site testing;
- assess the steady-state and dynamic performance of the power system, including the determination of operating and stability limits that define the boundaries of secure operation ;.
- support efficient system operation and dispatch of offered;
- perform studies to ascertain the frequency capabilities of equipment, including the reserve assessments (where offered) and incident investigations;
- perform system frequency response and voltage stability studies in the context of contingent and extended contingent events.

3 Software Specifications

3.1 Software Package and Version

You must submit models using the following software formats:

- DigSILENT's **PowerFactory V2024** (or more recent)

The above software version will allow you to utilise up-to-date PowerFactory case files of the New Zealand power system that the Electricity Authority *makes available for system studies*.

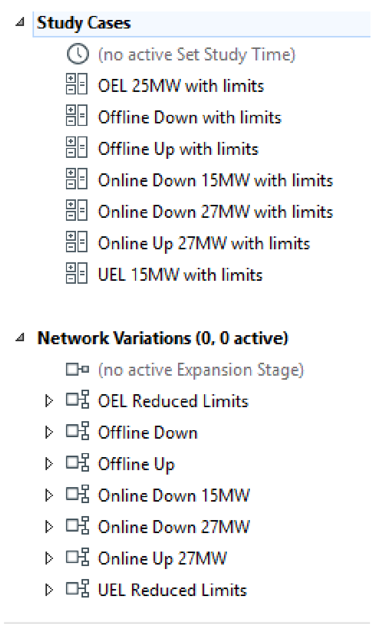
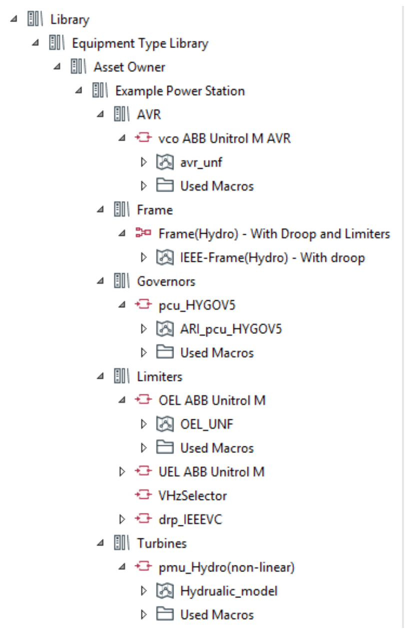
For synchronous generators, it is usually sufficient to use the appropriate Root Mean Square (RMS) stability models for simulations. Generic models available in standard libraries are acceptable for the generation control systems if you provide enough information to demonstrate they accurately represent the actual control systems.

The RMS model of your asset must be submitted in accordance with Appendix C.

3.2 File Structure

To facilitate your model's integration into System Operator model cases, use the study case and library structures and naming conventions in Table 1. For further guidance, refer to the example PowerFactory model and accompanying readme file on our Power System Studies and Modelling webpage.

Table 1: Proposed Study Case Structures for Storing DIgSILENT PowerFactory Models

Study Case Structure	Library Structure
	

You should also:

- organise your models into the appropriate folders named after the equipment type they belong in. For instance, store AVR and voltage control system models in a "voltage control system" folder. Place the models in the standard "Equipment Type Library" folder.

- store the user macros of each component in the individual component library pack (pack macros).
- store the Element.dsl in the relevant component library with the as-left controller parameters.
- provide the model in a ready-to-run validation case or project. As part of the initial checks of your submission, the System Operator must be able to activate the project and easily replicate all test results and graphs included in the model validation report.

3.3 User Guide and Version Control

Models must be accompanied by user guide documentation containing all the information required to use the model as part of system studies *without* needing to have any prior knowledge of the equipment, content of validation package or validation techniques in question. The guide should include:

- block diagrams showing all control system components and how they are interlinked;
- a parameter list including a comprehensive explanation of setting values and their impact of asset performance.
- provide clear instruction to replicate model setup including external dependencies.
- the calculation or methodology used to estimate key parameters such as inertia, water starting time and droop (if they are not included in the manufacturer's data);
- known limitations of the model during initialisation or normal operation of asset or abnormal operation of asset;
- details of any manufacturer 'user defined model' (UDM) or control block diagrams that the System Operator could use to rebuild the models in other software (if needed);
- a description of secondary or station control system able to act within 5 minutes to change the active or reactive power output;

To ensure that both you and System Operator are able to refer to the same version of any submitted models, include the following labels:

- the software version you developed the model in;
- the version number and author of the model itself;
- the date of last modification;
- data/information source (e.g. user guide block diagram);
- a discrete list of changes since the last version; and
- if your software has the functionality, the versions of the components that make up the model.

4 Model Quality

4.1 Model Encryption

Submitted models must be **unencrypted**, to allow the System Operator to:

- fully access, review, and understand the internal structure and behaviour of the model;
- understand the control logic and mathematical implementation;
- access and modify all signals, equations, and initial conditions;
- use the model for operational and planning studies over the life of the asset; and
- validate model performance and investigate asset compliance following system disturbances.

