Annexure-I (E) (a): Guidelines for Model Compatibility and Support, IBR Testing and Certification, PPC Technical Requirement, Model Benchmarking and Validation Report

1. Model Compatibility and Support Guidelines:

i) Following RMS and EMT models along with detailed model user guide shall be submitted for the Wind/Solar/BESS/Hybrid Plant:

Type of Model	Description
RMS (Root Mean Square)	**IBR Unit Model**
	Detailed Plant Model (including PPC model)
	Equivalent[1] Plant Model (including PPC model)
EMT (Electro Magnetic Transient)	**IBR Unit Model**
	Equivalent Plant Model (including PPC model)
	Power Quality Assessment Model

ii) The models shall be compatible with the power system software simulation products as specified by Grid-India (formerly POSOCO) below: -

a) RMS models shall be compatible with **PSS/E version 35** and above.

Provided that the concerned RLDC may accept the model compatible with version 34 also under special circumstances. The decision in this regard will be at the discretion of the concerned RLDC only.

The RMS models are required to be **generic**[2] models and shall not contain any encrypted or compiled parts, as the system operator must be able to maintain the same without the restrictions of software updates etc.

If there is significant difference in the actual performance of the plant vis-à-vis the response of the generic model, then **user defined model (UDM)** shall also be submitted in addition to the generic RMS model.

[1] **Recommended procedure for calculating the equivalent collector impedance -** E. Muljadi, S. Pasupulati, A. Ellis, D. Kosterev, "Method of Equivalencing for a Large Wind Power Plant with Multiple Turbine Representation", presented at the IEEE Power Engineering Society, General Meeting, Pittsburgh, PA, July 20-24, 2008.

Annexure-I (F) may also be referred for single generator equivalent model configuration.

[2] **Annexure – I(C), I(D) and I(G)** may be referred for submitting generic RMS modelling data of Wind, Solar and BESS respectively.

In case of submission of User Defined Models (UDMs), the submission of the **source code and compiling procedure** along with the model is mandatory.
Further, a comparison report highlighting the difference between the simulation response obtained from Generic and UDM for the tests specified in **Part-B (point 3 onwards) of Annexure-I (E)** shall be required in case of UDM submission.

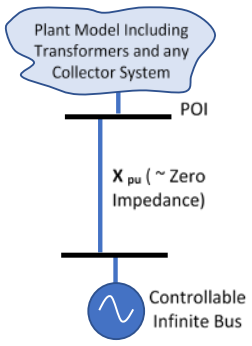
b) EMT models shall be compatible with PSCAD version 4.6.3 and above with the following –

i. Intel 15 Update 5 and newer (32-bit) and Visual Studio 2015 and newer and
ii. Intel 15 Update 5 and newer (64-bit) and Visual Studio 2015 and newer
iii. Model works across a range of time steps and does not require a specific time step

These models must not be dependent on a specific Intel Visual FORTRAN version and should not have dependencies on additional external commercial software.

iii) The plant simulation models (applicable for generic and UDMs) shall:

a) Be able to accurately represent the characteristics of the generating station at the point of inter-connection (POI). The POI bus can be connected to controllable infinite bus whose voltage and frequency can be adjusted to regulate the POI bus fault level, SCR etc. for verification/testing of compliances. A typical representation is as below:



For Short circuit ratio (SCR), following formula can be used-

$$\boldsymbol{X_{pu} = \frac{100}{MW_{Capacity} * SCR}}$$

Where,

$\boldsymbol{MW_{Capacity}}$ = Total MW capacity of generator(s) under study
$\boldsymbol{SCR}$ = Desired short circuit ratio to test
X_{pu} = Per unit line reactance, on a 100 MVA system base

b) Be supported by model descriptions that, as a minimum, shall include Laplace domain transfer functions (for RMS models), and function descriptions of the arithmetical, logical and sequence-controlled modules used in the simulation model.

c) Include descriptions of the individual model components and related parameters including saturation, non-linearity, dead band, time delays, polling rates, and constraint functions (non-wind-up/anti wind-up) etc.

d) Include descriptions of the set-up of the simulation model as well as any limitations to the application thereof. There shall be no initialization errors for the dynamic models. The warning messages shall be reviewed and resolution or explanation shall be provided.

e) Work for a range of dynamic simulation solution parameters rather than for specific settings only.

