Implementation of IEC Generic Model Type 1A using RTDS

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Implementation of IEC Generic Type 1 Wind Turbine Generator Model using RTDS

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Abstract – This paper presents the implementation of the IEC generic model of Type 1 wind turbine generator (WTG) in the real time digital simulator (RTDS) environment. The model is based on the IEC 61400 TC88 under wind turbine working group's standardization efforts are implemented. Several case studies have been carried out to verify the dynamic performance of the IEC generic Type 1 WTG model under both steady state and dynamic conditions. The case study results show that the IEC generic Type 1 WTG model can represent the relevant dynamic behavior of WTG to ensure grid integration compatibility.

Keywords: Generic WTG; IEC standard, RTDS, Transient Stability, Two-Mass Model, Wind Power Generation.

1. Introduction

Wind power has been one of the fastest-growing sources of new electric power generation for several years and the use of wind power for electricity generation is no doubt still growing in many places around the globe. With this ever increasing penetration of the wind power generation, transmission system operators (TSOs) and distribution system operators (DSOs) are demanding an accurate dynamic wind turbine generator (WTG) models for power system stability studies. The recent concern of the TSOs and DSOs are very legitimate, since it is their responsibility to design and manage the power system global production and its adjustment to the consumer loads as well as to assure the technical quality of the overall service, both in steady-state and under transient disturbances [1]. These concerns are not anymore a negligible grid integration issue that some years ago they tended not to give too much attention or relevance. The typical behavior of high amount of time-dependent renewable based power plants must be addressed by the TSOs and DSOs. However, the confidential requirements from wind turbine manufacturers prevent the academia, system operators and researchers from working on a real or/and manufacturer specific models. A generic WTG model is therefore of great interest that does not contain the confidential information meanwhile represents the manufacturer specific models. Generic wind turbine generator models have to be developed and to allow the TSO and DSO to simulate the large wind farms connected to the transmission or distribution network in order to study their grid integration, address their behavior and assess their stability under various conditions [2]. These generic dynamic simulation models are useful tools to evaluate the impact of the wind power on the power system stability. Thus, a strong stimulus exists for the development of a generic dynamic model in order to further investigate the dynamic response of WTG under grid disturbances. So far, International Electrotechnical Commission (IEC) started the standardization work–IEC 61400-27 to define standard, and to develop publicly available generic wind turbines and wind power plants models for dynamic simulation. The working group is composed of both modeling and validation subgroups. The working group WG27 held the first meeting in October 2009. The committee draft has been completed at the end of 2011 specifying wind turbine models and validation procedures. 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 [3]. To enable simulation of large power networks and several power converters that employ switches operating at a few kHz switching frequencies, we propose the use of real-time digital simulator (RTDS). RTDS is a powerful tool that accomplishes the task of real-time simulation via parallel computation. The system is capable of performing time-domain simulation at real-time speed using microsecond time step level. Such small time step enables RTDS to accurately and reliably simulate power system phenomena.

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It has also hardware-in-the-loop (HIL) simulation function which can't be realized with traditional simulation tools and method. Currently, more researchers have focused on developing test and research platform based on RTDS [4][5]. The simulation results in this paper are very close to the results obtained using DigSILENT PowerFactory (PF) simulation tool as described in the previous author's research work [6, 7, 8]. The purpose of this paper is to implement and validate generic dynamic electrical simulation model for IEC type 1 WTG, which retain enough fidelity with respect to the dynamic behavior of the turbine terminals and can therefore be applied in power system stability studies. The rest of the paper is organized as follows. A brief description of the electrical and mechanical components of IEC Type 1 WTG model is provided in Section II. The simulation results are presented in Section III and a conclusion is drawn in Section IV.

2. IEC WIND TURBINE GENERATOR MODEL

2.1 Model Description

Fig. 1 shows the main electrical and mechanical components of Type 1 WTG. More detailed description of the IEC model development has been provided in [2].

