Comparative Analysis of Generic and Complex Models of the Type-3 Wind Turbine

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***Abstract*— With the increasing penetration of the wind power generation, the impact of the wind power integration on power systems becomes more significant. For power system operators, maintaining power system security is the first priority. If a complete wind turbine model is used to analyze the steady-state operation and dynamic stability for a large-scale power system with wind power integration, it would take much computation burden and time. Thus, the generic models of various wind turbines have been developed to reduce the simulation time for wind power systems. The characteristics of a generic model should be similar to that of a complete model, but its structure is simpler than a complete model. This study developed both generic model and complete models for a doubly-fed induction generator (DFIG) based wind turbine, which is also called type-3 wind turbine. Additionally, this study compared the characteristics of the developed complex and generic models. According to the simulation results, this study demonstrates that the developed generic model of a DFIG-based wind turbine has the good approximation of a complete wind turbine model.**

***Index Terms*—generic models; complete models; doubly-fed induction generator.**

I. INTRODUCTION

As the wind power penetration increases, the stability and the dynamic performance of a power system are expected to be affected because the dynamic behavior of the wind turbine generators (WTGs) is quite different from the traditional synchronous generators. For the system operator, it is important to guarantee that the system is still in the safety operation when a large amount of wind power is integrated into the system. Thus, the accuracy of the dynamic modeling of WTGs plays a critical role in the stability analysis of the power system. Generally, the dynamic models of WTGs developed by the wind turbine manufacturers are not easily accessible. It is not convenient for the system operators to manage the numerous vendor-specific models, which has motivated the development of the generic models that can be obtained in public and demonstrate the characteristics of a wide variety of DFIG-based WTGs [1].

Renewable Energy Modeling Task Force (REMTF), one working group of the Western Electricity Coordinating Council (WECC), has made much effort on the development of the generic models for four types of wind turbines. Those developed models have been validated and implemented in two commercial stability simulation programs, i.e., GE PSLF and Siemens PSS/E [2]. This study constructed both complete and generic models of the DFIG-based WTGs, and compared the characteristics of them. The purpose of this study is to confirm the feasibility of the generic model

II. SPECIFICATIONS FOR DEVELOPING THE DFIG-BASED GENERIC MODEL

The basic analyses for power systems commonly ignore the high-frequency components of the electronic converters. Several important specifications proposed by WECC are summarized below [3].

- The models must be non-proprietary and accessible to the transmission planners and grid operators without the need for non-disclosure agreements.
- The models need to provide a reasonably good approximation of dynamic electrical performance at the point of the interconnection, not inside the wind turbine.
- The models should be applicable to both strong and weak grids with the different short-circuit ratio at the point of interconnection.
- The aerodynamic characteristics are represented without the need for the C_p curve.
- The reactive power support and protection equipment are modeled separately.

III. STRUCTURE OF THE TYPE-3 GENERIC MODEL

As indicated in Fig. 1, generator/converter model, converter control model, wind turbine model and pitch control

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model are the four main blocks of the generic model of the DFIG-based WTG [3, 4]. In the following subsections, each block is described in detail.

A. Generator/converter model

The generator/converter model represents the equivalent of the generator and rotor converter. It provides an interface between WTG and the grid. As shown in Fig. 2, the generator is modelled as a controlled-current source and the rotor converter is modelled as two low-pass filters. The amount of the current injected by the current source is determined by the converter control model, which will be explained in the next subsection. Two low-pass filters with a time constant 20 ms represent the time delay that is caused by rotor converter. Additionally, the phase-lock loop (PLL) is implemented to synchronize the rotor current with the stator. X_{eq} in Fig. 2 represents the equivalent reactance of the generator.

Note that the system operators mainly focus on the electrical disturbance, not the wind disturbance. Therefore, the fast dynamics of the stator and rotor flux are neglected. Moreover, the mechanical variables are simulated in the wind turbine model, not in the generator/converter model. This is the difference between the generator/converter model and the conventional synchronous generator model.