f) Be numerically stable for the full operating range including a wide range of grid SCR.

g) Include all relevant control and protection settings i.e. the models shall have all pertinent protection systems modelled in detail for power system transient and voltage stability analysis, including balanced and unbalanced fault conditions, frequency and voltage disturbances. Provision for disabling/modifying the protection systems shall be provided. Further, protection settings like K-factors, LVRT, HVRT, frequency settings, over/under voltage, momentary cessation, ramp rates, local control modes, enable/disable local remote-control mode etc. shall be available to user. MW, MVAR, Voltage Ratings of IBRs & other components shall be clearly included.

h) Evacuating transmission line shall be modelled as frequency dependent (phase) model with tower geometry.

i) Plant controllers input, output parameters/reference parameters etc. shall be available to user for view & modification using GUI. Important control functions enable/disable feature shall be available in plant controllers.

j) Accurately represent any time delay due to PPC or IBR processing time, polling rates, communication delay etc.

iv) Any model validity limitations due to system impedance or strength or any other reason shall be clearly defined.

v) Models shall not show any characteristics that are not present in the actual plant response.

vi) **Model user guide** including model setup procedure, RMS & EMT software version, compiler, visual studio version etc. shall be submitted along with the model.

vii) Description of IBR and plant level settings with units and range of adjustability for any applicable settings shall be included.

viii) Model limitations, maximum solution time step etc. to be included in user guide

ix) EMT model shall not contain any dependant libraries. The submitted workspace file (.pswx) must not load any PSCAD library (.pslx) files apart from the PSCAD master library. The model shall be capable of running with no extra steps aside from clicking "Run" option in PSCAD. EMT model shall have snapshot capability.

x) **Model Aggregation –** The aggregated/equivalent[3] model shall be developed using the benchmarked IBR unit model (benchmarking guidelines provided in subsequent section).
The aggregated/equivalent model must:

a) Supported by documentation which shall include descriptions of the principles used for aggregation and any limitations on the use of this.

b) Any switching controls like OLTCs, FACTs or filter banks etc. used in the plant shall be included in model along with switching logic.

c) Ensure that aggregation is not used to combine power system elements of different types or makes and shall have accurate representation. There might be some generation plants that consist of individual installations of multiple types (e.g. hybrid plants comprising of a combination of wind, solar, storage etc.) or make (e.g. solar plants with inverters of different make or wind plants with WTGs of different make) but come over as an aggregate generation facility at the POI. The model aggregation for such plants shall be carried out separately for each type of individual installation (e.g. separate aggregation model for solar, wind, storage installation etc.) and for each make of individual installation (e.g. one separate aggregated model for each make of inverter/WTG) so that the modelling of these individual installations of different types/make can be verified separately. Further, any representation due to permanent bus split arrangements in the collector system shall be suitably incorporated.

d) The generation plant shall be dispatched at full real power output and the Point of Interconnection (POI) bus voltage is initialized to nominal 1.0 per-unit unless the test requires otherwise. The initial reactive power exchange at the POI should be near zero unless the test requires otherwise.

[3] **Recommended procedure for calculating the equivalent collector impedance -** E. Muljadi, S. Pasupulati, A. Ellis, D. Kosterev, "Method of Equivalencing for a Large Wind Power Plant with Multiple Turbine Representation", presented at the IEEE Power Engineering Society, General Meeting, Pittsburgh, PA, July 20-24, 2008.

e) Station transformer taps and static switched shunts should be initialized to a nominal position appropriate for the initial POI voltage and real power dispatch.

f) Aggregate Generation Resources, such as wind and solar, should be represented by a single equivalent aggregate model and include a representation for the collector impedance and pad-mount transformer. Multi-unit aggregated representation due to different make/model of IBRs & permanent bus split arrangements in the collector system shall be suitably incorporated along with accurate representation with dynamic models.

g) Explicit frequency protection relay models shall be provided for all IBRs where relays are set to trip.

h) Explicit voltage protection relay models shall be provided for all IBRs where relays are set to trip the resource.

