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Modeling and Analysis of Wind Farms Connected to the Egyptian Power System

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Abstract: *It has been observed in the past few years that wind, as a source of energy, has been growing worldwide. Its penetration in the power system has increased dramatically. At the present time, wind turbines are seen to be connected to both transmission and distribution systems. These connected turbines incorporate different technologies. The most dominating technology is the variable speed technology. Doubly Fed Induction Generator (DFIG), one of the generators utilizing this technology is the most used generator type today. This is because it has many advantages that makes it superior over other types of generators. Among these are, the presence of power electronic equipment which facilitates the process of control.*

In this paper, the various DFIG models are described.A case study was then conducted on an area of the Egyptian grid. This area has two wind farms; one wind farm utilizing the fixed speed induction generator concept whereas the other wind farm utilizing the doubly fed induction generator concept. A fault was simulated at one of the two lines connecting the two wind farms to the external grid. The wind farm interaction with the power system was evaluated and it was shown that the doubly fed induction generator wind farm had the ability to support the fixed speed induction generator wind farm during the fault and also support the process of voltage reestablishment.

Keywords-*Aggregated model, digsilent, doubly fed induction generator, fixed speed induction generator, grid interaction, system support, wind farm*

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I. Introduction

Modern power system networks in the whole world are increasingly characterized by large-scale wind generation integration. The global wind power generating capacity reached 539 GW by the end of 2017 [1]. At the same time,the annual generation of wind power is estimated to be over 260TWh(around 1.3%of total electricity generation) [1].Thus, this tremendous increase in the integration of the wind energy is due to some reasons. Among these are, improved wind technology, encouragement of governmental authorities to incorporate more renewable energy sources into the power networks so as to attain a clean environment free of pollution.

Now, wind power plants with large power ratings are incorporated into the power system which will affect the system stability to a great extent. Most of the generators connected to the system are the traditional synchronous generators. They have the role to support the grid voltage and to sustain a balance between generation and consumption.In case of a short circuit occurrence, it is the role of the traditional power plants to participate in the voltage control and support the system frequency.

Nowadays, most wind turbines are equipped with induction generators having different characteristics than the conventional synchronous generators. Thus, shifting from this known technology of conventional generators to another new technology arises several problems, including security and stability of the power system, which must be tackled.

The main concern of the present paper is thus to assess the incorporating of wind farms utilizing such induction generators into the power system. It starts with introducing the construction of the doubly fed induction generator wind turbine. The dynamic models associated with such a generator type are then introduced. Finally, a case study was performed, using the DIgSILENT Power Factory [2], on an area of the Egyptian grid indulging two different types of wind farms so as to evaluate its performance during a system fault. The two wind farms were represented using the aggregated technique.

II. Doubly Fed Induction Generator Wind Turbine Model

Figure 1 shows the arrangement of the doubly fed induction generator based wind turbine concept. It consists of a wound rotor induction generator of which the circuit of the stator is connected to the power network through a three phase transformer while the circuit of the rotor is coupled to a frequency converter. This frequency converter is further subdivided into two converters;the rotor side converter and the grid side converter.Each converter is operated independently through its respective control.The performance of the generator relies mainly on the behavior of the converters during both normal operating and fault circumstances. A pitch angle control is used to control the blades of the rotor whereas the crowbar protection is used to protect the rotor circuit from being exposed to high transient current during system faults and to temporarily block the rotor side converter so as to protect it from being damaged[3].

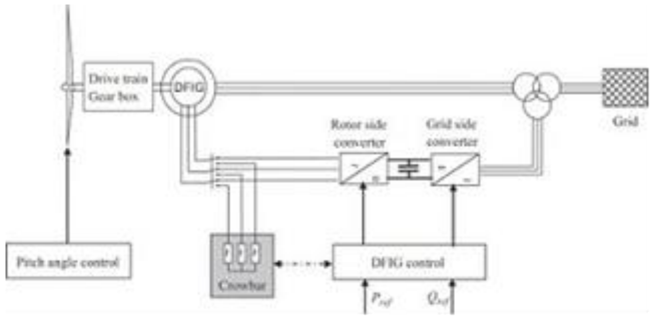

Figure 1. Arrangement of the doubly fed induction generator wind turbine concept

III. Doubly Fed Induction Generator Models

3.1 Wind Model

In the here presented work, considering dynamic impact studies, the speed of the wind was kept constant and remained unchanged as the speed fluctuation is negligible compared to the duration of the fault. The utilized wind speed in this study is 12 m/s as it is the nominal wind speed in the area including the network under study.

