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

Seung Tae Cha*, Haoran Z., Qiuwei W., Jacob Ø., Ioannis M., Poul Sørensen

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.
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].

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 $\omega_{gen}$ as input, the mechanical power is the input. Therefore, a modified block diagram shown as Fig. 5 is used.

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

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

### 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. 6. RTDS implementation of the test system](image)

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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_{WTR}$</td>
<td>p.u.</td>
<td>Inertia constant of wind turbine rotor</td>
<td>Manufacturer</td>
</tr>
<tr>
<td>$H_{gen}$</td>
<td>p.u.</td>
<td>Inertia constant of generator</td>
<td>Manufacturer</td>
</tr>
<tr>
<td>$k_{sh}$</td>
<td>p.u.</td>
<td>Shaft stiffness</td>
<td>Manufacturer</td>
</tr>
<tr>
<td>$c_{sh}$</td>
<td>p.u.</td>
<td>Shaft damping</td>
<td>Manufacturer</td>
</tr>
<tr>
<td>$w_{init}$</td>
<td>p.u.</td>
<td>Initial steady state shaft rotor speed</td>
<td>Initialization</td>
</tr>
<tr>
<td>$T_{init}$</td>
<td>p.u.</td>
<td>Initial steady state shaft torque</td>
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1) **External Grid**: It is modeled by the Thevenin equivalent circuit. \( U_{\text{Th}} = 50\text{kV} \), \( R_{\text{Th}} = 2.516\Omega \), \( X_{\text{Th}} = 8.2998\Omega \) .

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: \( S_n = 16\text{MVA} \), \( U_p = 50\text{kV} \), \( U_a = 10.5\text{kV} \), \( R_n = 0.4052\Omega \), \( X_n = 7.655\Omega \), \( X_m = 1953\Omega \), \( R_s = 0.4052\Omega \), \( X_s = 7.655\Omega \).

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 \( \Omega \) (star impedance).

4) **10 kV Collection Cable**: The wind farm 10 kV collection cable is modeled by the \( \pi \)-equivalent: \( C_1 = 1.58\mu\text{F} \), \( R = 0.7568\Omega \), \( X = 0.4473\Omega \), \( C_2 = 1.58\mu\text{F} \).

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: \( S_n = 2\text{MVA} \), \( U_p = 10.5\text{kV} \), \( U_a = 0.96\text{kV} \), \( R_p = 0.2756\Omega \), \( X_p = 1.654\Omega \), \( X_m = 6890\Omega \), \( R_s = 6890\Omega \), \( X_s = 1.654\Omega \).

6) **Capacitor Bank CB**: The capacitor bank in the wind turbine is delta connected, with the capacity \( C_\Lambda = 1333\mu\text{F} \) in series with \( R_\Lambda = 0.003\Omega \).

7) **Wind Turbine Generator and two mass model**: The induction generator in the wind turbine is modeled by the \( T \)-equivalent: \( S_n = 2.3\text{MVA} \), \( U_n = 0.96\text{kV} \), \( N_0 = 1500\text{rpm} \), \( R_s = 0.0004\Omega \), \( X_s = 0.05\Omega \), \( X_m = 1.6\Omega \), \( R_i = 0.04\Omega \), \( X_i = 0.05\Omega \). The inertias of the two-mass model: \( H_{\text{WTR}} = 3.5\text{p.u.} \), \( H_{\text{gen}} = 0.5\text{p.u.} \), \( k_{sh} = 150.0052\text{p.u.} \), \( c_{sh} = 0\text{p.u.} \).

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 \( \mu \text{s} \) is used.

### Table II

#### CASE STUDY SCENARIOS

<table>
<thead>
<tr>
<th>Study Scenario</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wind variation</td>
</tr>
<tr>
<td></td>
<td>Simulation time</td>
</tr>
<tr>
<td>Normal operation</td>
<td>For Type 1A, aerodynamic torque ( T_{\text{init}} ) is specified as piece wise function:</td>
</tr>
<tr>
<td></td>
<td>0–10 s: ( T_{\text{init}} = 1.0836 )</td>
</tr>
<tr>
<td></td>
<td>10–25 s: ( T_{\text{init}} = 0.9 )</td>
</tr>
<tr>
<td></td>
<td>25–50 s: ( T_{\text{init}} = 1.1 )</td>
</tr>
<tr>
<td></td>
<td>For Type 1B, reference ( p_{\text{WTRref}} ) is specified as piece wise function:</td>
</tr>
<tr>
<td></td>
<td>0–10 s: ( p_{\text{WTRref}} = 0.8894 )</td>
</tr>
<tr>
<td></td>
<td>10–25 s: ( p_{\text{WTRref}} = 0.8 )</td>
</tr>
<tr>
<td></td>
<td>25–50 s: ( p_{\text{WTRref}} = 1 )</td>
</tr>
</tbody>
</table>

#### A. Normal operation mode

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

\[
T_{\text{init}} = \frac{p_{\text{gen}}}{p_{\text{WTR}}}
\]

\( T_{\text{init}} \) 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 \( t = 0 \text{ s} \) to \( t = 50 \text{ s} \). In the first 10 s time frame, \( T_{\text{init}} = 1.0836 \) p.u. which is derived from the above equation. In the following next 15 s time frame, the wind becomes weaker and \( T_{\text{init}} \) decreases to be 0.9 p.u. During the last 25 s time frame, the wind becomes stronger and \( T_{\text{init}} \) increases to be 1.1 p.u. The response of generator rotation speed, \( w_{\text{gen}} \), and active power, \( p_{\text{WTT}} \), are illustrated in Fig. 8.

