Development of an Aggregated Dynamic Model of a Type 4 Wind Power Generator in Real Time Digital Simulation

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Overview

1. Introduction
2. Model Description and Structure
3. Model Simulation Testing
4. What can the model be used for?
5. Conclusions

1. Introduction

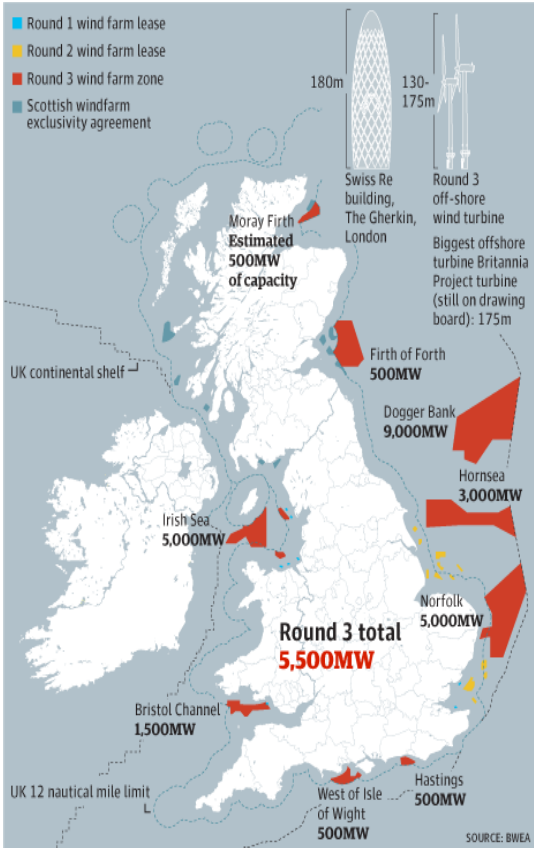
Wind energy is playing a critical role in low carbon economy.

Up to 320GW expected to be installed in the EU by 2030, and 66GW to be offshore

Imposes significant changes in the system dynamics and controls

Important to understand and quantify their impacts on the existing AC grids to ensure secure and reliable operation under different operating conditions

Requires more representative models with acceptable details and simplifications

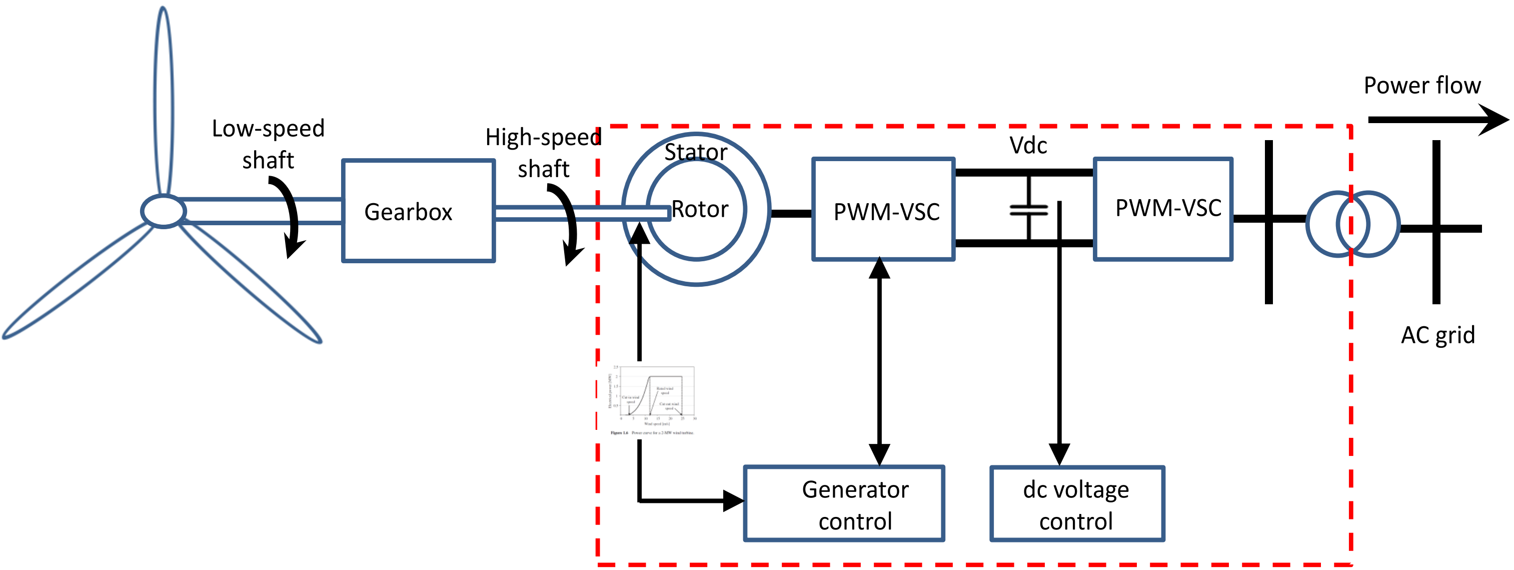


https://www.theguardian.com/environment/2010/jan/08/uk-offshore-windfarms-100bn

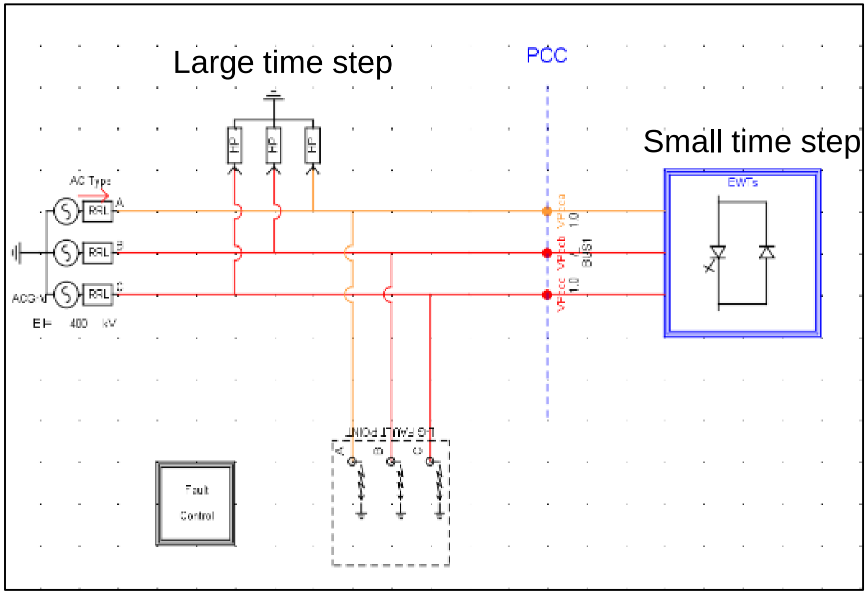
Key objective

Development of a dynamic semi aggregated wind turbines model in Real Time Digital Simulation (RTDS) using dual time step technique

