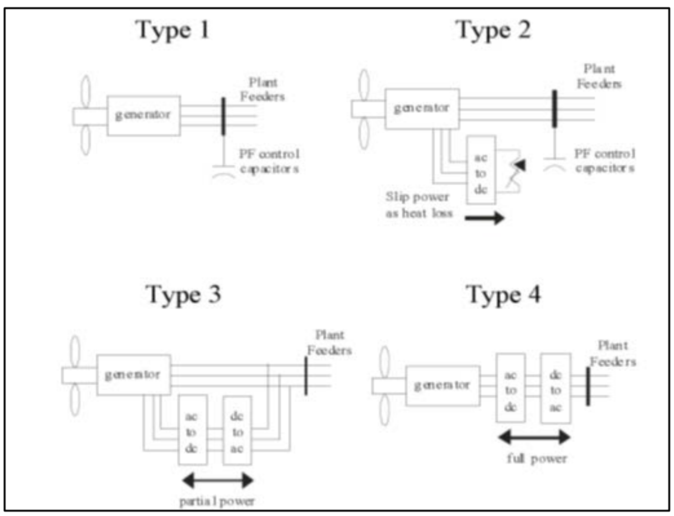
Annexure-I(C): Guidelines for Exchange of data for RMS modelling (Generic) of Wind Generating Stations

1. Wind generation technologies:

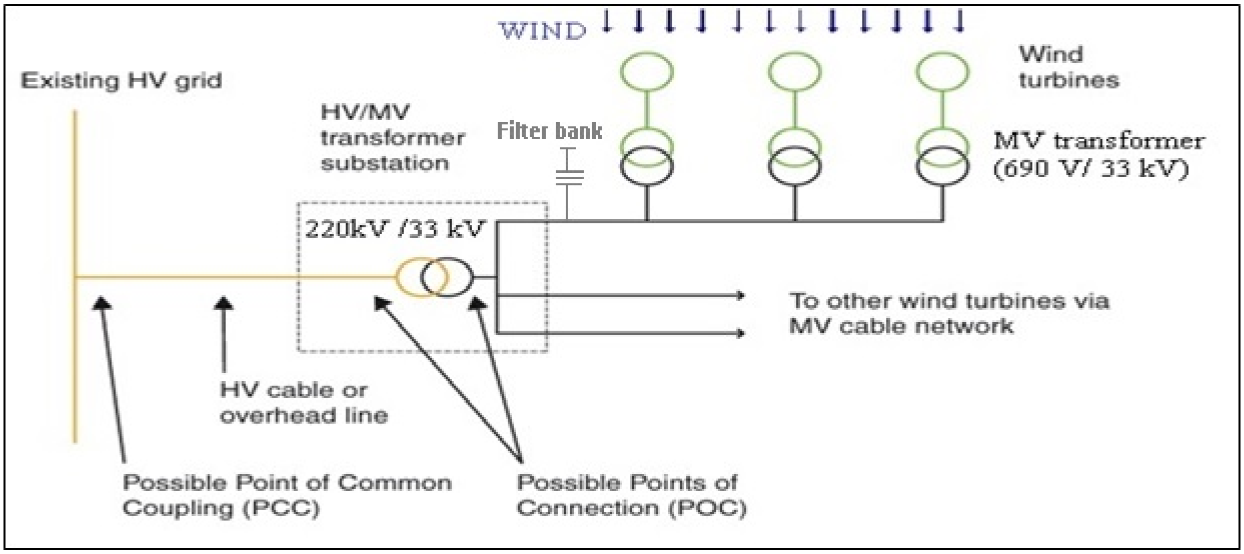
The majority of commercially available wind power plants use one of the wind turbine-generator (WTG) technologies listed below:

- Type-1 : Direct connected (Squirrel cage) induction generator (SCIG)
    - Fixed Speed stall control
    - Fixed Speed Active control
- Type-2 : Wound rotor induction generator (WRIG) with a variable resistor in the rotor circuit
- Type-3 : Doubly fed induction generator (DFIG) wind turbines ; Variable speed with rotor side converter
- Type-4 : Full converter wind turbine
    - Synchronous generator
    - Permanent Magnet Generator (PMG)



Wind energy plants are being increasingly coupled with complimentary Battery Energy Storage Systems (BESS) to reduce the variability of net power output from the renewable energy plant, provide higher output, or provide complimentary grid services such as frequency regulation. Modelling batteries / storage devices assume importance in such cases to capture the net impact of the plant on grid.

2. Models for Wind generators:

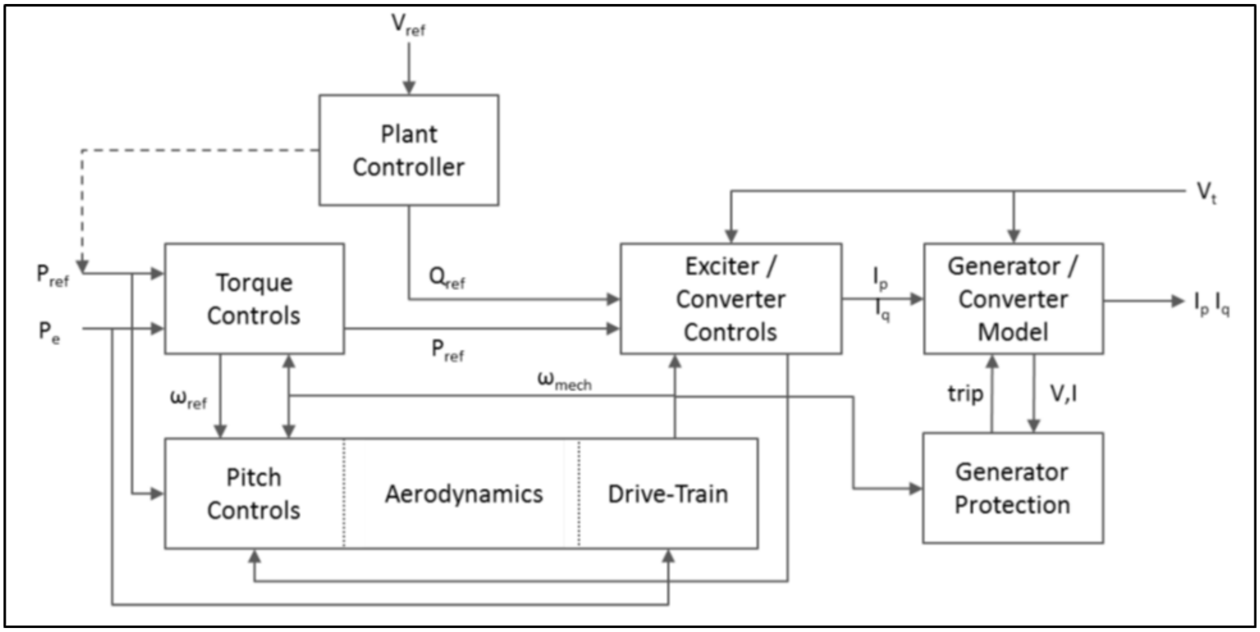


In a typical wind farm / park, individual WTGs (typically rated 3 MW or less) are connected in a system of twigs and feeders. Wind generation at around 660 V / 690 V is stepped up to a MV level of typically 33 kV in Indian system and finally pooled to grid at 220 kV / 400 kV through step-up transformers. A typical wind farm of 300 MW will be spread over an area of 600 acres, and power transmission within the farm is typically at 33 kV through overhead lines or underground cables. A Power Plant controllers (PPC) is usually installed at the point of interconnection to grid or at the reticulation system. The PPC(s) control behavior of wind farms in accordance with mandates as per grid codes.

The dynamic components of a wind farm consists of the following elements (illustrated in picture below):

1. Generator or Converter
2. Electrical control
3. Drive-Train model
4. Aerodynamics
5. Pitch controller
6. Torque controller
7. Power Plant Controller (PPC)
8. Energy storage (As applicable)

The components may or may not be present depending on the nature of technology used for wind power generation (i.e. type of turbine). Depending on the nature of technology, usage/configuration of components at site ('As built'), the requirements for steady state and dynamic modelling evolves.