2. IBR Unit Testing, Certification and Report Submission Guidelines:

i) Statement of Compliance (SoC) or Evaluation report shall include the final firmware/controller software version etc. for which the IBR is tested & certified.

ii) If there is any upgrade in the firmware/controller software version w.r.t. the tested IBR unit, the same shall be certified/approved by the Accreditation agency and the relevant changes shall be clearly highlighted in the evaluation report.

iii) Testing of IBR shall be carried out for extreme voltage, frequency, power factor, other parameters (terminal level settings shall be coordinated w.r.t. compliance of extant CEA Technical Standards at POI) etc.

For e.g. Compliance of continuous operation of the plant at 1.1 p.u. voltage at POI may result in continuous operation of individual IBRs at voltage >1.1 p.u. Therefore, design and testing of IBRs shall be carried out so as to factor in the maximum voltage difference between POI and IBR terminal.

iv) Assessment of behaviour of IBR unit during and after the fault shall be stable and shall not cause any abnormal behaviour.

v) Final list of protection settings kept in IBR unit during testing shall be included in the evaluation/measurement report. Further, configurable range of settable parameters shall also be specified.

vi) Actual LVRT & HVRT capability curve along with Reactive Power Capability Curve of IBR unit shall also be included in measurement/evaluation report.

vii) Control Response time[4] of the IBR unit during transient condition shall preferably be in the range of 20 – 40 ms.

viii) IBR unit shall be able to operate in coordinated Q/V control with PPC and provision for the same shall also be tested.

[4] **Control Response Time** is the time between the step change in a system quantity measured at a defined location and when the output of the system reaches 90% of required output change, before any overshoot.

Reference: IEEE Standard (2800-2022) for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems

3. IBR Unit - Model Benchmarking

The response of IBR unit simulation model (RMS and EMT both) shall be benchmarked against lab/factory/field test results for all the technical requirements specified in CEA's *"Technical Standards for Connectivity to the Grid, 2007"* and subsequent amendments. Before testing, the IBR unit models (both RMS & EMT) shall be tuned such that error w.r.t. lab/factory/field test results is minimum.

These results shall be submitted as benchmarking report which shall include the following:

i) For RMS models, a table of all simulation model parameters - STATEs, VARs, CONS, ICONs, their values as implemented in the dynamic data files and a description of each function.

ii) For EMT models, provide a table of all user-definable settings and status code outputs for all plant within the generating system, a range of acceptable values for each user-changeable variable and a description of each entry's function.

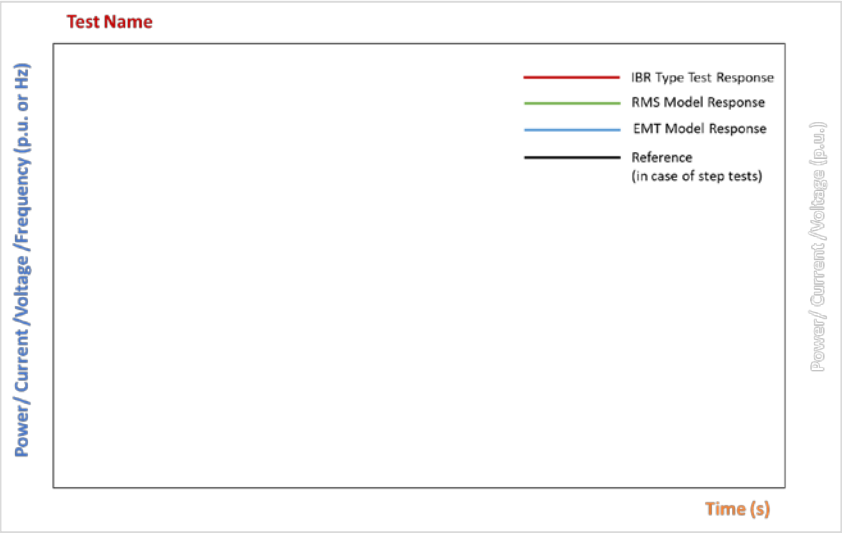
iii) Software version of controller & Firmware version of converter unit shall be mentioned.

iv) Lab/factory/field test reports shall be referenced in the benchmarking report.

v) The settings kept in IBR unit during testing & actual unit installed at site must be kept same. A table demonstrating the similarity between simulation model parameters/settings and tested IBR unit shall be provided.

   If there is any mismatch in settings, justification for the same shall be included.

vi) Comparison of type/lab/factory test measurement with simulation results as per the format shown below.



