RE Plant Modelling, Validation & Data Measurement: Global Scenario

Presented by

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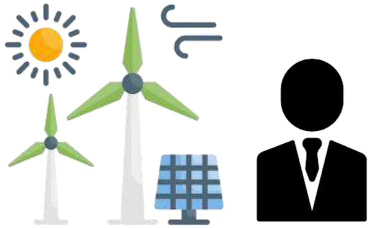
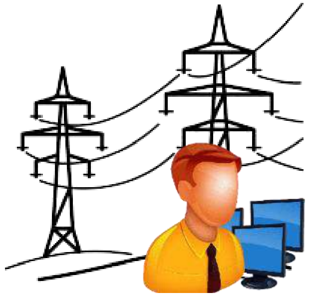
Grid Code Compliance: Objective



RE Plant Owners

Responsible for demonstrating grid code compliance to relevant network operator



Network Operator

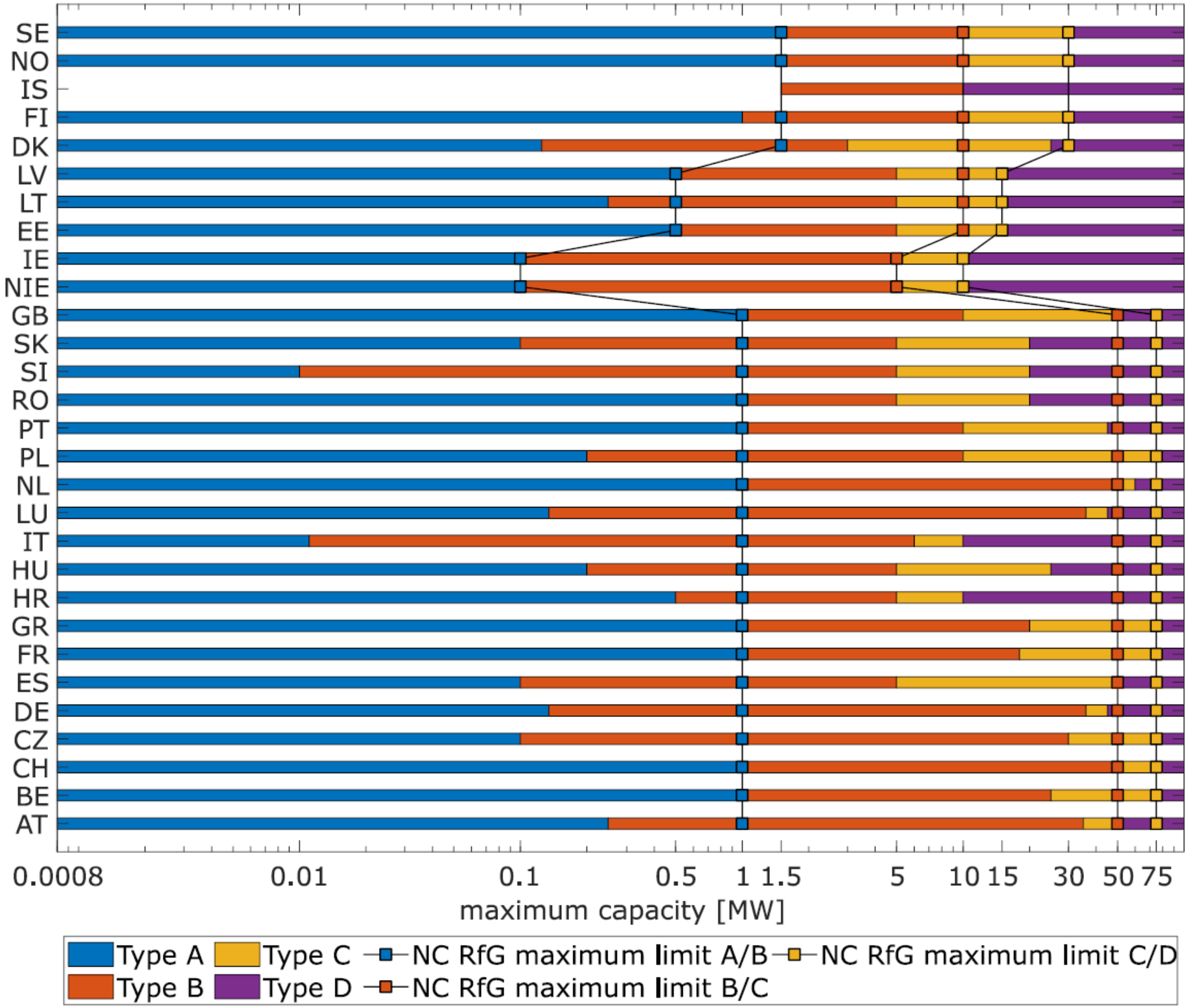
Needs to assess compliance to ensure that new plant will not adversely affect the secure operation of power system

- Grid code compliance testing required before installation of new RE plant
- Periodical compliance monitoring for existing RE plants