3. Generic models in PSS/E for different technologies of Wind Turbines

Wind Turbine type	Technology	Generic model	Model Description
Type-1	Direct connected (squirrel cage) induction generator (SCIG) a) Fixed Speed Stall Control b) Fixed Speed Active Control	WT1G1	Generator model (conventional induction generator)
		WT2T1	Drive train model (two-mass drive train model)
		wt1p_b	Pitch controller *(Use only for Type 1 with active stall)*
Type-2	Wound rotor induction generator (WRIG) with a variable resistor in the rotor circuit, and typically employs pitch control	WT2G1	Generator model (induction generator with external rotor resistance
		WT2E1	External resistance controller
		WT12T1	Drive train model
		wt1p_b (no equivalent in PSS/E)	Pitch controller
Type-3	Doubly fed induction generator (DFIG) wind turbines ; Variable speed with rotor side converter	REGCA1	Renewable energy generator converter model
		REECA1	Renewable energy controls model
		WTDTA1	Drive train model

Wind Turbine type	**Technology**	**Generic model**	**Model Description**
		WTARA	Wind turbine aerodynamic model
		WTPTA1	Simplified pitch controller model
		WTTQA1	Wind generator torque control
		REPCTA1	Renewable energy plant controller
Type-4	Full converter wind turbine Generator types: a) Synchronous b) Permanent Magnet type	REGC	Renewable energy generator converter model
		REEC	Renewable energy controls model
		WTDTA1	Drive train model
		REPCA	Renewable energy plant controller
Storage	Utility Scale Battery Energy Storage System (BESS)	REECCU	Electrical Control Model (To be used along with REGCA1 and REPCA1)

4. Details of models in PSS/E for modelling Wind plants / farms / parks:

Category	Parameter Description	Data
Generator Nameplate	Connection point voltage (kV)	
	Terminal voltage (kV)	
	Wind Farm - Rated active power (sent out) in MW	
	Turbine – Rated MVA	
	Turbine – Rated active power (PMAX) in MW	
	Number of wind turbines (Type wise)	
Reactive power capability	Capability chart at connection point [If not available, then for each individual wind turbine, and mode of operation of Power Plant Controller]	-
	QMAX	
	QMIN	
Single Line Diagram	Single line diagram of the wind farm/park showing number and location of turbines, cable run, transformers, feeders (including type of cables and electrical R,X,B parameters), and connection to transmission system Preferable : Electrical Single Line Diagram including details between individual WTGs and b/w WTGs and aggregation points	
Wind Turbine Details	Manufacturer and product details (include Year of Manufacture)	
	Year of commissioning	
	Fixed speed or variable speed	
	Type of turbine: stall control, pitch control, active stall control, limited variable speed, variable speed with partial or full-scale frequency converter	
	Hub height (in metre)	
	Rotor diameter (in metre)	
	Number of blades	
	Rotor speed (in rpm)	
	Gearbox ratio	
Generator	Type of generator: Type 1/ Type 2 / Type 3 / Type 4	
	Number of pole pairs	
	Stator resistance (in Ohms)	
	Rotor resistance (in Ohms)	
Speed control	Details of speed controller in wind turbine	
	Efficiency (Cp) curves	
	Cut-in wind speed	
	Wind speed at which full power is attained Cut-out wind speed	
	Pitch angle at low wind speed	

Category	Parameter Description	Data
Reticulation System	Voltage of the reticulation system	
	Number of feeders	
	Cable schedules (lengths, cable size, conductor material, rating info)	
Turbine Transformer	Details of the turbine transformer, including vector group, impedance, and number of taps, tap position, tap ratio	
	Nameplate details	
Wind-farm Step-up transformer	Details of the main wind farm step up transformer, including vector group, impedance, and tap position	
	Nameplate ; OLTC?	
	Controlled bus	
	Voltage setpoint	
	Dead band	
	Number of taps	
	Tap ratio range	
Connection Details	Voltage influence (maximum change etc)	
	Short circuit ratio (SCR)	
	· Min	
	· Max	
	Harmonic filters	
	STATCOM	
	Synchronous condensers	
	Battery Energy Storage System (if applicable)	
Power Plant Controller (PPC) Details	Does the wind farm have a PPC? If yes, whether PPC controls all or part of the WTGs in wind farm	
	What is the method of control – voltage regulation, power factor control, reactive power control?	
	Voltage control strategy (operating mode) - Controls MV Bus - Controls HV Bus - PF control - Q control - Voltage control	
	Is there a droop setting? - Voltage control - Frequency Control - Is there line drop compensation?	
	Is reactive power limited?	
	Temperature dependency	
	Active power ramp rate limiters	
	FRT protocols and setpoints - LVRT - HVRT	
	Provide settings from controller.	

5. Generic Models for Type-1 and Type-2 Wind turbine generators:

Description of some generic models available in PSS/E Library is provided below:

Category	Parameter Description	Data
GENERATOR model		
Generator : Type-1 (WT1G1)	Synchronous reactance (ohms or pu) Xs	
	Transient reactance (ohms or pu) X’	
	Wound rotor induction generator (WRIG) with a variable resistor in the rotor circuit, and typically employs pitch control	
	Leakage reactance, X_L	
	Saturation curve (E1, S(E1), E2, S(E2)	
Generator : Type-2 (WT2G1)	XA, stator reactance (pu)	
	Doubly fed induction generator (DFIG) wind turbines ; Variable speed with rotor side converter	
	X1 rotor reactance (put)	
	R_Rot_Mach, rotor resistance (pu)	
	R_Rot_Max (sum of R_Rot_Mach + total external resistance) in pu	
	Saturation curve (E1, S(E1), E2, S(E2)	
	Power – slip curve (Top 5 points in the T-s curve)	
Electrical Control model		
Rotor Resistance Control : Type-2 (WT2E1)	TsP, rotor speed filter time constant, sec.	
	Tpe, power filter time constant, sec.	
	Ti, PI-controller integrator time constant, sec.	
	Kp, PI-controller proportional gain, pu	
	ROTRV_MAX, Output MAX limit	
	ROTRV_MIN, Output MIN limit	
Drive Train model		
Two-Mass Turbine Model for Type 1 and Type 2 Wind Generators : (WT12T1)	H, Total inertia constant, sec	
	DAMP, Machine damping factor, pu P/pu speed	
	Htfrac, Turbine inertia fraction (Hturb/H)1	
	Freq1, First shaft torsional resonant frequency, Hz	
	Dshaft, Shaft damping factor (pu)	

6. Generic Models for Type-3 and Type-4 Wind turbine generators:

Description of some generic models available in PSS/E Library is provided below:

Category	Parameter Description	Data
GENERATOR model		
Type-3 or Type-4 (REGCA1)	Tg, Converter time constant (s)	
	Rrpwr, Low Voltage Power Logic (LVPL) ramp rate limit (pu/s)	
	Wound rotor induction generator (WRIG) with a variable resistor in the rotor circuit, and typically employs pitch control	
	Zerox, LVPL characteristic voltage 1 (pu)	
	Lvpl1, LVPL gain (pu)	
	Volim, Voltage limit (pu) for high voltage reactive current manage-	
	Doubly fed induction generator (DFIG) wind turbines ; Variable speed with rotor side converter	
	Lvpnt1, High voltage point for low voltage active current manage-	
	ment (pu)	
	Lvpnt0, Low voltage point for low voltage active current manage-	
	ment (pu)	
	Iolim, Current limit (pu) for high voltage reactive current manage-	
	ment (specified as a negative value)	
	Tfltr, Voltage filter time constant for low voltage active current man-	
	agement (s)	
	Khv, Overvoltage compensation gain used in the high voltage reac-	
	tive current management	
	Iqrmax, Upper limit on rate of change for reactive current (pu)	
	Iqrmin, Lower limit on rate of change for reactive current (pu)	
	Accel, acceleration factor (0 < Accel <= 1)	
Electrical Control model		
Type-3 and Type-4 Wind turbines : (REECA1) [Refer Block Diagrams]	Vdip (pu), low voltage threshold to activate reactive current injection logic	
	Vup (pu), Voltage above which reactive current injection logic is activated	
	Trv (s), Voltage filter time constant	
	dbd1 (pu), Voltage error dead band lower threshold (≤0)	
	dbd2 (pu), Voltage error dead band upper threshold (≥0)	
	Kqv (pu), Reactive current injection gain during over and undervoltage conditions	
	Iqh1 (pu), Upper limit on reactive current injection Iqinj	
	Iql1 (pu), Lower limit on reactive current injection Iqinj	
	Vref0 (pu), User defined reference (if 0, model initializes it to initial terminal voltage)	
	Iqfrz (pu), Value at which Iqinj is held for Thld seconds following a voltage dip if Thld > 0	

Category	Parameter Description	Data
Electrical Control model		
Type-3 and Type-4 Wind turbines : (REECA1) [Refer Block Diagrams]	Thld (s), Time for which Iqinj is held at Iqfrz after voltage dip returns to zero (see Note 1)	
	Thld2 (s) (≥0), Time for which the active current limit (IPMAX) is held at the faulted value after voltage dip returns to zero	
	Tp (s), Filter time constant for electrical power	
	QMax (pu), limit for reactive power regulator	
	QMin (pu) limit for reactive power regulator	
	VMAX (pu), Max. limit for voltage control	
	VMIN (pu), Min. limit for voltage control	
	Kqp (pu), Reactive power regulator proportional gain	
	Kqi (pu), Reactive power regulator integral gain	
	Kvp (pu), Voltage regulator proportional gain	
	Kvi (pu), Voltage regulator integral gain	
	Vbias (pu), User-defined bias (normally 0)	
	Tiq (s), Time constant on delay s4	
	dPmax (pu/s) (>0) Power reference max. ramp rate	
	dPmin (pu/s) (<0) Power reference min. ramp rate	
	PMAX (pu), Max. power limit	
	PMIN (pu), Min. power limit	
	Imax (pu), Maximum limit on total converter current	
	Tpord (s), Power filter time constant	
	VQ-IQ characteristic (at least two pairs, up to 4 pairs of voltage and current in pu)	
	VP-IP characteristic (at least two pairs, up to 4 pairs, of voltage and current in pu)	[Refer Block Diagrams]
	Is turbine in PF control or Q control (including controlled by external signal)?	
	Is the turbine controlling voltage (directly, not than through PPC)?	
	If controlling voltage directly what bus does it control?	
	Is the turbine in P or Q priority mode?	
Drive Train model		
	H, Total inertia constant, sec	
	DAMP, Machine damping factor, pu P/pu speed	
	Htfrac, Turbine inertia fraction (Hturb/H)1	
	Freq1, First shaft torsional resonant frequency, Hz	
	Dshaft, Shaft damping factor (pu)	