3.2 Aerodynamic Model

The power associated with the wind is transformed into mechanical power by means of the blades of the rotor.This mechanical or rotational powerP_{rot} is usually expressed as [4]:

$$P_{rot} = \frac{1}{2}\rho\pi R^2 u^3 C_p(\theta,\lambda) \quad (1)$$

where$R$is the radius of the rotor,$u$is the speed of the wind, ρis the air density and C_p is the aerodynamic efficiency.
The aerodynamic torque T_{rot} which is then produced on the wind turbine's main shaft is given by:

$$T_{rot} = \frac{1}{2}\rho\pi R^3 u^2 C_q(\theta,\lambda) \quad (2)$$

whereC_q is the torque coefficient, θ is the blade pitch angle and λ is the tip speed ratio; expressed as $\left(\frac{R\omega_{rot}}{u}\right)$.

3.3 Drive Train Model

The drive train model is considered to be the most important part of the wind turbine as it directly affects the system stability[5].Some other wind turbine components, as the tower, are not considered here as they have a negligible effect on the wind farm's interactionwith theentire power system. From Fig. 2, it can be seen that the most suitable representation of the drive train is the two-mass model as it takes into consideration the shaft oscillations[3].

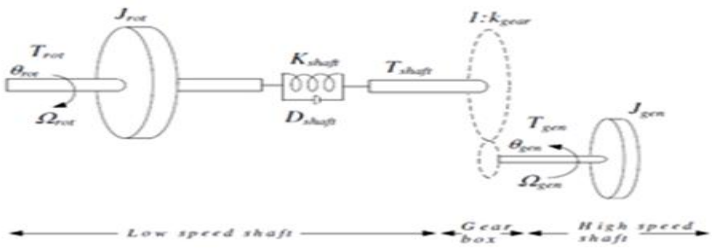

Figure 2. Drive train model

The equations representing this two-mass model are given by:

$$\omega_k = \Omega_{rot} - \frac{\Omega_{gen}}{k_{gear}} \quad (3)$$

$$\Omega_{rot} = \frac{T_{rot} - T_{shaft}}{J_{rot}} \quad (4)$$

$$T_{shaft} = D_{shaft}\,\omega_k + K_{shaft}\,\theta_k \quad (5)$$

where Ω_{gen} and Ω_{rot} are the generator and rotor angular speeds respectively. θ_k and ω_k are the angle and angular speed differences between the two ends of the flexible shaft respectively. T_{rot} and T_{shaft} are the aerodynamic torques on the low and high speed shafts respectively. K_{shaft} and D_{shaft} are the stiffness and damping coefficients respectively. k_{gear} is the gear ratio.

3.4 Pitch Angle Controller Model

The main function of the pitch control system is to either direct or turn away the rotor blades into or out the wind when the associated power becomes too low or too high. From Fig.3, it can be observed that it is made up of two main components; a PI controller and a servo system[3], [6].

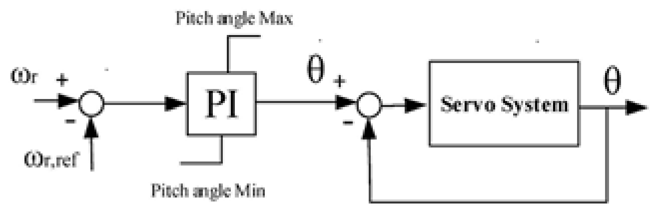

Figure 3. Pitch angle controller

3.5 DFIG Dynamic Model

The doubly fed induction generator stator and rotor voltage equations can be written in the d-q reference frame as follows:

$$u_{sd} = R_s i_{sd} + j\omega_{syn}\psi_{sd} + \frac{d\psi_{sd}}{dt} \quad (6)$$

$$u_{sq} = R_s i_{sq} + j\omega_{syn}\psi_{sq} + \frac{d\psi_{sq}}{dt} \quad (7)$$

$$u_{rd} = R_r i_{rd} + j(\omega_{syn} - \omega_r)\psi_{rd} + \frac{d\psi_{rd}}{dt} \quad (8)$$

$$u_{rq} = R_r i_{rq} + j(\omega_{syn} - \omega_r)\psi_{rq} + \frac{d\psi_{rq}}{dt} \quad (9)$$

where R_s and R_r are the stator and rotor resistances respectively. i_s and i_r are the stator and rotor currents respectively. Ψ_s and Ψ_r are the stator and rotor flux linkages respectively. ω_{syn} is the synchronous speed and ω_r is the rotor speed.