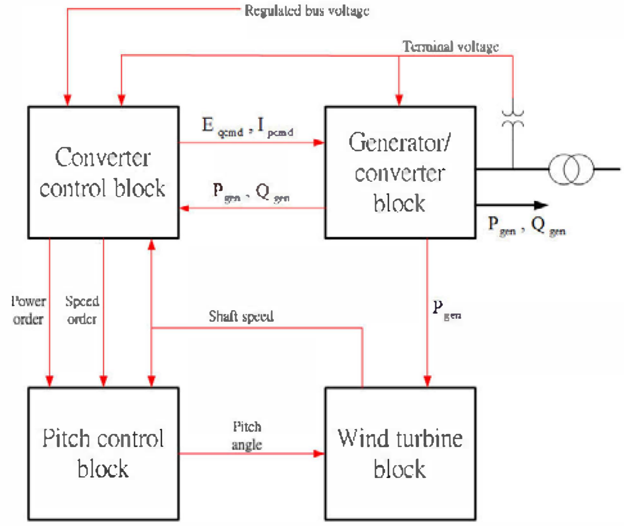


Figure 1. Block connection for the generic model of the type-3 WTG

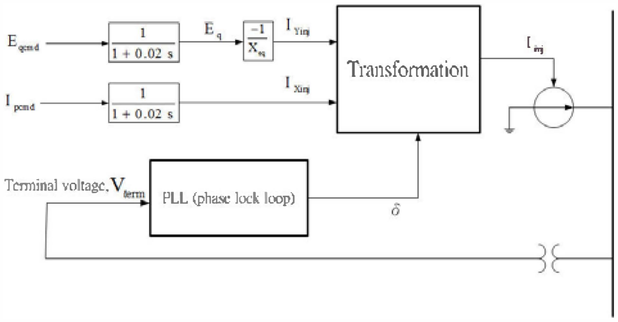


Figure 2. Generator/converter model

B. Converter control model

The converter control model determines the amount of the active and reactive power that must be delivered to the grid. The converter control model consists of two sub-models, active and reactive power control models. The current command I_{pcmd} and voltage command E_{qcmd} are generated by the active and reactive power control models, respectively, and send to the generator/converter model.

The active power control model is shown in Fig. 3. First, the reference value of the generator rotor speed is obtained according to a curve $f\,(P_{gen})$, which is the relation between the rotational speed and active power output. An example of the curve $f\,(P_{gen})$ is shown in Fig. 4. Then, a PI controller with upper and lower limits is used to control the torque. The active power order is obtained by multiplying the torque by the rotational speed and limited by the power limit. Finally, the current command I_{pcmd} is obtained by dividing the active power order P_{ord} by the magnitude of the terminal voltage.

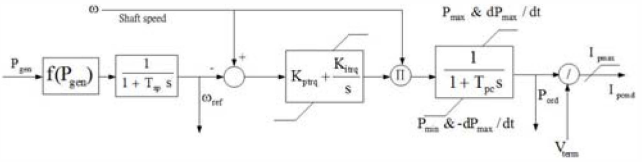


Figure 3. Active power control model

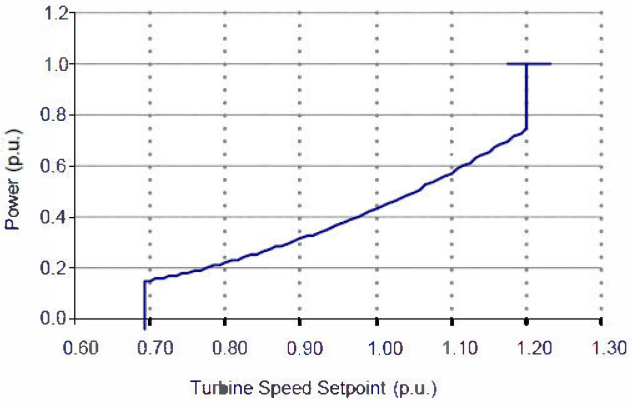


Figure 4. Turbine speed setpoint (p.u.) vs. active power (p.u.)