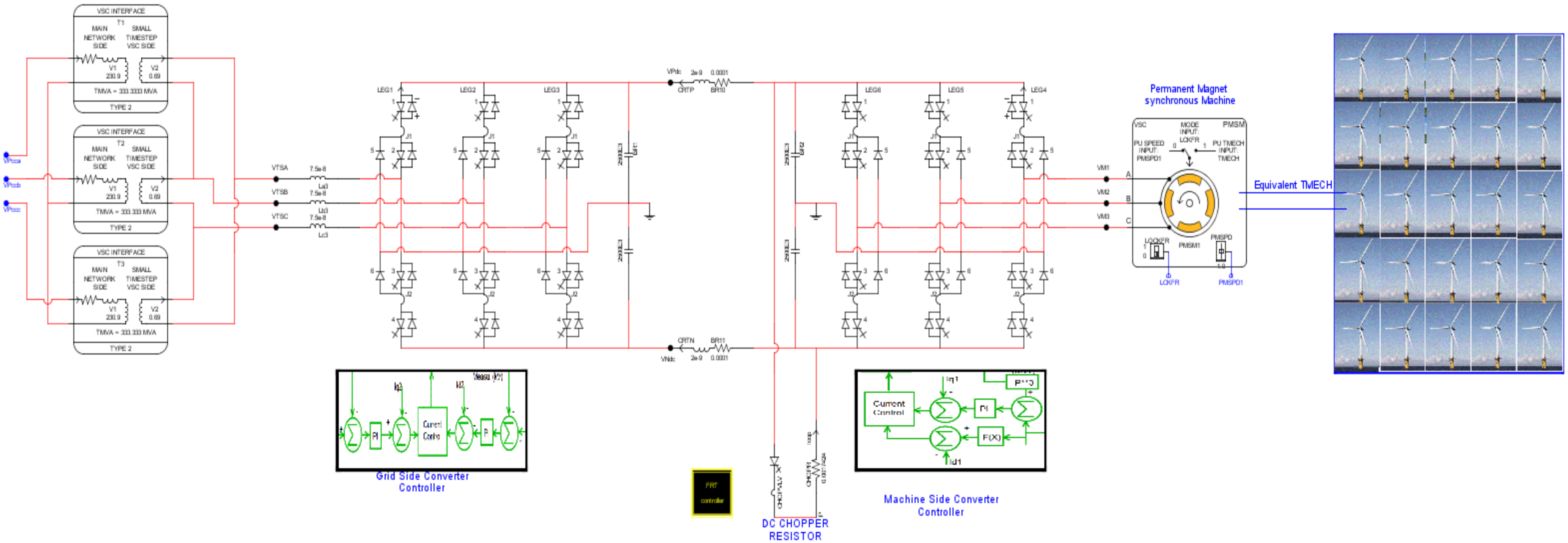
2. Model Description and Structure



Schematic block diagram of type 4 wind generation

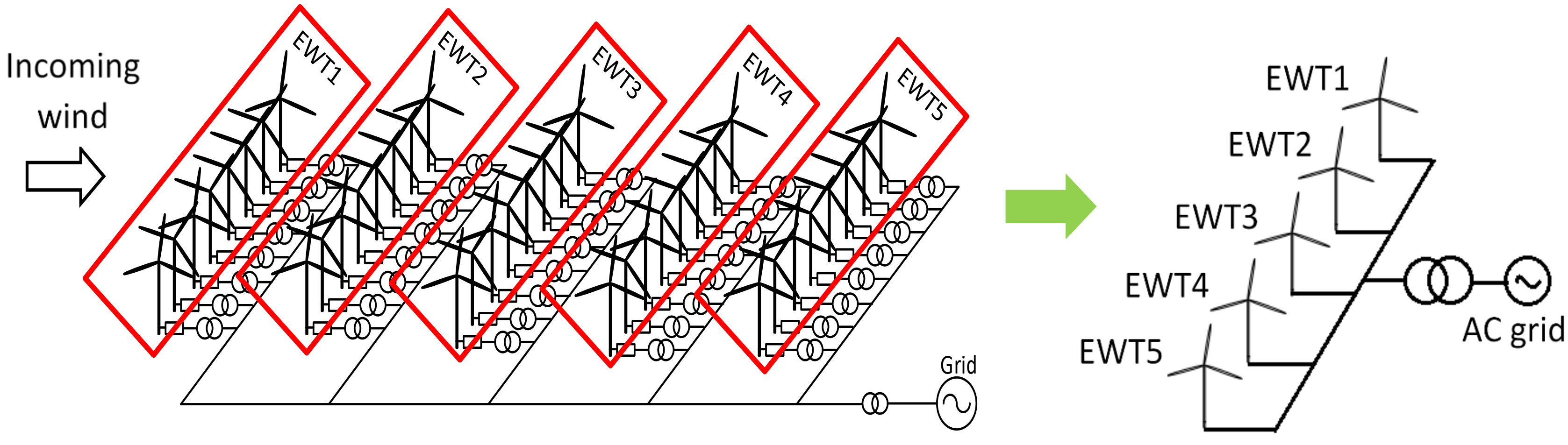


Wind farm aggregated model in small time step subnetwork



Aggregation method

- Full aggregation method
- Multi-machine equivalent aggregation method
- Semi aggregation method



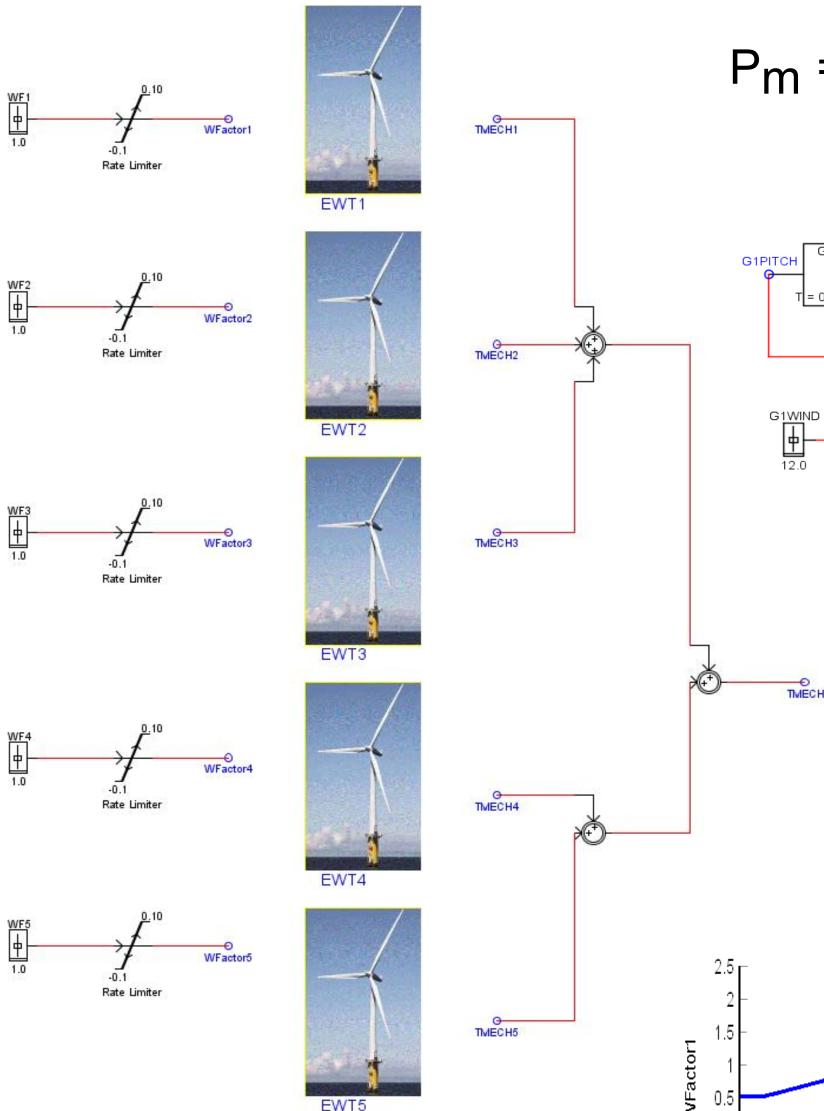
Wind farm semi aggregation approach also called ‘the approximate mechanical torque method’

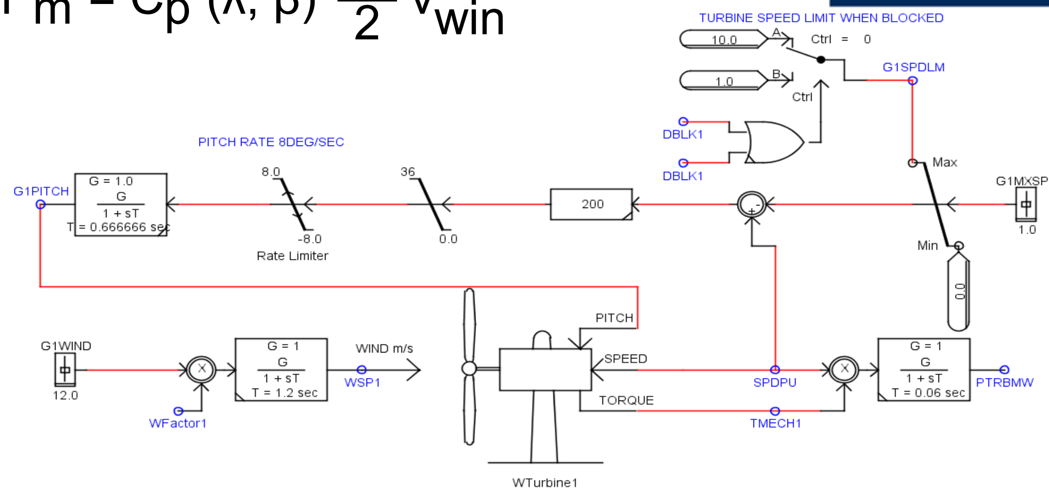
$$S_{agg} = \sum_{1}^{n} S_i = \sum_{1}^{500} 2MVA = 500 \times 2MVA = 1000MVA$$