The above model equations are expressed in the fifth-order model. The third-order machine model can be obtained by neglecting the transients in the stator[7], [8].

3.6 Frequency Converter Model

From Fig.2, it can be seen that the frequency converter is mounted on the circuit of the rotor. It is usually made up of active semiconductors such as IGBTs and GTOs so as to allow a bi-directionality in the flow of power. The AC-voltage is usually related to the DC-voltage by the following equation [3]:

$$U_{AC} = K_0 \, P_m \, U_{DC} \qquad (10)$$

whereP_m is known as the pulse width modulation index. It is normally having values between (0) and (1) so as to prevent the effects of saturation. The factor K_0 is determined based on the utilized modulation method; whether it is sinusoidal or rectangular[6]. As in most power applications, the sinusoidal modulation is the widely used type; the value of K_0 inthis case becomes:

$$K_0 = \frac{\sqrt{3}}{2\sqrt{2}} \qquad (11)$$

3.7 Frequency Converter Control Model

The control model of the frequency converter is made up of two controllers. One controller is dedicated to the rotor side converter and the other controller is dedicated to the grid side converter. The control of the frequency converter is achieved using a vector control technique. By this technique, it becomes possible to separately control the active and the reactive power. The rotor side converter is used to regulate active and reactive power whereas the grid side converter maintains a constant DC-link voltage. This control model is coordinated with the blade angle control model[3], [6], [7].

IV. Network under Study

Figure 4 shows the considered network under study. It includes two distinct types of wind farms; fixed speed induction generator wind farm and doubly fed induction generator wind farm. Both wind farms incorporate 20 wind turbines, each with a power rating of 2 MW and represented as aggregated models [6], [9]. Each wind farm has its own power transformer that raises the voltage from 0.69 kV to 33 kV. Another power transformer is used to step up the voltage from 33 kV to the voltage of the power network, that is; 220 kV. The high voltage terminal is connected to the external grid through two 220 kV overhead transmission lines. The external grid is represented by means of a Thevenin equivalent. The network is characterized by a maximum short circuit capacity of 9999 MVA and a minimum short circuit capacity of 150 MVA at the 220 kV bus.

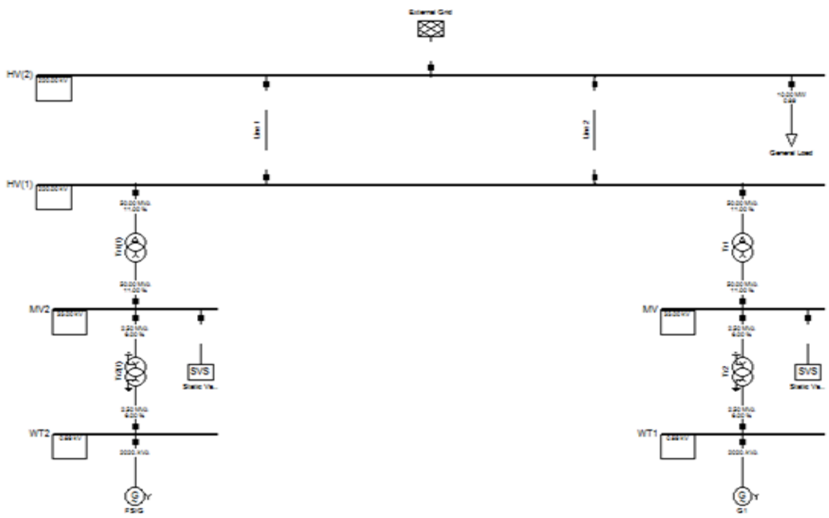

Figure 4. Wind farm grid connection model

V. Simulation and Analysis

After the simulation setup is terminated, a three-phase short circuit with a duration of 300 ms is applied at one of the two overhead lines near to the wind farmterminal. Before the fault occurs, the two wind farms were delivering their rated power. This scenario is considered to be a worst case scenario. To evaluate the different interaction between the two wind farms, two cases were considered and compared together. The first case, shown by the black colored line, did not require the doubly fed induction generator to support the system.