Implemented through

- Steady State and Dynamic Modelling
- Validation of the Model

NC RfG Implementations



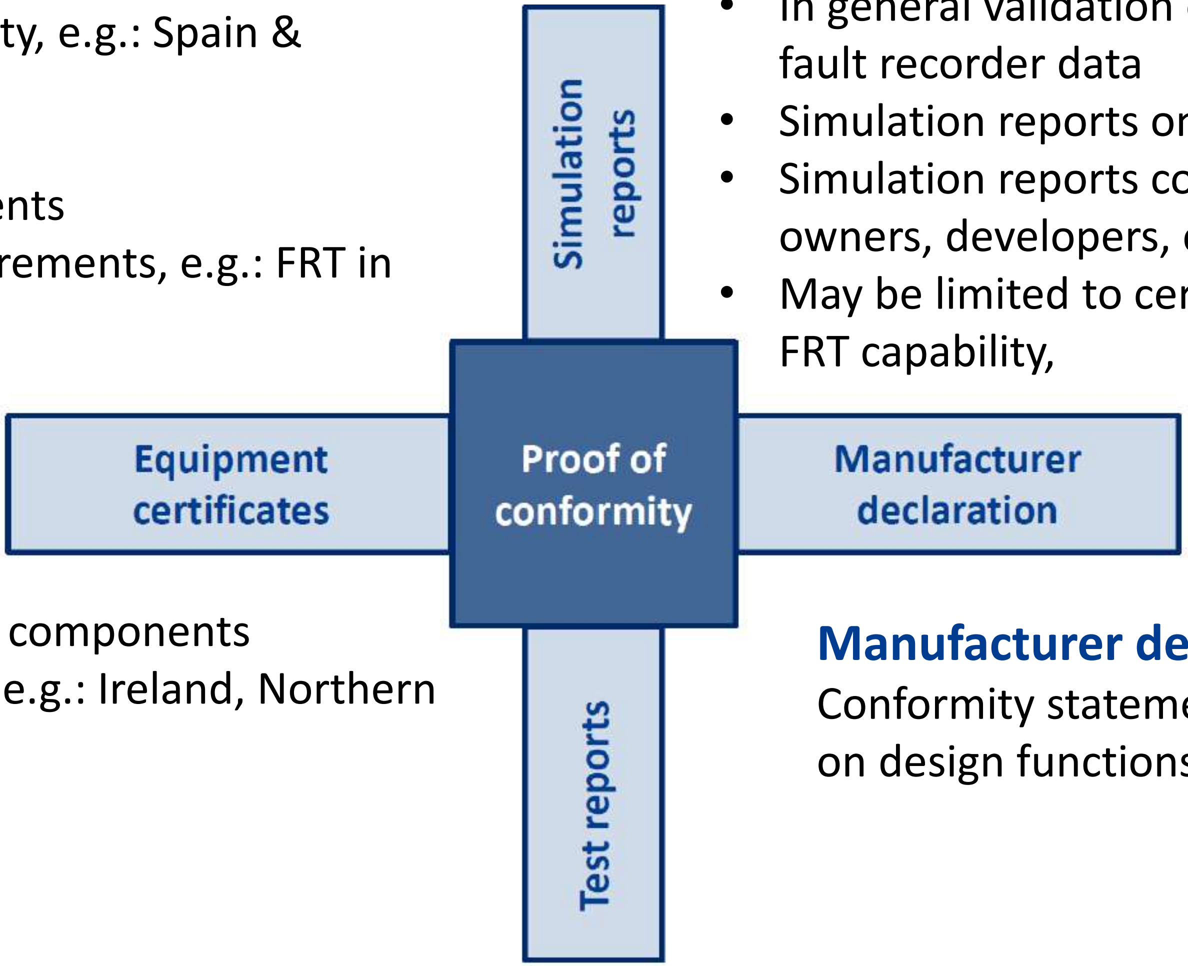
Compliance/Conformity Methods

Equipment certificates

- Power generation modules
- Power generation facility, e.g.: Spain & Germany
- Specific components
- All electrical requirements
- Certain electrical requirements, e.g.: FRT in Poland & Romania

Models and simulation reports

- In general validation of models against type test results or fault recorder data
- Simulation reports on performance of the PPM
- Simulation reports could be from manufacturers, facility owners, developers, consultants or certification bodies
- May be limited to certain electrical characteristics such as FRT capability,



Test reports

- Type testing on PGM or components
- On-site testing on PGFs e.g.: Ireland, Northern Ireland & Sweden
- Accredited testing
- Non-accredited testing

Manufacturer declarations

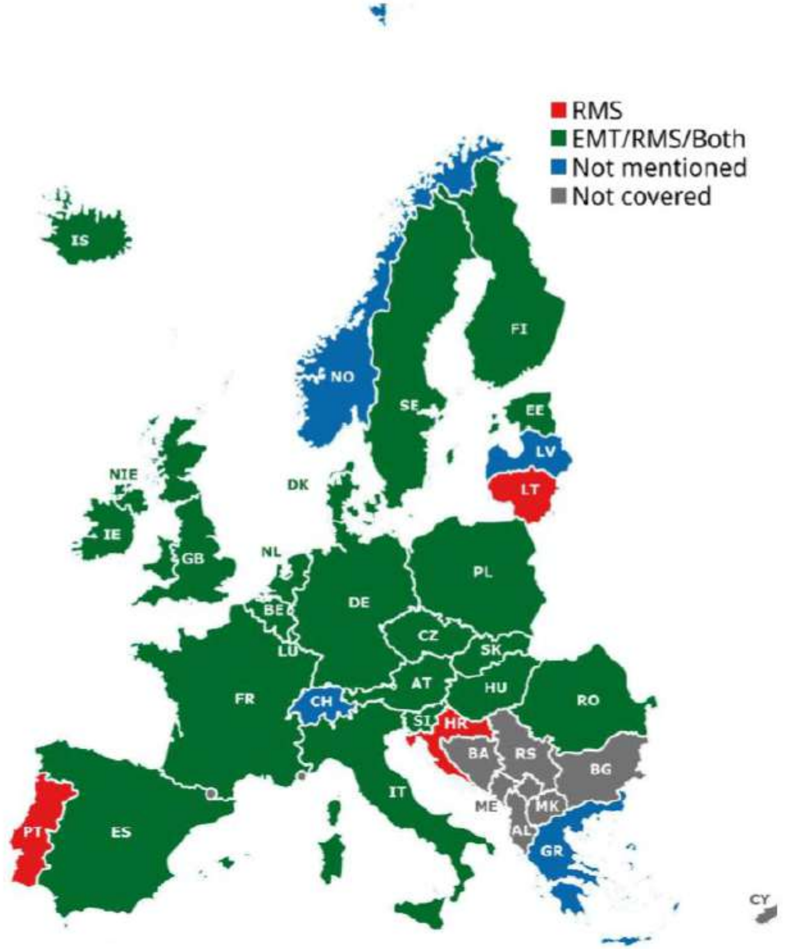
Conformity statement with comprehensible evidence on design functions and technical specifications

