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Implementation and Validation of IEC Generic Type 1A Wind Turbine Generator Model

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Abstract **- This paper presents the implementation of the IEC generic Type 1A wind turbine generator (WTG) model in PowerFactory (PF) and the validation of the implemented model against field measurements. The IEC generic Type 1A WTG model structure is briefly described. The details are explained regarding how the two mass mechanical model is implemented when the generator mass is included in the PF built-in generator model. In order to verify the IEC generic Type 1A WTG model, the model to field measurement validation method was employed. The model to field measurement validation of the implemented model was carried out by using the 'play-back' approach and the measurement data from Siemens Wind Power. The results of the model to field measurement validation show that there is a good match between the simulation results and the measurements. The errors between the simulation results and measurements were calculated according to the voltage dip windows and the index definition specified in the IEC 61400-27-1 committee draft (CD).**

Keywords **– IEC, Model Validation, Play-back Approach, Type 1A WTG Model**

1. Introduction

With the increasing installed capacity of wind power in power systems, the validated dynamic wind turbine generator (WTG) models are of particular interest for the grid operators to investigate the impact of the high penetration of wind power on the stability of the power system. Most of the existing dynamic WTG models are proprietary user defined models developed by manufacturers or consultants. These vendor-specific models reproduce the behavior of their WTGs with a great level of accuracy and detail. However, it creates a major obstacle for efficiently performing stability studies with wind power. Firstly, many inputs required for the models are proprietary and can't be publicly shared or distributed. Secondly, these vendor-specific models are user written and needed to be complied and implemented in different simulation programs. It takes a lot of time for the user to incorporate a large number of these models into power system network models. Thirdly, the simulation time will be quite long and is not suitable for the power system stability analysis. Therefore, it is of high importance to develop publicly available generic WTG dynamic models.

The Wind Generation Modeling Group (WGMG) of the Western Electricity Coordinating Council (WECC) and the IEEE Working Group on Dynamic Performance of Wind Power Generation (DPWG) have developed generic WTG models for each of the four major WTG topologies [1], [2]. The WECC generic models were developed by simplifying detailed transient stability models. These models have been implemented and validated in at least two widely used commercial transient stability simulation programs, PSLF and PSS/E. Generic simulation models of DFIG and full size converter based wind turbines have been proposed in [3] in order to handle the specific reactive power delivery requirements specified by European grid codes and have a relatively simple model approach. Working group (WG) 27 of International Electrotechnical Commission (IEC) technical committee (TC) 88 is developing a standard IEC 61400-27 for "Electrical simulation models for wind power generation" to define standard dynamic simulation models of wind turbines and wind power plants for power system stability studies. The committee draft (CD) was completed at the end of 2011 specifying wind turbine models and validation procedures [4]. These models should be applicable for dynamic simulations of power system events such as short circuits (low voltage ride through), loss of generation or loads, and typical switching events [5]. The modeling part of the IEC standard has a substantial overlap with WECC WGMG. However, it also considers input from other sources including the publications from European researchers and vendors. The aim is that the generic WTG models shall have a reasonable representation of the actual wind turbines for the power system stability analysis.

The goal of model validation is to verify that a model and its chosen parameters adequately represent the dynamic performance of the "as-installed" device being modeled for the purpose of power system studies. The concept of model validation and how this applies to wind turbine generation systems are described in [6]. The examples of the most recent efforts to achieve model validation for wind turbine generation systems are presented in [6] and it is concluded that the measurement based model validation is the most fruitful exercise. Modeling and validation of an induction generation wind turbine and a DFIG wind turbine were presented in [7], [8]. Besides the model validation of wind turbine generators, there is quite intensive work done on the validation of wind power plant models for power system analysis [9] - [14].

The wind turbines are generally divided into four types. The Type 1 WTG is the one studied in this paper which is a wind turbine generator with an asynchronous generator directly connected to the grid with fixed rotor resistance. The Type 1 WTG might have fixed blade pitch angles or blade angle control. The Type 1 WTG without blade angle control is defined as Type 1A WTG which is the focus of the study in this paper.

The PowerFactory (PF) is widely used commercial power system analysis software. Therefore, it is beneficial to implement the IEC generic WTG models in PF to serve the needs of both industry and academia. The intention of this paper is to briefly describe the IEC Type 1A WTG model, explain the details of the model implementation in PF, and the validation of the implemented model against measurements.

