Electric Power Systems Research 148 (2017) 220–229

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

A new simplified model for assessment of power variation of DFIG-based wind farm participating in frequency control system

Sadegh Ghani Varzaneh*, Mehrdad Abedi, G.B. Gharehpetian

Department of Electrical Engineer, Amirkabir University of Technology (Tehran Polytechnic), No. 424, Hafez Ave., Tehran 15914, Iran

ARTICLE INFO

Article history:
Received 8 August 2016
Received in revised form 21 January 2017
Accepted 30 March 2017

Keywords:
Doubly fed induction generator (DFIG)
Droop control
Frequency control
Inertial control
Modeling
Wind farm (WF)

ABSTRACT

Due to the ever-increasing use of wind farms (WFs), an investigation of their impact on the power system stability and control is essential. Especially, assessing the active power variation of WF is one of the important issues, since it can affect the power system frequency. Unlike traditional power plants, a WF consists of many units (wind turbines) with different operating conditions; therefore, studying the behavior of each unit is necessary and this kind of study undoubtedly involves a myriad of calculations. This paper aims to propose a simple and effective equivalent model for a DFIG-based WF participating in the frequency control system. The model is intended to accurately show the behavior of WF as well as individual wind turbines. It is analytically shown that under nominal frequency conditions, a first-order system can accurately evaluate the WF output power. Also, the paper deals with further considerations that should be taken during frequency disturbances to preserve the accuracy. In order to verify the accuracy and effectiveness of the proposed model, the performance of the proposed model is compared to the detailed and the conventional models.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

With the continuous increasing demand for electrical energy and also due to environmental concerns about the use of conventional power plants, special attention is being given to renewable energy in many countries. Wind as a clean source of energy that can be converted to electricity by a wind energy conversion system (WECS) has received a lot of attention.

With regard to the increasing number of wind farms (WFs) and to improve the stability of the power system, WFs are required to participate in frequency control [1]. A WF can either participate in the inertial or droop control, or both, to support the power system frequency. The inertial control is a short-term phenomenon and generally lasts 10–60 s [2]. During this period of time, sufficient energy can be injected into (or absorbed from) the grid to reduce the sudden variation of frequency. This energy is supplied by the kinetic energy stored in the rotating mass of turbines. The droop control is a long-term phenomenon. It is activated for several minutes to minimize the difference between load and generation [2].

A WF has several turbines which each of them experiences different wind speeds. Therefore, the operating point and the dynamic behavior of WECSs are diverse. In order to accurately study the effect of a WF on the frequency control of the power system, a detailed model of units, their controllers and interaction among controllers should be investigated. However, this procedure is very complicated and involves time-consuming calculations. Therefore, using a simplified model to assess the WF behavior is necessary.

All simplified models proposed for assessing the active power variation of a WF can be classified into six categories [3–27]. The first category is based on statistical approaches [3–6] and focuses on the steady-state representation of WECSs. But, the dynamic behavior of generators and their controller have been neglected in this method. Therefore, it is inappropriate for frequency control studies.

The second category focuses on the transient behavior of WF [7–11]. The proposed models reduce the order of the system and keep the accuracy of the calculation during fault conditions. However, in most of these models, the wind speed is assumed to be constant. Furthermore, the complexity of the models is high and they cannot be applied for long-term studies, such as frequency droop control studies.

The third category uses one equivalent WECS to represent a WF where the nominal power of the equivalent WECS is the sum of the rated power of individual WECSs. This category consists of two models known as the generic models [12–15] and the user-defined models [18–21]. The generic models have been developed by Western Electricity Coordinating Council (WECC) and they neglect the variation of the stator and rotor fluxes. Therefore, the models are suitable for large transmission planning studies. However, the iner-

* Corresponding author.
E-mail address: sadegh_ghani@aut.ac.ir (S.G. Varzaneh).

http://dx.doi.org/10.1016/j.epsr.2017.03.033
0378-7796/© 2017 Elsevier B.V. All rights reserved.

tial control has not been included in these models [12] and the wind speed is assumed to be constant during the time of study, which is about 20–30 s [15]. In the user-defined models, the variation of the wind speed is taken into account. The wind speed of the equivalent WECS can be evaluated either by calculating the average value of the wind experienced by the turbines (in the case of similar wind profiles) or by employing the power curve of turbines [20]. These models significantly mitigate the complexity and reduce the simulation time. But, the accuracy of the models is reduced, too [17]. Furthermore, the dynamic behavior of individual WECSs has not been considered in these models.

In the fourth category, by using clustering approaches, WECSs with similar operating conditions are grouped together and the entire WF is represented by limited numbers of equivalent WECSs [22–25]. As a result, for short-term investigations, the accuracy is improved and the simulation time decreases. But, this approach cannot effectively model the dynamic behavior of the WF in long-term studies [20].

In the fifth category, the electrical system of WECSs is aggregated and the mechanical system of the individual WECSs is separately represented by a first-order model. Then, the mechanical torques are aggregated as the input for an equivalent generator represented by the third-order system [26]. By separately modeling mechanical torque of turbines, the accuracy is improved. But, a large number of differential equations must be solved and the model still has high complexity [17].