Category	Parameter Description	Data
Pitch Control model [for Type-3 only]		
Generic Pitch Control model for Type-3 : (WTPA1)	Kiw, Pitch-control Integral Gain (pu)	
	Kpw, Pitch-control proportional gain (pu)	
	Kic, Pitch-compensation integral gain (pu)	
	Kpc, Pitch-compensation proportional gain (pu)	
	Kcc, Gain (pu)	
	Tp, Blade response time constant (s)	
	TetaMax, Maximum pitch angle (degrees)	
	TetaMin, Minimum pitch angle (degrees)	
	RTetaMax, Maximum pitch angle rate (degrees/s)	
	RTetaMin, Minimum pitch angle rate (degrees/s) (< 0)	
Aerodynamic model [For Type-3 only]		
(WTARA1)	Ka, Aerodynamic gain factor (pu/degrees)	
	Theta 0 Initial pitch angle (degrees)	
Torque Controller model [For Type-3 only]		
Generic Torque Controller for Type-3 wind machines : (WTTQA1)	Kpp, Proportional gain in torque regulator (pu)	
	KIP, Integrator gain in torque regulator (pu)	
	Tp, Electrical power filter time constant (s)	
	Twref, Speed-reference time constant (s)	
	Temax, Max limit in torque regulator (pu)	
	Temin, Min limit in torque regulator (pu)	
	p1, power (pu)	
	spd1, shaft speed for power p1 (pu)	
	p2, power (pu)	
	spd2, shaft speed for power p2 (pu)	
	p3, power (pu)	
	spd3, shaft speed for power p3 (pu)	
	p4, power (pu)	
	spd4, shaft speed for power p3 (pu)	
	TRATE, Total turbine rating (MW)	

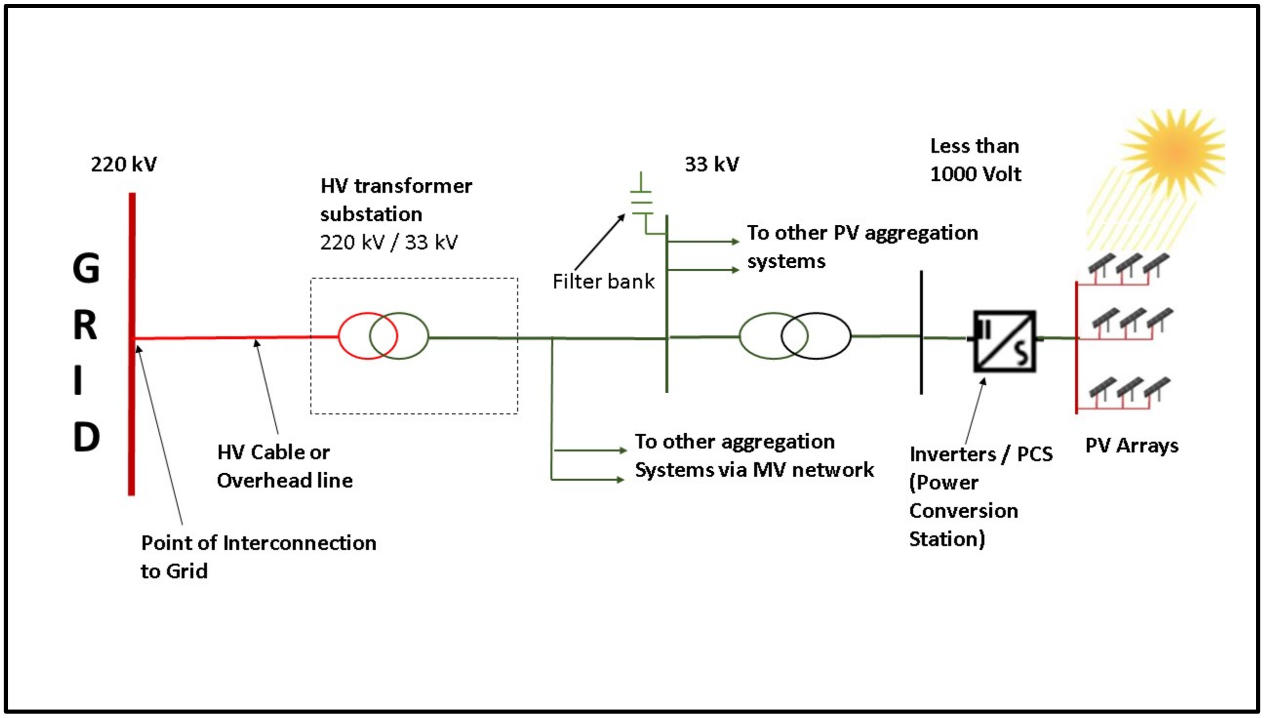
Category	Parameter Description	Data
Power Plant Controller (PPC) model		
Generic Power Plant Controller (PPC) model for Type-3 and Type-4 wind turbines : REPCTA1 for type 3, and REPCA1 for type 4 turbines	Tfltr, Voltage or reactive power measurement filter time constant (s)	
	Kp, Reactive power PI control proportional gain (pu)	
	Ki, Reactive power PI control integral gain (pu)	
	Tft, Lead time constant (s)	
	Tfv, Lag time constant (s)	
	Vfrz, Voltage below which State s2 is frozen (pu)	
	Rc, Line drop compensation resistance (pu)	
	Xc, Line drop compensation reactance (pu)	
	Kc, Reactive current compensation gain (pu)	
	emax, upper limit on deadband output (pu)	
	emin, lower limit on deadband output (pu)	
	dbd1, lower threshold for reactive power control deadband (<=0)	
	dbd2, upper threshold for reactive power control deadband (>=0)	
	Qmax, Upper limit on output of V/Q control (pu)	
	Qmin, Lower limit on output of V/Q control (pu)	
	Kpg, Proportional gain for power control (pu)	
	Kig, Proportional gain for power control (pu)	
	Tp, Real power measurement filter time constant (s)	
	fdbd1, Deadband for frequency control, lower threshold (<=0)	
	Fdbd2, Deadband for frequency control, upper threshold (>=0)	
	femax, frequency error upper limit (pu)	
	femin, frequency error lower limit (pu)	
	Pmax, upper limit on power reference (pu)	
	Pmin, lower limit on power reference (pu)	
	Tg, Power Controller lag time constant (s)	
	Ddn, droop for over-frequency conditions (pu)	
	Dup, droop for under-frequency conditions (pu)	

Category	Parameter Description	Data
Electrical Control model : BESS		
Generic Electrical Control model for Utility Scale BESS: (REECCU1)	Vdip (pu), low voltage threshold to activate reactive current injection logic	
	Vup (pu), Voltage above which reactive current injection logic is activated	
	Trv (s), Voltage filter time constant	
	dbd1 (pu), Voltage error dead band lower threshold (≤0)	
	dbd2 (pu), Voltage error dead band upper threshold (≥0)	
	Kqv (pu), Reactive current injection gain during over and undervoltage conditions	
	Iqh1 (pu), Upper limit on reactive current injection Iqinj	
	Iql1 (pu), Lower limit on reactive current injection Iqinj	
	Vref0 (pu), User defined reference (if 0, model initializes it to initial terminal voltage)	
	Tp (s), Filter time constant for electrical power	
	QMax (pu), limit for reactive power regulator	
	QMin (pu) limit for reactive power regulator	
	VMAX (pu), Max. limit for voltage control	
	VMIN (pu), Min. limit for voltage control	
	Kqp (pu), Reactive power regulator proportional gain	
	Kqi (pu), Reactive power regulator integral gain	
	Kvp (pu), Voltage regulator proportional gain	
	Kvi (pu), Voltage regulator integral gain	
	Tiq (s), Time constant on delay s4	
	dPmax (pu/s) (>0) Power reference max. ramp rate	
	dPmin (pu/s) (<0) Power reference min. ramp rate	
	PMAX (pu), Max. power limit	
	PMIN (pu), Min. power limit	
	Imax (pu), Maximum limit on total converter current	
	Tpord (s), Power filter time constant	
	Vq and Iq curve (Reactive Power V-I pair in p.u.) : 4 points	
	Vp and Ip curve (Active Power V-I pair in p.u.) : 4 points	
	T, battery discharge time (s) (<0)	
	SOCini (pu), Initial state of charge	
	SOCmax (pu), Maximum allowable state of charge	
	SOCmin (pu), Minimum allowable state of charge	

Note: SOCini represents the initial state of charge on the battery and is a user entered value. This is entered in pu; with 1 pu meaning that the batter is fully charged and 0 means the battery is completely discharged

Annexure-I(D): Guidelines for Exchange of data for RMS modelling (Generic) of Solar Generating Stations

1. Models for Utility scale Solar generation farms:



In a typical utility scale solar farm / park, arrays of Solar PV panels connected to an inverter (Power Conditioning System / Power Conversion Station – PCS), which is stepped up to form part of the MV reticulation system (typically at 33 kV or less). A number of inverters are pooled and then stepped up to the voltage of 220 kV / 400 kV prior to connection to EHV grid. A Power Plant controllers (PPC) is usually installed at the point of interconnection to grid or the reticulation system. The PPC(s) control behavior of solar farms in accordance with mandates as per grid codes.