Simulation model requirement among EU Member States+

Direct mention of a simulation software tool

Country	Simulation tool
Spain	PSS/E
France	EMTP (Others allowed)
Greece	PSS/E
Croatia	PSS/E (Preferred)
Netherlands	PSS/E, PowerFactory
Portugal	PSS/E
Romania	Eurostag, PSS/E
Slovenia	PowerFactory
Great Britain	PowerFactory, PSCAD
Northern Ireland	PSS/E, PSCAD and PowerFactory
Ireland	PSS/E, PSCAD and PowerFactory
Estonia	PSS/E, PSCAD (Others allowed)
Lithuania	PSS/E
Denmark	PowerFactory, PSCAD
Finland	PSS/E, PSCAD

Direct mention of a simulation model type

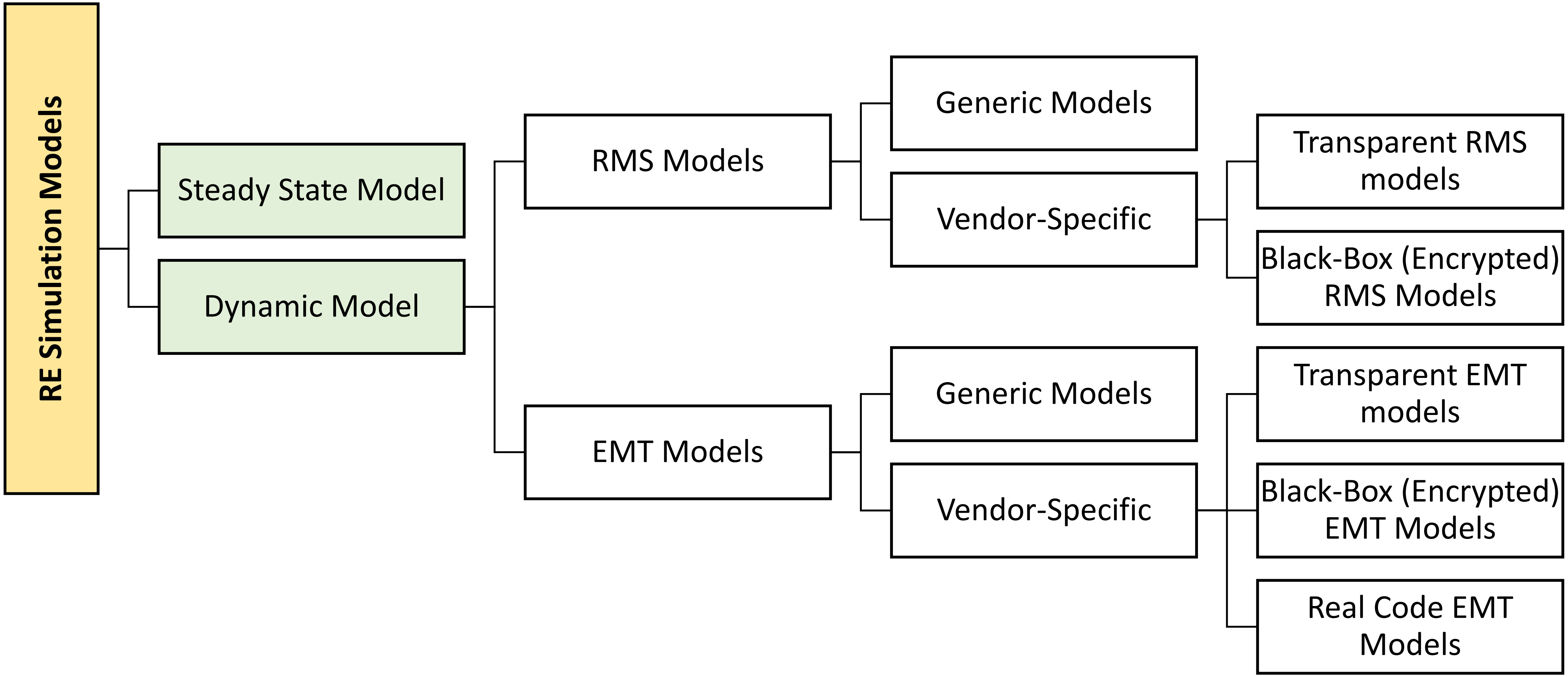


Simulation model requirement among EU Member States+

Synchronous region	Country	Mention of validation /verification	PGM types
Continental Europe	Austria	Yes	C,D
	Belgium	No	-
	Czech Republic	Yes	B2,C,D
	Germany	Yes	B,C,D
	Spain	Yes	B,C,D
	France	Yes	B,C,D
	Greece	No	B,C,D
	Croatia	No	-
	Hungary	Yes	B,C,D
	Italy	Yes	B,C,D
	Luxembourg	Yes	B,C,D
	Netherlands	Yes	B,C,D
Continental Europe	Poland	Yes	B,C,D
	Portugal	Yes	C,D
	Romania	Yes	B,C,D
	Slovenia	Yes	B,C,D
	Slovakia	Yes	D

Synchronous region	Country	Mention of validation /verification	PGM types
NORDIC	Denmark	Yes	B,C,D
	Finland	Yes	C,D
	Iceland	Yes	D
	Norway	No	-
	Sweden	Yes	B,C,D
Ireland and Northern Ireland	Northern Ireland	Yes	C,D
	Ireland	Yes	C,D
Great Britain	United Kingdom	Yes	A,B,C,D
BALTIC	Estonia	Yes	C,D
	Lithuania	No	-
	Latvia	Yes	D