$$P_{Magg} = \Sigma_1^{100} P_{Mi} = 100 \text{ X } 2MW = 200MW$$

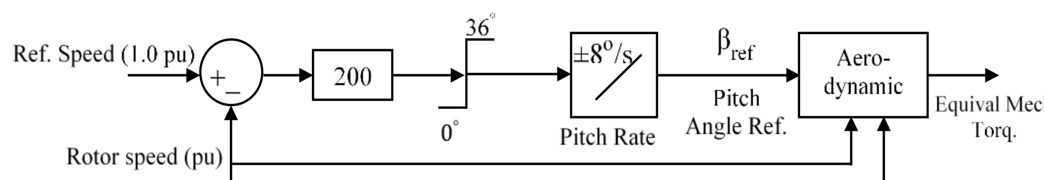
Equivalent Wind Turbine Model

$$P_m = C_p(\lambda, \beta)\,\frac{\rho A}{2}\,v_{win}^3$$

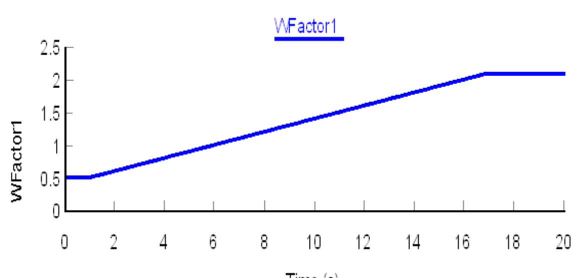


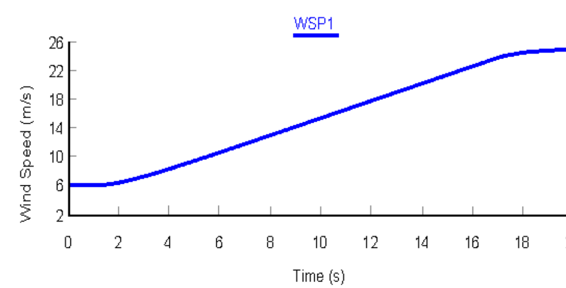


Aerodynamic wind turbine model and pitch control

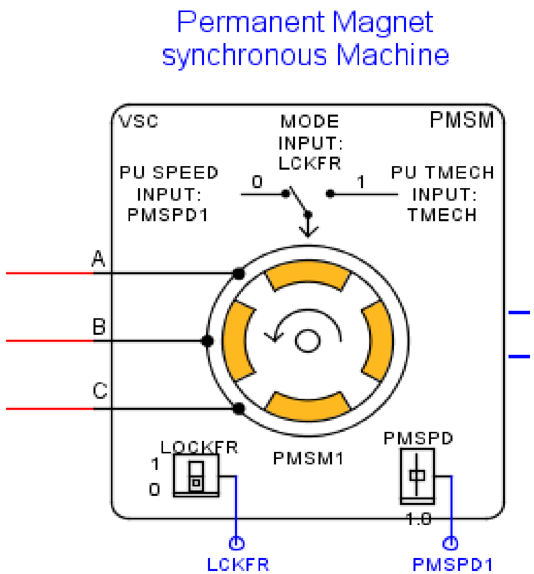


Pitch Angle Control

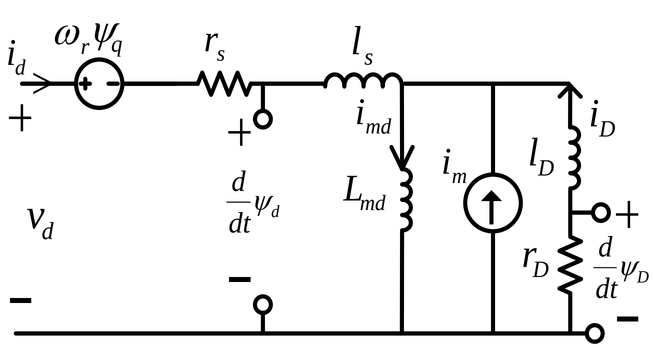


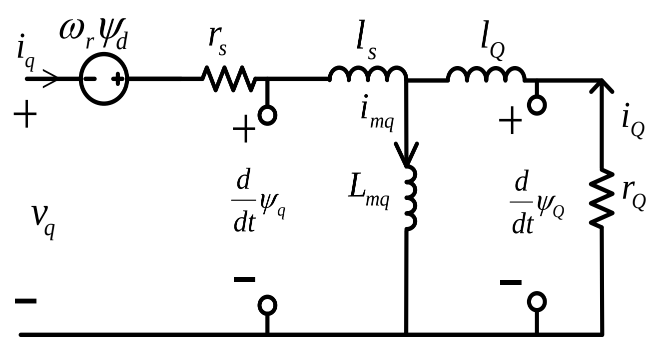


Equivalent Permanent Magnet Synchronous Machine (PMSM) Model



Parameters	Values
Rated Voltage (L-L RMS)	0.690kV
Rated MVA of the Machine	1000MVA
Rated Frequency of the Machine	9.55HZ
Stator Leakage Reactance (X_s)	0.1pu
D-axis Unsaturated Magnet Reactance (X_{md})	0.5pu
D-axis Damper Leakage Reactance (X_D)	2.265pu
Q-axis Magnetizing Reactance (X_{mq})	0.2pu
Q-axis Damper Leakage Reactance (X_Q)	2.265pu
Stator Resistance (r_s)	0.01pu
D-axis Damper Resistance (r_D)	2.0pu
Q-axis Damper Resistance (r_Q)	2.0pu
Magnetic Strength	1.3Norm
Inertia Constant	3.0MWs/MVA





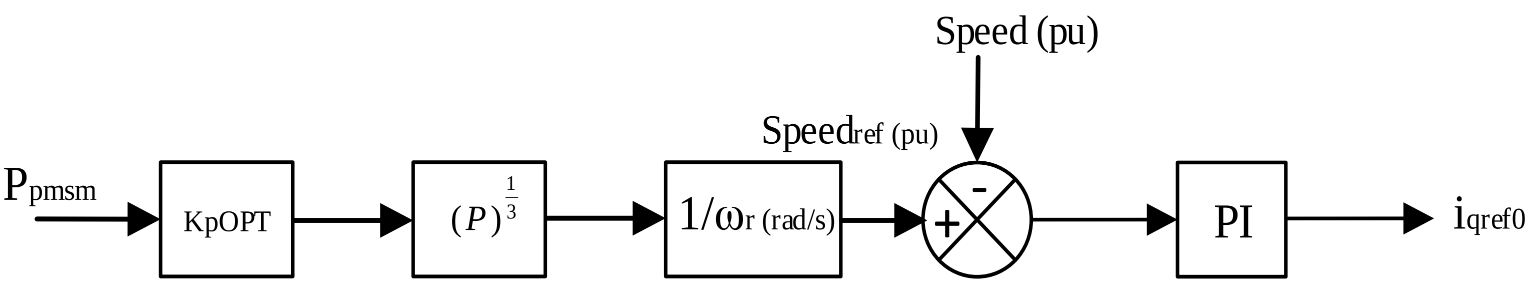
B2B Converter Model

Parameters	Values
Rated DC voltage (pole-pole)	1.2kV
DC link R and L	0.1mΩ, 2μH
Aggregated Smoothing capacitor (C/2)	2000mF
Switching Frequency (PMSM-side converter)	0.3kHz
Switching Frequency (Grid-side converter)	1.9kHz