The dynamic components of a solar farm or park consists of the following elements (illustrated in picture below):

1. Generator or Converter
2. Electrical control including fault ride through
3. Power Plant Controller (PPC)
4. Energy storage (i.e. battery), if applicable

Depending on the nature of technology and usage of components at site ('As built'), the requirements for steady state and dynamic modelling evolves.

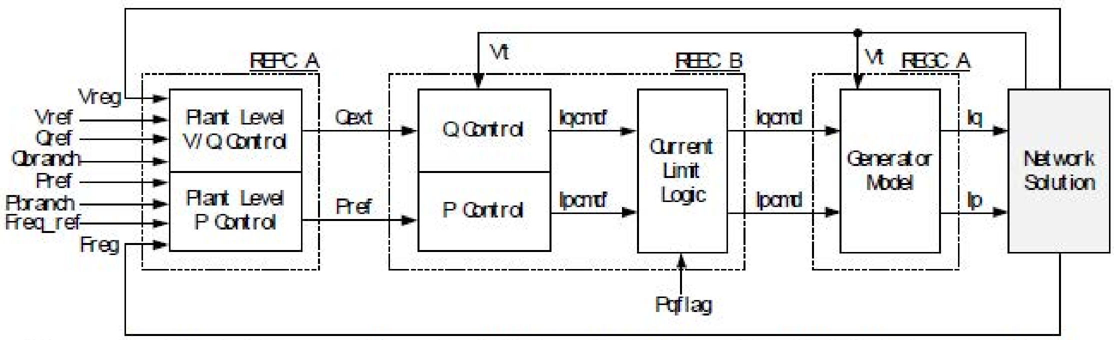


Figure 4 – Block Diagram Showing Different Modules of the WECC Generic Models

2. Generic models in PSS/E for modelling utility scale Solar PV and BESS installations:

Solar Technology	Generic model	Model Description
Utility Scale Solar PV	REGC	Renewable energy generator converter model
	REEC	Renewable energy controls model
	REPC	Renewable energy plant controller
Utility Scale Battery Energy Storage System (BESS)	REECCU	Electrical Control Model (To be used alongwith REGCA1 and REPCA1)

3. Details of models in PSS/E for modelling Solar plants / farms / parks:

Category	Parameter Description	Data
Inverter Details	Manufacturer, model number and product details	
	Year of commissioning	
	As found settings (obtained either from HMI or downloaded from controller in digital systems)	
Technology	• Grid following • Grid forming (viz. Assist in regulation of Voltage and Frequency) • Reactive power priority (Controls Pf or Voltage? Point of control?)	-
Single Line Diagram	Single line diagram of the solar farm showing number and location of inverters and PV arrays behind each inverter, cable run, transformers, feeders (including type of cables and electrical R,X,B parameters), and connection to transmission system Preferable : Electrical Single Line Diagram including details between PV-array to Inverters, Inverters to MV reticulation system, MV reticulation system till Point of Interconnection (POI) at EHV level (220 kV/400 kV)	
Capability	DC/AC ratio	
	Number of inverters	
	Panel type	
	Number of modules per string	
	Tracking in 0/1/2 axes	
	Capability diagram at nominal (STC) and typical temperature	
Controls	Does the solar farm have a PPC? If yes, whether PPC controls all or part of the inverters in Solar farm	
	What is the method of control – voltage regulation, power factor control, reactive power control?	
	Voltage control strategy (operating mode) • Controls MV bus • Controls HV bus • PF control • Q control	
	Is there a droop setting? • Voltage control • Frequency control	
	Is reactive power limited? Details thereof	
	Is active power limited below MPPT at high output? Details thereof	
	Temperature dependency details	
	Active power ramp rate limiters	
	Fault Ride Through (FRT) protocols and setpoints • LVRT • HVRT	
	Provide settings from controller	

Category	Parameter Description	Data
Reticulation System	Voltage of the reticulation system	
	Number of feeders	
	Cable schedules (lengths, cable size, conductor material, rating info)	
Inverter station transformer	Details of the turbine transformer, including vector group, impedance, and number of taps, tap position, tap ratio	
	Nameplate details	
Solar Farm step-up transformer	Details of the main solar farm step up transformer, including vector group, impedance, and tap position	
	Nameplate ; OLTC?	
	Controlled bus	
	Voltage setpoint	
	Dead band	
	Number of taps	
	Tap ratio range	
Connection Details	Voltage influence (maximum change etc)	
	Short circuit ratio (SCR)	
	· Min	
	· Max	
	Harmonic filters	
	STATCOM	
	Synchronous condensers	
	Battery Energy Storage System (if applicable)	
Power Plant Controller (PPC) Details	Does the solar farm have a PPC? If yes, whether PPC controls all or part of the inverters in solar farm	
	What is the method of control – voltage regulation, power factor control, reactive power control?	
	Voltage control strategy (operating mode) - Controls MV Bus - Controls HV Bus - PF control - Q control - Voltage control	
	Is there a droop setting? - Voltage control - Frequency Control - Is there line drop compensation?	
	Is reactive power limited?	
	Temperature dependency	
	Active power ramp rate limiters	
	FRT protocols and setpoints - LVRT - HVRT	
	Provide settings from controller.	

4. Generic Models for Utility Scale Solar-PV generation

Description of some generic models available in PSS/E Library are provided below:

Category	Parameter Description	Data
GENERATOR model		
Solar PV (REGCA1)	Tg, Converter time constant (s)	
	Rrpwr, Low Voltage Power Logic (LVPL) ramp rate limit (pu/s)	
	Brkpt, LVPL characteristic voltage 2 (pu)	
	Zerox, LVPL characteristic voltage 1 (pu)	
	Lvpl1, LVPL gain (pu)	
	Volim, Voltage limit (pu) for high voltage reactive current manage-	
	Lvpnt1, High voltage point for low voltage active current management (pu)	
	Lvpnt0, Low voltage point for low voltage active current management (pu)	
	Iolim, Current limit (pu) for high voltage reactive current management (specified as a negative value)	
	Tfltr, Voltage filter time constant for low voltage active current management (s)-	
	Khv, Overvoltage compensation gain used in the high voltage reactive current management	
	Iqrmax, Upper limit on rate of change for reactive current (pu)	
	Iqrmin, Lower limit on rate of change for reactive current (pu)	
	Accel, acceleration factor (0 < Accel <= 1)	
Electrical Control model		
Large Solar PV : (REECB1) [Refer Block Diagrams]	Vdip (pu), low voltage threshold to activate reactive current injection logic	
	Vup (pu), Voltage above which reactive current injection logic is activated	
	Trv (s), Voltage filter time constant	
	dbd1 (pu), Voltage error dead band lower threshold (≤0)	
	dbd2 (pu), Voltage error dead band upper threshold (≥0)	
	Kqv (pu), Reactive current injection gain during over and undervoltage conditions	
	Iqh1 (pu), Upper limit on reactive current injection Iqinj	
	Iql1 (pu), Lower limit on reactive current injection Iqinj	
	Vref0 (pu), User defined reference (if 0, model initializes it to initial terminal voltage)	
	Tp (s), Filter time constant for electrical power	

Category	Parameter Description	Data
Electrical Control model		
Large Solar PV : (REECB1) [Refer Block Diagrams]	QMax (pu), limit for reactive power regulator	
	QMin (pu) limit for reactive power regulator	
	VMAX (pu), Max. limit for voltage control	
	VMIN (pu), Min. limit for voltage control	
	Kqp (pu), Reactive power regulator proportional gain	
	Kqi (pu), Reactive power regulator integral gain	
	Kvp (pu), Voltage regulator proportional gain	
	Kvi (pu), Voltage regulator integral gain	
	Tiq (s), Time constant on delay s4	
	dPmax (pu/s) (>0) Power reference max. ramp rate	
	dPmin (pu/s) (<0) Power reference min. ramp rate	
	PMAX (pu), Max. power limit	
	PMIN (pu), Min. power limit	
	Imax (pu), Maximum limit on total converter current	
	Tpord (s), Power filter time constant	