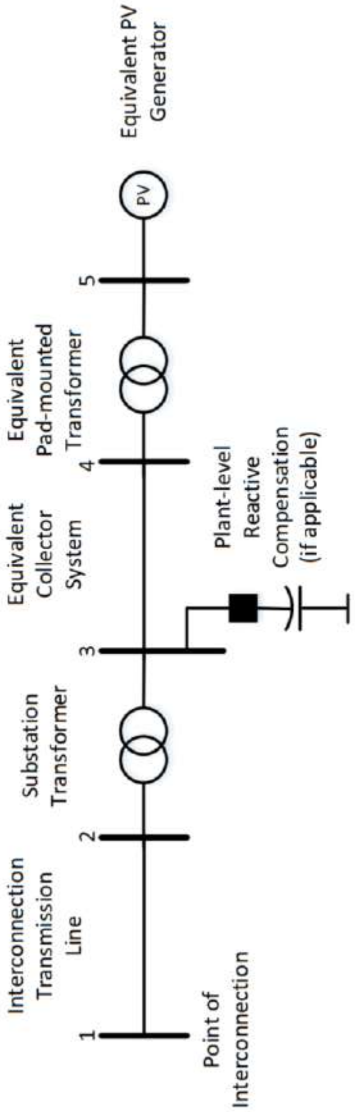
Types of Models Based on Use Cases & Accessibility



RE Plant Modelling:

Steady State

Key requirements from Steady State Model



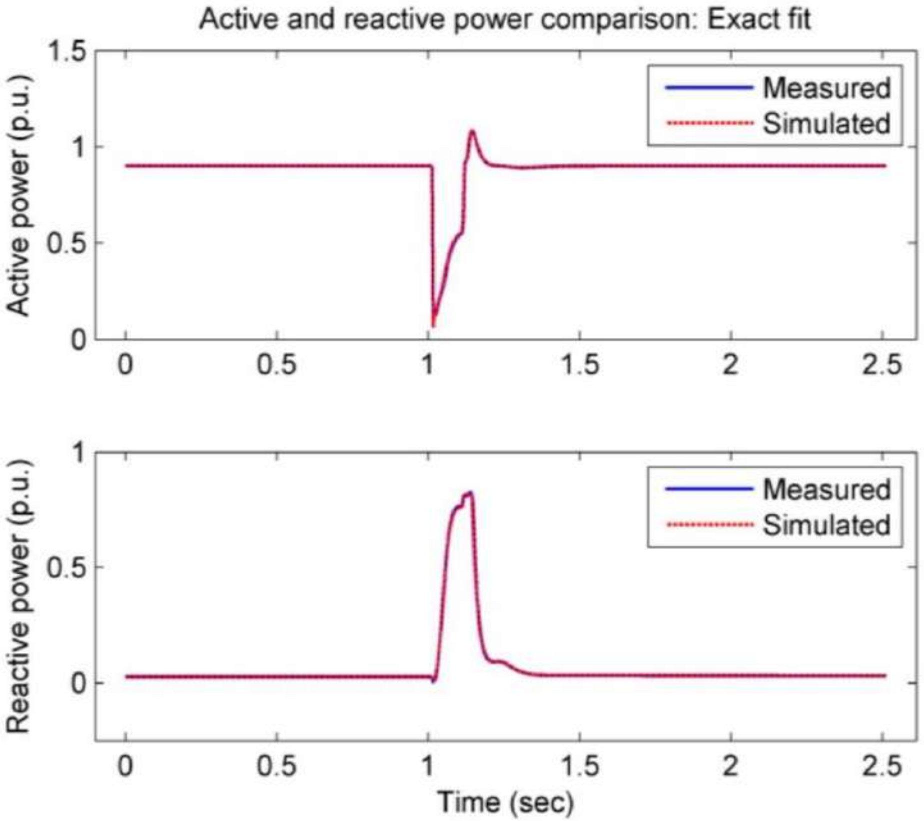


Fig.: Exact fit output comparison

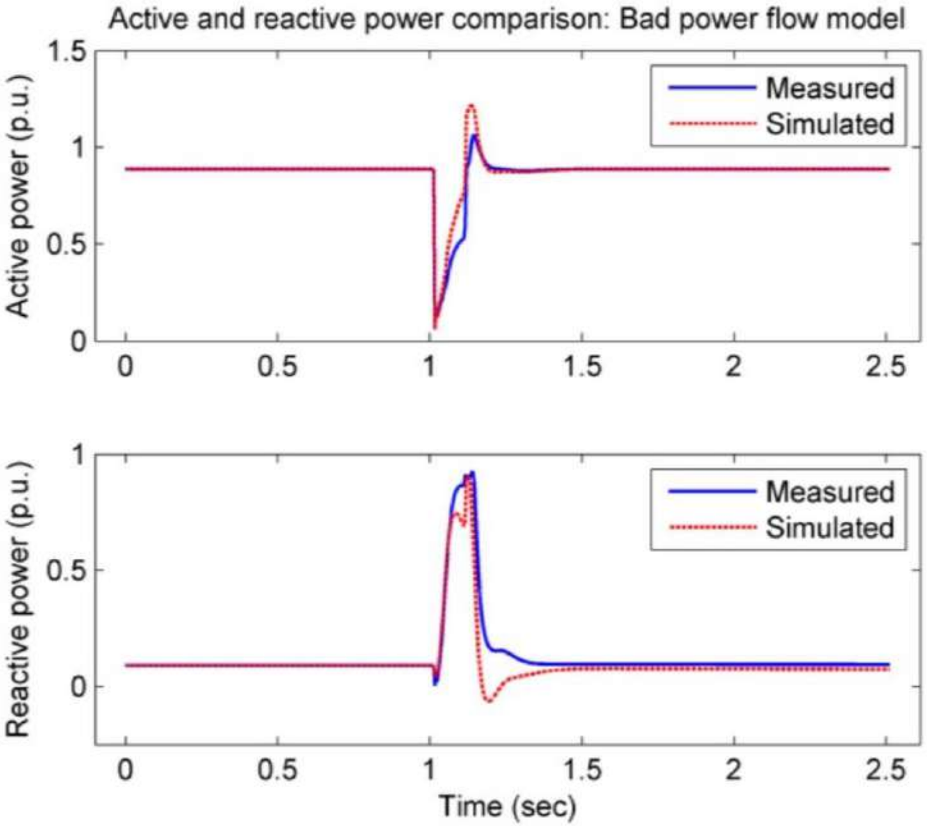


Fig.: Bad power flow model output comparison

Equivalent generator parameters & collector impedance must be correctly represented