$$C_{agg} = \sum_{1}^{n} C_i$$

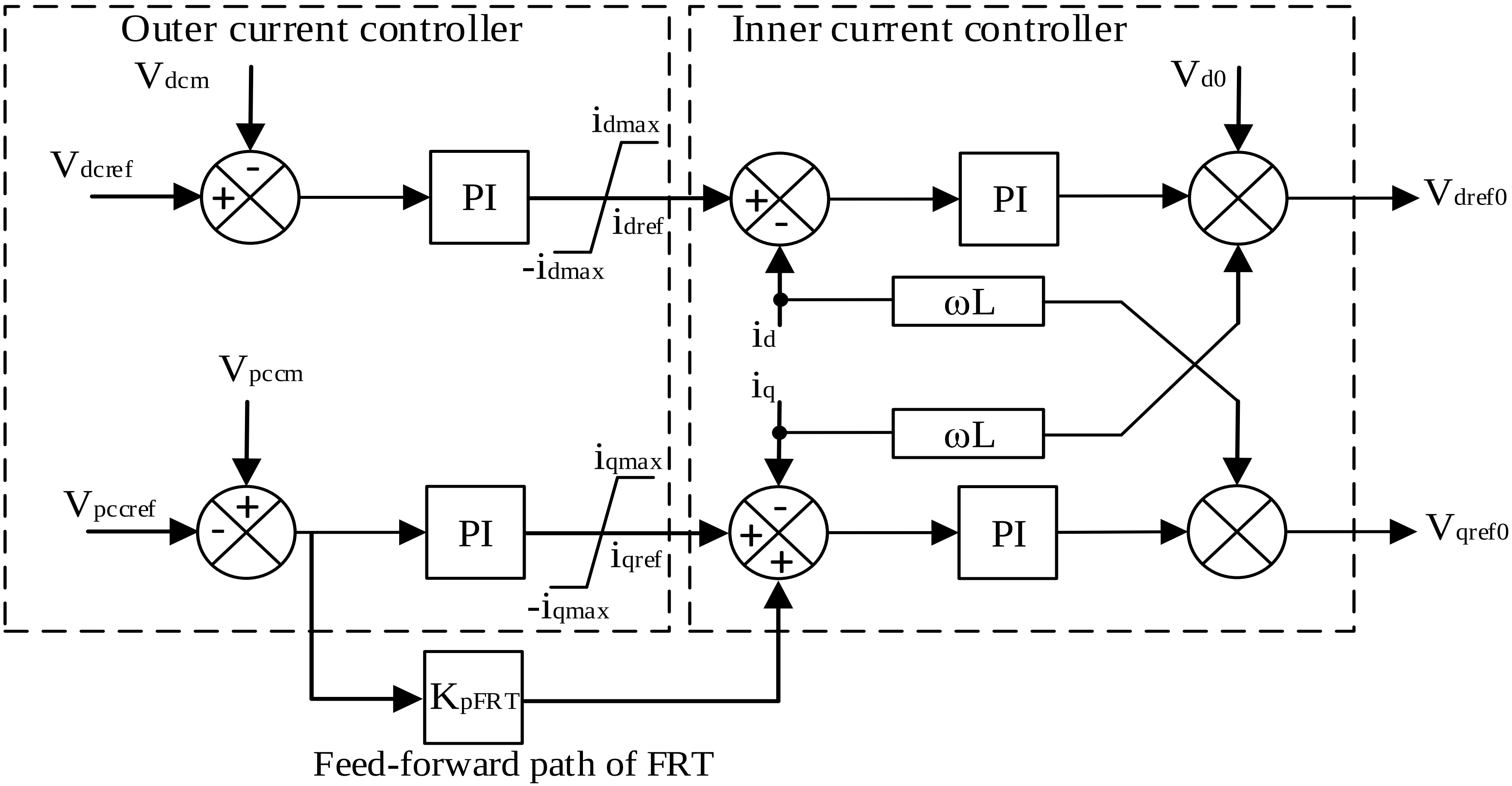
(PMSM) Machine-Side Converter (MSC) Control

$$P_{mequiv.} = K_{op} * \omega_r^3$$



Machine speed regulator

Grid-side Converter Control (GSC)



d-q Outer and inner control loops of the GSC

Fault Ride Through (FRT) controller

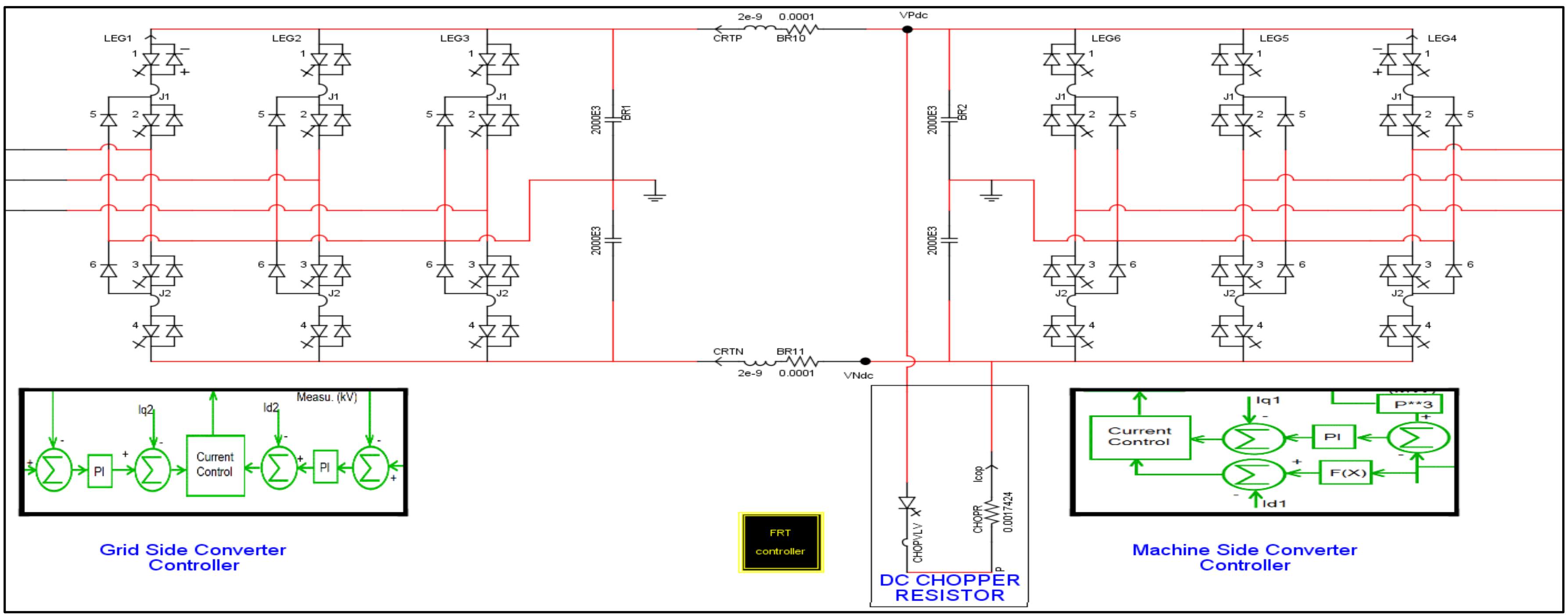
A liner function with dead band (5% of Vpcc) is added to the GSC controller to provide the maximum reactive power during the PCC voltage dips

$$K_{pFRT}=\frac{\Delta i_q}{\Delta V_{pcc}}=2$$

A DC chopper resistor is added to the DC link to control the rise in DC voltage during the AC grid fault.

- controlled by an IGBT switch turned ON when the DC link voltage exceeds 1.1pu of its nominal

$$R_{chopper}=\frac{(1.1*V_{dc})^2}{P_{rated}}=\frac{(1.1*1.2kV)^2}{1GW}=1.742x10^{-3}\Omega$$