The model can be developed and submitted in one of the following formats:

A. Model Block Diagram Format

In this format, the model is constructed using basic control blocks with a graphical representation of the control system components.

This format requires that:

- all control blocks, logic, mathematical equations, signal flows, and programming code are visible and accessible to the System Operator;
- no parts of the model are hidden, locked, or compiled in a manner that prevents inspection or modification; and
- the internal structure of excitation systems, governors, limiters, and supplementary controls can be reviewed and validated.

B. Model Source Code Format

In this format, the model is provided as source code, with the control system functions implemented using written and organised programming code. The source code format must:

- clearly represent the control logic and mathematical implementation of the model;
- allow the System Operator to trace signals, parameters, and control actions; and
- be provided without encryption or compilation that would restrict access.

Refer to our *Power System Studies and Modelling* webpage for more information about how we safeguard the confidentiality of models shared with us.

4.2 Root Mean Square (RMS) Model Components

A synchronous generating station must be modelled as a full generating station in the RMS domain. The RMS model needs to be sufficiently detailed to accurately represent the dynamic response of the generating station to voltage and frequency disturbances at the point of connection.

As a minimum, the RMS model must include:

- individual generating units, including synchronous machine representations;
- generating unit transformers and relevant network interfaces;
- generating station auxiliary loads, where these materially affect station behaviour;

- the control systems for each generating unit, including voltage control system, frequency control system, power system stabilisers (where fitted), and associated limiters; and
- any control or protection functions that are capable of disconnecting the generating unit or generating station within a simulation timeframe of up to 60 seconds.

In addition, the RMS model must:

- represent all control modes within the voltage and frequency control systems, including the ability to transition between modes and accept external signals for use in real-time operation;
- **use signals** as inputs and outputs of DSL models for simulation (e.g. use the signal 'ut' instead of a network measurement value 'u:bus1' for a machine terminal voltage, using the signal xspeed instead of the state speed);
- not contain any unused, inactive, or redundant control blocks or program code; and
- be compatible with the modelling software package versions specified in section 3.1.

Further details on the representation of physical components and associated modelling considerations are provided in section 4.6.

4.3 RMS Model Initialisation

Models submitted to the System Operator must initialise correctly from load-flow solutions within the normal operating envelope of the equipment.

Successful model initialisation must meet the following requirements:

- initialise without run-time errors;
- initialise without run-time warnings related to incorrect or incomplete model initialisation;
- initialise successfully across the full operating range of active and reactive power;
- initialise successfully across the allowable voltage range at the point of connection; and
- use numerical integration time steps appropriate to the model, and not greater than **5 ms**.

Demonstrate successful initialisation through a no-disturbance simulation of at least **120 seconds**, during which the model remains within the limits specified in Table 2.

Table 2: Initialisation Simulation Testing Boundaries

Quantity	Acceptable range
Generator MW and MVAR	With in ±1% of MW and MVAR setpoint
Synchronous generator speed (where applicable)	With in 1 pu ± 0.005 pu
Controlled voltages	With in ±0.005 pu of Voltage setpoint

Note: If initialisation problems occur, you must resolve these before validating the model. Submitted models with unresolved initialisation problems will fail the System Operator's verification process.

4.4 Model Performance and Reliability

Models submitted to the System Operator must demonstrate adequate numerical performance and reliability across a representative range of operating and system conditions.

The model must be numerically stable for:

- a suitable range of ESCR and fault-level X/R ratios at the point of connection;
- operation at leading, lagging, and unity power factors when the network circuits closest to the point of connection are subjected to balanced and unbalanced faults;
- step changes to:
  - the voltage or reactive power set-point of the voltage control system; and
  - the frequency or active power reference of the frequency control system; and
- system faults that are cleared by normal protection relay operation.

Model performance and reliability must be demonstrated by running dynamic simulations of at least 60 seconds' duration, sufficient to identify any small-signal instability, or control interaction, or numerical issues, with reference to:

- active power,
- reactive power,
- voltage, and
- frequency.

4.5 Adequacy of Simulation

In addition to representing all control modes used during normal operation, models must be capable of simulating a representative range of operating conditions, including extreme operating points (that is, the highest and lowest levels of active and reactive power output).

Where simulation of specific operating conditions results in a change of control mode or operating state, these transitions must be:

- explicitly modelled; and
- clearly documented in the model user guide, including a description of the triggering conditions and resulting control behaviour.

To demonstrate adequacy, simulations must include, where applicable:

- defined step changes to controller set-point references or inputs;
- defined signal injections to controller inputs;
- switching of static reactive devices;
- load rejection events;
- operation at maximum and minimum transformer tap positions; and
- correct application of rate-of-change limits (both positive and negative) where these are implemented in plant controls.

During testing and simulation, ensure you record sufficient data to enable meaningful comparison between simulation results and commissioning or test data, where such data is available.