RE Plant Modelling:
RMS & EMT

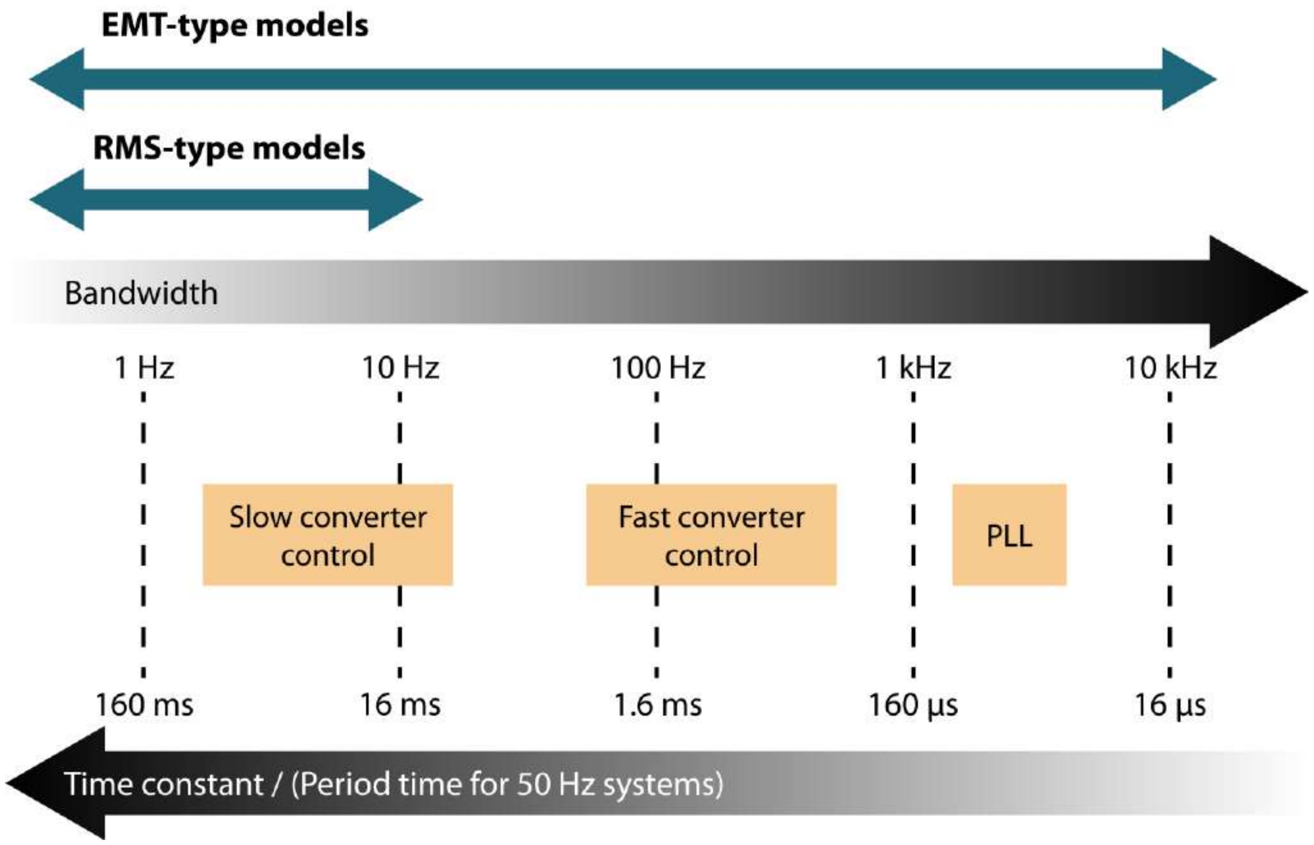
Introduction

RMS Simulation

Used for system integration studies and stability studies within a small frequency band around system's fundamental frequency

EMT Simulation

Required to study the effect of fast transients and electromagnetic interference, which require higher frequency components.



Range of Applicability

Global Practices for RMS & EMT Simulation: **Australia**

Australian Energy Market Operator **(AEMO)**

Key Requirements from Generators

To be submitted to AEMO and Network Service Provider

- ☑ Complete data sheets
- ☑ Site-specific RMS models including model block diagram and model source code
- ☑ Site-specific EMT models
- ☑ Releasable User Guide for both RMS and EMT models
- ☑ Pre-commissioning model confirmation test report prior to a hold point test
- ☑ R2 test report - Registered data after connection derived from on-system testing

Exemptions for Generators

Exemptions for Generators from providing full complement of plant models

Condition	Reason	Exemption for	
		RMS model	EMT model
Plant Size ≤ 5 MVA Connection point's aggregate SCR > 10	Less impact of proposed plant on network and surrounding plant Proposed plant unlikely to be impacted by low system strength	No	Yes
Plant Size < 1 MVA	Insignificant effect of proposed plant on network and surrounding plant	No	No

Requirements from RMS and EMT models

Model should work for a range of dynamic simulation parameters rather than specific settings

Numerical Stability

- Maintained under full operating range
- Maintained for wide range of SCR (min. 3), and grid & fault X/R ratio
- Stable operation up to at least five minutes of simulation time
- Avoid displaying characteristics absent in the actual plant response

Requirements from RMS and EMT models

Model Composition & Operating Range

- **Non-linearities**
  - Limits
  - Mathematical Functions
  - Saturation
  - Dead Bands
- **Steady state output & system strength levels performance**
  - Generating System
  - Reactive compensation
- **Plant response for set-point changes**
  - Active Power
  - Reactive Power
  - Power Factor
  - Voltage and Frequency
  - *Along with Associated Ramp Rates*
- **Representation of all plant components**
  - Generation & Bidirectional Units
  - Transformer
  - Governors
  - Compensation device
  - Park Controllers
  - Protection device

Requirements from RMS and EMT models

Model Composition & Operating Range

Requirement	Elements
Delays between plant elements impacting plant performance	SCADA; Park Controller; PLC; Communication Delay
Modelling of components impacting plant stability during disturbance	Mechanical components; Generating units; Bidirectional Energy Storage Components
Represent plant performance in normal dispatch range	Vary between maximum and minimum active power output; Initialise at any power dispatch within the provided range