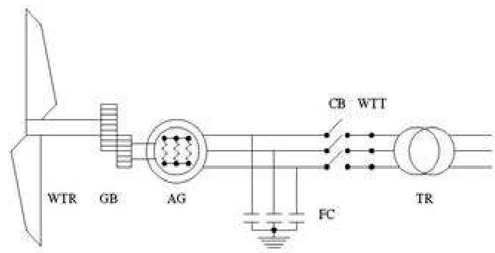


Fig. 1. IEC wind turbine generator type 1 model

The wind turbine rotor (WTR) is connected to the asynchronous generator (AG) via a gearbox (GB). The capacitor bank provides reactive power compensation. Most Type 1 WTGs are equipped with mechanically switched capacitor (MSC) banks and fixed blade angles, which are considered to be fixed during short-term simulations. Therefore, the capacitor is denoted as fixed capacitor (FC). As the protection device, the main circuit breaker (CB) disconnects generator and fixed capacitor simultaneously. The wind turbine terminal (WTT) is located at the low voltage side of the step-up transformer (TR).

The blade pitch angles of the Type 1 wind turbines can either be fixed or controllable (i.e turned away from stall or into stall). The blade pitch angle control in some wind turbines is used for fault-ride through (FRT) control. From the perspectives of power system stability studies, the type 1 WTGs can therefore be divided into two subgroups:

- Type 1A: without FRT control.
- Type 1B: with blade angle FRT control.

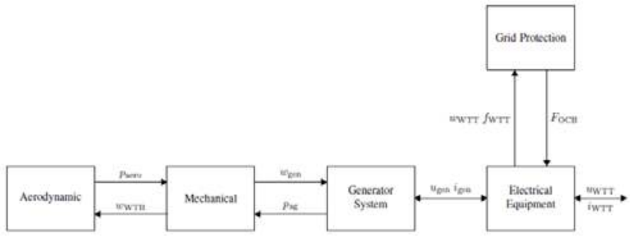


Fig. 2. Structure of type 1 WTG model

2.2 Structure of Generic Type 1A WTG Model

Fig. 2 shows the structure of the generic type 1A WTG model. It is comprised of aerodynamic, mechanical, generator system, electrical equipment and grid protection blocks.

1) Aerodynamic block: The aerodynamic torque is assumed to be constant during the short time period. Therefore, constant aerodynamic torque model is used instead of pseudo governor model described in [9]. The model block diagram is given in Fig. 3.

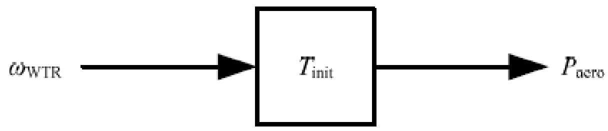


Fig. 3. Generation System

2) Mechanical block: The mechanical part is represented by a two-mass model, in which the separated masses are used to represent the low-speed turbine and the high-speed generator. The connecting resilient shaft is modeled as a spring and a damper. The block diagram of IEC standard model is shown in Fig. 4.

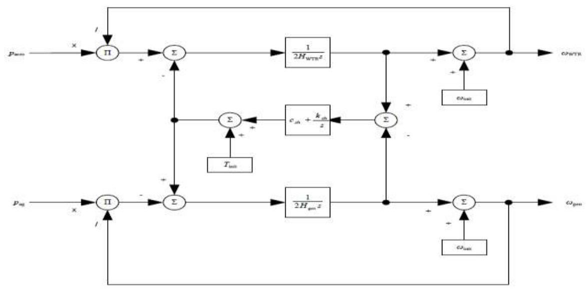


Fig. 4. IEC standard block diagram for two-mass model

In the IEC standard, it is assumed the built-in induction generator model in simulation software does not include its inertia equation. In fact, the inertia part is integrated in the RTDS induction generator model. Moreover, instead of generator rotation speed ω_{gen} as input, the mechanical power is the input. Therefore, a modified block diagram shown as Fig. 5 is used.