4.6 Representation of Physical Components

Your models must accurately represent the different physical components of your synchronous asset. Additionally, your models must represent all required characteristics and identifiable physical components where each block or a combination of blocks represents the dynamic behaviour of a physical component. Refer to the sections below for the relevant specifications.

4.6.1 Generator

Generic generator models are adequate for steady-state power flow and positive sequence dynamic simulations. Specialist studies may require higher-order models, which the System Operator will advise you about.

Parameters: Confirm the parameters of your generator with your equipment manufacturer, especially if using standard generator models such as GENTPJ, GENROU, and GENQEC.

Generator manufacturers typically provide parameters that include d-axis and q-axis reactances, time constants, inertia and saturation factors. Occasionally, manufacturer data may be insufficient or your testing may identify deficiencies (e.g. in the inertia values) where the values provided by the manufacturer may only consider the synchronous generator and not any other rotating equipment such as the turbine, hence needing to verify the parameters yourself.

V Curves: Generator manufacturers may also supply V Curves. If these are available, submit them as part of your model to represent the generator stator current vs excitation field current for various levels of MW output.

4.6.2 Voltage Control System

Excitation performance largely determines synchronous machine behaviour in stability assessments.

Complexity of Model: Standard sources such as 'IEEE Recommended Practice for Excitation System Models for Power System Stability Studies' contain details of standard models currently in use, although these are simplified models. The models from your manufacturer may be more detailed and contain more control loops. In some situations, standard IEEE models may be too simplistic to accurately represent the performance of your excitation component. If this is the case, you must provide detailed models that represent the excitation control system's actual performance.

Sufficiency: Your excitation control system model must:

- include any control loops that can dynamically change the machine field excitation. These may include the main voltage control system, compensator droop, automatic voltage regulator, over-excitation limiter, under-excitation limiter, power system stabiliser, stator current limiter, and volts/Hz (over flux) limiter; and
- have the capability to:
  - regulate the voltage with or without a droop setting;
  - use a voltage setpoint at the generator terminals or another agreed point such as the point of connection; and
  - limit dynamic controls (such as over-excitation limiter, under-excitation limiter, and stator current limiter) to simulate the actual dynamic behaviour within its operating and protection limits.

Some control loops may have time-based control actions, and these, too, need to be represented. For example, the over-excitation limiter may have multiple controlled levels over specified periods of time to manage heating effects.

4.6.3 Frequency Control Systems and Turbines

You must model the frequency control system based on your specific synchronous generation type below. For all these models, you must also include:

- common parameters, such as droop; and

- common modes, e.g. frequency sensitive, limited frequency sensitive and reserves (fast, slow, tail water depression).

Ensure you validate your simulations within the frequency range of 45-55 Hz, where the equipment can stay connected.

4.6.3.1 Hydro Turbines

Hydro generation plays a dominant role in the New Zealand power system, so the accuracy of hydro frequency control system models greatly impacts power system performance.

Parameters: You must provide key parameters and their derivation for:

- water starting time constant;
- gate vs power curve;
- gate opening and closing rate limits; and
- deadbands in the control system, along with any deadbands observed in tests.

> *Note: Some frequency control system models contain a feed forward path that directly influences the gate position controller. This path allows an open command to be applied to the gate immediately, without being proportional to the frequency deviation. This occurs before the Proportional-Integral-Derivative (PID) path implements its own open command based on the frequency deviation.*
>
> *Ensure your model accurately represents the governor's expected performance both when the feed forward path is active, and when it is inactive (i.e. when it is a triggered operation).*

4.6.3.2 Steam Turbines

Frequency control system models for steam turbines depend on the type of frequency control system available, turbine control modes, and the configuration of the steam turbine. Generally, it is not necessary to include boiler dynamics in steam turbine generators unless the generator offers sustained instantaneous reserves (SIR).

The IEEEG1 model features valve opening/closing rates, valve time constant, turbine time constant and droop. There is an augmented IEEEG1 model that captures boiler dynamics and co-ordinated control.

Sufficiency: Ensure that your model includes:

- reheat turbines where significant time delays can occur between valve movements and changes in turbine power output;
- backpressure turbines where steam used in the co-generation application may impact frequency control system response;
- extraction turbines where steam at the extraction stage may impact frequency control system response;
- steam supplied from a common header where boiler dynamics may be influenced by the controls implemented;
- intentional deadband in the controls.

> *Note: In some situations, you may also need to model the shaft; contact the System Operator if shaft dynamics need to be modelled in your particular case.*

Parameters: You must provide key parameters and their derivation for:

- rate of opening and closing main frequency control system valves; and
- steam chest time constant.

4.6.3.3 Gas Turbines / Combined Cycle

NERC (North American Electric Reliability Corporation) has determined that GAST, GAST2A, GASTWD, GFT8WD, and WESGOV turbine-frequency control system models do not have the capabilities and the flexibility of more recently developed models. We suggest using the more flexible GGOV1 model if a generic model is considered appropriate[1].