The paper is organized as follows. Section II briefly describes the IEC generic Type 1A WTG model. The implementation of the IEC Type 1A WTG model is presented in detail in Section III. The results of model to field measurement validation are described and discussed in Section IV. In the end, conclusions are drawn according to the model validation results.

2. IEC Type 1A WTG Model

The main electrical and mechanical components of the Type 1 WTG are shown in Figure 1. The Wind Turbine Rotor (WTR) is connected to the Induction Generator (IG) via a Gearbox (GB). The capacitor bank provides reactive power compensation. Most Type 1 WTGs are equipped with mechanically switched capacitor (MSC) banks which are considered to be fixed during short-term simulations. Therefore, the capacitor is represented by a fixed capacitor (FC). As the protection device, the main circuit breaker (CB) disconnects generator and capacitor simultaneously. The Wind Turbine Terminal (WTT) is located at the low voltage side of the step-up Transformer (TR).

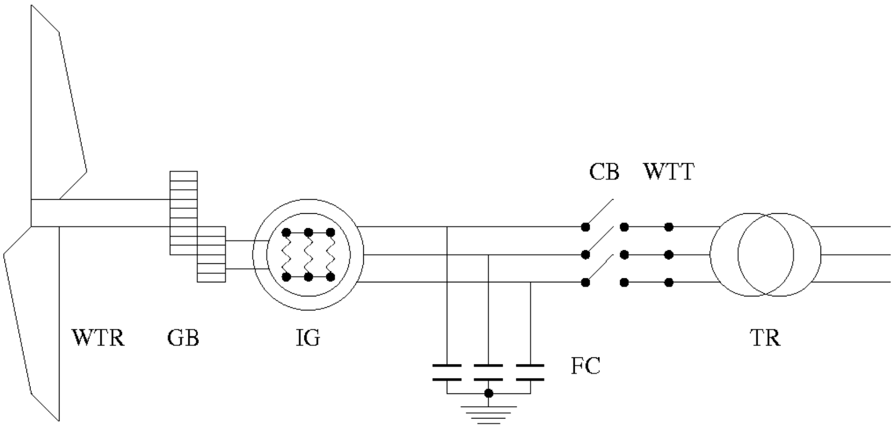

Figure 1 IEC Wind Turbine Generator Type 1 [4]

The structure of the generic Type 1A WTG model is shown in Figure 2. The generic model is comprised of aerodynamic, mechanical, generator system, electrical equipment and grid protection blocks. The details of the blocks of the IEC Type 1A WTG model can be found in [4].

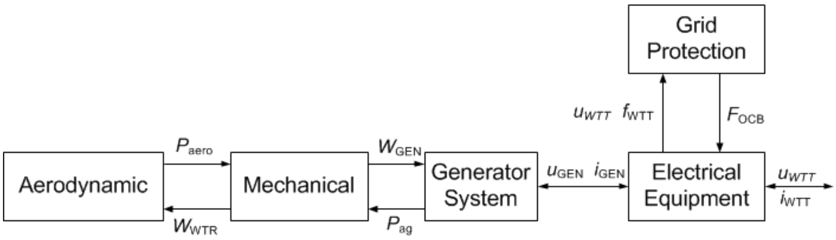

Figure 2 WTG model structure of Type 1A [4]

3. IEC Generic Type 1A WTG Model Implementation in PF

The built-in induction generator model in PF has mechanical power as an input and the generator mass embedded. Therefore, the IEC WTG model structure is adjusted in order to use the built-in induction generator model in PF which is shown in Figure 3. In the modified structure of the IEC Type 1A WTG model, the data exchange between the mechanical and the generator system blocks are flipped, i.e. the power from the mechanical block is the input to the generator system block and the generator speed is fed back to the mechanical block.

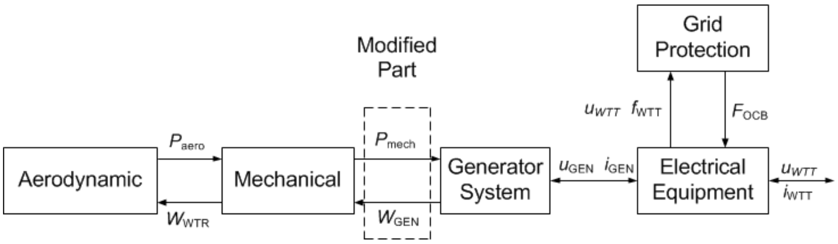

Figure 3 Modified structure of the IEC Type 1A WTG model

In PF, the interaction between the different blocks of the WTG model is realized by a defined composite frame which replicates the connections between the blocks in Figure 3. The composite frame representing the IEC Type 1A WTG model structure is shown in Figure 4. The composite frame consists of the aerodynamic, mechanical, generator and protection blocks.