Figure 5 shows the reactive power control model. There are three modes for determining the reactive power command, including the wind plant reactive power control emulator, power factor regulator and user-defined constant value. The wind plant reactive power control emulator is the equivalent of the supervisory VAR controller for the entire wind farm. By changing the switch position varflg, one of the control modes is selected. For instance, when the varflg is 1, the reactive power control emulation mode is selected and the voltage at the particular bus is regulated at the reference value. When the varflg is -1, the power factor regulation mode is selected and the reactive power command is determined according to the required power factor. When the varflg is 0, the reactive power command is a certain amount of the reactive power. Then, the reference voltage is determined by the PI controller according to the error between the reactive power command and the reactive power generation.

C. Wind turbine model

The wind turbine model, as shown in Fig. 6, determines the generator rotor speed according to the mechanical power P_{mech} and the electrical power P_{gen}. In this study, one-mass model was chosen to describe the dynamic behavior of the drive train, as indicated in equation (1). The electrical power is from the generator/converter model and the mechanical power is determined by the simplified aerodynamic model. The simplified aerodynamic model was initially proposed by Price and Sanchez-Gasca [5] and accepted by WECC. It is the linear approximation of the power coefficient curve based on the assumption of a constant wind speed. The relation between the mechanical power P_{mech} and pitch angle θ is shown in equation (2), which can be transferred to equation (3).

$$\frac{d\omega}{dt} = \frac{1}{2H\omega}(P_{mech} - P_{gen}) \qquad (1)$$

$$\frac{dP_{mech}}{dt} = -K_{aero}\theta \qquad (2)$$

$$P_{mech} = P_{m0} - K_{aero}\theta(\theta - \theta_0) \qquad (3)$$

According to the equation (3), the mechanical power is only related to the pitch angle θ. Although this model is simpler than the two- and three-dimensional models, the proper initialization of the mechanical power and the pitch angle is required for better approximation. For example, in PSS/E, the initial value of mechanical power P_{m0} is determined by the power flow and the initial value of the pitch angle θ_0 is determined by following principles.

- If $P_{m0} < 1.0$ p.u., then $\theta_0 = 0$.
- If $P_{m0} = 1.0$ p.u. and $V_{wind,user} > 11.35$, then $\theta_0 = 1.46\,V_{wind,user} + 5.6$.
- If $P_{m0} = 1.0$ p.u. and $V_{wind,user} < 11.35$, then $\theta_0 = 0$.

D. Pitch control model

The pitch control model determines the pitch angle to maximize the mechanical power extracted from the wind. As shown in Fig. 7, the pitch control model consists of two PI controllers. One is for generator rotor speed control and the other is for the active power control. Owing to a large size of the blades, the pitch angle cannot be changed in a short time. Consequently, the pitch angle is limited within a range. Also, the rate of change of the pitch angle is limited at 10 degree per second typically. Moreover, a low-pass filter with time constant T_{PI} represents the time delay caused by the translation of the blade.