Whereas, in the second case, shown by the colored lines, there was a contribution from the doubly fed induction generator to support the system through its associated controllers.

At the instant of the occurrence of the fault,Fig.5 shows that the voltage drops to a great extent at the PCC. Figure 6 also implies a voltage dropat the terminal of the wind farm.Consequently, areduction in the output of the wind farm is observed in Fig.7. The crowbar protection is now indulged so as to protect the rotor circuit and it momentarily blocks the rotor side converter from operation. With a voltage reduction, the generator flux also decreases and thus needs to be demagnetized. This in identified in Fig.8 by a spike at the moment when the fault occurs.The electromagnetic torque will be also decreasing when the active power decreases and as shown in Fig.9,the generators of the fixed speed wind farm will start toaccelerate.The machine will thus be exposed, as shown in Fig.10, to large torque fluctuations. When the fault is terminated and as a result of their acceleration,these fixed speed generators will need more reactive power and so the procedure of voltage reestablishment becomes a very tough task. In this case, this wind farm will be disconnected from the system resulting in a high loss of wind power.

On the contrary, when the crowbar is coupled and the doubly fed induction generator is nowparticipating in the supply of reactive power through its grid side converter, it can be seen that the voltage profiles are enhanced. After crowbar disconnection, this task of reactive power supply will be assigned back to the rotor side converter and that assists the system to restore its voltage levels back again very quickly. Speed and torque fluctuations associated with the fixed speed induction generator are decreased. So, when the doubly fed induction generator is supporting the system, there is no need to disconnect the nearby wind farm. Instead, it can be enabled to ride-through the fault.Loss of large amounts of power will thus be avoided. Therefore, enhancing the system stability.