Sufficiency: Ensure that your model includes:

- all the different modes of operation used, including (if applicable) base load, temperature control, load control and any combinations of the available controls operating simultaneously;
- each fuel the gas turbine runs on, since different parameters may be required for different fuel types where gas turbines run on both liquid and gaseous fuels;
- whether or not there is an impact on output power due to a change in speed, which may be due to:
  - some multiple-shaft turbines having slower frequency responses than single-shaft; and/or
  - some turbines having 'gas generators' where the compressor shaft differs from the turbine shaft;
- controlled inlet guide vanes (IGV) – these can impact output at lower MW output;
- both the ambient temperature and pressure, where significant;
- MW loading rate controls, if used; and
- all combined cycle gas turbine (CCGT) control systems including the gas turbine, steam turbine and the heat-recovery steam turbine. These are likely to have been developed specifically for each generating unit.

The CIGRE technical brochure on 'Modelling of Gas Turbines and Steam Turbines in Combined Cycle Power Plants', Task Force C4.02.25, December 2003 is a good reference for building models.

Parameters: You must provide key parameters and their derivation for:

- droop values for two ranges of generation levels to accommodate varying droops;
- gas turbine time constants;
- intentional deadband in the controls; and
- steam turbine time constants – only for simulations longer than 100 seconds.

[1] IEEE Task Force on Turbine-governor Modeling, *Dynamic Models for Turbine-governor in Power System Studies, IEEE Technical Report PES-TR1*, January 2013 https://site.ieee.org/fw-pes/files/2013/01/PES_TR1.pdf

5 Testing

5.1 Testing Parameter Integrity

All testing must be conducted using the final (as-left) set of parameters. Once testing has commenced, no changes to model parameters are permitted. If any model parameter is modified at any stage, all previously completed tests must be repeated in full using the updated parameter set.

This requirement ensures:

- the integrity and traceability of test results;
- consistency between tested and submitted models; and
- that test outcomes remain valid for the final parameter configuration.

The only exception to this requirement is for limiter testing. Testing of limiters may be conducted using reduced or adjusted setting values, where necessary to safely or practically demonstrate limiter operation. Any such reduced settings must be clearly identified, justified, and not used for any other testing or for final model submission.

5.2 Measurement Points

Record measurement signals:

- at the point of connection (voltage and frequency);
- at the input and output of control components such as voltage control system, frequency control system etc.; and
- at any physical points on the equipment where data is needed for model validation.

Refer to Figure 2 for a diagram of measurement points on a typical synchronous generation asset:

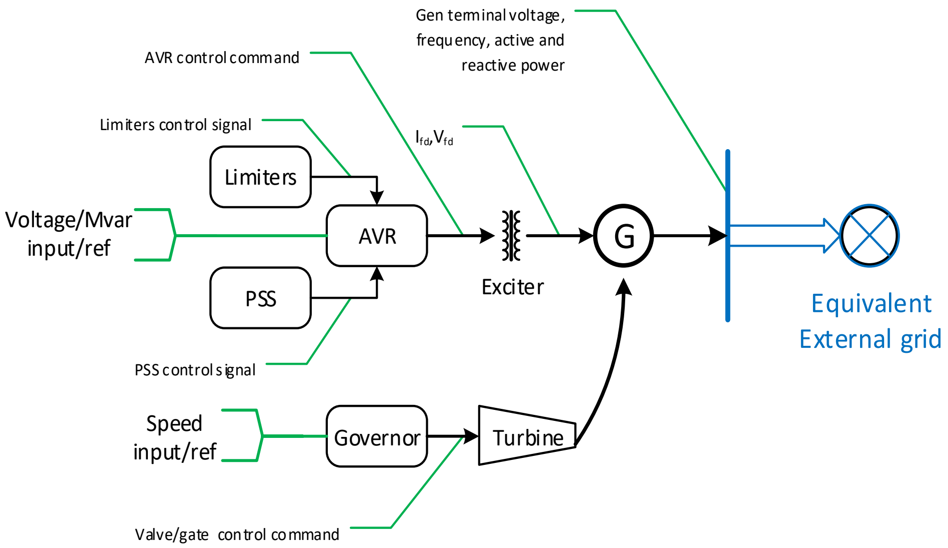


Figure 2: Typical Synchronous Generator Configuration and Measurement Points.

5.3 Commissioning and Routine Tests

Follow the relevant guidance in [GL-EA-010 Generator Testing Requirements].

6 Validation Process

6.1 Validation against Test Data

After testing, you must re-create the operating conditions to validate your model. These simulations must ensure the adequacy, reliability, and accuracy of your models. Validate your models in conjunction with the equipment manufacturer, where possible, especially for new installations. Commissioning is a good time to ensure alignment of simulated model response against measured test results while the manufacturer is on-hand.

Often, manufacturer-sourced models are created using one or more of the following techniques:

- practically derived from analysis of factory test data;
- theoretically derived, based on the design of plant; and/or
- formed after analysis of operational data from other similar equipment installed elsewhere.

