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Dynamic model of wind energy conversion systems with variable speed synchronous generator and full-size power converter for large-scale power system stability studies

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Abstract

This paper presents a dynamic model for variable speed wind energy conversion systems, equipped with a variable pitch wind turbine, a synchronous electrical generator, and a full power converter, specially developed for its use in power system stability studies involving large networks, with a high number of buses and a high level of wind generation penetration. The validity of the necessary simplifications has been contrasted against a detailed model that allows a thorough insight into the mechanical and electrical behavior of the system, and its interaction with the grid. The developed dynamic model has been implemented in a widely used power system dynamics simulation software, PSS/E, and its performance has been tested in a well-documented test power network.

Keywords: Modeling; Power system stability; Wind power generation

1. Introduction

Electrical energy production from renewable sources, and particularly wind power, is increasingly important in industrialized countries. Indeed, wind power is now a not-so-small percentage of the power generation industry and it is rapidly becoming higher. With the massive penetration of wind energy conversion systems in the power network, some new problems arise, not only in technical areas, but also in economy, policy and regulatory fields [1–5]. The results presented in this paper are related to the development of new tools needed to face the technical problem of integrating a large number of wind generators (WGs) in the power grid.

Dynamic models for conventional generators and other power network components, and their corresponding control systems, are generally well described in the literature and known by power system engineers [6,7]. However, WGs behave in different ways because of their differences in size, technology, and prime movers. Detailed models have been developed for the different technologies used in the megawatt class of WGs, mainly organized into four categories: squirrel-cage induction generator connected directly to the grid, wound-rotor induction generator with variable rotor resistance, doubly fed asynchronous generator, and synchronous or induction generator with full-size power converter [8]. These detailed models are useful for a thorough insight into the mechanical and electrical behavior of the system and its interaction with the grid.

When studying the dynamic behavior of an electric power system with high wind generation penetration, the level of detail of the models used does not need to be so high. Furthermore, detailed models do not work well because of the high number of state variables and the small time constants involved. Thus, simplified models are used for representing WGs in power system dynamics simulations that facilitate the investigation of the impact of a large number of WGs on the behavior of a large power system [9].

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This paper presents the development of a dynamic model, suitable for its use in power system stability studies involving large networks, with a high number of buses and a high level of wind generation penetration, for a type of variable speed wind energy conversion system not covered yet in the scientific literature: a variable pitch wind turbine (WT) with a synchronous electrical generator with wounded excitation, and a full power converter. The suitability of the model for this kind of studies has been demonstrated by means of its implementation in a widely used power system dynamics simulation software, PSS/E. The dynamic behavior of the model is compared with that of a detailed model of the same WG implemented in Matlab/Simulink [10], showing an adequate tracking of the relevant dynamics. Finally, the performance of the PSS/E implemented model is tested in a well-documented test network for dynamic studies [11].

Besides, wind power plants are composed of a large number of few megawatt generators, linked together by a medium voltage network. Obviously, the dynamic behavior of such clusters does not fit well in the models of conventional generators, so reduced-order or aggregation models have been investigated [12–17]. An additional application of the model described in this paper is the assessment of aggregation models for this class of WGs.

The paper is organized as follows. Section 2 presents the developed model, based on the particular requirements of power system dynamics simulations. Section 3 compares the developed model with the detailed one, and Section 4 shows its performance in a test network when integrated in PSS/E.

2. Model description

The developed model is able to represent the transient performance of any wind energy conversion system belonging to the Variable Speed Wind Turbine Synchronous Generator System (VS-WTSG) family, as shown in Fig. 1.

The WT is composed of a rotor with three blades and, habitually, it has a pitch angle controller mechanism (PAC) to modify the blade pitch angle and, as a consequence, to limit the rotor speed and, obviously, the generated power at high wind speeds. The electrical generator unit (SG) can be of both, permanent magnet synchronous generator, or a wounded rotor synchronous generator. It can be a conventional SG with two or three pairs of salient poles and a gearbox to couple it to the WT, or a special multipole machine directly driven by the WT (no gearbox is needed).

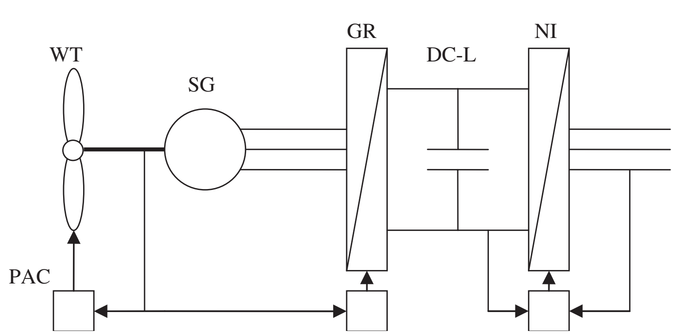

Fig. 1. General description of a VS-WTSG system.

An electronic power conditioner system (EPS) is needed to control the variable speed operation of the system. The EPS is composed by two electronic converters connected trough a dc link: a generator side rectifier (GR) and a network side inverter (NI). GR must control the electromagnetic torque of the generator. It can consist of a diode rectifier and a boost converter, or of a voltage source converter. The NI must control the power injected to the grid, and it consists of a voltage source converter.

Fig. 2 shows the WT torque speed curves for several wind speed values. The torque–speed control strategy, usually followed in a VS-WTSG system, is also represented (thick line) [18,19]. This control strategy is achieved through the coordinated action of the GR and the pitch angle WT controller (PAC), as it will be shown later. Three different regions can be distinguished in the curve that represents this control strategy: A, for low and medium winds, a maximum power tracking strategy is followed; B, medium wind speeds, the rotational speed must be maintained inside limits; C, high wind speeds, both the rotational speed and the power must be maintained within limits.

Fig. 3 shows the general programming structure of the model, where the different simulation blocks are

- WT, wind turbine aerodynamics;
- PAC, pitch angle controller;
- DV, mechanical drive system;
- G-RECT, generator, rectifier, and the system that controls the torque of the generator;

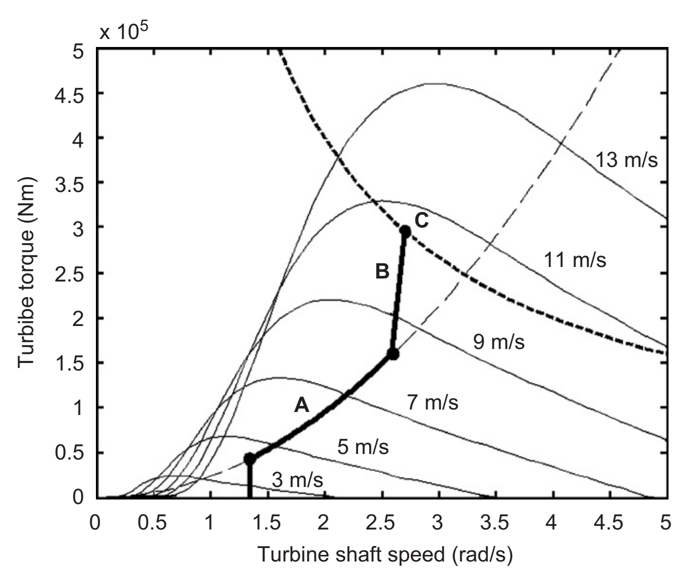

Fig. 2. Torque–speed curves and control strategy.