Requirements from RMS and EMT models

Model Multiple Operating Modes & Control Functions

Representation of all modes of operation compatible with plant operation

- Q control
- V control
- $cos\phi$ control
- Frequency control and fast frequency response

Automatic changes to operating modes should occur within the model as they do in reality

Representation of simultaneous control functions

- Represent both active power control and frequency control operating simultaneously

Without changing model setup, variables or configuration parameters

Requirements from RMS and EMT models

Medium & Long-term Dynamics

Model adequate for simulation of response of individual plant equipment

Allowable controller time delay response up to 120 s

Equipment: *Onload tap changer controllers, turbine governors, over-excitation or stator current limiters and any other thermal, voltage or frequency related controller*

No disturbance during flat-run simulation

No disturbance study range: 10 to 300 seconds

Requirements from RMS and EMT models

Remedial Action Scheme: Designed to detect predetermined system conditions and take corrective actions, that may include, but are not limited to, adjusting or tripping generation (MW and MVAR), tripping load, or reconfiguring a system(s).

Remedial Action Scheme model Requirements

- Communication, measurement, filtering and processing delays
- Calculation algorithms and logic/tripping sequence
- Output actions including associated delays
- Monitoring of parameters, signals and status

❖ *Models must be represented by standard objects from library of relevant simulation software*

Key requirements from RMS models

- Model Bandwidth : 0.05 Hz to 10 Hz (for linear part of the response)
- Settle to correct final value for applicable system conditions and disturbance
- Approval required for special tunning of load flow case from AEMO and NSP
- Park controllers must remain functional when one or more (but not all) regulated plant elements are out of service.
- Rigorous testing of models required with a NEM-wide simulation for integration compatibility for large-scale power system studies

Key requirements from EMT models

- ☑ Model Bandwidth : At least DC to 10 kHz
- ☑ Settle to correct final value for applicable power system conditions and disturbance
- ☑ Detailed representation of plant's inner and outer control loops
- ☑ Represent all electrical, mechanical, & control features relevant to study (external voltage controllers, plant level controllers, customized PLLs, ride-through controllers, SSCI damping controllers or others)
- ☑ Fully represent switching algorithms of power electronic converters for harmonic studies
- ☑ Operate with a time-step greater than or equal to 1μsec, ideally consistent with plant switching frequency
- ☑ Capable of self-initialisation, to user defined terminal conditions within 3 seconds of simulation time

Global Practice for RMS & EMT Simulation: **Denmark**

TSO: Energinet

Model Requirement Based on Generation Type

Generation facility types	Generation facility type	Model Required		
		RMS model	EMT model	Harmonic Simulation model
Type A	$V_{connection}$ < 110kV $11\text{kW} < P_{max} \leq 50kW$	No	No	No
Type B	$V_{connection}$ <110kV $50\text{kW} < P_{max} \leq 1.5MW$	No	No	No
Type C	$V_{connection}$ <110kV $1.5\text{MW} < P_{max} \leq 25MW$	Yes	No	No
Type D	$V_{connection}$ > 100kV	Yes	Yes	Yes
	$V_{connection} \leq$110kV P_{max} >25MW			

General Simulation model requirements

Models submitted to TSO

- Steady State model
- Quasi-Steady State model
- RMS model
- EMT model

- ☑ Facility owner must verify simulation models with compliance test results
- ☑ External components need to be modelled if they are installed in plant
- ☑ Updated model must be shared if significant modifications are made in existing generation facility
- ☑ Model is deemed complete once it is approved by TSO

General Simulation Model User Guide Provided by Generation Facility

- Single-line representation of the simulation model's electrical main components up until POI
- Description of model's electrical input & output signals, including measuring point, units, and base value
- Provide a comprehensive parameter list with all values in the enclosed data sheets.
- Description of structure and activation levels of protective functions used
- Description of set-up and initialisation of the simulation model as well as any limitations to the application
- Description of structure and activation levels of protective functions used
- Description on model integration into a large grid and system model of the public electricity supply grid

RMS model requirements

Model Representation & Operation	Operation in all normal operating conditions and disturbances Ability to represent generator's dynamic properties in case of grid events
Model Component Description	Saturation; Non-linearity; Dead band; Constraint functions; Time Delays; Look-up tables; Principles applied to interpolation
Model Input & Output Component Description	Active Power; Reactive Power; Activation signal for system protection; Control signals for external grid components (STATCOM, Storage, etc)
Set point requirements	Active Power control; Reactive Power control; Voltage control; Frequency control; System protection measures

RMS model requirements

Requirement	Details
Protective & Control Functions Requirement	Protective functions activated by external grid events Control function for Fault ride through properties
Mechanical mass model requirements	Inertia constant Natural frequency Spring and damping constants
Frequency and Voltage Range	Frequency Range: 47.5 Hz to 51.5 Hz Voltage range: 0 to 1.4 pu
Dynamic operating range requirements	Generation facility's dynamic properties description after set point change: 60 sec Sample lengths for numerical equation solvers: 1 to 10 msec

EMT model requirements

- ☑ EMT model requirement is for each generation unit
- ☑ Model Initialization time duration: 3 seconds
- ☑ Representation of all components, control systems , protection system
- ☑ Locally or Remotely adjustable control system settings of model
- ☑ Modelling of each grid components connected in plant (STATCOM, cables, transformers, filters, etc)
- ☑ Generation facilities with a grid-connected converter must be modelled at transistor level for a proper representation in transient studies
- ☑ EMT model must represent the generation facility's FRT properties
- ☑ Model must be usable for EMT simulations of balanced and unbalanced faults and interruptions of generation facility's connection

Global Practice for EMT Simulation: **California**

California Independent System Operator (CAISO)

EMT Model Requirements

Control loops requirements for power electronics

- Detailed fast inner controls required as implemented in installed equipment
- Approximate transient response modelling not allowed

Model Representation

- IGBT model representation preferred
- Average source representation approximating IGBT switching is acceptable if it maintains detailed inner controls and DC side protection