The equipment manufacturer is in the best position to advise you on model performance, expectations, and any limitations, particularly where equipment is connected to weaker parts of the power system.

> The System Operator will accept the PowerFactory model once the following conditions are met:
>
> - the models have been validated against test results using the same test steps and conditions applied during commissioning or compliance testing; and
> - the simulated responses are demonstrated to be within the model acceptance criteria specified in Appendix D.

6.2 Model Validation Parameter Integrity

Model validation must be performed using the final, as-left set of parameter values. Any change to a model parameter after validation, including but not limited to changes to PID gains, time constants, limits, dead-bands, ramp rates, or control logic, shall invalidate the previously completed validation.

Where any parameter value is modified, repeat all applicable validation testing using the updated parameter set.

> Note: For clarity, adjusting PID gains or time constants during validation testing to obtain results at different operating points, or using different parameter sets for different tests, are **not acceptable** as model validation. Only validation results obtained using a single, consistent, final parameter set can be considered valid for model acceptance.

Where, during validation, it is necessary to adjust model parameters from the values implemented in the actual control system, such adjustments must **not exceed ±5%** of the corresponding as-left parameter values. Ensure that any such parameter adjustments are fully justified and clearly documented in the validation report.

6.3 Network Model Integration

Once validated, the model must be integrated into the complete system network model. Incorporate your validated model into the peak and light-load cases provided on the *Electricity Authority's website*. Perform the tests specified below (6.3.1 and 6.3.2) to confirm acceptable performance under system conditions.

6.3.1 No Disturbance Test

Demonstrate the required performance through a no-disturbance simulation of at least 120 seconds, during which the model remains within the limits specified in Table 2.

The no-disturbance test must confirm the stable behaviour of active power, reactive power, voltage, and frequency, with no unintended oscillations, drifts, or numerical instability.

6.3.2 Disturbance Response

The performance of the network-integrated model must be demonstrated by applying the following system-level disturbances, as appropriate, to verify the dynamic response of the asset within the wider network:

- balanced network faults
- three-phase-to-ground (3-ph-G) faults
- under-frequency events, represented by tripping of the largest generating unit within the relevant island; and
- over-frequency events, represented by tripping of a large system load within the relevant island.

The simulations must demonstrate that the integrated model responds appropriately to these disturbances and remains stable following fault clearance and system recovery.

6.4 Validation Report

You must submit a validation report that meets our requirements. It should:

- follow the report template in Appendix B;
- clearly demonstrate equipment performance and capability based upon either manufacturer data, test data, or simulation results as agreed with the System Operator; and
- include:
  - the user guide outlined in section 3.3;
  - a statement explaining how the model meets the model quality requirements and satisfies model acceptance criteria specified in this guideline;
  - details of any identified performance limitations, assumptions, or constraints;
  - all recorded test results, compiled in the PowerFactory case, used to support model validation; and
  - any other supporting information not listed above that the System Operator reasonably requires to utilise and translate the model into other software platforms.

To facilitate your gathering of information, refer to the checklist in Appendix A.

Appendix A. Model Submission Checklist

Use the checklist below to verify that you have progressed through the model submission process. If you have followed our guidelines, you should be able to check 'yes' to all of these.

ID	Description		Check
1	**Model Testing**		
	a.	If a single machine network has been used, was the short circuit power estimated from the case files provided on the *Electricity Authority's website*?	
	b.	Was the model tested in a PowerFactory case file (see above link)?	
	c.	Does the model meet the quality requirements of section 4?	
	d.	Was the model tested with cases with the lowest and highest short circuit levels?	
	e.	Was the model tested across the whole range of active power, reactive power and voltage?	
	f.	Does the model meet the accuracy requirements os section 4?	
	g.	Have you removed any unwanted/unused control blocks in the model?	
2	**PowerFactory Model Development**		
	a.	Does the model use the standard frame/user-defined model structure?	
	b.	Is the library structure created as specified in this guideline document?	
	c.	Have you confirmed the confidentiality status of your model (tick below as appropriate)? **PowerFactory** — Confidential: ☐	
	d.	Is the model provided with user guide with all details mentioned in section 3.3?	
3	**Validation Report**		
	a.	Is the model validated across the whole range of active power, reactive power and voltage?	
	b.	Does the model validation process meet the acceptance criteria as per Appendix D?	
	c.	Does the validation process respect parameter integrating requirements outlined in section 5.1?	
	d.	Has the performance of limiters been verified by overlaying simulated performance on tested performance?	
	e.	Does the validation report follow the template in Appendix B?	

Appendix B. **Validation Report Template**

Structure

Your should submit your validation report in either Adobe Portable Document format (PDF) or Word Document format (DOCX). Every report must consist of the following sections:

- Cover page
- Table of contents
- Revision history
- Completed checklist (see Appendix A)
- Description of plant connection
- Description of generator connection
- Description of control system
- A valid model of the generator, of each control systems (GOV, AVR, PSS, or all), both with a version number
- Plots demonstrating models validated against test results
- Appendices containing nameplates and data sheets
- The procedure followed during the testing.
- Description of the data files submitted, including units of measure; where per-unit (pu) values are recorded the base value used must be explicitly stated
- Accompanying data file containing all test results and model simulation results in table form with appropriate column headings.