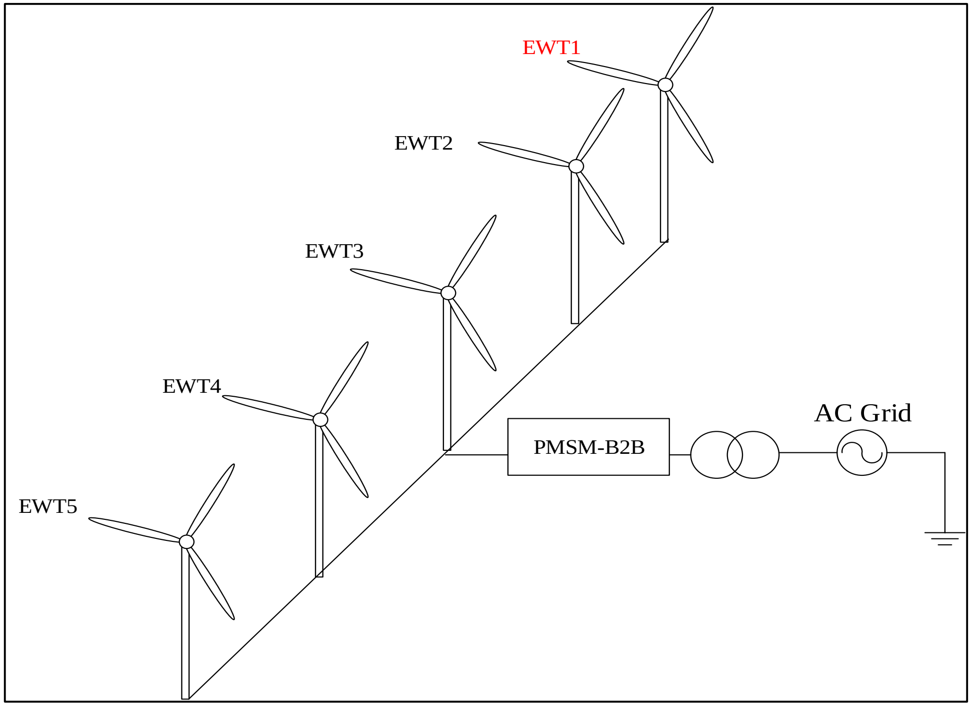
3. Model Simulation Testing

Testing the model response under steady state condition

- testing the response of the pitch angle control against different reference speed values
- testing the machine output power and machine speed performance against different wind speed
- testing the GSC performance against DC voltage and PCC voltage step changes

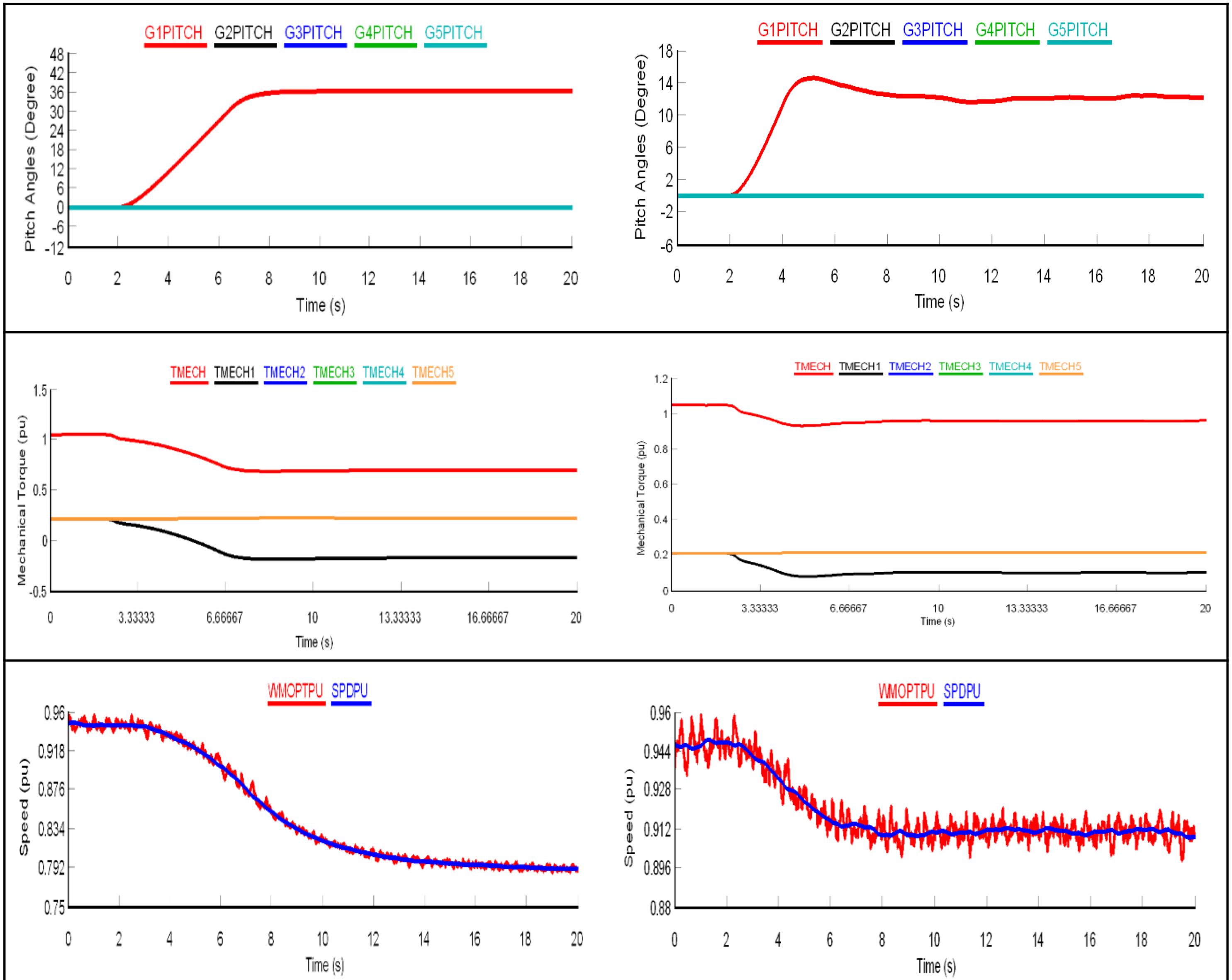
Testing the model response against voltage dips under AC grid faulted Condition

Pitch angle control simulation testing



- A large and small mismatch between the wind turbine rotor speed and the reference speed of the pitch angle control is applied
- This test is applied only to one EWT

Pitch angle control simulation testing



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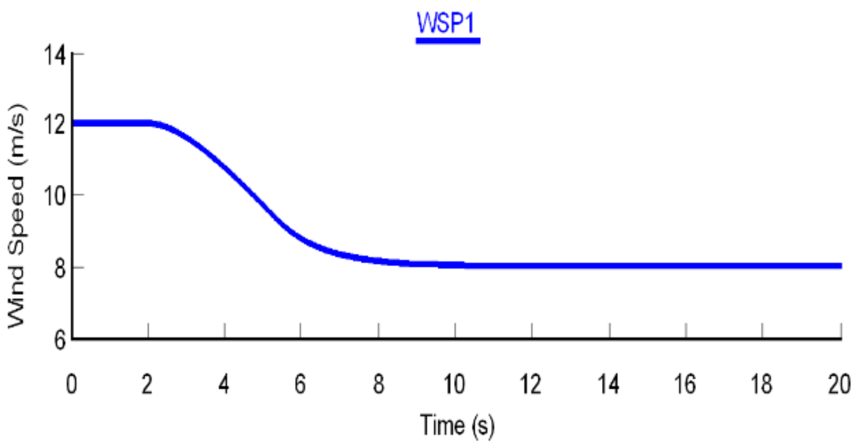
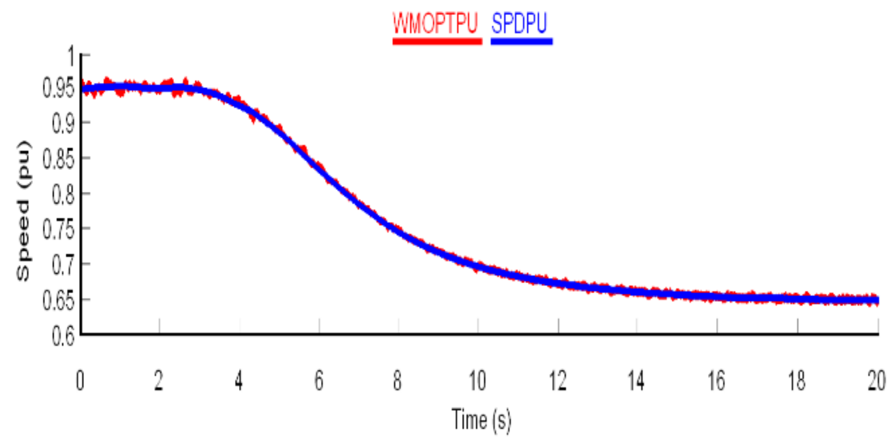
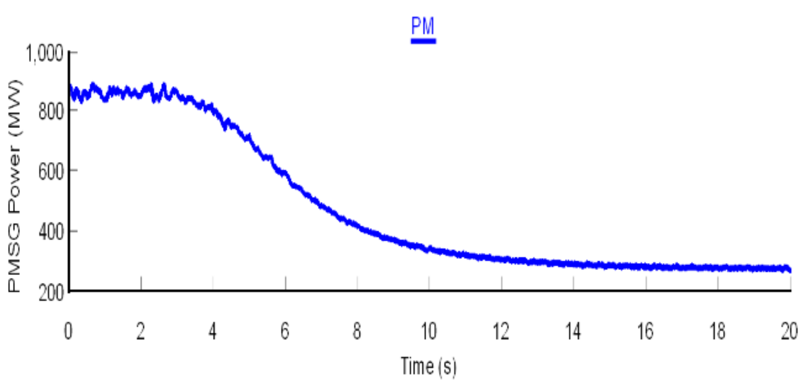
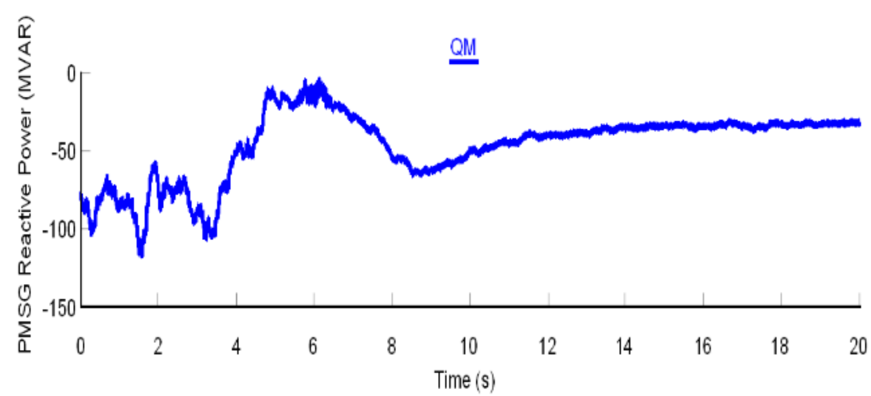
Machine output power and machine speed simulation testing