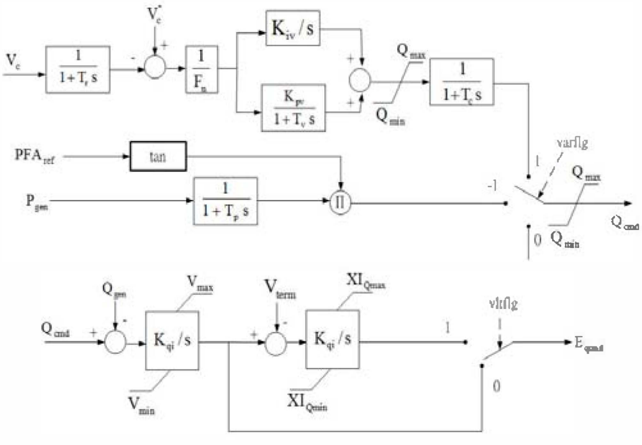


Figure 5. Reactive power control model

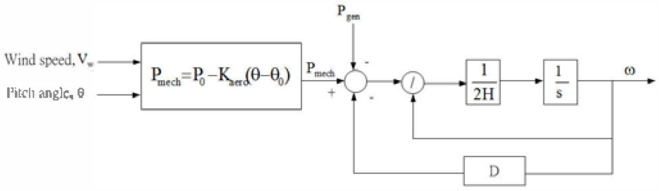


Figure 6. Wind turbine model

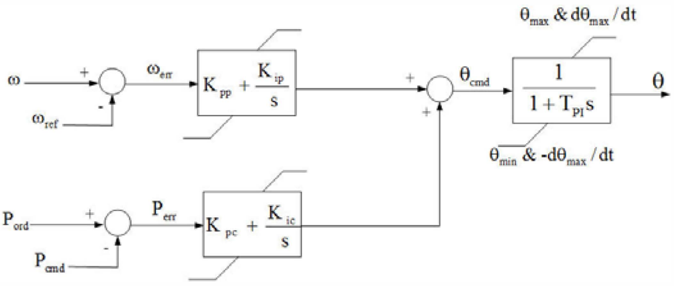


Figure 7. Pitch control model

IV. SIMULATION RESULTS

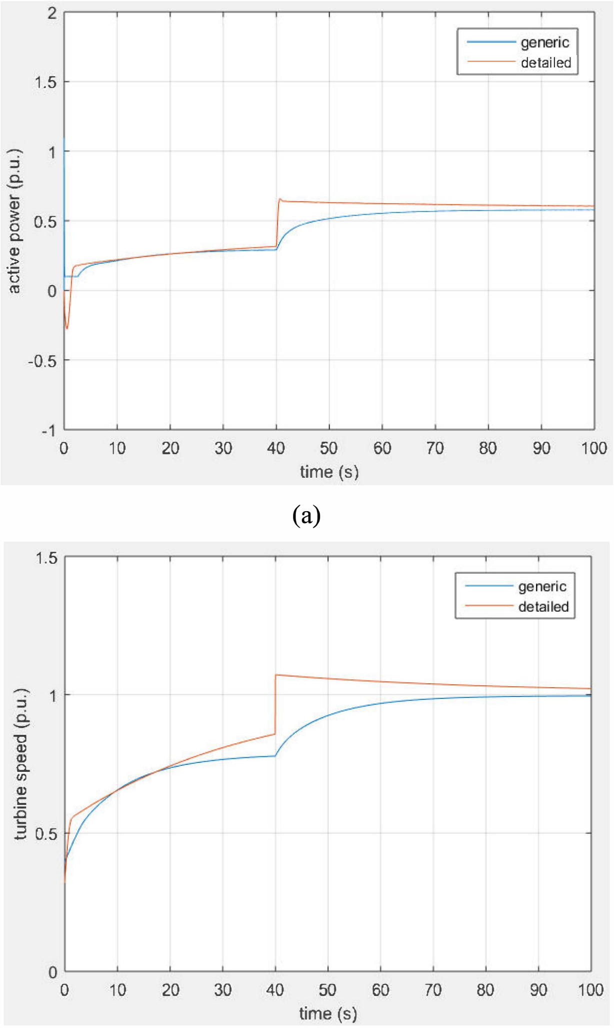
In this paper, both generic and detailed models of the DFIG-based WTG are implemented in PSCAD/EMTDC. The construction of the detailed WTG model can be referred to reference [6]. The dynamic of a 1.5 MW WTG that is connected to an infinite bus is discussed in this work. The total simulation time is 100 seconds.

