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A novel aggregated DFIG wind farm model using mechanical torque compensating factor

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ABSTRACT

A novel aggregated model for wind farms consisting of wind turbines equipped with doubly-fed induction generators (DFIGs) is proposed in this paper. In the proposed model, a mechanical torque compensating factor (MTCF) is integrated into a full aggregated wind farm model to deal with the nonlinearity of wind turbines in the partial load region and to make it behave as closely as possible to a complete model of the wind farm. The MTCF is initially constructed to approximate a Gaussian function by a fuzzy logic method and optimized on a trial and error basis to achieve less than 10% discrepancy between the proposed aggregated model and the complete model. Then, a large scale offshore wind farm comprising of 72 DFIG wind turbines is used to verify the effectiveness of the proposed aggregated model. The simulation results show that the proposed aggregated model approximates active power (P_e) and reactive power (Q_e) at the point of common coupling more accurately than the full aggregated model by 8.7% and 12.5%, respectively, during normal operation while showing similar level of accuracy during grid disturbance. Computational time of the proposed aggregated model is slightly higher than that of the full aggregated model but much faster than the complete model by 90.3% during normal operation and 87% during grid disturbance.

1. Introduction

Wind power has been the fastest growing energy source since the last decade due to its inherent attribute of the reproducible, resourceful and pollution-free characteristics. Wind power capacity reached 215 GW (3% of global electricity consumption) worldwide with a growth rate of 22.9% in 2010. With this growth rate, wind power capacity will be doubled every three years. Based on this accelerated development and further improved policies, 12% of global electricity demand (1900 GW) is predicted to be provided by wind energy systems by the year 2020 [1].

Wind farms of 50 MW ratings or more are integrated into high voltage transmission networks [2]. With the increasing amount of wind power penetration in power systems, wind farms begin to influence power systems. This justifies the need for adequate models for wind farms in order to represent overall power system dynamic behavior of grid-connected wind farms during both normal operations and grid disturbances. A wind farm may consist of tens to hundreds of wind turbines. This leads to model complexity and computation burden [3,4]. Fig. 1 shows a complete wind farm model with n number of wind turbines equipped with doubly-fed induction generator (DFIG).

To simplify the complete wind farm model, an aggregated wind farm model is required to reduce the size of the power system model, the data requirement and the simulation computation time [5–7], where this aggregated model can (1) represent the behavior (active and reactive power exchanged with the power system at the point of common coupling (PCC)) of the wind farm during normal operation, characterized by small deviations of the grid quantities from the nominal values and the occurrence of wind speed changes and (2) represent the behavior of the wind farm during grid disturbances, such as voltage drops and frequency deviations.

Two types of wind farm aggregation techniques have been proposed: the full aggregated and the semi aggregated techniques. Fig. 2 shows the full aggregated and semi aggregated wind farm models. The full aggregated model consists of one equivalent wind turbine and one equivalent generator for a wind farm with one operating point at an average wind speed for all the wind turbines in the wind farm [7–12]. The semi aggregated model consists of all the wind turbines in the wind farm and one equivalent generator [13,14].

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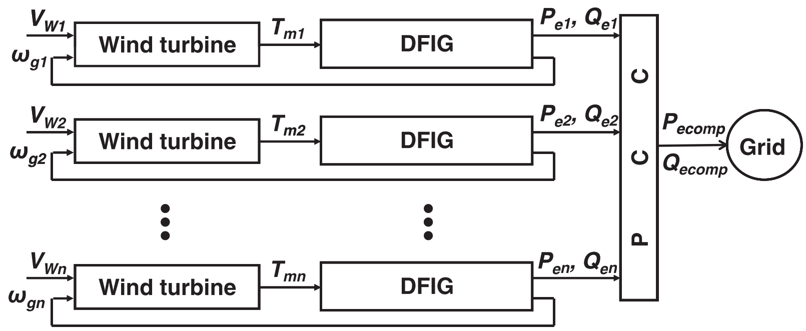

Fig. 1. Block diagram of a complete DFIG wind farm model.