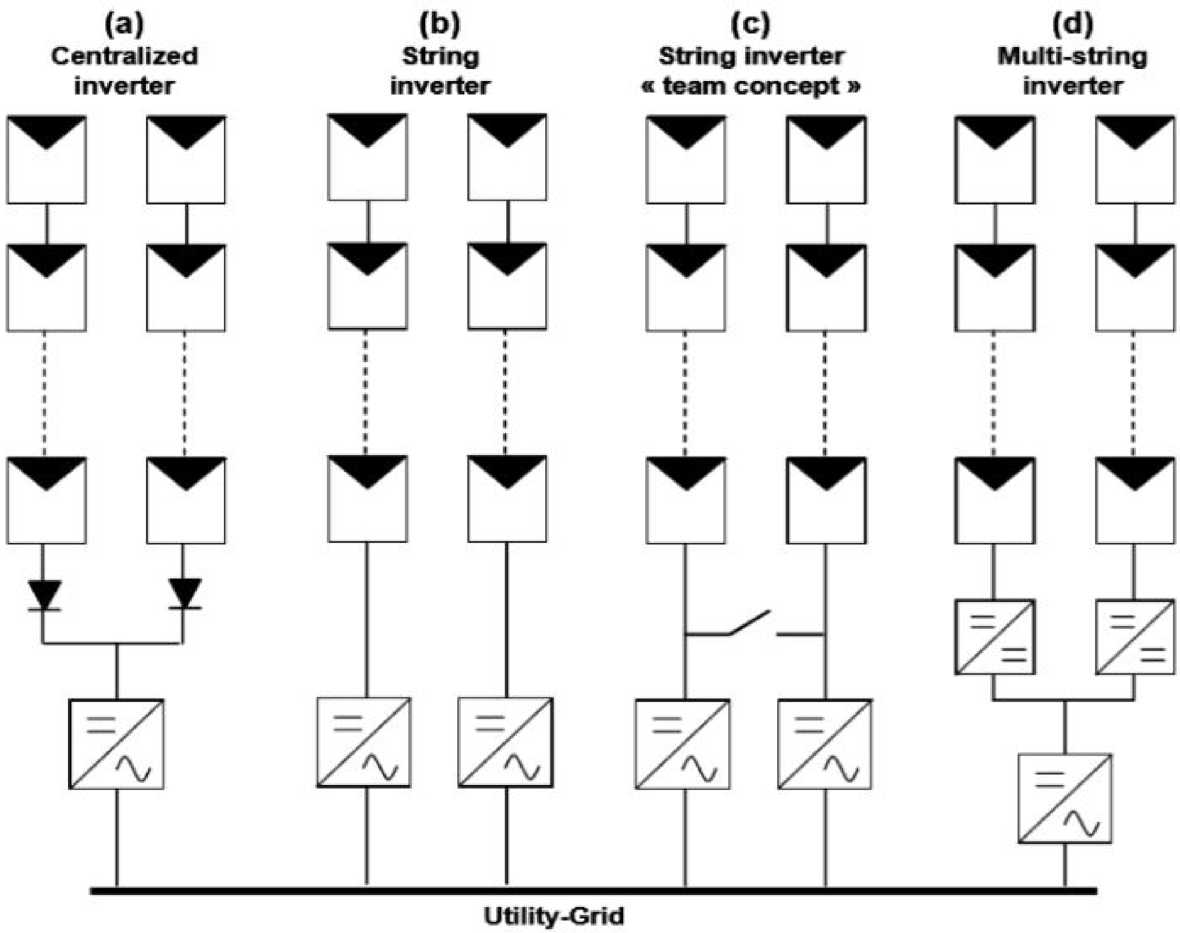
Category	Parameter Description	Data
Power Plant Controller (PPC) model		
Generic Power Plant Controller (PPC) model: (REPCA1)	Tfltr, Voltage or reactive power measurement filter time constant (s)	
	Kp, Reactive power PI control proportional gain (pu)	
	Ki, Reactive power PI control integral gain (pu)	
	Tft, Lead time constant (s)	
	Tfv, Lag time constant (s)	
	Vfrz, Voltage below which State s2 is frozen (pu)	
	Rc, Line drop compensation resistance (pu)	
	Xc, Line drop compensation reactance (pu)	
	Kc, Reactive current compensation gain (pu)	
	emax, upper limit on deadband output (pu)	
	emin, lower limit on deadband output (pu)	
	dbd1, lower threshold for reactive power control deadband (<=0)	
	dbd2, upper threshold for reactive power control deadband (>=0)	
	Qmax, Upper limit on output of V/Q control (pu)	
	Qmin, Lower limit on output of V/Q control (pu)	
	Kpg, Proportional gain for power control (pu)	
	Kig, Proportional gain for power control (pu)	
	Tp, Real power measurement filter time constant (s)	
	fdbd1, Deadband for frequency control, lower threshold (<=0)	
	Fdbd2, Deadband for frequency control, upper threshold (>=0)	
	femax, frequency error upper limit (pu)	
	femin, frequency error lower limit (pu)	
	Pmax, upper limit on power reference (pu)	
	Pmin, lower limit on power reference (pu)	
	Tg, Power Controller lag time constant (s)	
	Ddn, droop for over-frequency conditions (pu)	
	Dup, droop for under-frequency conditions (pu)	

Category	Parameter Description	Data
Electrical Control model : BESS		
Generic Electrical Control model for Utility Scale BESS: (REECCU1)	Vdip (pu), low voltage threshold to activate reactive current injection logic	
	Vup (pu), Voltage above which reactive current injection logic is activated	
	Trv (s), Voltage filter time constant	
	dbd1 (pu), Voltage error dead band lower threshold (≤0)	
	dbd2 (pu), Voltage error dead band upper threshold (≥0)	
	Kqv (pu), Reactive current injection gain during over and undervoltage conditions	
	Iqh1 (pu), Upper limit on reactive current injection Iqinj	
	Iql1 (pu), Lower limit on reactive current injection Iqinj	
	Vref0 (pu), User defined reference (if 0, model initializes it to initial terminal voltage)	
	Tp (s), Filter time constant for electrical power	
	QMax (pu), limit for reactive power regulator	
	QMin (pu) limit for reactive power regulator	
	VMAX (pu), Max. limit for voltage control	
	VMIN (pu), Min. limit for voltage control	
	Kqp (pu), Reactive power regulator proportional gain	
	Kqi (pu), Reactive power regulator integral gain	
	Kvp (pu), Voltage regulator proportional gain	
	Kvi (pu), Voltage regulator integral gain	
	Tiq (s), Time constant on delay s4	
	dPmax (pu/s) (>0) Power reference max. ramp rate	
	dPmin (pu/s) (<0) Power reference min. ramp rate	
	PMAX (pu), Max. power limit	
	PMIN (pu), Min. power limit	
	Imax (pu), Maximum limit on total converter current	
	Tpord (s), Power filter time constant	
	Vq and Iq curve (Reactive Power V-I pair in p.u.) : 4 points	
	Vp and Ip curve (Active Power V-I pair in p.u.) : 4 points	
	T, battery discharge time (s) (<0)	
	SOCini (pu), Initial state of charge	
	SOCmax (pu), Maximum allowable state of charge	
	SOCmin (pu), Minimum allowable state of charge	

Note: SOCini represents the initial state of charge on the battery and is a user entered value. This is entered in pu; with 1 pu meaning that the batter is fully charged and 0 means the battery is completely discharged

Inverter Configurations:

Inverters within a Solar farm can be present in different configurations, as indicated below:



The data furnished must take into account the individual inverter configurations accordingly.

Document Revision History

Revision No.	Release Date	Prepared By*	Checked/Issued by*	Changes

**Mention organisation name, designation & contact details*

1) General Information

Name of the RE/BESS[1] plant : ……………………………………………………………………

RE/BESS Plant Capacity : ……………………………………………………………………

ISTS Connectivity Point (POI[2] Bus) Name : ……………………………………………………………………

Type of RE Plant (Wind, Solar, Hybrid, BESS) : ……………………………………………………………………

Name of RE plant Developer : ……………………………………………………………………

Name of the Consultant for Simulation Study : ……………………………………………………………………

Ambient Temperature Considered in Study : ……………………………………………………………………

Short circuit ratio (SCR) considered in Study : ……………………………………………………………………

Whether Study is Complete or Partial : ……………………………………………………………………

Part A: Plant Technical Details

2) Technical Details

i) IBR[3] unit details for each make-

Table 1: Details of IBR units in the plant

IBR Unit Details	
IBR unit type (WTG or Inverter)	
Model & Make	
No of IBR units	
Terminal Voltage	
Rated MVA	
Rated power (MW)	
Source Impedance (R, X[4])*	
Ambient temperature	
Qmax & Qmin limits (MVAR)	

**pu values on machine MVA base or %. Add columns in same table for different make IBR units in the plant.*

Include IBR unit (s) technical datasheets. Power curve, Derating curve, PQ capability curve at 0.95 pu, 1 pu & 1.05 pu voltage level & ambient temperature considered in the study.