The wind farm nominal wind speed 12m/s is ramped down to 8m/s

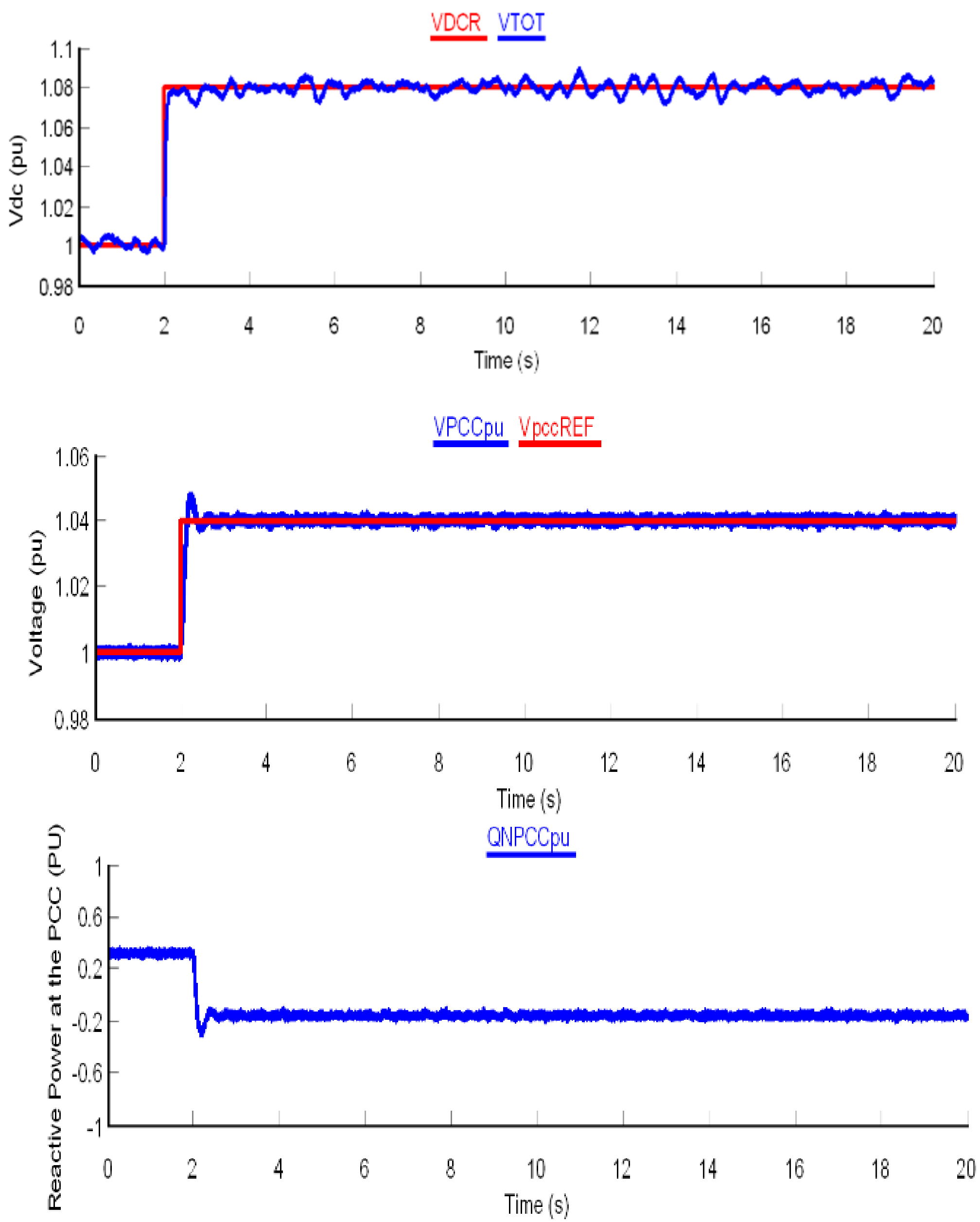




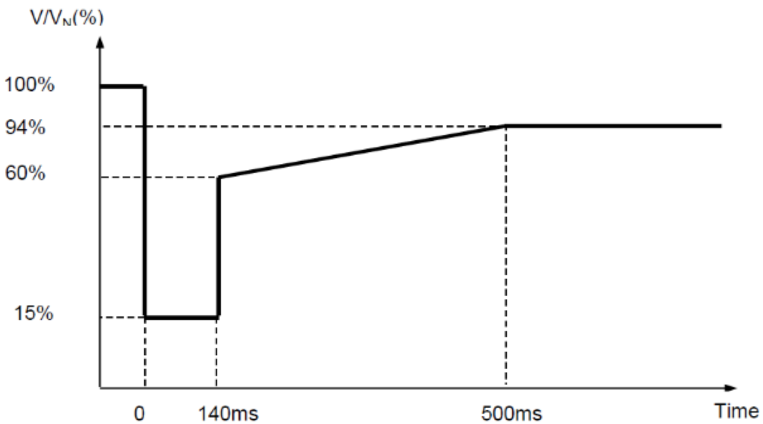


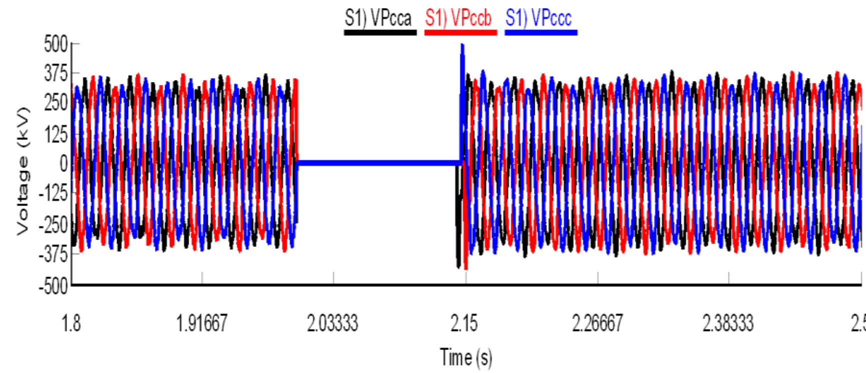


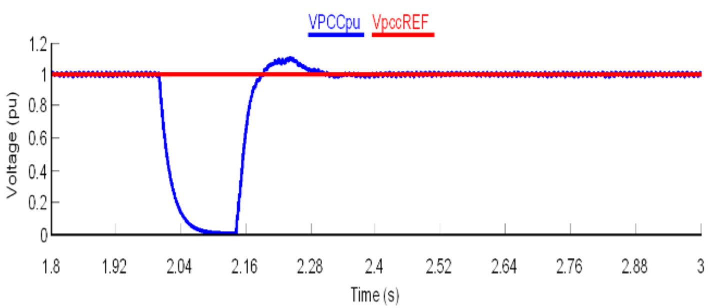
The GSC performance against DC voltage and PCC voltage