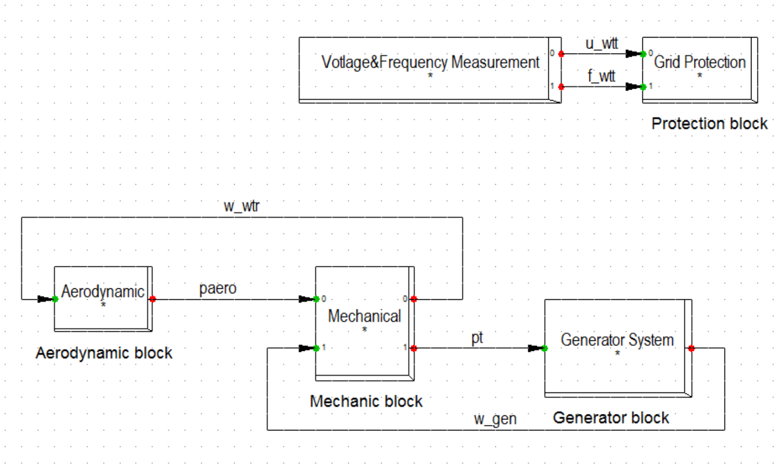

Figure 4 Composite frame representing the IEC Type 1A WTG model structure

Because the generator mass is embedded in the built-in induction generator model in PF, the two mass mechanical model needs to be split into two parts to accommodate that– the generator mass part and the wind turbine rotor mass part including the shaft. The splitting of the two mass mechanical model is shown in Figure 5. The wind turbine rotor mass part including the shaft is implemented in PF as a DSL model and the generator mass is embedded in the PF built-in generator model.

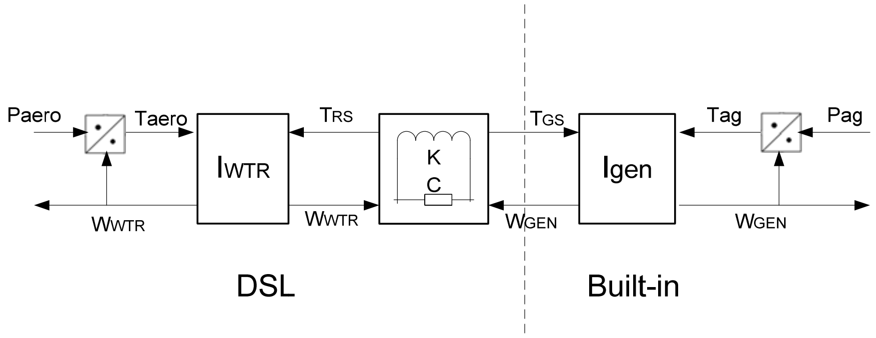

Figure 5 Splitting of the two mass mechanical model

The implemented mechanical model excluding the generator mass in PF is shown in Figure 6. The modified mechanical model has aerodynamic power and generator speed as inputs, and wind turbine rotor speed and generator mechanical power as outputs. The wind turbine rotor mass is represented using the inertia constant and the shaft is represented by the shaft stiffness and the damping constant.