Control Features & Model Requirements for Study

Represent all control features pertinent to the type of study being done, including

- External voltage controllers
- Plant level controllers
- Ride-through controllers
- SSCI damping controller
- Customized PLL systems
- All other relevant controllers

EMT Model Requirements

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Operating Mode

- Operating modes requiring system-specific adjustments should be user accessible
- Represent plant-level voltage control with adjustable droop characteristics
- Use model parameters reflecting actual installed settings, not manufacturer default settings

- ☑ Represent ability to enable and disable Sub-Synchronous Oscillation (SSO) mitigation and/or protection, if applicable
- ☑ Represent dynamic reactive devices likeautomatically controlled capacitor and reactor banks
- ☑ Representation of all components, control systems , protection system
- ☑ Represent all pertinent electrical and mechanical configurations, such as filters and specialized transformers
- ☑ Include mechanical features (e.g., gearboxes, pitch controllers) in model if they affect electrical performance
- ☑ Represent all installed protection systems in detail for both balanced and unbalanced fault conditions
- ☑ Accurately reflect behaviour across the entire MW and MVAr output range, from minimum to maximum power

EMT Model Requirements

- ☑ Accurately reflect behaviour across entire MW and MVAr output range, from minimum to maximum power
- ☑ Model capable of running at time steps anywhere in the range from 10 μs to 20 μs
- ☑ Models should initialize by itself and ramp to full output without external input from simulation engineers
- ☑ Model should accept and dynamically change reference set point variables if required in mid-simulation
- ☑ Ability to dispatch to values less than nameplate (for testing plant behaviour at various operating points)
- ☑ Initialize as quickly as possible (for example < 5 seconds) to user supplied terminal conditions

Model Validation

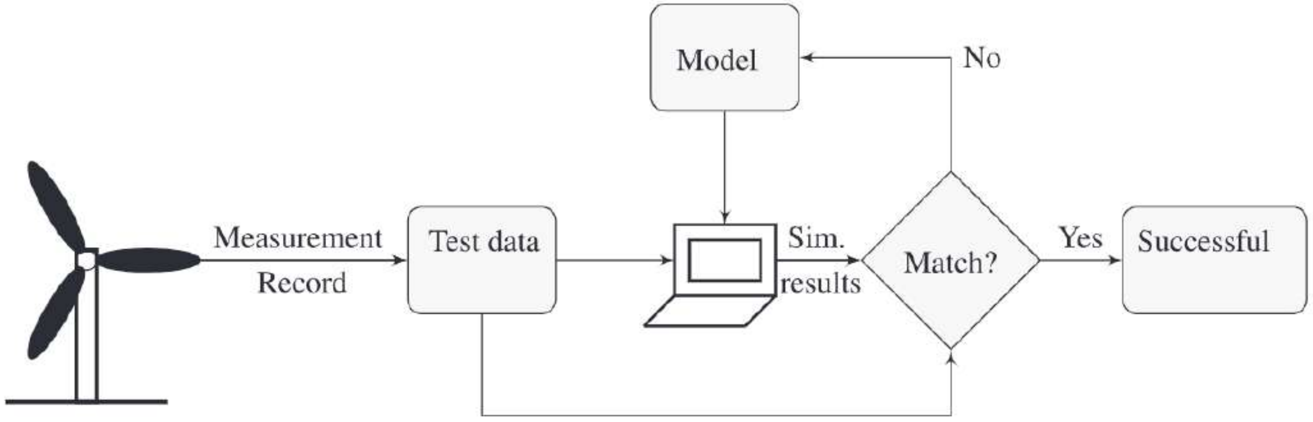
Background

Purpose

Ensure correct performance of control systems and validate simulation models used for stability analysis

Steps necessary to evaluate correspondence of model with reality

1. Collect actual measurement data from the device under modelling
2. Simulate same set of events that happened originally and obtain measurement data
3. Match measurement data and simulation data
4. Model is validated if the match is successful



Global Practice on Model Validation: **Australia**

Model Validation: AEMO

Model is rigorously derived from design information and its performance is confirmed against actual plant response

For plant expected to have limited foreseeable impact on surrounding network and nearby plant, model validation requirements may be relaxed by AEMO and NSP

Pre-connection model confirmation

Requirement of OEM confirmation by AEMO by factory or laboratory testing

- Connections are proposed to areas with low system strength where standard plants may not suffice
- Plant is designed to provide functionality not offered previously
- New plant is introduced to the NEM with unexpected or inferior modelling responses

Principles applicable for pre-connection model confirmation tests

- ☑ Application of two-phase ground or three-phase fault equivalent disturbance as experienced by generating units on installation
- ☑ Tested fault levels & network impedances should be close or lower than experienced by the plant
- ☑ Individual item of plant tested is identical to the ones to be installed
- ☑ Adjust control systems or settings if EMT-type model shows unexpected responses and characteristics
- ☑ Model response should be generally aligned with expected response
- ☑ Tests should cover pre-disturbance active and reactive power levels across various operating conditions

Post-connection model validation

R2- Registered data after connection, as derived from on-system testing

R2 model validation ensures submitted models meet quality standards for secure grid operation

Simulation tools required for R2 model validation

	RMS	EMT	Harmonic
Reactive Power Capability	Yes	No	No
Quality of electricity generated	No	Maybe*	Yes
Response to frequency disturbances	Yes	No	No
Response to voltage disturbances	Yes	Yes	No
Response to disturbances following contingency events	Yes	Yes	No
Quality of electricity generated and continuous uninterrupted operation	No	Yes	No
Partial Load Rejection	Yes	No	No
Protection from power system disturbances	Yes	Yes	No
Frequency control	Yes	Yes	No
Impact on network capability	Yes	No	No
Voltage and reactive power control	Yes	Yes	No
Active Power Control	Yes	Yes	No