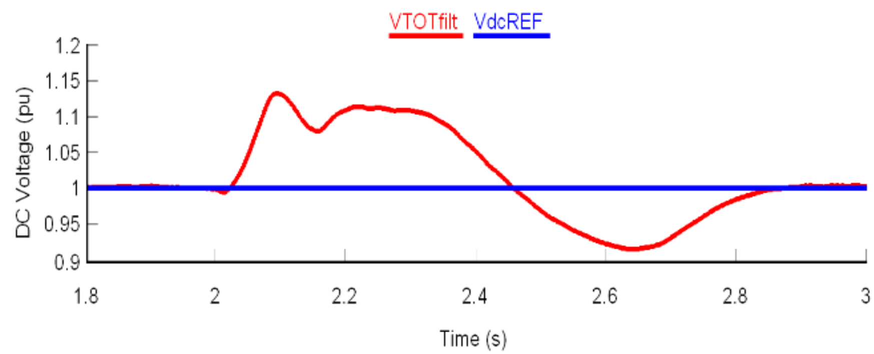


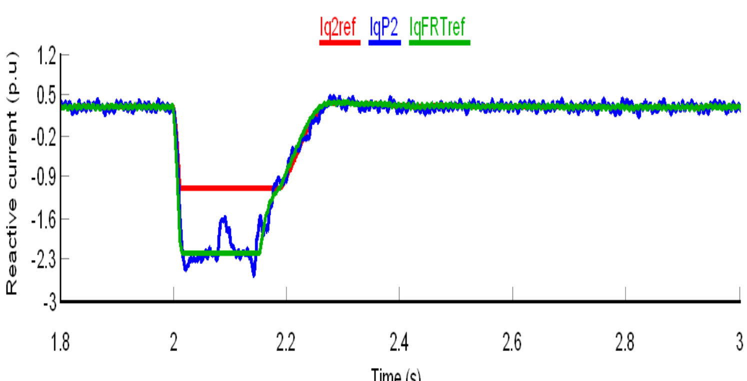
Testing the Model Response against Voltage Dips under AC Grid Faulted Condition