In the analyzed case, the wind speed is increased from 8 m/s to 10 m/s at t=40s. The turbine rotational speed and the active power are shown in Fig. 8. To validate the accuracy of the generic model, the error between two models must be defined. As defined in equations (4) - (6), the errors for the turbine rotational speed and the active power are calculated by subtracting the value of the detailed model from the value of the generic model. The errors for the turbine rotational speed and the active power are shown in Fig. 9.

$$\varepsilon_p = P_{generic} - P_{detailed} \tag{4}$$

$$\varepsilon_\omega = \omega_{generic} - \omega_{detailed} \tag{5}$$

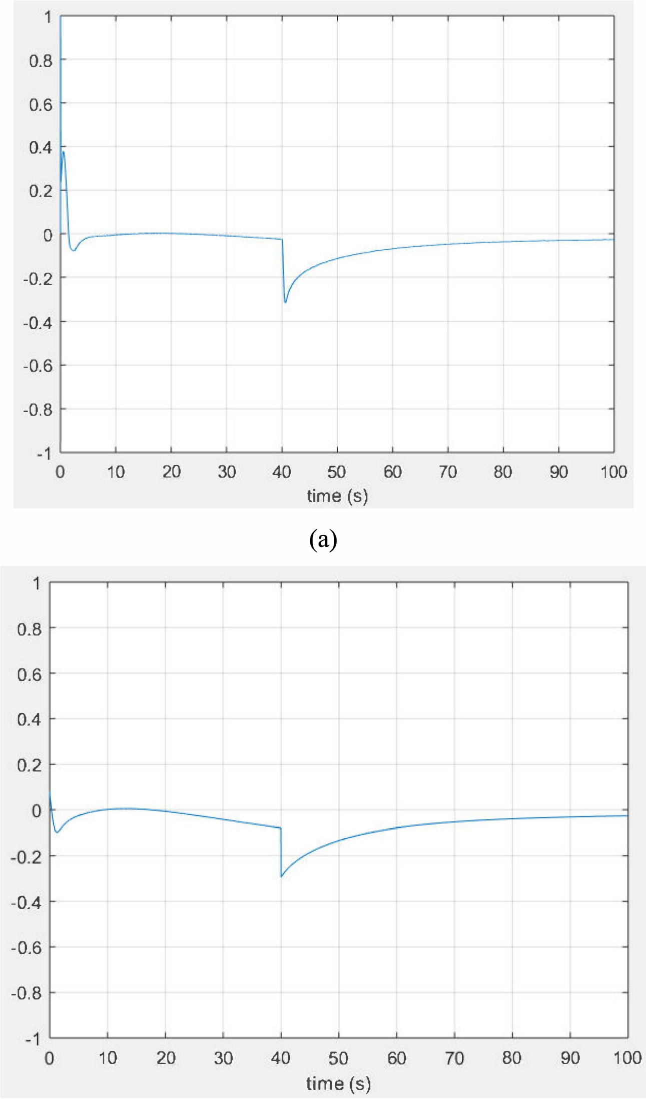
$$\varepsilon_\theta = \theta_{generic} - \theta_{detailed} \tag{6}$$



(a)

(b)

Figure 8. (a) turbine rotational speed (p.u.) (b) the active power (p.u.)



(a)

(b)

Figure 9. The error for (a) turbine rotational speed (b) the active power

V. CONCLUSIONS

Considering the nature of the wind, the power system with a large amount of wind power integration must be analyzed carefully to ensure that it is highly stable. For the analysis of a large-scale power system, it is necessary to build a simple WTG model with moderate accuracy. The simplification of the structure leads to the reduction of the computation time and burden while it still has a good approximation of the dynamic behavior.

In this study, the generic model of the DFIG-based WTG is compared with the detailed DFIG model to validate the performance of the generic model. The results show that the error of the turbine rotational speed and the active power are within the range of 4%. It means that the generic models have a good representation of the dynamic behavior of the DFIG-based WTG.

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