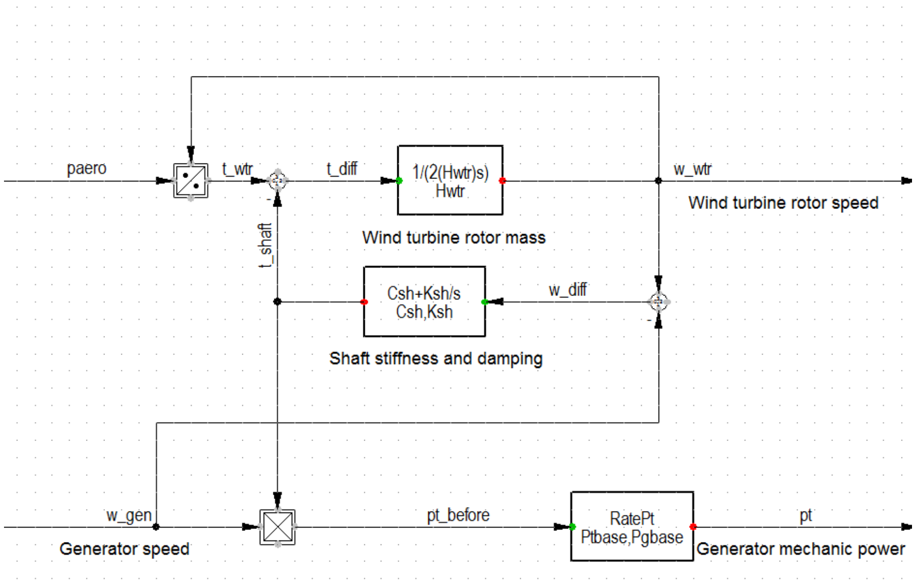

Figure 6 the modified mechanical model of IEC Type 1A WTG model

The aerodynamic model is implemented as a constant torque which is calculated by the initial wind turbine rotor speed and the initial aerodynamic power. The implemented aerodynamic model in PF is shown in Figure 7.

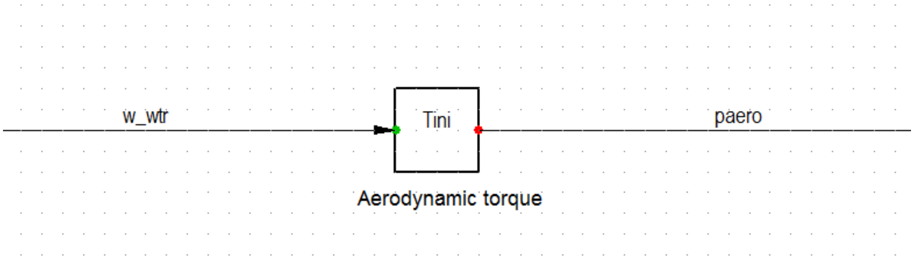

Figure 7 Aerodynamic model in PF

Besides the composite frame, mechanical model and aerodynamic model, the induction generator, cap banks, circuit breaker and terminals are modeled in PF as well which is shown in Figure 8.

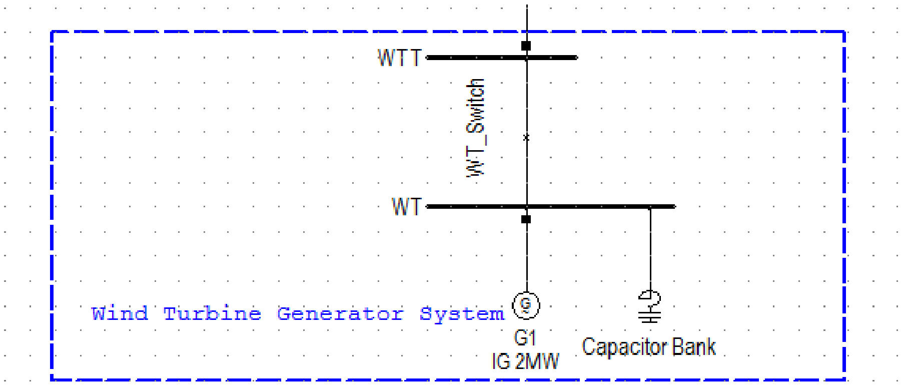

Figure 8 The wind turbine generator system

4. Model Validation Against the Field Measurement

It is concluded in [6] that the measurement based model validation is the most fruitful exercise. Therefore, the model validation against the field measurement was carried out. In order to validate the dynamic performance of the IEC generic Type 1A WTG model, the WTG parameters and measurement data under balanced fault conditions of a Siemens Wind Power Type 1 WTG were obtained. The rated power of the WTG is 2 MW and the rated voltage of the WTT is 0.69 kV. The test was carried out with a test container with series and parallel impedance. For the test, the pre-fault active power is 0.6 pu and a three phase fault was applied at the MV side of the WTG step-up transformer. The measurement data at both the MV side and LV side of the WTG step-up transformer were obtained and consist of positive sequence data of voltage, current and power.

For the model validation against the field measurements, the ‘play-back’ approach was used to carry out the case studies. Since the ‘play-back’ approach was used and the transformer model is not of the interest of the model validation, the measurement data at the WTT were used to carry out the model validation studies. The system used for validation case studies is shown in Figure 9. The WTG under study is connected to a voltage source through a CB and the voltage source gets measured positive sequence voltage during the play-back simulation.