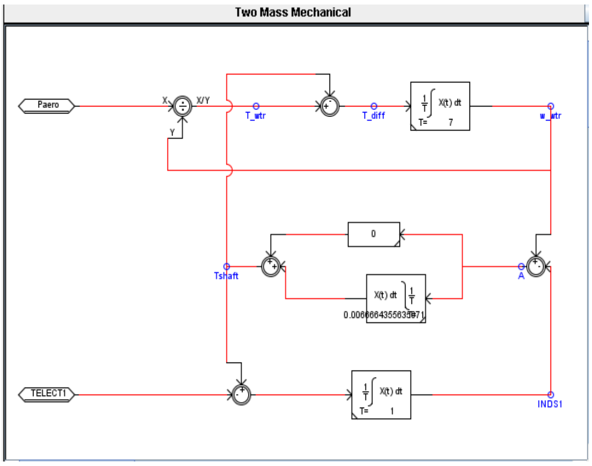


Fig. 5. Modified RTDS block for two-mass model

TABLE I
PARAMETERS FOR THE TWO MASS MODEL

Symbol	Unit	Description	Source
H_{WTR}	p.u.	Inertia constant of wind turbine rotor	Manufacturer
H_{gen}	p.u.	Inertia constant of generator	Manufacturer
k_{sh}	p.u.	Shaft stiffness	Manufacturer
c_{sh}	p.u.	Shaft damping	Manufacturer
w_{init}	p.u.	Initial steady state shaft rotor speed	Initialization
T_{init}	p.u.	Initial steady state shaft torque	Initialization

The parameters of the two-mass block are listed in Table I. The wind turbine model structure should also be changed accordingly for implementation purpose.

However, this modification will not cause any difference in the simulation results as there will still be two masses as a whole. The interaction between the two masses will result in the torsional oscillation and has a significant impact on the dynamic behavior of WTG. The torsional oscillation is typically between 0.2 to 4 Hz. This dynamic response is later presented in the next section of simulation result part.

For the sake of simplicity, a discussion of the other blocks such as generator system, grid protection and electrical equipment will not be included. Further detailed description of the IEC model development has been provided in [2, 6, 7]. The nature frequencies are given by

$$f_1 = \frac{1}{2\pi}\sqrt{\frac{k_{\mathrm{sh}}}{2H_{\mathrm{WTR}}}}$$

$$f_2 = \frac{1}{2\pi}\sqrt{\frac{k_{\mathrm{sh}}(H_{\mathrm{WTR}} + H_{\mathrm{gen}})}{2H_{\mathrm{WTR}}H_{\mathrm{gen}}}}$$

3. Simulation Results

The test system from [6, 7] has been used to carry out case studies. The single line diagram and RTDS implementation of the test system are shown in Fig. 6 and Fig. 7, respectively.

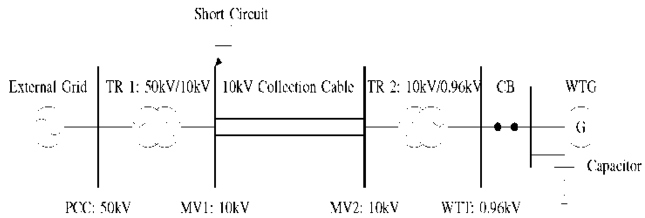


Fig. 5. Single line representation of the test system

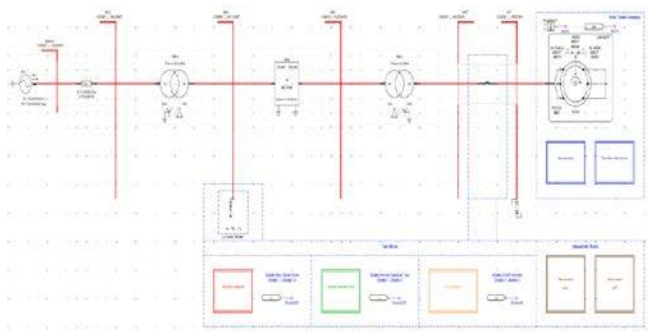


Fig. 6. RTDS implementation of the test system

As it can be seen that the test system is comprised of an external grid using a Thevenin equivalent model, two step-up transformers TR1 and TR2, the collection cable, circuit breaker CB, reactive power compensation and wind turbine generator WTG. The power grid with a 50 kV line to line rms voltage is modeled by a three phase voltage source in 50 µs time step system, while the wind power generation system with a 0.96 kV line to line rms voltage are modeled. The modeled IEC generic type 1 WTG model in RSCAD is set to run at full output power. The test system is used for both Type 1A and Type 1B. The parameters of the electrical components are described as follows.