For Type 1B, the blade angle is controllable. The output active power \( p_{\text{WTT}} \) can be regulated by the reference \( p_{\text{WTRref}} \) 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 \( t = 0 \text{ s} \) to \( t = 50 \text{ s} \). In the first 10 s time frame, \( p_{\text{WTRref}} = 0.8894 \) p.u., which is derived from induction machine setting. In the following 15 s time frame, the wind is weaker and \( p_{\text{WTRref}} \) decreases to be 0.8 p.u.. During the last 25 s time frame, the wind becomes stronger again and \( p_{\text{WTRref}} \) increases to be 1 p.u.. The response of generator rotation speed, \( w_{\text{gen}} \), and active power, \( p_{\text{WTT}} \), are illustrated in Fig. 9.
The figures show a very close agreement between RTDS, PF RMS, and PF EMT results. The waveforms of \( w_{\text{gen}} \) {Fig. 8 plot (a)} and \( p_{\text{WTT}} \) {Fig. 8 plot (b)} follow the wind variation. Because of direct connection to the grid, \( w_{\text{gen}} \) is very close to the network frequency. The wind variation doesn’t influence \( w_{\text{gen}} \) apparently, the range is still between 1.01 p.u. and 1.013 p.u.

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.

![Graphs showing generator rotation speed and active power](image1)

![Graphs showing generator rotation speed and active power](image2)

![Graphs showing generator rotation speed and active power](image3)
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].

The torsional oscillations between different sections of the turbine-generator rotor can be observed due to the perturbation 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

The authors would like to thank the IEC TC88 WG27 for providing the draft of the relevant IEC standard.

References


Seung Tae, Cha

He received his B.S degree in Electrical Engineering from Illinois Institute of Technology, Chicago, U.S. in 1992 and M.S degree in Electrical Engineering from Yonsei University, Korea in 1997. Upon graduation, he joined Korea Electric Power Research Institute, KEPCO where he was actively engaged in the development of KEPCO’s Enhanced Power system Simulator (KEPS), a fully digital real-time simulator, and other various power system related research projects. He is a Ph.D candidate at Technical University of Denmark & Korea University. His research interests include real-time simulation of power systems, power hardware-in-the-loop (PHIL) testing, integration of renewable energy resources, energy storage system in future power systems, model development, agent-based simulation & optimization, studies involving load flow, system planning and operation.

Haoran Zhao

He received the B.E from Shandong University, China, in 2005 and the M.E. degree from Technical University of Berlin, Germany in 2009. He is now pursuing the Ph.D. degree in the Center for Electric Technology, Technical University of Denmark, Denmark. He worked as Electrical Engineer in State Grid Corporation of China (SGCC) shortly in 2005. From Aug. 2010 to Sep. 2011, he worked as Application Developer in DlgSILENT GmbH, Germany. His research interests are modeling and integration study of wind power, control of energy storage system and voltage stability analysis.
Qiuwei Wu

He obtained the B. Eng and M. Eng from Nanjing University of Science and Technology, Nanjing, P.R. China, in 2000 and 2003, respectively, both in Power System and Automation. He obtained the PhD degree from Nanyang Technological University, Singapore, in 2009 in Power System Engineering.

He worked as a senior R&D engineer in Vestas Technology R&D Singapore Pte. Ltd. from Mar. 2008 to Oct. 2009. He joined Centre for Electric Technology (CET), Department of Electrical Engineering, Technical University of Denmark (DTU) as PostDoc in Nov. 2009 and has been an assistant professor with CET since Nov. 2010.

His research interests are integration of electrical vehicles (EVs) into power systems, integration study for wind power, dynamic performance of power systems, real time simulation of power systems using RTDS and reliability analysis and improvement of restructured power systems using demand response programs.

Jacob Østergaard (M'95-SM' 09)

obtained his MSc in Electrical Engineering from Technical University of Denmark (DTU) in 1995. He was with Research Institute of Danish Electric Utilities for 10 years where he did research within power system transmission and distribution and was responsible for developing industrial-academic collaboration. Since 2005 he has been Professor and Head of Centre for Electric Technology (CET), DTU. His research interests cover SmartGrids with focus on system integration of renewable energy and distributed energy resources, control architecture for future power system, and flexible demand. Prof. Jacob is serving in several professional organizations, boards and steering committees. He is head of the Danish experimental platform for electric power and energy, PowerLabDK, and he has been member of the EU SmartGrids advisory council. In 2009 he received the IBM Faculty Award.