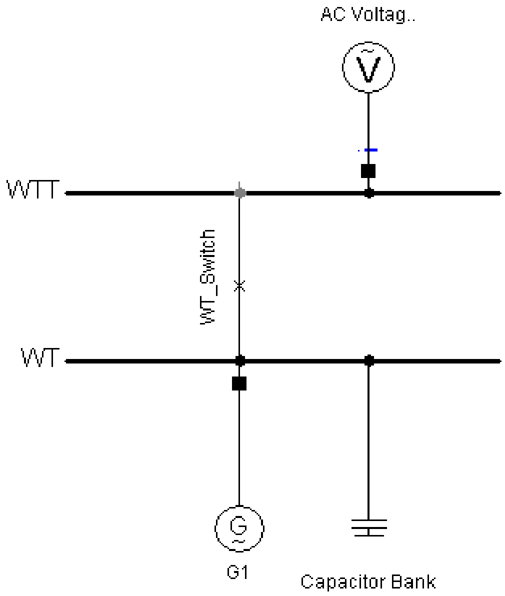

Figure 9 System for WTG model validation studies

The active and reactive power, and active and reactive currents at the WTT were obtained according to the played-back voltage at the WTT and compared to the measurements. In order to compare the simulation results against measurements and calculate the characteristic quantities, the voltage dip windows were determined according to the voltage measurements at the WTT and the window definitions specified in [4]. The voltage dip windows were determined according to the voltage dip in the field test and are shown in Figure 10. The measurement data were divided into three adjacent windows – the pre-fault window Wpre, the fault window Wfault and the postfault window Wpost. On top of the three windows, two more windows are defined in [4] for calculating the characteristic quantities – the quasi steady state part of the fault wind $W_{faultQS}$ and the quasi steady state part of the post-fault window W_{postQS}.

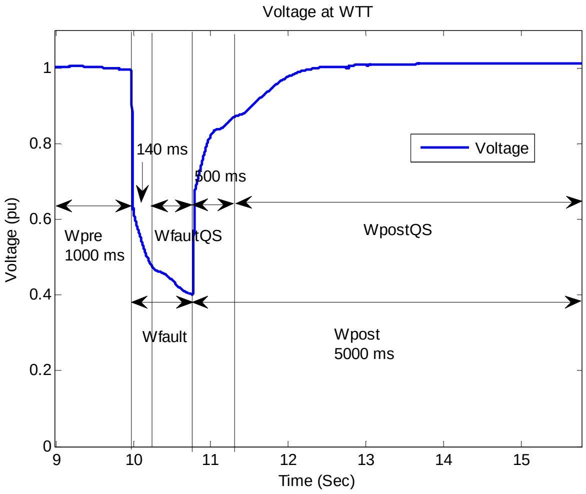

Figure 10 Voltage dip windows

The comparison of active power and active current against measurement is shown in Figure 11 to Figure 12. It is shown that there is a good match of the simulated active power and active currents against the measurements during the fault and after the fault. However, it is shown that there is a big difference between the simulation results and the measurements before the fault. The reason for that is that the active power right before the fault is used for initialization. It can be observed that the active power is fluctuating before the fault which could be caused by wind speed change or due to the opening of the bypass switch across the series impedance.

The comparison of reactive power and reactive current against measurement is shown in Figure 13 to Figure 14. According to the waveforms, it is shown that the simulated reactive power and reactive currents are quite close to the measurements during the fault and after the fault.