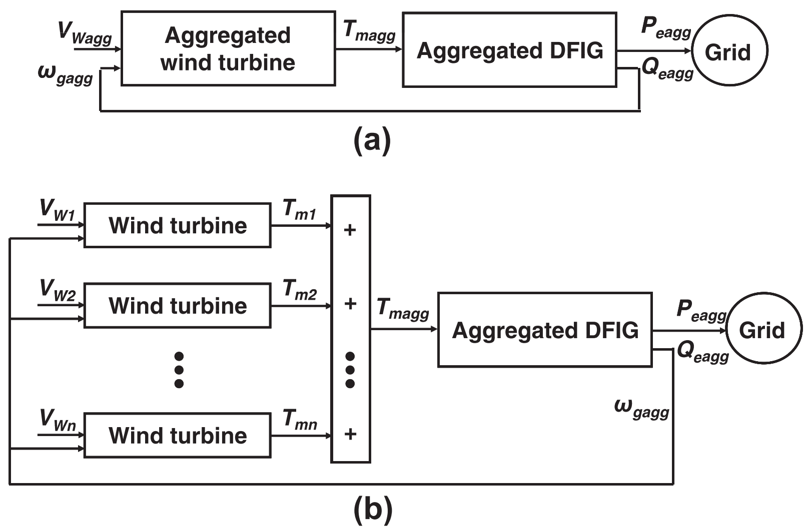

Fig. 2. Block diagram of (a) full aggregated and (b) semi aggregated DFIG wind farm models.

For a wind farm consisting of DFIG wind turbines, the ability of the full or semi aggregated model to approximate the complete model depends on the operating region of the DFIG wind turbines. The operating regions of the DFIG wind turbine adopted in this paper is shown in Fig. 3, which can be segmented into two parts: a partial load region, where the wind speed ranges between 4.5 m/s and 14.5 m/s and a full load region, where the wind speed ranges between 14.5 m/s and 25 m/s). The DFIG wind turbine is stopped when wind speed is less than 4.5 m/s or greater than 25 m/s.

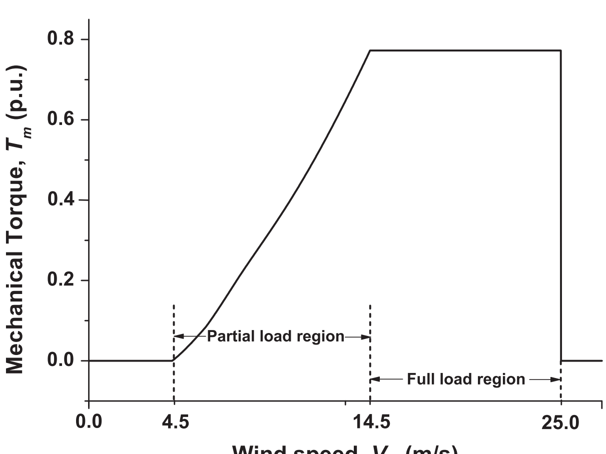

Fig. 3. Operating regions of the DFIG wind turbine at the turbine rotor speed of 1 p.u.

The full or semi aggregated model can represent the complete model when DFIG wind turbines in the wind farm operate in the full load region regardless of the differences in the operating points of the wind turbines in the wind farm. This is due to the fact that all generators produce the same current at its maximum rating in this region.

But, the full aggregated model cannot provide an accurate approximation of a complete model when DFIG wind turbines in the wind farm operate in the partial load region. This is due to the fact that the full aggregated technique does not consider the operating points of all corresponding wind turbines in the wind farm and a nonlinear relationship between wind speed (V_W) and mechanical torque (T_m) as shown in Fig. 3.

The semi aggregated model, on the other hand, improves the approximation of a complete model in the partial load region by considering the operating points of all corresponding wind turbines in the wind farm. The use of an average generator rotor speed (ω_g) for all of the wind turbines still contributes to discrepancies in the magnitude of mechanical torque and consequently electromagnetic torque.

This paper proposes a new aggregation technique with the incorporation of a mechanical torque compensation factor (MTCF) into the full aggregated wind farm model to deal with the nonlinearity of wind turbines in the partial load region and to make it behave as closely as possible to a complete model of the wind farm. The MTCF is initially constructed to approximate a Gaussian