Cover page

Each model validation report must have a cover page that displaying the following information:

- Station name
- Test unit name and ID
- The name of the engineer responsible for writing the model validation report
- The name of the person who has reviewed the model validation report
- The name of the person who has approved the model validation report
- The name of the System Operator engineer who witnessed the testing (if any)
- The date on which the tests were performed
- The date the report was submitted
- The name, date and version of the PowerFactory project the report refers to.

Table of Contents

Each model validation report must have a table of contents with the main sections showed below.

1. Model validation checklist
2. Plant connection description
   - 2.1. Single line diagram
   - 2.2. Plant electrical parameters
     - 2.2.1. Plant rating (MVA)
     - 2.2.2. Unit transformer information
     - 2.2.3. Auxiliary loads
     - 2.2.4. Fuel type
3. Generator description
   - 3.1. Manufacturer model
   - 3.2. Parameters proposed and validated
   - 3.3. Validation
4. User guide for model

5. Frequency control system and turbine system
    5.1. ..
6. Automatic Voltage Regulator (AVR) and Excitation
    6.1. ..
7. PSS and Limiters system
    7.1. ..
8. Appendices
    8.1. Nameplates and data sheet
    8.2. Recorded test results in .CSV format.
    8.3. Test procedure

Revision History

Provide information on the revision history of the report, including a description of any changes between versions.

Plant Connection Description

Describe the plant's internal layout, electrical characteristics and connection to the power system. You must include:

- Single line diagram(s)
- Station service load

Generator Description

You must include the following, at a minimum:

- Unit name
- Unit rated MVA
- Unit max continuous rating
- Prime mover rating
- Fuel source
- Inertia of the unit (generator + turbine, including shaft)
- Generator winding resistance, impedances, time constants and saturation factor
- Zero-sequence impedances
- Reactive power capability curve
- Air-gap saturation curve
- Voltage control system time constant
- Voltage control system and field resistance
- Voltage control system and field ceiling current and voltage
- Voltage control system rated current and voltage
- Voltage control system and field saturation curve

You can source this data from prime mover and generator nameplates and manufacturer's data sheets.

The results are best compared using graphical methods. An example of such a comparison is shown in Figure 3.