[1] BESS- Battery Energy Storage System

[2] POI- Point of Interconnection – means a point on the grid, including a sub-station or a switchyard, where the interconnection is established between the facility of the requester and the grid

[3] IBR-Inverter based resource. An IBR unit can be the single solar inverter, single WTG or single BESS inverter.

[4] NERC's (North American Electric Reliability Corporation) following guidelines (page-36) may be referred for short circuit modelling guidelines https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf#search=Reliability%5FGuideline%5FIBR%5FInterconnection%5FRequirements%5FImprovements%2Epdf

ii) **IBR unit transformer details-**

Table 2 Details of IBR transformers in the plant

IBR Unit Transformer Details	
Rating (MVA)	
Type (…………) of cooling	
Voltage Ratio (HV to LV)	
Vector Group	
Tap changer (OLTC* or other)	
Tap changer in LV side or HV side	
Total Number of taps	
Nominal Tap position	
Current Tap Position	
Impedances (r, x) in %	
Short circuit Impedance (r_0 , x_0)	
Whether IBR transformer is the part of IBR unit or separate?	

**OLTC-Online tap changing*

Include transformer data sheet and nameplate.

iii) **Power Transformer Details-**

Table 3 Details of Power transformers in the IBR plant

Power Transformer Details	
Rating (in MVA)	
Type	
Ratio (HV to LV)	
Vector Group	
Tap changer	
Tap changer (OLTC or other)	
Tap changer in LV side or HV side	
Total Number of taps	
Nominal Tap position	
Considered Tap Position	
Impedances (r,x) in %	
Short circuit Impedance (r_0 , x_0) in %	
Over load capacity (Loading at 110%, 120%, 130%, 140% & 150% with time) to be provided else include Overload capability in MVA vs time curve	

Include transformer data sheet and nameplate.

iv) **Conductor/Cable details-**

Table 4 Details of Collector system/reticulation system & EHV line details

Voltage (kV)	From Bus	To Bus	Ckt ID	Length (kM)	Conductor Type	Positive*			Zero*			Ampacity (In Ampere, with specified AT & CT) **	MVA Rating
						r_1	x_1	b_1	r_0	x_0	b_0		

**Positive & Zero Sequence impedance values in pu/ckt/km, **AT- Ambient temperature, CT-Conductor temperature.*

v) **Single line diagram (SLD) of the plant**

Single line diagram of the IBR plant showing number and location of IBR units, cable run, transformers, feeders (including type of cables and lengths), and connection to transmission system. Preferable: Electrical Single Line Diagram including details between individual IBR units and b/w IBR units and aggregation points. Include as Annexure.

vi) **Power Plant Controller (PPC) Details-**

Whether Only Master or Master with Slave PPC Configuration: Specify whether the plant having single or multiple PPC, If multiple PPCs then specify the details of master & slave PPC as below-

Master PPC OEM :
Master PPC Manual[5] :
Slave PPC-1 OEM (if applicable) :
Slave PPC-1 Manual :
Slave PPC-2 OEM (if applicable) :
Slave PPC-2 Manual :
Similarly specify for all the slave PPCs.
Specify Master PPC Control modes – Active, Reactive, frequency etc.
Specify the bus name/feeders where input to master PPC is taken for Voltage, Current, P, Q & frequency.
Specify the sampling rate of PPC input parameters measurement :
Specify whether line drop compensation is available in master PPC (Yes/No) : (whether it compensates collector system loss only or also includes EHV line loss)
Communication diagram for master/slave PPC control.

[5] Manual shall at least consist of PPC architecture, control strategies (voltage control, power factor, Q control & associated curves), configurable control & parameters, technical specification among other details

Part B: Simulation Model and Study Report Details

3) **Wind/Solar/BESS/Hybrid Plant Simulation Models and Supporting Files:** The simulation study report shall include the RMS & EMT model file names, supporting files, model setup procedure, model user guide, RMS & EMT software version, compiler version etc.

Type of Model	Description	File Names
RMS (Root Mean Square)	**IBR Unit Model**	
	Detailed Plant Model (including PPC model)	
	Equivalent[6] Plant Model (including PPC model)	
EMT (Electro Magnetic Transient)	**IBR Unit Model**	
	Equivalent Plant Model (including PPC model)	
	Power Quality Assessment Model	

Case preparation: Ensure line lengths, line & transformer rating (Rate-1 SIL, Rate-2 Thermal, Rate-3 110% of Thermal), short circuit parameters, Qmax & Qmin limits are updated in the model. Further, actual IBR unit bus name shall be same as OEM of the machine. Include **100 sec** flat run plot for P, Q, V at POI.

4) **Simulation results showing the comparison of detailed plant model and equivalent model of the Wind/Solar farm/BESS/Hybrid - (Requirement is only for RMS model)**

a) Steady state comparison of P, Q, V, I to be included at **POI**
b) Detailed v/s Equivalent model response comparison of P, Q, V & I at POI to be demonstrated for different tests like P control, Q control, Voltage control, LVRT, HVRT, frequency response control operation etc.

The error between the detailed v/s equivalent model response shall be within a tolerance band as specified by respective RLDC. Suitable measures shall be taken to minimized the error.

[6] **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.

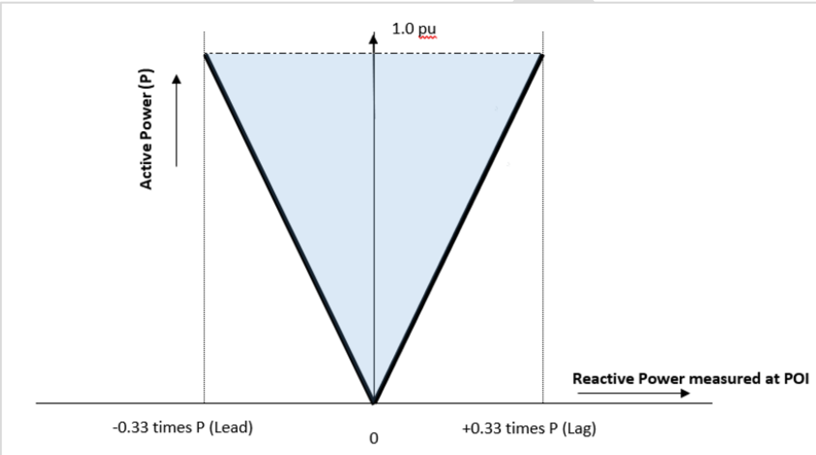
Annexure-I (F) may also be referred for single generator equivalent model configuration.

5) **PQ Reactive Capability Curve plot of Wind/Solar Farm/BESS/Hybrid at POI -**

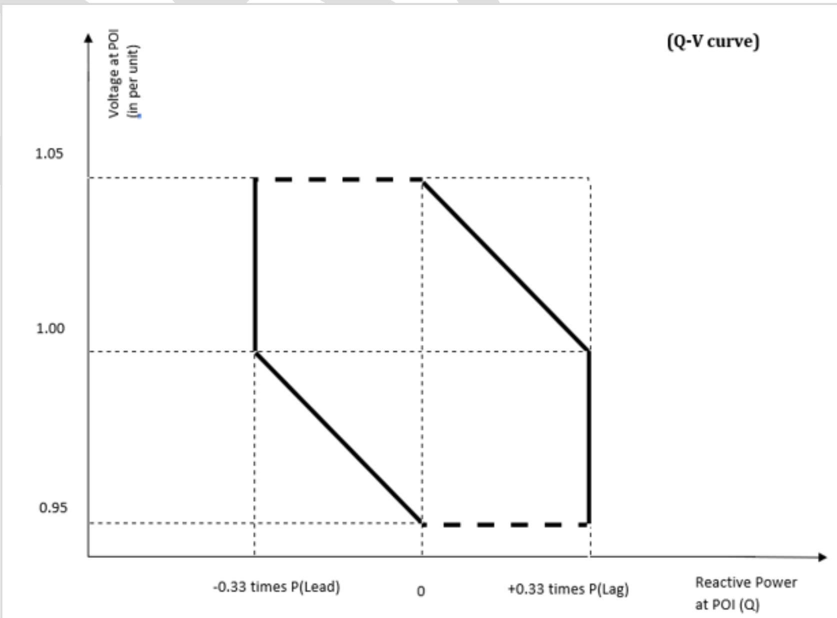
a) Simulation study results/plots demonstrating PQ capability of the plant at **POI** for **0.95 pu, 1 pu & 1.05 pu voltage at POI** (factoring in specified ambient temperature) shall be included for following cases:

- Without any additional reactive power compensation[7]
- With additional reactive power compensation (if required for compliance of reactive power capability at POI)
  The study shall be carried out on both **detailed RMS and equivalent EMT model.**

- Generating station shall be able to deliver rated output at **POI** (at specified ambient temperature) for the above-mentioned conditions at least up to the capability shown in the PQ curve below:



- The voltage dependence of reactive power capability of RE Generator shall be governed as per the QV curve shown below:



7 **Additional dynamic Reactive Power Compensation devices** may include FACTS devices like STATCOMs additional inverter,SVG or any combination of such devices

- For all cases, the report shall include details of both active and reactive power exchange by generation pooling station with the grid at **point of interconnection (POI).**

6) Short circuit study results for 3-phase/ single phase fault at POI -
The short circuit contribution from the plant for different fault conditions **at POI** shall be tabulated.