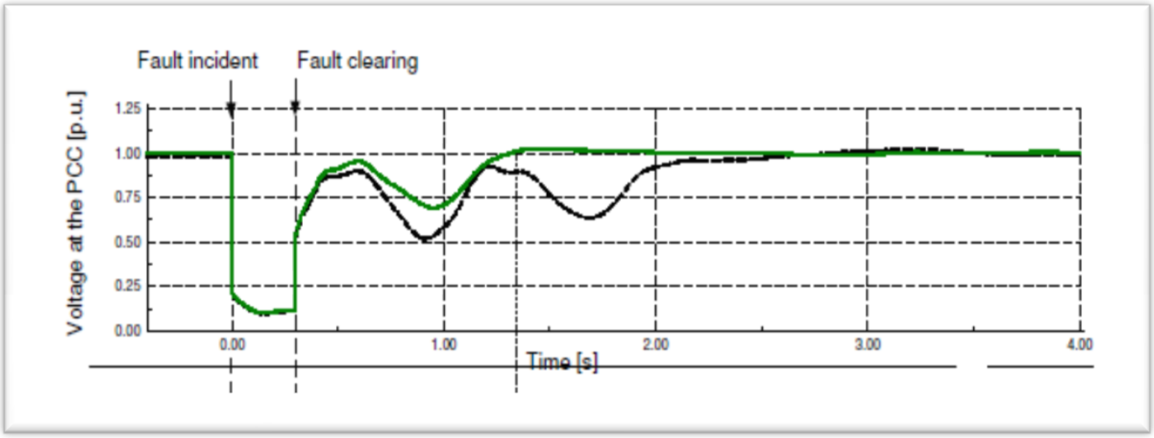

Figure 5. Voltage at the point of common coupling

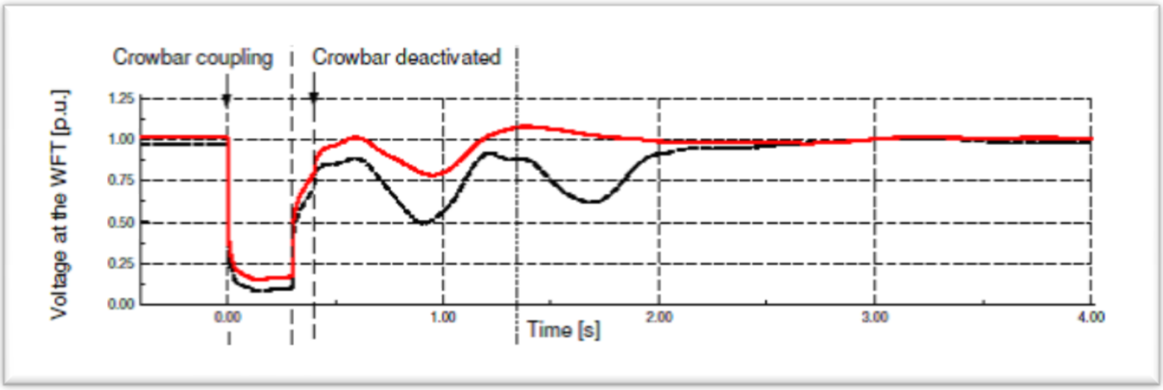

Figure 6. Voltage at the wind farm terminal

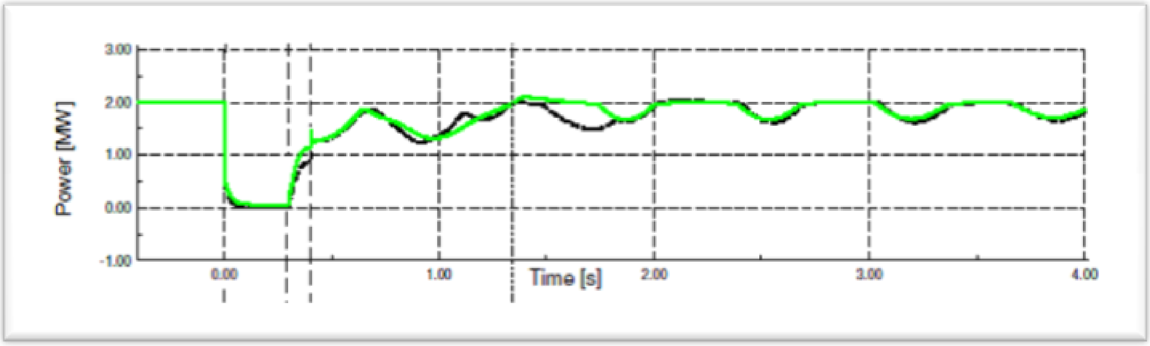

Figure 7. Active power output of the wind farm

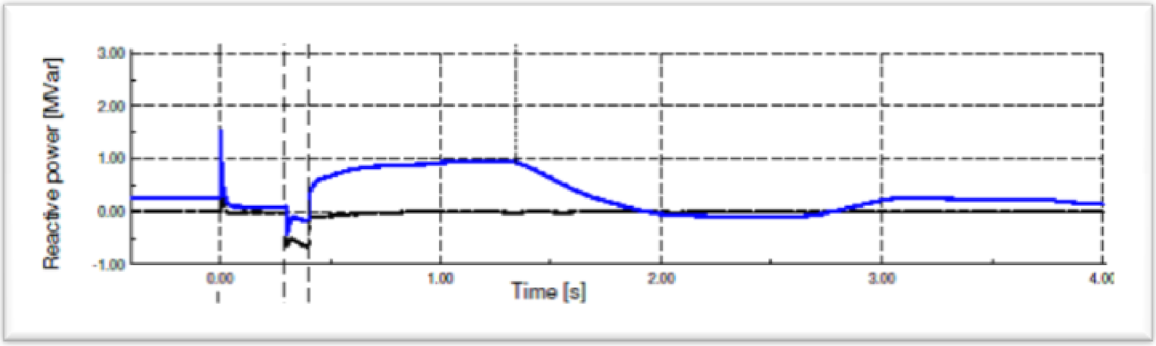

Figure 8. Reactive power output of the wind farm

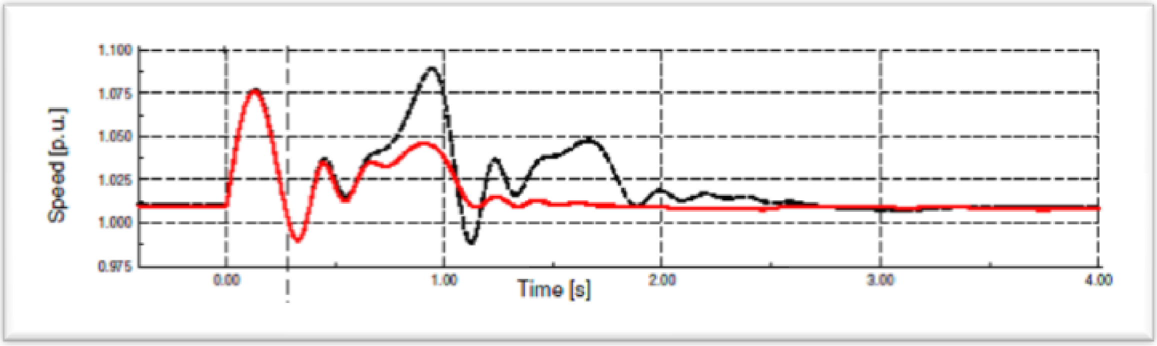

Figure 9. Speed of the fixed speed induction generator

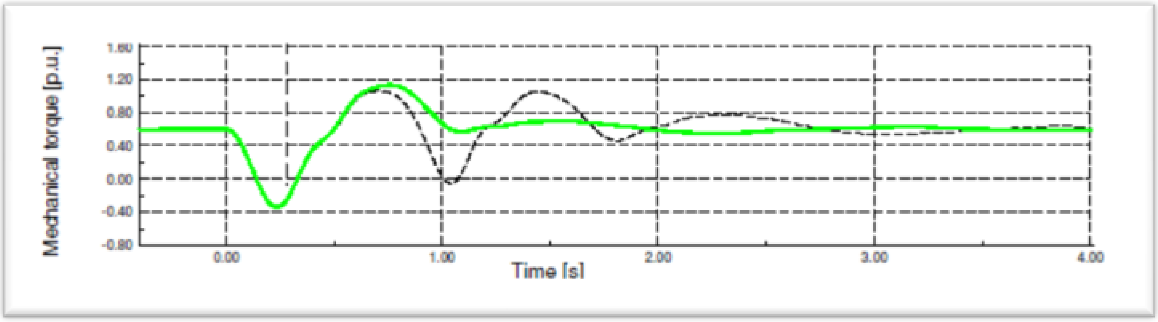

Figure 10. Torque fluctuations of the fixed speed induction generator

VI. Conclusion

Due to the increasing penetration of the doubly fed induction generator wind farms into the power system, it becomes important to analyze and assess its interaction with the power networks together with its interaction with any nearby wind farms. The main concern of the present paper was thus to interpret this type of variable speed induction generators and evaluate its performance when connected to the power system.

The paper started with introducing the different dynamic models associated with such a wind turbine concept. The next section of the paper concentrated on investigating the impact of a wind farm on the power system. The network considered for the entire study contains two various wind farms; fixed speed induction generator and doubly fed induction generator. The wind farms were simulated in the DIgSILENT simulation software.