1) *External Grid:* It is modeled by the Thevenin equivalent circuit. $U_{Th} = 50kV$, $R_{Th} = 2.516\Omega$, $X_{Th} = 8.2998\Omega$.
2) *50/10 kV Transformer Tr1:* It is modeled by the T-equivalent. The transformer saturation and no-load losses are not considered. The phase connection is YNd5. The transformer is directly grounded: $S_n = 16MVA$, $U_p = 50kV$, $U_s = 10.5kV$, $R_p = 0.4052\Omega$, $X_p = 7.655\Omega$, $X_m = 19530\Omega$, $R_s = 0.4052\Omega$, $X_s = 7.655\Omega$.
3) *Short Circuit:* The 3-phase short circuit fault lasts 0.1 s. The error impedance before the fault is 1 $M\Omega$ (star impedance). The short circuit impedance is 0.00011 Ω (star impedance).
4) *10* kV *Collection Cable:* The wind farm 10 kV collection cable is modeled by the π-equivalent: $C_1 = 1.58\mu F$, $R = 0.7568\Omega$, $X = 0.4473\Omega$, $C_2 = 1.58\mu F$.
5) *10/0.96* kV *Transformer Tr2:* It is modeled by the T-equivalent. The transformer saturation and no-load losses are not considered. The phase connection is Dyn5. The transformer is directly grounded: $S_n = 2MVA$, $U_p = 10.5kV$, $U_s = 0.96kV$, $R_p = 0.2756\Omega$, $X_p = 1.654\Omega$, $X_m = 6890\Omega$, $R_s = 6890\Omega$, $X_s = 1.654\Omega$.
6) *Capacitor Bank CB:* The capacitor bank in the wind turbine is delta connected, with the capacity $C_\Delta = 1333\mu F$ in series with $R_\Delta = 0.003\Omega$.
7) *Wind Turbine Generator and two mass model:* The induction generator in the wind turbine is modeled by the T-equivalent: $S_n = 2.3MVA$, $U_n = 0.96kV$, $N_0 = 1500rpm$, $R_s = 0.0004\Omega$, $X_s = 0.05\Omega$, $X_m = 1.6\Omega$, $R_r' = 0.004\Omega$, $X_r' = 0.05\Omega$. The inertias of the two-mass model: $H_{WTR} = 3.5p.u.$, $H_{gen} = 0.5p.u.$, $k_{sh} = 150.0052p.u.$, $c_{sh} = 0p.u.$.

The execution scenarios for normal operation cases are listed in Table II. The simulation time is also dependent on the cases. To ensure the stable simulation of the generator dynamics, the time step of 20 μs is used.

TABLE II
CASE STUDY SCENARIOS

Study Scenario	**Event**	
Normal operation	Wind variation	
	Simulation time	50 s
	For Type 1A, aerodynamic torque T_{init} is specified as piece wise function.	0~10 s: $T_{init} = 1.0836$
		10~25s: $T_{init} = 0.9$
		25~50s: $T_{init} = 1.1$
	For Type 1B, reference p_{WTTref} is specified as piece wise function:	0~10 s: $p_{WTTref} = 0.8894$
		10~25s: $p_{WTTref} = 0.8$
		25~50s: $p_{WTTref} = 1$

A. Normal operation mode

For Type 1A, the blade angle is fixed. The output active power p_{WTT} can only be affected by the aerodynamic torque T_{init}.

$$T_{init} = \frac{p_{aero}}{w_{WTR}}$$

T_{init} can be specified as a linear piece-wise function to simulate the wind variation as defined in the Table II. The simulation time is from $t = 0$ s to $t = 50$ s. In the first10 s time frame, $T_{init} = 1.0836$ p.u. which is derived from the above equation. In the following next 15 s time frame, the wind becomes weaker and T_{init} decreases to be 0.9 p.u.. During the last 25 s time frame, the wind becomes stronger and T_{init} increases to be 1.1 p.u.. The response of generator rotation speed, w_{gen} and active power, p_{WTT} are illustrated in Fig. 8.

For Type 1B, the blade angle is controllable. The output active power p_{WTT} can be regulated by the reference p_{WTTref} through adjusting the blade angle. During the normal operation, this reference value can be specified as a linear piece-wise function to simulate the wind variation as defined in the Table II. The simulation time is from $t = 0s$ to $t = 50s$. In the first 10s time frame, $p_{WTTref} = 0.8894p.u.$, which is derived from induction machine setting. In the following 15s time frame, the wind is weaker and p_{WTTref} decreases to be 0.8p.u.. During the last 25s time frame, the wind becomes stronger again and p_{WTTref} increases to be 1p.u.. The response of generator rotation speed, w_{gen} and active power, p_{WTT} are illustrated in Fig. 9.

The figures show a very close agreement between RTDS, PF RMS, and PF EMT results. The waveforms of w_{gen} {Fig. 8 plot (a)} and p_{WTT} {Fig. 8 plot (b)} follow the wind variation. Because of direct connection to the grid, w_{gen} is very close to the network frequency. The wind variation doesn't influence w_{gen} apparently, the range is still between 1.01 p.u. and 1.013 p.u..