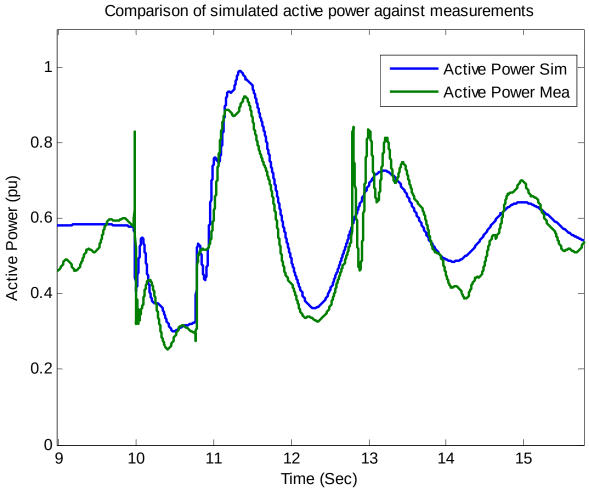

Figure 11 Comparison of simulated active power against measurements

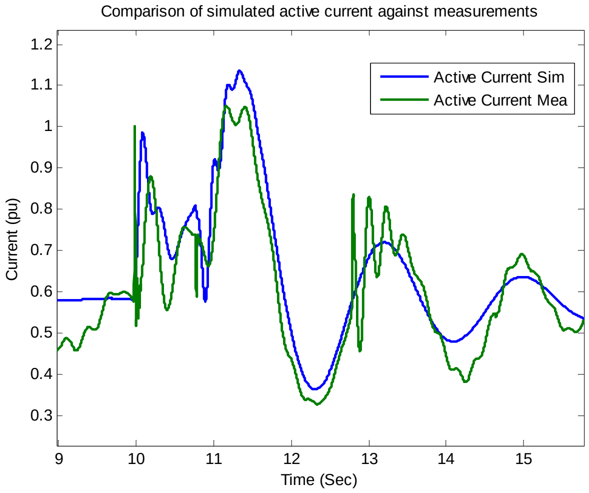

Figure 12 Comparison of simulated active current against measurements

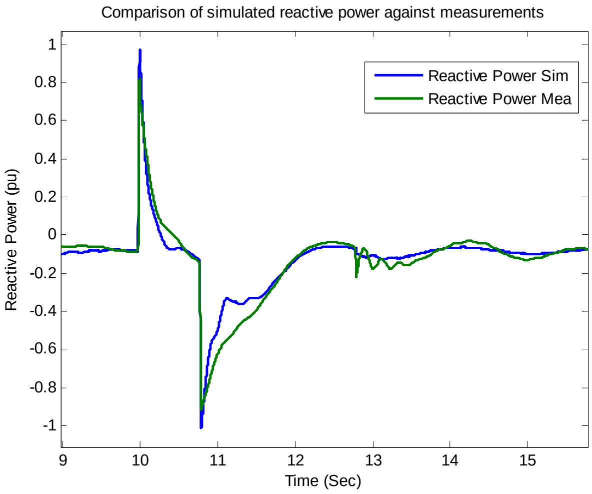

Figure 13 Comparison of simulated reactive power against measurements

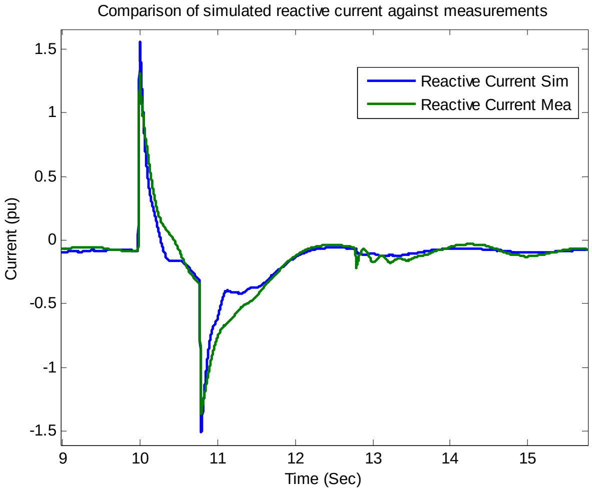

Figure 14 Comparison of simulated power and current against measurements

In order to quantify the difference between the simulation results and the measurements, three characteristic quantities are defined in [4] which are the maximum error X_{MA}, the mean absolute error X_{MAE}, and the mean error X_{ME}. X is the variable to be validated against measurements. The three characteristic quantities were calculated for active and reactive currents and are listed in Table 1 - Table 2.

It is shown that the characteristic quantities have the highest value in the fault window. It is also shown that the characteristic quantities of active current in the fault window are smaller than the ones of reactive current.

5. CONCLUSION

The IEC generic Type 1A WTG model is briefly described in this paper. The details of implementing the IEC generic Type 1A in PF are presented. In order to comply with the IEC generic model structure and use the PF built-in generator model, the data exchange between the mechanical and generator system blocks are adjusted, and the two mass mechanical model is adjusted in order to accommodate the change.

In order to verify the implemented IEC Type 1A WTG model, the model against measurements validation was carried out. The 'play-back' model validation approach has been employed to verify the IEC generic Type 1A WTG model against measurements. The comparison of the waveforms of the simulated power and currents and the measurements show that there is a good match between the simulation results and the measurements. In order to give an indication of the errors between the simulation results and the measurements, the characteristic quantities have been obtained for active current and reactive current. The results show that the characteristic quantities of active current in the fault window are smaller than the ones of reactive current.