7) Below mentioned tests shall be performed:

a) Power Quality[8] - The power quality study results **(at POI)** for the following shall be included:

i) Harmonics
ii) DC Current injection
iii) Flicker

b) LVRT Test - Plot of P, Q, Vac, Iac at POI and Plot of P, Q, Vac, Iac, Id, Iq, Vd,Vq at IBR terminal (for any one IBR of each make) shall be included for:

i) Case-1: 3-ph impedance fault at POI for 3 sec for voltage of 0.85 pu during fault
ii) Case-2: 3-ph impedance fault at POI for 1.65 sec for voltage of 0.5 pu during fault
iii) Case-3: 3-ph impedance fault at POI for 300 msec for voltage of 0.15 pu during fault
iv) Case-4: 1-ph fault at POI for 3 sec for voltage of 0.85 pu during fault
v) Case-5: 1-ph fault at POI for 1.65 sec for voltage of 0.5 pu during fault
vi) Case-6: 1-ph fault at POI for 300 msec for voltage of 0.15 pu during fault

- Above cases shall be simulated for **both full (100%) and partial (25% and 50%) active power dispatch.**
- Id, Iq, Vd and Vq are IBR output current and voltage along with reference in d-q frame. To be provided only in case of EMT model response.

- **LVRT settings** (including "K" factor), Response Time (ms) shall be mentioned in the study results.
- **Suitable margin** shall be incorporated in inverter level settings (through line drop compensation studies) to enable LVRT operation at specified voltage at POI.

c) HVRT Test - Plot of P, Q, Vac, Iac at POI and Plot of P, Q, Vac, Iac, Id, Iq, Vd,Vq at IBR terminal (for any one IBR of each make) shall be included for:

i) Case-1: 3-Phase voltage rise at POI is up to 1.2 pu for 2 sec
ii) Case-2: 3-Phase voltage rise at POI is up to 1.3 pu for 200 msec
iii) Case-3: 1-ph voltage rise at POI is up to 1.2 pu for 2 sec
iv) Case-4: 1-ph voltage rise at POI is up to 1.3 pu for 200 msec

- Above cases shall be simulated for **both full (100%) and partial (25% and 50%) active power dispatch.**
- Id, Iq, Vd and Vq are IBR output current and voltage along with reference in d-q frame. To be provided only in case of EMT model response.

- **HVRT settings** (including "K" factor), Response Time (ms) shall be mentioned in the study results.

[8] Power quality study is required to be carried out either in Detailed EMT model or in Power Quality Assessment model

- **Suitable margin** shall be incorporated in inverter level settings (through line drop compensation studies) to enable HVRT operation at specified voltage at **POI**.
- The Protection settings of 33 kV feeders, Generator PS & Dedicated Trans. Line shall be coordinated to enable HVRT compliance at **POI**. Same shall also be specified in the study results.

d) Operating Frequency Range [Frequency control flag (F_{flag}) set 0 in PPC model]

i) Case -1: Rated Active Power Generation in the frequency range of 49.5 – 50.5 Hz.

Plots of P, Q, V, f at **POI** demonstrating the ability of the plant to deliver rated active power in the frequency range of 49.5 – 50.5 Hz shall be included.

ii) Case -2: Capability to operate (stable operation) in the frequency range of 47.5 – 52 Hz.
Plot of P, Q, V, f at **POI** demonstrating the ability of the plant to operate in the frequency range of 47.5 to 52 Hz shall be included.

PPC control parameter setting shall also be specified for the above cases.

e) Frequency Response Test – Perform frequency response test with dead band of **±0.03 Hz** and droop of **both 3% and 6%** for the following cases:

i) Case-1: Step change/increase in grid frequency from 50 Hz to 50.5 Hz
ii) Case-2: Step change/decrease in grid frequency from 50 Hz to 49.5 Hz

Above cases shall be conducted for active power output of **10%, 50% and 100%** of rated active power.

PPC settings & plots of P, Q, V, f at POI shall be included for above mentioned cases.

f) Dynamic Reactive Power Support (DPRS) at POI - Perform dynamic reactive power test for the following control modes and cases:

i) Voltage Control Mode - Perform test for dead band & droop of 2%
   a) Case-1: Step increase in Voltage at **POI** from 1 pu to 1.05 pu
   b) Case-2: Step decrease in Voltage at **POI** from 1 pu to 0.95 pu

ii) Q Control Mode
   a) Case-1: Step change in Reactive Power (Q) injection at **POI** from 0 to 16.5% and subsequently to 33% of Active Power Output (P)
   b) Case-2: Step change in Reactive Power (Q) absorption at **POI** from 0 to 16.5% and subsequently to 33% of Active Power Output (P)

iii) Power factor control mode-
   a) Case-1: Step change in Power factor at **POI** from unity to +0.98 pf and subsequently to +0.95pf
   b) Case-2: Step change in Power factor at **POI** from unity to -0.98 pf and subsequently to -0.95pf

Above cases shall be conducted for active power output of **50% and 100%** of rated active power.
Plots of P, $Q_{desired}$, Q & V at **POI** along with IBR unit terminal voltage, P & Q shall be included.

g) **Ramping Capability -** Simulation test response demonstrating the rate of change of power output of the RE plant at a rate not more than +10% per minute shall be provided. The report shall include capability demonstration for both active power ramping up and ramping down scenario.

8) Conclusion: This section shall clearly indicate the compliance status as below-

S. No.	Simulation Test Description	Pass/Fail	Remarks
1.	Reactive Power Capability		
2.	Power Quality		
3.	Low Voltage Ride Through		
4.	High Voltage Ride Through		
5.	Operating Frequency Range		
6.	Frequency Response		
7.	Dynamic Reactive Power Support		
8.	Ramping Capability		

9) Recommendation:

Any parameter change, suggested setting to be kept in plant while commissioning shall be clearly indicated here like voltage, frequency, gain-parameters, Qmax, Qmin limits, active & reactive power ramp rates in IBR & PPC, droop, dead-band, polling rate coordination etc. or any other setting which require modification during commissioning.

10) Guidelines for Simulation Studies – The specified simulation tests shall be carried out on the simulation models mentioned below:

S. No.	Simulation Test Description	Simulation to be carried out on:
1.	Reactive Power Capability	Both - Detailed RMS and Equivalent EMT Model
2.	Power Quality	Detailed EMT / Power Quality Assessment Model
3.	Low Voltage Ride Through	Detailed and Equivalent RMS and Equivalent EMT Model
4.	High Voltage Ride Through	Detailed and Equivalent RMS and Equivalent EMT Model
5.	Operating Frequency Range	Both - Equivalent RMS and EMT Model
6.	Frequency Response	Both - Equivalent RMS and EMT Model
7.	Dynamic Reactive Power Support	Both - Equivalent RMS and EMT Model
8.	Ramping Capability	Both - Equivalent RMS and EMT Model

--xxx---xxx---xxx---xxx—

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.

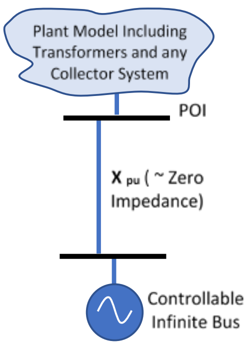
b) EMT models shall be compatible with PSCAD version 4.6.3 and above with the following –

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-

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

Where,

$MW_{Capacity}$	= Total MW capacity of generator(s) under study
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.

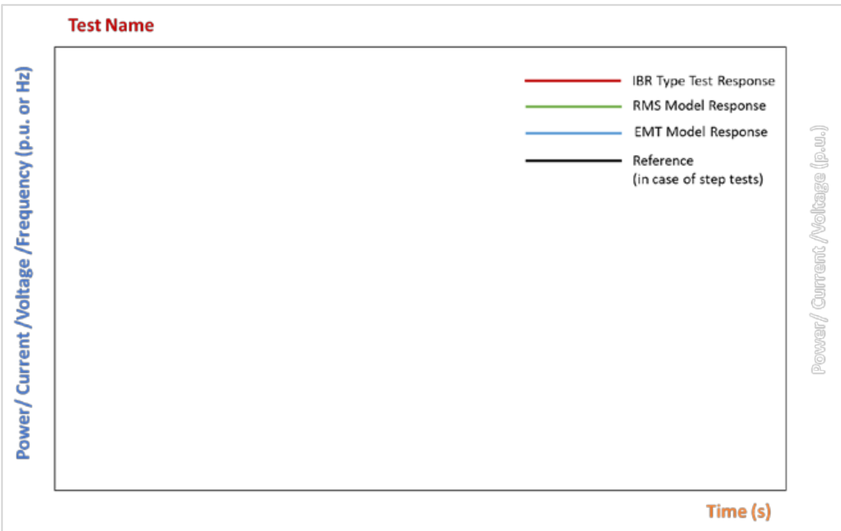
iii) Software version of controller & Firmware version of converter unit shall be mentioned.