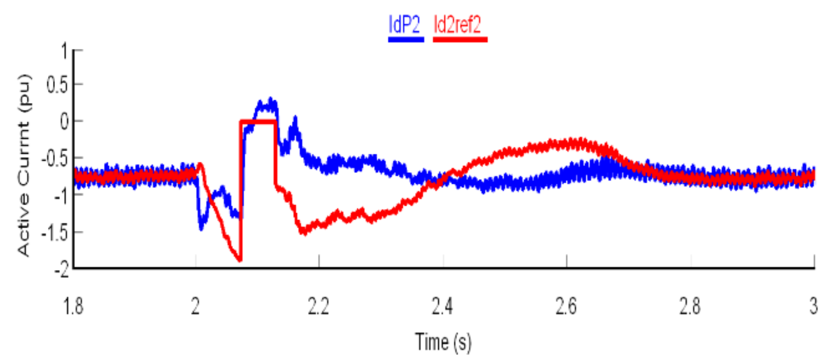




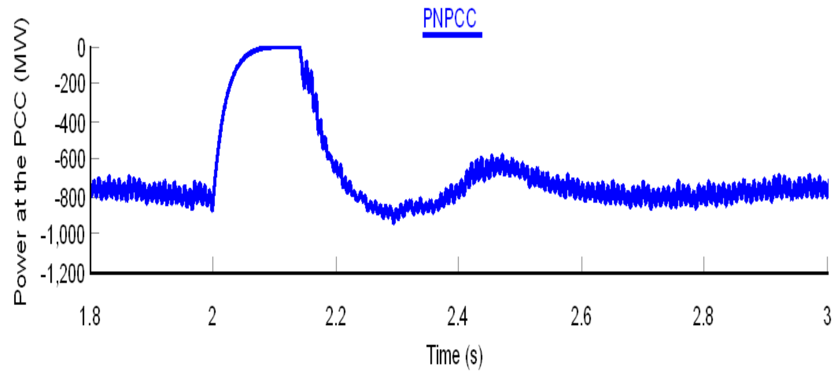


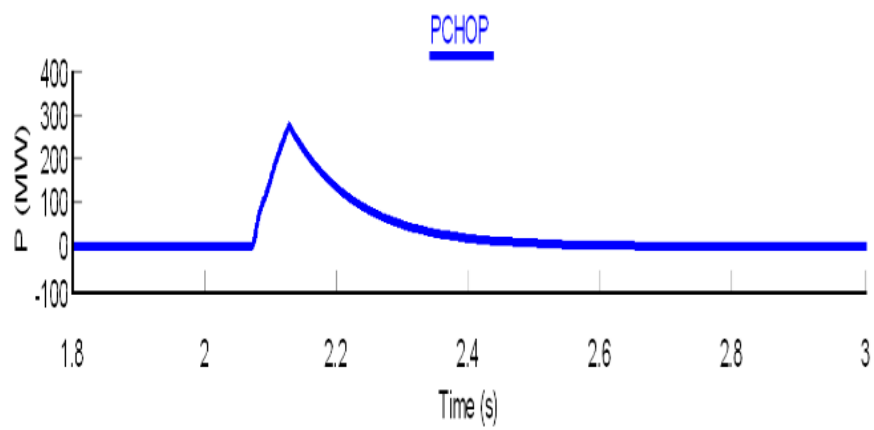


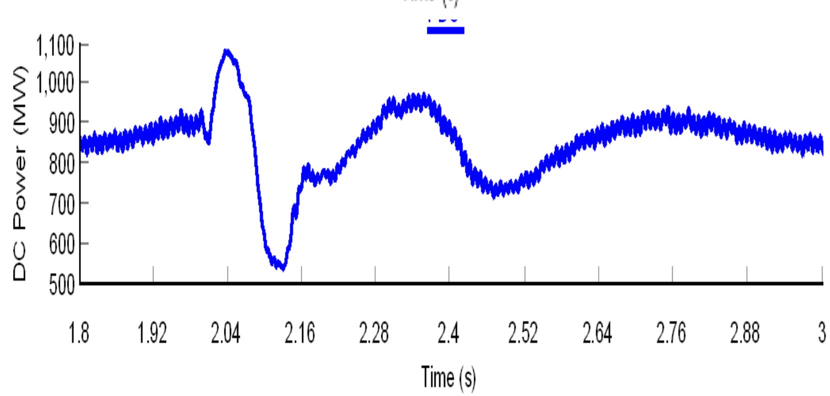




Testing the Model Response against Voltage Dips under AC Grid Faulted Condition

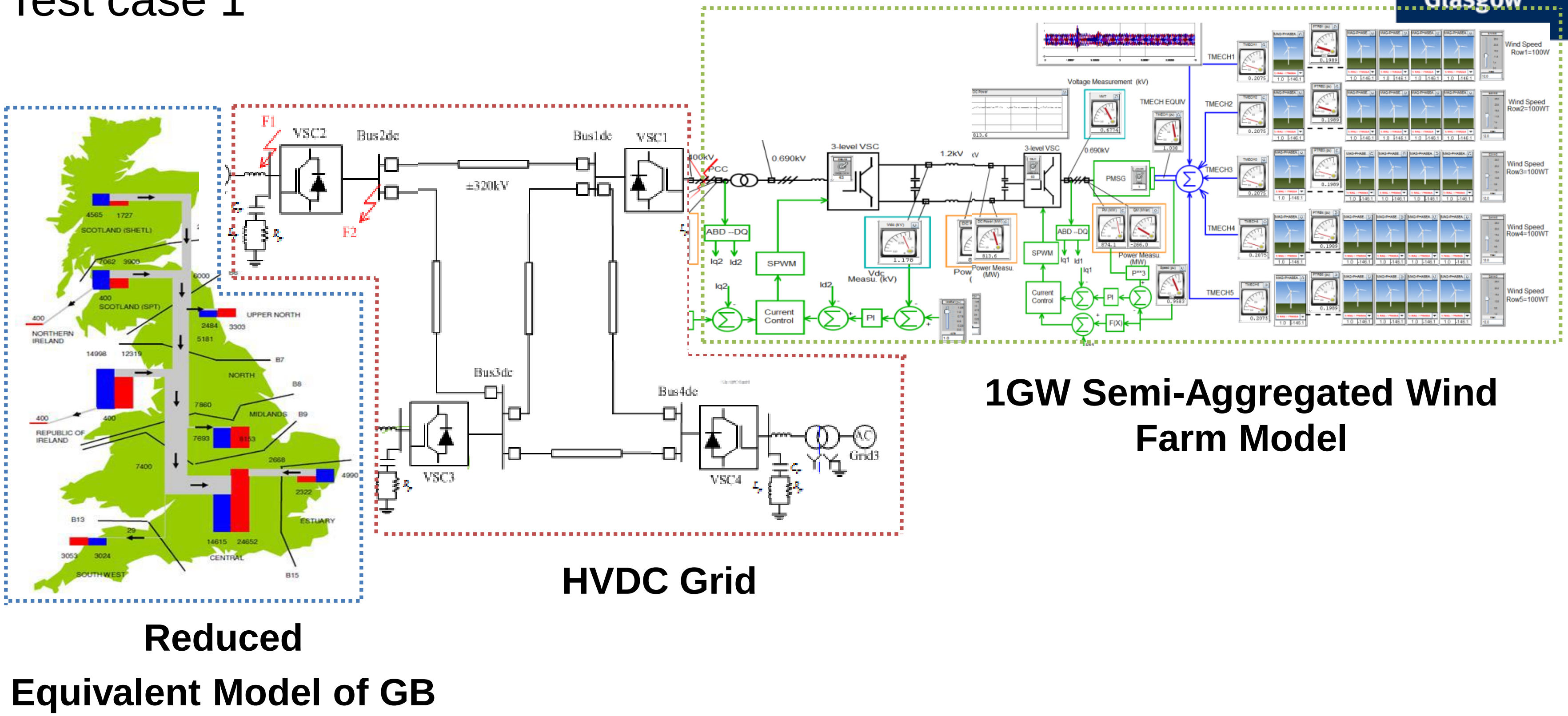






4. What can the model be used for?

Test case 1

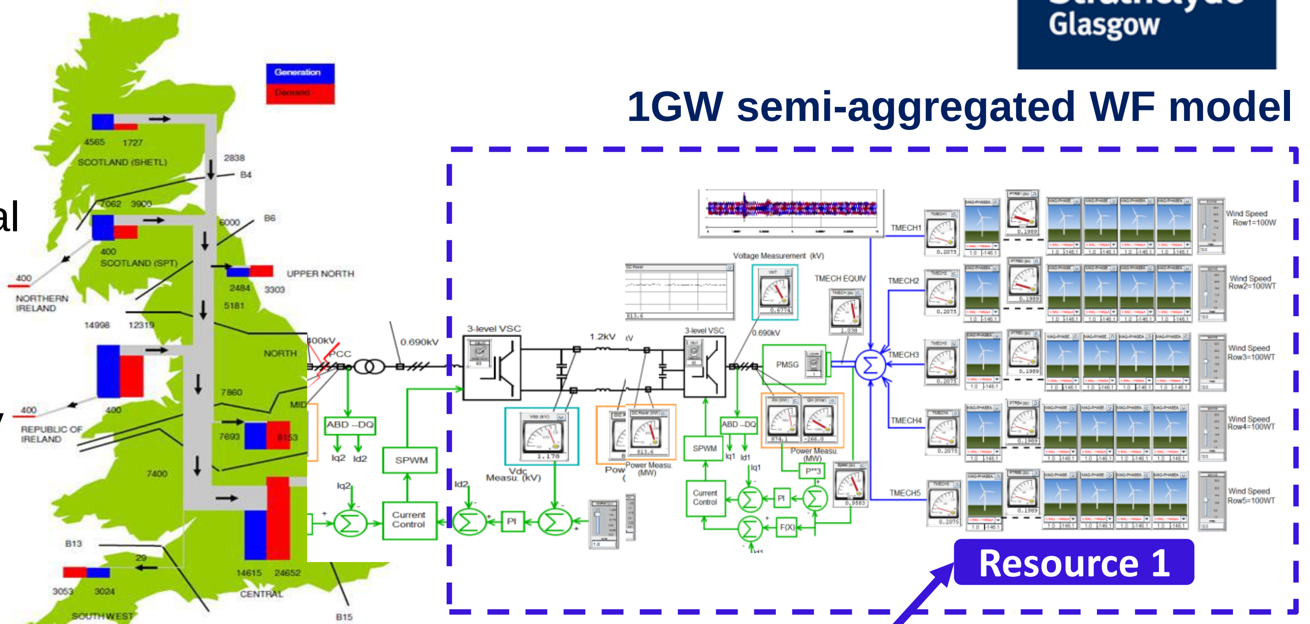


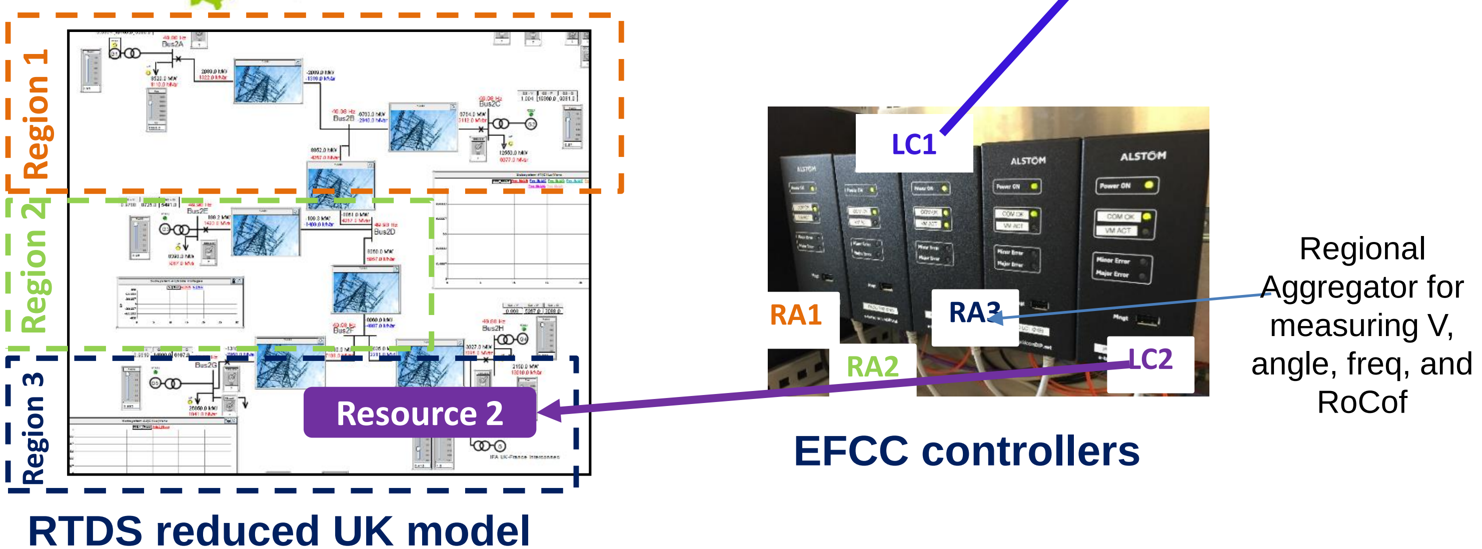
- Testing the developed wind farm model on a hybrid AC-DC grid
- Investigate the dynamic interaction between the WF controls and regional frequency controls

Test case 2– Offshore system frequency support in coordination with an enhanced regional frequency control

To study…

- The capabilities of offshore WF to provide RF support in coordination with regional frequency controls
- Communication impact on the coordinated controls by emulating the communication latency & jitters





5. Conclusions

- Generic semi-aggregated variable speed wind turbines Type 4 model developed and can be used for studying transient and dynamic performance of large wind farms connected to an AC grid

- The model tested under both steady state & transient faulted operating conditions, and the results have shown acceptable response and compliance with grid codes requirements

- The model included DC chopper resistor FRT strategy BUT the model users can use other different FRT methods such as wind turbine power set-point adjustment, wind turbine active current control, offshore voltage reduction, or an enhanced FRT as required

- The model built in pu system to enable the model users to scale the model to different power ratings.

- The model run in real time with reduced complexity and simulation time, and provide a representative test environment with acceptable performance for developing and testing associated hardware control and protection solutions