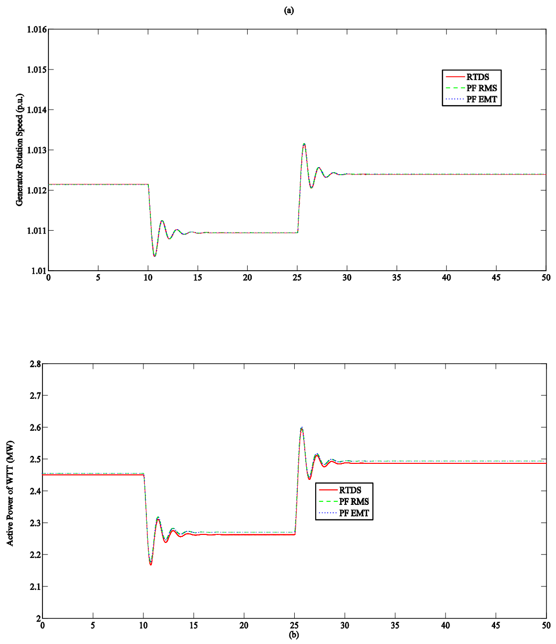


Fig. 8. Generator rotation speed w_{gen} and active power p_{WTT} in normal operation (Type 1A)

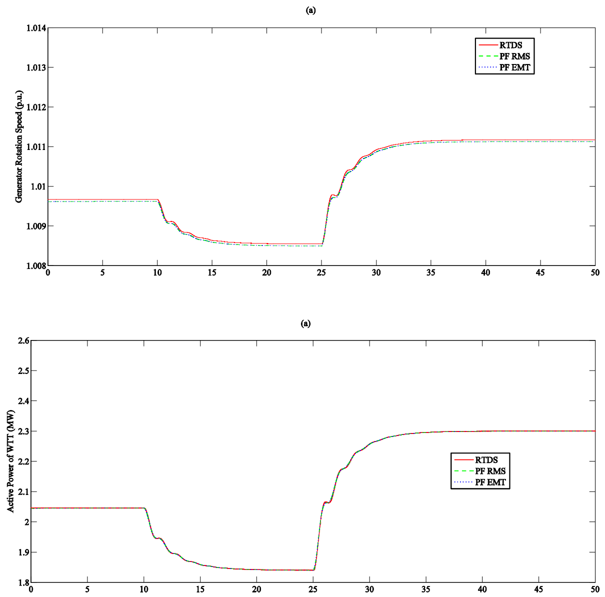
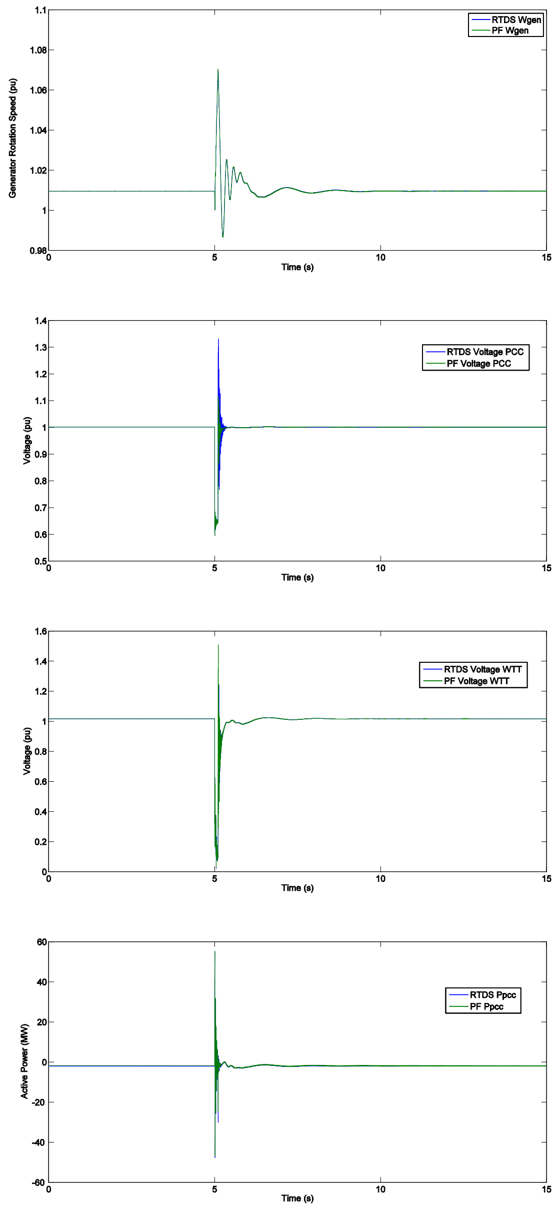