Acknowledgement

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References

[1] Ellis A., Kazachkov Y., Muljadi E., Pourbeik P., and Sanchez-Gasca J.: 'Description and technical specifications for generic WTG models-a status report', 2011 IEEE/PES Power Systems Conference and Exposition (PSCE), Mar. 2011, pp. 1–8.

[2] Muljadi E. and Ellis A.: 'WECC Wind Generator Development', Tech. Rep., Mar. 2010.

[3] Fortmann J., Engelhardt S., Kretschmann J., Feltes C., Jarben M., Neumann T. and Erlich I.: 'Generic simulation model for DFIG and full size converter based wind turbines', The 9th International Workshop on Large-Scale Integration of Wind Power into Power Systems, Quebec, Canada, Oct. 2010, pp. 1-8.

[4] IEC 61400-27 Committee Draft (CD): 'Wind Turbines Part 27-1: Electrical simulation models for wind power generation Wind turbines', January 2013.

[5] Sørensen P., Andresen B., Fortmann J., Johansen K., and Pourbeik P., "Overview, status and outline of the new IEC 61400 -27 electrical simulation models for wind power generation," The 10th International Workshop on Large-Scale Integration of Wind Power into Power Systems, Aarhus, Denmark, Oct. 2011, pp. 1-6.

[6] Asmine M., Brochu J., Fortmann J., Gagnon R., Kazachkov Y., Langlois C.-E., Larose C.,

Muljadi E., MacDowell J., Pourbeik P., Seman S.A. and Wiens K.: ‘ Model Validation for Wind Turbine Generator Models’, IEEE Trans. Power Syst., Aug. 2011, 26, (3), pp. 1769–1782.

[7] G. Quinonez-Varela, A. Cruden: ‘Modelling and validation of a squirrel cage induction generator wind turbine during connection to the local grid’, IET Gener. Transm. Distrib., Mar. 2008, 2, (2), pp. 301–309.

[8] Trilla L., Gomis-Bellmunt O., Junyent-Ferre A., Mata M., Sanchez Navarro J., Sudria-Andreu A.: ‘Modeling and Validation of DFIG 3-MW Wind Turbine Using Field Test Data of Balanced and Unbalanced Voltage Sags’, IEEE Trans. Sustain. Energy, Oct. 2011, 2, (4), pp. 509-519.

[9] Kazachkov Y., Feltes J., and Zavadil R.: ‘Modeling wind farms for power system stability studies’, IEEE PES 2003 General Meeting, Toronto, ON, Canada, 2003, pp. 1-8.

[10] Y. Kazachkov and R.Voelzke: ‘Modeling wind farms for power system load flow and stability studies’, IEEE PowerTech 2005, St. Petersburg, Russia, Jun. 2005, pp. 1-8.

[11] E. Muljadi and A. Ellis: ‘Validation of wind power plant models’, IEEE PES 2008 General Meeting, Pittsburgh, PA, Jul. 20–24, 2008, pp. 1-7.

[12] Zhao S. and Nair N.-K.C.: ‘Assessment of wind farm models from a transmission system operator perspective using field measurements’, IET Renew. Power Gener., 2011, 5, (6), pp. 455–464.

[13] MacDowel J. M., Clark K., Miller N. W. and Sanchez-Gasca J. J.: ‘Validation of GE Wind Plant Models for System Planning Simulations’, 2011 IEE PES General Meeting, Detroit, USA, Jul. 2011, pp. 1-8.

[14] Canroy, J., Watson R.: ‘Aggregate modelling of wind farms containing full-converter wind turbine generators with permanent magnet synchronous machines: transient stability studies’, IET Renew. Power Gener., 2009, 3, (1), pp. 39–52.

Table 1 Characteristic quantities of active current

Period	I_{pMA} (pu)	I_{pMAE}(pu)	I_{pME} (pu)
Pre-fault	0.387	0.061	0.044
Fault	0.198	0.069	0.082
Post-fault	0.251	0.055	0.029

Table 2 Characteristic quantities of reactive current

Period	I_{qMA} (pu)	I_{qMAE} (pu)	I_{qME} (pu)
Pre-fault	0.037	0.018	-0.016
Fault	0.218	0.110	-0.076
Post-fault	0.141	0.026	0.024