In the last category, a simplified model of a WF has been introduced for automatic generation control (AGC) studies [27]. It is assumed that the WF operates in the set-point control mode and the WECS has been simply modeled by a first-order system with fixed time constant. However, as will be discussed, the equivalent time constant of the system varies significantly during frequency disturbances. Furthermore, the model cannot show the behavior of the WF during the inertial control.

For frequency control studies, the following requirements should be considered in the modeling of a WF:

1. The active power variation of WF should be represented.
2. The complexity of the model should be low.
3. In short term (inertial control) and long term (droop control), the accuracy of the model should be preserved.
4. The dynamic behavior of individual WECSs should be considered in the model.
5. The inertial control should be included in the model.
6. The droop control should be included in the model.

The aforementioned simplified models may not be so efficient in frequency control studies. For example, the AGC model (introduced in Ref. [27]) does not meet the third, fourth and fifth requirement.

In the present paper, an attempt is made to introduce a simplified model that meets these requirements and, therefore, can be employed for the purpose of frequency control studies. To do this, a simplified first-order system is introduced to accurately evaluate the power variation of WF in normal conditions. The variation of rotational speed and pitch angle of individual WECSs are also determined. Then, the model is extended to be applicable during frequency disturbances. The proposed model is tested in a 16 MW WF including 12 DFIG-based WECS and the results of the proposed simplified model are compared with those obtained by the conventional ones. The comparisons are made in the maximum power point tracking (MPPT), the de-loaded and the inertial modes of operation.

The structure of the paper is organized as follows: the detailed and the conventional simplified models of the WF are reviewed in Section 2. The participation of the WF in frequency control is discussed in Section 3. In Section 4, the proposed simplified model

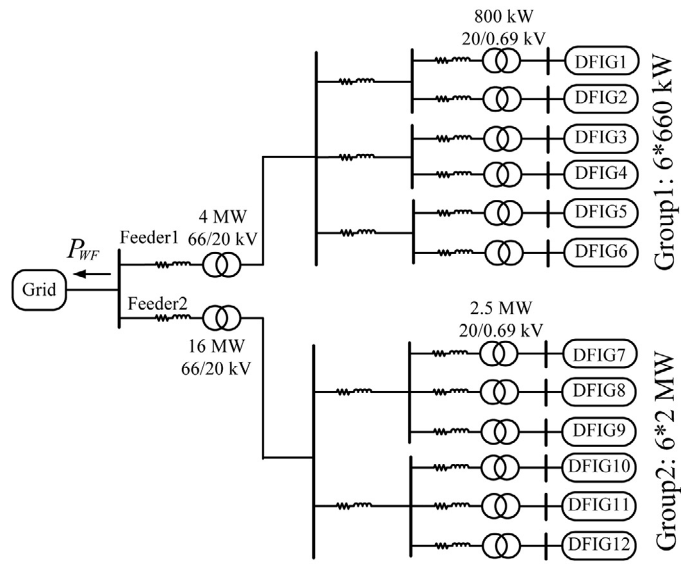

Fig. 1. Configuration of the WF chosen for the present study.
Source: taken from [20].

is introduced. Comparisons among the detailed, the conventional and the proposed models are made in Section 5. The capabilities and limitations of the proposed model are discussed in Section 6. Finally, a conclusion is drawn in the last section.

2. Models of DFIG-based WF

2.1. Configuration of power system under study

In order to harness the maximum available power of the wind and also to mitigate the stress imposed on the blades of the turbine, a variable-speed WECS can be used. One of the most popular generators used in these structures is the doubly fed induction generator (DFIG).

The configuration of the power system under study is shown in Fig. 1. The WF contains two sets of DFIG-based WF. Each set has six generators [20]. The nominal power of the DFIG for the first and the second sets is 660 kW and 2 MW, respectively. More details about the WECS parameters are given in Appendix A. Each unit includes the turbine, the gearbox, the generator and the power electronic converter. The converter involves the rotor side converter (RSC), the grid side converter (GSC) and the DC-link capacitor.

2.2. Detailed model

As discussed earlier, there are many models for studying a DFIG-based WF. The detailed model of DFIG can be used to investigate the performance of WF during normal and contingency conditions. In this type of model, the generator is represented by a 5th-order system [28] and the WECS drive-train is considered by the one-mass model [29].

2.2.1. Modeling of the turbine

The mechanical power of the turbine can be given as follows:

$$P_t = \frac{1}{2}\rho A C_p v^3 \quad (1)$$

where P_t is the turbine mechanical power in Watt, ρ is the air density in kg/m^3, A is the swept area of the rotor in m^2, v is the wind speed in m/s and C_p is the aerodynamic efficiency of the turbine

Download English Version:

https://daneshyari.com/en/article/5001085

Download Persian Version:

https://daneshyari.com/article/5001085

Daneshyari.com