- The tests to be conducted are mentioned in **Point – 5 to 7 of Annexure – I (E).**
- **The testing methodology specified in Annexure- I (E)** shall be applicable for the purpose of benchmarking also.

vii) Along with graphical comparison of lab/factory/field test measurement with simulation results, time series measurements/data of lab/factory/field test and simulation response (of same time resolution) shall also be provided in suitable soft format (preferably .csv file).

viii) Inverter/WTG unit model files which shall include .sav, .dyr, .py, .idv, .sld, .out files and PSCAD .pscx and other supporting files shall be provided along with the benchmarking report.

Note: The benchmarked single inverter / WTG models shall be used for preparing the detailed and equivalent models of the plant.

4. Power Plant Controller (PPC) – Technical Requirement

a) PPC shall be certified by an Accredited agency.

b) Simulation models (both EMT & RMS) of PPC shall also be benchmarked.

5. Plant Model Validation Report

Post-commissioning of the complete RE plant, the response of models (RMS and EMT both) shall be validated against field measurements/on-site test results and validated models along with the validation report shall be submitted within 03 months of the complete commissioning RE plant. The guidelines to be followed for model validation are given below:

i) For LVRT and HVRT, the response of the models (RMS and EMT both) shall be validated preferably against field test results. In case the same is not possible within prescribed time-frame, the plant model shall be validated against grid event, if any, after complete plant commissioning and same shall be included in the validation report.

ii) For all other tests mentioned in **Annexure – I (E) Point – 5 to 7**, the response of the models (RMS and EMT both) shall be validated against field measurements/on-site test results. **The testing methodology specified in Annexure- I (E)** shall be applicable for the purpose of model validation also.

iii) The validation report shall include the following:

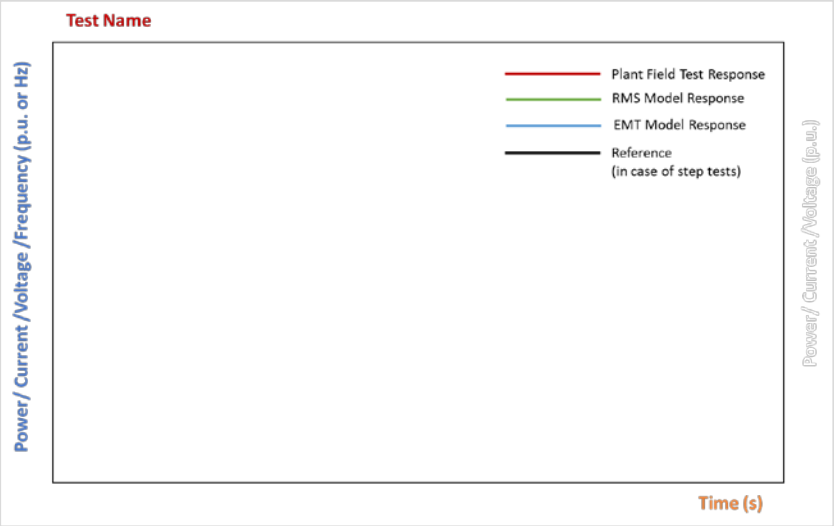
a. Model file names of RMS & EMT model.

b. Final simulation model parameters of Generator model, Electrical control model, drive train model, PPC etc. (for both RMS & EMT model).

c. The settings kept in inverter/WTG units as well as PPC during testing shall be same as the settings implemented at site. The table demonstrating the similarity between simulation model parameters/settings and settings implemented at site shall be provided.

d. Table for inverter/WTG unit controller setting and RMS & EMT model parameter for different control parameters (for both RMS & EMT) shall be provided.

e. Comparison of field measurement/on-site test measurement with simulation results as per the format shown below.



f. For model validation, all the field test signals shall be measured at point of inter-connection.

g. Along with graphical comparison of field test measurement with simulation results, time series measurements/data of field test and simulation response (of same time resolution) shall also be provided in suitable format (preferably .csv file).

h. Model Validation report shall provide details of the causes of deviation from simulated behaviour and suggest corrective actions.

iv) Actual/implemented controller and protection settings of IBR units, PPC and other elements as downloaded from control software shall be provided as per the format specified in **Annexe-I(E)(b).** These settings shall be signed by company's (RE Developer) authorized official.