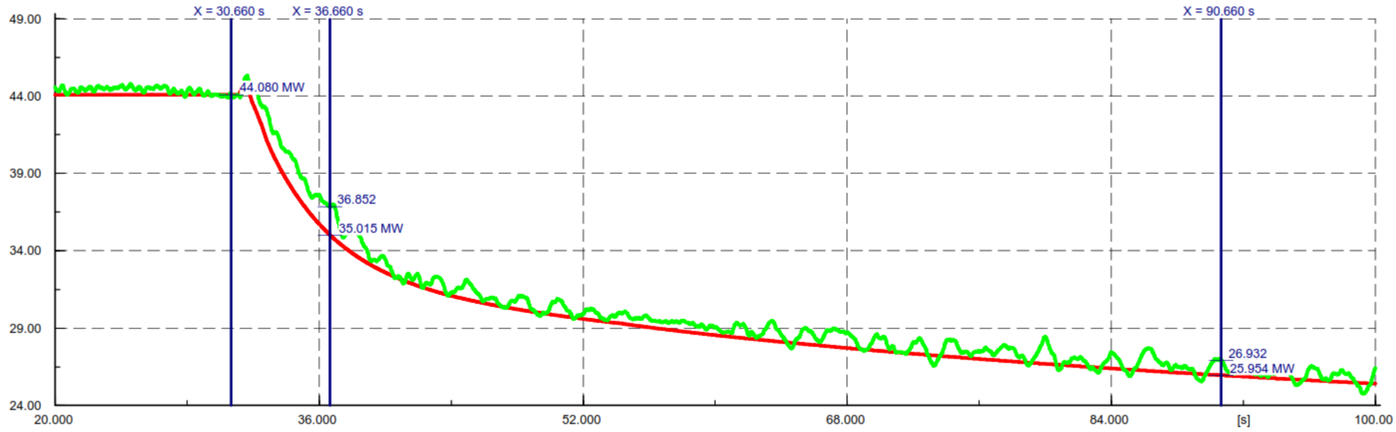
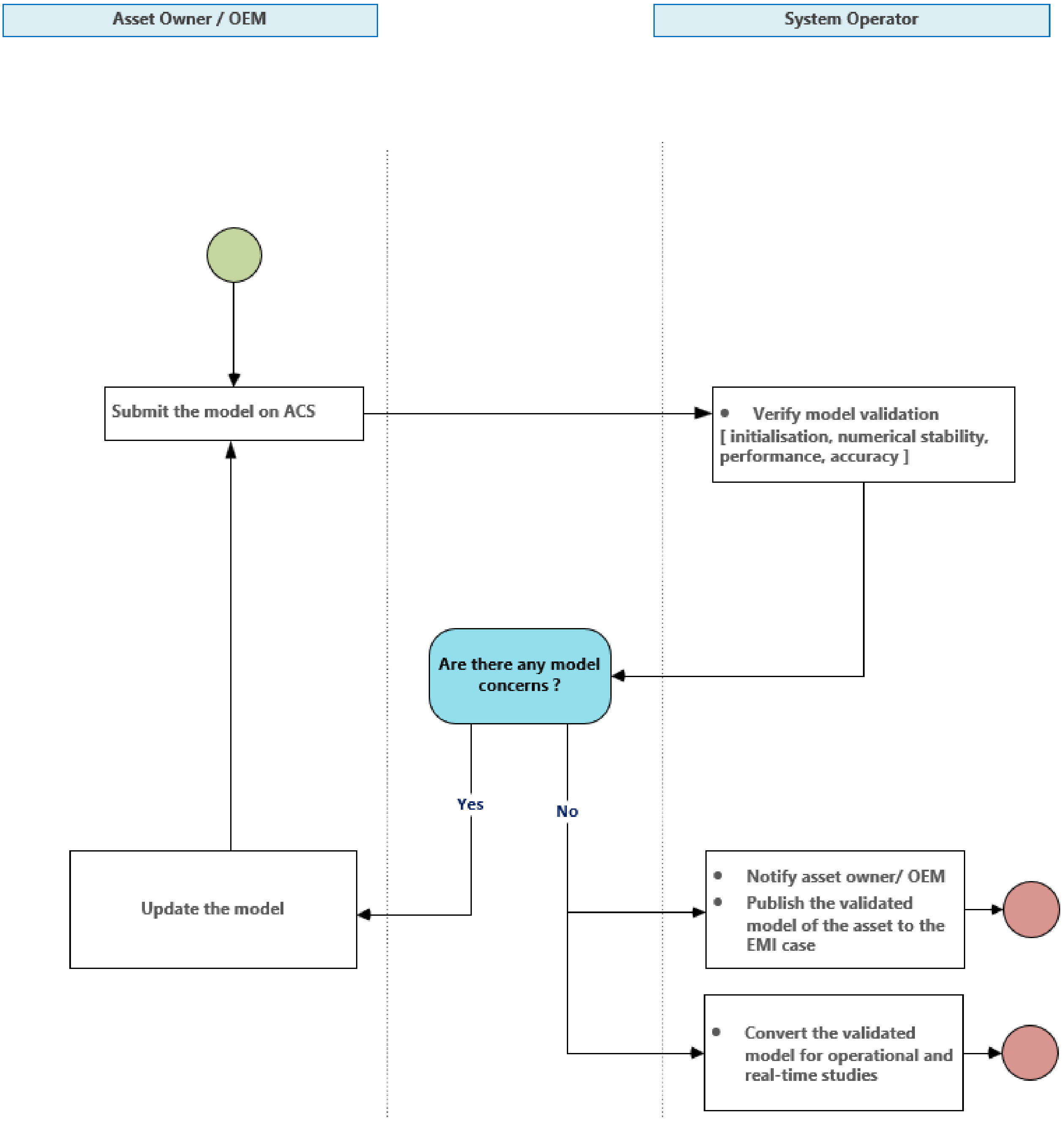


Figure 3: Example Plot Showing 'Good Fit' between Model Performance and Test Results

Appendix C. **Process for RMS Model Submission**



Appendix D. Model Acceptance Criteria

D.1 Steady-State Response (No Disturbance)

Numerical Robustness: No solver divergence or instability during RMS.

Active power, reactive power, voltage and frequency remain within acceptable ranges as set out below for 120 seconds (RMS).

Quantity	Acceptable Range
Generator MW and MVAR	Within ±1% of MW and MVAR setpoint
Synchronous generator speed	Within 1 pu ± 0.005 pu
Controlled voltages	Within ±0.005 pu of Voltage setpoint