Fig. 9. Generator rotation speed w_{gen} and active power p_{WTT} in normal operation (Type 1B)

B. *Fault condition*

The 3-phase short circuit event is used to represent the fault condition. The short circuit event happens at t = 5s on the terminal MV1 and is cleared at t = 5.1s. The simulation time is 15 seconds. And, the simulation time step of 20 µs is used. During the short circuit, the dynamic responses of generator rotation speed, voltage at both point of common coupling (PCC) and wind turbine terminal (WTT), frequency of both PCC and WTT, active power of both PCC and WTT, reactive power of both PCC and WTT are captured in Fig. 10 (only the results of Type 1A are shown because the results are very similar for the Type 1B). The typical response of low frequency oscillations is also captured and analyzed in this paper.



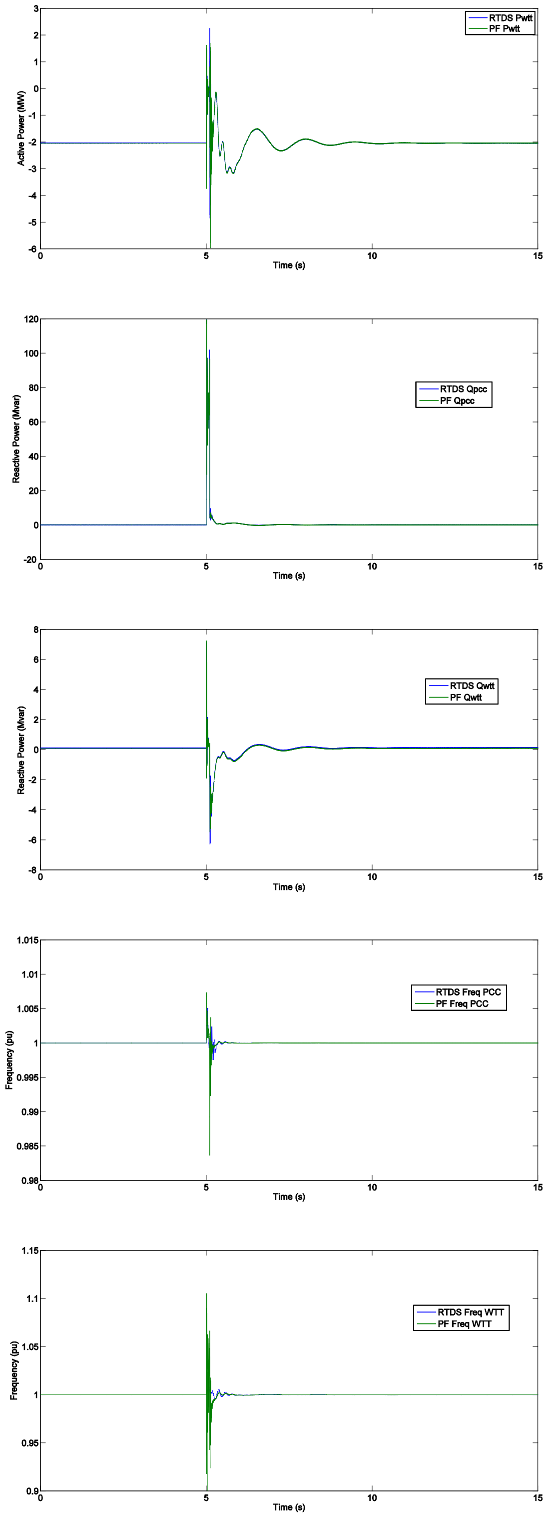


Fig. 10. Dynamic response of generic type 1A WTG model

The waveforms between RTDS and PF are almost identical. The results exhibit good agreement between the RTDS and the PF simulation. Two resultant curves match to a very high degree of accuracy, which gives the confidence that the generic model has been implemented properly [7].