Two cases were analyzed and compared. In the first case, the doubly fed induction generator did not support the system whereas in the second case, it participated in system support. Comparison of the simulation results have revealed that; in the first case, there was a risk of disconnecting the FSIG wind farm leading to a great loss of power which may affect the system stability. While in the second case, the same wind farm can be able to ride-through the fault avoiding the loss of power and thus improving the system stability.

References

[1] Global Wind Report, Global Wind Energy Council, Brussels, Belgium, 2017.

[2] DIgSILENT GmbH. DIgSILENT Power Factory Version 14.1 User Manual, 2005.

[3] A.D. Hansen, C. Jauch, P. Sørensen, F. Iov, F. Blaabjerg, Dynamic wind turbine models in power system simulation tool DIgSILENT, *Risø National Laboratory, Roskilde*, 2003.

[4] S. Heier, *Grid integration of wind energy conversion system*(John Wiley & Sons Ltd., 1978).

[5] V.Akhmatov, *Analysis of dynamic behavior of electric power systems with large amount of wind power*, PhD thesis, Ørestad-DTU, Denmark, 2003.

[6] M. Poller and S. Achilles, Aggregated wind park models for analyzing power system dynamics, *Proc. Fourth International Workshop on Large Scale Integration of Wind Power and Transmission Networks*, 20-21 October, Denmark.

[7] S. Zhao, *Dynamic modeling of wind farms-A contribution towards large-scale wind integration into the New Zealand power system*, PhD Thesis, the University of Auckland, New Zealand, 2011.

[8] G. Michalke, *Variable speed wind turbines-modeling, control, and impact on power systems, PhD Thesis*, Risø National Laboratory, 2007.

[9] L. M. Fernandez, F. Jurado, and J. R. Saenz, Aggregated dynamic model for wind farms with doubly fed induction generator wind turbines, *Renewable Energy 33(1)*, 2003, 129-140.

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