D.2 Transient Response: Step Change Test

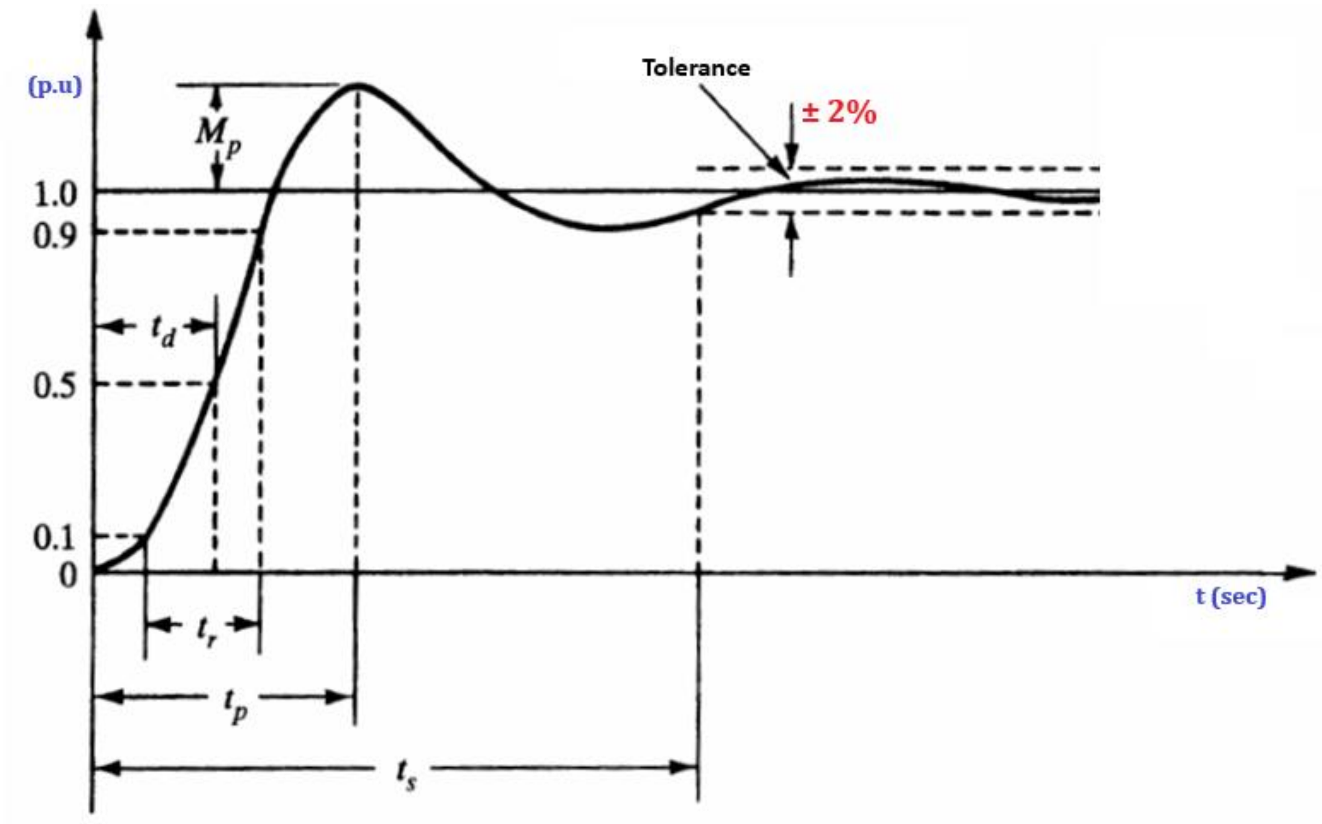


Figure 4: Transient Window Definition

The above measurements are defined as follows:

- Delay time (**td**): Time from the application of a disturbance (e.g., step change, fault) to the initial observable response in the output variable (such as voltage, active power, or frequency).

- Rise time (**tr**): Time taken for the output to rise from 10% to 90% of the total induced change following a disturbance.
- Peak time (**tp**): Time taken for the output to reach its first maximum (peak) value after the disturbance.
- Maximum overshoot (**Mp**): Maximum amount by which the output exceeds its final steady-state value after the disturbance, expressed as a percentage of the induced change.
- Settling time (**ts**): Time required for the output to remain within a specified tolerance band (typically ±2% of the final value) following a disturbance.

Table 3 : Acceptance Criteria for Transient Response

Category	Metric	Criteria
Delay Time (td)	Synchronous Generators (SG)	0.05–0.2 sec
Rise Time (tr)	SG	0.2–1.0 sec
Peak Time (tp)	SG	0.3–1.5 sec
Maximum Overshoot (Mp)	SG	5–20%
Settling Time (ts)	SG	2–10 sec (RMS)
Voltage Recovery	All	Within ±10% in 0.5 sec, then ±2% steady-state within ts
Frequency Recovery	All	Deviation ≤ ±0.5 Hz, settle within ±0.2 Hz in ts
Power Recovery	All	Active/reactive power within ±5% of pre-disturbance after ts
Control Saturation	All	No hard limit > 100 ms

D.3 Model Validation Against Measured Response

Metric	Criteria *
Steady-state error (power)	≤ ±5% of measured value AND ≤ ±2% of rated plant capacity
Steady-state error (voltage)	≤ ±0.01 pu
Time alignment (initial response)	≤ ±0.05 s
Rise time difference	≤ ±10-15%

Metric	Criteria *
Settling time difference	≤ ±10-15%
Peak overshoot difference	≤ ±10-15%

*Acceptance criteria must be expressed using a combination of relative (%), absolute (rated capacity), and per-unit limits to ensure consistency across plant sizes.

Voltage, frequency, and power recovery behaviour must be validated against measured response and must comply with the corresponding acceptance criteria defined in section D.2.

7 Document Information

7.1 Metadata

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Process:	
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