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:

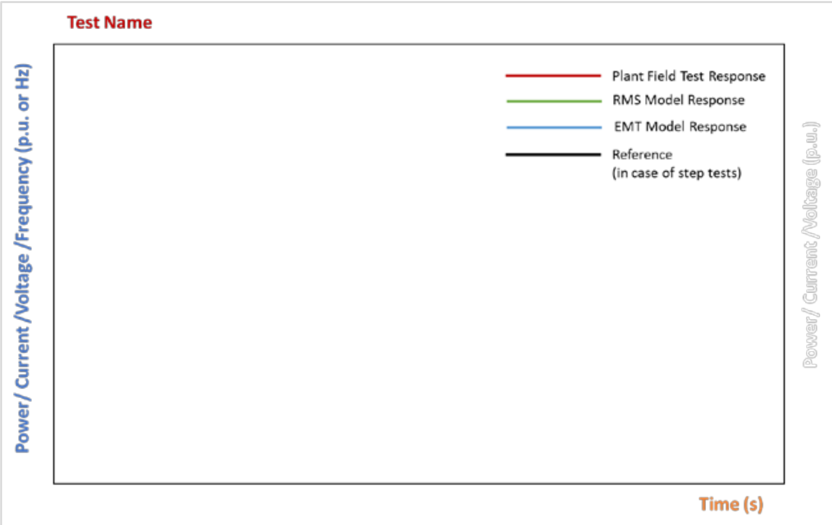
a. Model file names of RMS & EMT model.

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.

Annexure - I(E)(b)

Renewable Plant Details	
RE plant substation	
RE developer	
ISTS Pooling station	

Document classification		
Document Number	NLDC/FTE&I/Renewables/Annex-I E(b)	
Document description	IBR unit controller & PPC protection & control settings	
Document classification	Public	
Document revision history		
Date	**Rev. No.**	**Description**
11.05.2023	1.0	Initial release for protection & controller settings.

Note- Check for updated format in Grid-India website

IBR Controller and Protection Settings (Downloaded)					
	Date of setting extraction from IBR unit :				
S. No.	**Feature**	**Enabled/Disabled**	**Setting/Detail**	**Time Delay (seconds)**	**Controller Snapshot**
1	**General**				
	IBR unit OEM				
	IBR unit model				
	IBR unit capacity				
2	**Software/Firmware details**				
	Converter Firmware Version				
	Controller Software Version				
3	**IBR Voltage Range**				
	Operating Voltage- Max				
	Operating Voltage- Nominal				
	Operating Voltage- Min				
	Withstand Voltage - Max				
4	**HVRT related-**				
	HVRT enabled or disabled ?	Not Available			
	Alarm				
	Level-1				
	Level-2				
	Level-3				
	Level-4				
	Level-5				
	HVRT Activation level (voltage)				
	HVRT activation type (select from drop down)				
	HVRT Reset level (voltage)				
	HVRT grid support mode (symetric fault)	No support (reactive current is set to zero)			
	HVRT grid support mode (asymetric fault)	No support (reactive current is set to zero)			
	Maximum reactive current support during HVRT (in pu)				
	HVRT Response Time (ms)				
	HVRT dead time (minimum time required b/w two consecutive fault for successful ride through)				
	How many number of consecutive faults IBR unit can sustain ?				
5	**LVRT related**				
	LVRT enabled or disabled ?	Not Available			
	Alarm				
	Level-1				
	Level-2				
	Level-3				
	Level-4				
	Level-5				
	LVRT Activation level (voltage)				
	LVRT activation type (select from drop down)				
	LVRT Reset level (voltage)				
	LVRT grid support mode (symetric fault)	Disabled			
	LVRT grid support mode (asymetric fault)	Disabled			
	Maximum reactive current support during LVRT (in pu)				
	LVRT Response Time (ms)				
	LVRT dead time (minimum time required b/w two consecutive fault for successful ride through)				
	How many number of consecutive faults IBR unit can sustain ?				
	Voltage Threshold to block IBR current injection (for momentary cessation if any)		To be filled.		
6	**Frequency Settings**				
	Under Frequency				
	Alarm				
	Level-1				
	Level-2				
	Level-3				
	Level-4				
	Over Frequency				
	Alarm				
	Level-1				
	Level-2				
	Level-3				
	Level-4				
	Reactive power control (RPC)-				
	Reactive Power Control Method	Not Available			
	Reactive power control mode	Local constant power factor (pf) control			

7	Reactive Power at Rated Power-Max (injection)				
	Reactive Power at Rated Power-Min (Absorption)				
	Reactive power ramp rate (In steady state condition for all available RPC modes)				
	Extra Q mode	Not Available			
	If communication between IBR unit & PPC failed, then what would be the reactive control mode of operation of IBR unit.				
	IBR unit input command polling rate (minimum time required between two consecutive input commands)				
8	**Active power control-**				
	Active Power Control Method	Not Available			
	If communication between IBR unit & PPC failed, then what would be the active power set point in IBR unit.				
	IBR unit input command polling rate (minimum time required between two consecutive input commands)				
	IBR unit active power ramp rate (In steady state condition)				
	Enhanced or extra active power mode	Not Available			
9	LVRT to HVRT (and vice-versa) Transition Time				
10	**IBR unit night mode/ Standstill reactive mode**				
	Qmax (injection KVAr)				
	Qmin (absorption KVAr)				
11	**Post Fault characteristics of IBR unit**				
	Active Power recovery rate				
	Reactive Power recovery rate				
	Recovery time delay/ Hold time, if any ?				
	Active & reactive currrent freeze state during hold time. If any ?				
12	**Any other Protection Setting**				

Power Plant Controller & PQM Setting details				
	Date of setting extraction from PPC			
S. No.	**Perticulars**	**Enabled/Disabled**	**Setting**	**Snapshot**
1	**General**			
	OEM			
	Model			
	Hardware version			
	Software version			
	Configured as Master or Slave	Select		
	Actual input to PPC provided from	33kV feeder level		
	Number of IBRs handling capability			
2	**PQ meter related**			
	OEM			
	Model			
	Output update rate (time between two successive outputs)			
3	**Communcation & processing related**			
	PPC input refresh rate (time between two successive inputs)			
	Processing time taken by PPC controller			
	PPC output P & Q command update rate (time between two successive outputs)			
4	**Active Power Control Mode**			
	Active Power Control Mode Status	Not Available		
	Active Power Ramp rate (MW/second)			
	Active Power gain parameters (Kp, Ki, Kd parameters)			
	Active power set maximum limit (Pmax)			
	Active power set minimum limit (Pmin)			
5	**Reactive power control (RPC)-**			
	Reactive Power Control Mode Status	Not Available		
	Type of Reactive Power Control Enabled	Voltage		
	Reactive power gain parameters (Kp, Ki, Kd, Hysterisis parameters)			
	Reactive power ramp rate (In steady state condition for all available RPC modes)			
	Reactive power injection limit (Qmax)			
	Reactive power absorption limit (Qmin)			
	FACTs/Capacitor/Reactor control	Not Available		
6	**Frequency Control**			
	Frequency control mode	Not Available		
	Ripple factor			
	Droop			
	Deadband			

Annexure-I(E)(c): IBR Units - High Resolution Data Submission Format

S. No.	Description	Data - Single IBR1	
1	Date (DD-MM-YYYY)	...	...
2	Time(HH:MM:SS)	...	...
3	Milisecond	...	...
4	Active Power (KW)	...	...
5	Reactive Power (KVAR)	...	...
6	Wind Speed (MPS)	...	...
7	Voltage_R (VOLTS)	...	...
8	Voltage_Y (VOLTS)	...	...
9	Voltage_B (VOLTS)	...	...
10	Current_R (AMP)	...	...
11	Current_Y (AMP)	...	...
12	Current_B (AMP)	...	...
13	Frequency (HZ)	...	...
14	Ambient Temperature (Degree Centigrade)	...	...
15	PowerFactor (PF)	...	...
16	Positive Sequence Voltage Angle (Degree)	...	...

S. No.	Description	Data - Single IBRn	
1	Date (DD-MM-YYYY)	...	...
2	Time(HH:MM:SS)	...	...
3	Milisecond	...	...
4	Active Power (KW)	...	...
5	Reactive Power (KVAR)	...	...
6	Wind Speed (MPS)	...	...
7	Voltage_R (VOLTS)	...	...
8	Voltage_Y (VOLTS)	...	...
9	Voltage_B (VOLTS)	...	...
10	Current_R (AMP)	...	...
11	Current_Y (AMP)	...	...
12	Current_B (AMP)	...	...
13	Frequency (HZ)	...	...
14	Ambient Temperature (Degree Centigrade)	...	...
15	PowerFactor (PF)	...	...
16	Positive Sequence Voltage Angle (Degree)	...	...

Annexure-I (F): Single Generator Equivalent Model