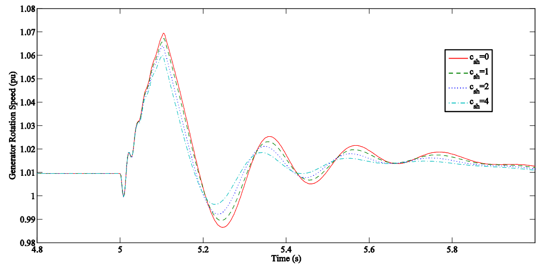


Fig. 11. Dynamic behaviors of different damping coefficients c_{sh}

The torsional oscillations between different sections of the turbine-generator rotor can be observed due to the perturbance in the short circuit. At the instant of the fault, the electrical torque reduces immediately and results in the sudden increase of the generator rotation speed. This phenomenon lasts until the fault is cleared. Due to interaction of two masses, the generator rotation speed variation causes the torsional oscillation. As mentioned earlier in Section II, the torsional oscillation is typically between 0.2 to 4 Hz and the oscillation frequency modes are given by:

$$f_1 = \frac{1}{2\pi}\sqrt{\frac{k_{sh}}{2H_{WTR}}} = 0.7368 \text{ Hz}$$

$$f_2 = \frac{1}{2\pi}\sqrt{\frac{k_{sh}(H_{WTR} + H_{gen})}{2H_{WTR}H_{gen}}} = 2.0839 \text{ Hz}$$

The oscillations with different damping coefficients are plotted in Fig. 11. As illustrated, the oscillation is damped by increasing the damping coefficient c_{sh} from 0 to 4.

4. Conclusion

In this paper, a generic dynamic electric simulation model for IEC type 1 WTG was introduced. The goal was to have exact or retain enough fidelity with respect to the dynamic behavior of the turbine terminals and can therefore be applied in power system stability studies. The results of RTDS simulation have been shown under both normal and fault conditions. It has been illustrated that the implemented IEC generic Type 1 models in RTDS can represent the relevant dynamics during normal operation and fault conditions. In normal operation, the wind power variation is simulated by changing the aerodynamic torque (Type 1A) or power output reference set point (Type 1B). The RTDS simulation results were compared against PF simulation results, and exhibited a good agreement. In fault case, the torsional oscillations of the two-mass model due to the disturbance are examined. Future work will be carried out on the comparison between the simulation results and measurements data provided by manufacturers.

Acknowledgment

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References

[1] Estanqueiro, “The future energy mix paradigm: How to embed large amounts of wind generation while preserving the robustness and quality of the power systems,” Wind Power, Charter 22, pp. 499–521, 2010

[2] IEC 61400-27 Committee Draft, Wind Turbines Part 27-1: Electrical simulation models for wind power generation Wind turbines, IEC Std. committee Draft (CD) 88/424/CD January 2012.

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

[4] Seung Tae Cha, J. andstergaard, Q. Wu, and F. Mara, “A real-time simulation platform for power system operation,” in IPEC, 2010 Conference Proceedings, Oct. 2010, pp. 909 –914.

[5] A.-R. Kim, S.-Y. Kim, K.-M. Kim, J.-G. Kim, S. Kim, M. Park, I. K. Yu, S. Lee, M.-H. Sohn, H.-J. Kim, J.-H. Bae, and K.-C. Seong, “Performance analysis of a toroid-type hts smes adopted for frequency stabilization,” Applied Superconductivity, IEEE Transactions on, vol. 21, no. 3, pp. 1367 –1370, Jun. 2011.

[6] Haoran Zhao, "Implementation and verification of wind turbine model in DigSILENT PowerFactory IEC 61400-27 type 1," Dept. Electrical Eng., Technical University of Denmark, Lyngby, Internal Report, pp. 1-28, Mar. 2012.

[7] Haoran Z., Qiuwei W., Ioannis M., and Poul S., “Implementation of IEC generic model of type 1 wind turbine generator in DigSILENT PowerFactory and RTDS,” in Dianli Xitong Zidonghua/Automation of Electric Power Systems (ISSN: 1000-1026), under review.

[8] A. D. Hansen, F. lov, P. Sørensen, N. Cutululis, C. Jaush, and F. Blaabjerg, “Dynamic wind turbine models in power system simulation tool DIgSILENT,” Risø National Laboratory, Roskilde, Denmark, Tech. Rep. Risø-R1400, Aug. 2007.

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

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