**only if harmonic simulation model fails to provide required accuracy*

Accuracy Criteria

Following key features needs to be in following tolerance limits

- ☑ Rapid changes in actual response must be within ±10% for 95% of samples within transient window
- ☑ Difference between start and finish of rapid slope should be less than 20 milliseconds
- ☑ Peak and trough sizes during rapid events must be within 10% of total change for 95% of the samples within transient window.
- ☑ Oscillations in plant response must exhibit damping and frequency within 10% of simulated response for 95% of samples within transient window
- ☑ Maximum of 10% from simulated responses for 95% of the samples within the transient window, for both active and reactive power is allowed

Global Practice on Model Validation: **Denmark**

Verification of simulation model

Generation facility owner verifies simulation model for overall facility, including all required control modes and static and dynamic properties through set point changes and external incidents in grid

Model verification relies on measuring results from type tests or compliance tests during commissioning of generation facility to ensure functional requirements and simulation accuracy

Generation facilities model verification must occur at an aggregate level to represent all properties at POI

Required signals for verification of asynchronous generation facilities

Required Signals for Validation	Point of measurement
Active Power	1. Measured at POI 2. Measured on primary side of generator transformer
Reactive Power	
Phase Voltage	
Grid Frequency	
Phase Current	
Phase Current (active & reactive component)	Measured on primary side of generator transformer

- Setpoints for P control, Q control, Power factor control, Voltage Control, Frequency Control
- Signal for activation of system protection
- Control signals for activation of fault ride through functions

Accuracy requirements in connection with external incidents in grid

Permissible deviations in below table for specified electrical signals are relative to generation facility base values of rated active power and nominal current.

		Synchronous and negative-sequence components											
		Active power			Reactive power			Power (active component)			Power (reactive component)		
		MXE	ME	MAE	MXE	ME	MAE	MXE	ME	MAE	MXE	ME	MAE
Permissible deviation	Pre-fault	0.150	±0.100	0.120	0.150	±0.100	0.120	0.150	±0.100	0.120	0.150	±0.100	0.120
	Fault	0.170	±0.150	0.170	0.170	±0.150	0.170	0.500	±0.300	0.400	0.170	±0.150	0.170
	Post-fault	0.170	±0.150	0.170	0.170	±0.150	0.170	0.170	±0.150	0.170	0.170	±0.150	0.170

- **MXE** - Maximum deviation (maximum error)
- **ME** - Average deviation (mean error)
- **MAE** - Mean absolute error

Accuracy requirements in connection with facility's operating point

To ensure an objective assessment of simulation model accuracy, quantitative requirements for the generation facility's step response must meet the specified deviations in below table

	Rise time	Reaction time	Settling time	Overshoot	Steady state
	$X_E = X_{sim} - X_{measured}$	$X_E = X_{sim} - X_{measured}$	$X_E = X_{sim} - X_{measured}$	$X_E = X_{sim} - X_{measured}$	$X_E = X_{sim} - X_{measured}$
Permissible de-viation	< 50 ms	< 50 ms	< 100 ms	< 15%	< 2% of P_{rated}

- X_E – Error Value
- X_{sim}- Simulated Value
- $X_{measured}$ – Measurement Value

Global Practice on Data Measurement: **Australia**

Information to be provided to AEMO and NSP on measurement equipment and its location

- Manufacturer, model and serial number of the equipment.
- Recommended Generators use instrument transformers with a higher accuracy class to minimise the errors
- Measurement equipment need to keep record for past seven years

Location of measurement equipment

- Connection point or HV terminals of plant transformers
- MV collector bus to which the generating units are connected
- One measurement device for each different type of generating unit
- Most common generating unit type would need to have high-speed data recorders at both the electrically closest and furthest generating units with respect to the MV collection grid

For e.g., a WPP with (30) x 3 MW type 3 WTGs, (15) x 3 MW type 4 WTGs, and (15) x 2 MW type 4 WTGs would require 2 high-speed data recorders for the 3 MW type 3 WTGs, and 1 for each of the other two types.

Information to be provided to AEMO and NSP on measurement equipment and its location

Location of measurement equipment

IBR-based generation technologies having generating units with multiple LV terminals (e.g. some designs of doubly fed asynchronous units have 2 LV terminals). Measurement locations for such technologies are expected to cover both LV terminals.

Each type of dynamic reactive support device, such as STATCOMs and synchronous condensers

Central park level controller

Typical sampling rate of such measurement equipment is over 10 kHz for IBR

Data to be made available to AEMO and NSP

- All pre-processed measurement (raw) data with minimum resolution of 100 Hz for electrical quantities and 1 kHz for control signals
- Signals to be measured at each measurement location
- Provide details on how measurement results will be synchronized to a GPS clock when multiple recorders are used
- Measured voltages and currents must be available in three-phase instantaneous waveforms, three-phase root mean square (RMS), per-phase RMS
- Measured reference signals (*Vref*, *Qref*, *Pref*, *Fref* etc), irradiance, wind speed and temperature

Global Practice on Data Measurement: Denmark

Fault Recording Equipment Settings

Fault recorder settings, including triggering criteria and sampling rates, to be agreed upon by facility owner, system operator, and TSO

Logging must be done with electronic equipment capable of logging relevant incidents for the specified signals at the point of connection during faults in the public electricity supply grid.

The facility owner must install logging equipment (fault recorder) in POI which records at least :

- Voltage of each phase of the facility
- Current of each phase of the facility
- Active power of the facility (can be computed values)
- Reactive power of the facility (can be computed values)
- Frequency of the facility

Other Requirements

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- Electronic logging of frequency deviations, internal protective function activations, & specific measurements as per grid connection agreement
- Correlated time series logging from 10 seconds before to 60 seconds after an incident
- Minimum sample frequency for fault logs: 1 kHz.
- Incident-based logging settings agreed with the transmission system operator
- All measurements logged with timestamp and accuracy for correlation with grid recordings
- Logs retained for at least three months, with a maximum of 100 incidents recorded
- Access to logged information granted to electricity supply undertaking & TSO upon request

Frequency Measurement Requirements

- Frequency change calculated from mean value over a 200 ms period.
- Continuous frequency measurements with calculation every 20 ms.
- Frequency measurements with ± 10 mHz accuracy or higher.

Questionnaire for Renewable Energy Stakeholders in India

Final Questionnaire_v3.pdf

THANK YOU