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Technical note

Comparison of fault-ride-through capability of dual and single-rotor wind turbines

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ABSTRACT

The majority of wind turbines currently in operation have the conventional concept design. That is a single-rotor wind turbine (SRWT) which is connected through spur gearbox to a generator. Recently, dual-rotor wind turbine (DRWT) has been introduced to the market. It has been proven that the steady state performance of the DRWT system for extracting energy is better than the SRWT. But, a comparison of fault-ride-through capability of these two types of turbines requires further research.

In this paper, the fault-ride-through capability of DRWT and SRWT are evaluated and compared when generating units are operating at constant pitch angle and constant speed modes. Constant pitch angle mode is simulated to investigate the natural damping of DRWT and SRWT. To verify the time domain simulation results, damping characteristics of DRWT and SRWT are also compared through eigenvalue analysis and speed droop characteristics of the control system. The accuracy of the aerodynamic model of the DRWT is enhanced by including the stream tube effect in the simulation. It was uncovered that DRWT introduces higher damping torque to the network in both constant speed and constant pitch angle modes. This advantage improves the transient performance of DRWT-based wind farms.

1. Introduction

Wind energy is one of the fastest growing energy resources and it is going to have remarkable share in the energy market. Thus, the consequences of the connection of wind turbine, specifically in the form of a wind farm, to the electrical grid must be investigated from steady state, dynamic and transient point of view. Different approaches have been introduced to improve the static and dynamic responses of the wind turbines [1,2].

The electrical, mechanical and aerodynamic performance quality of the wind turbine is very important to absorb energy as much as possible from wind. In this direction, a new wind turbine generator system (WTGS) has been recently introduced as shown in Fig. 1. This new WTGS, which is called as dual-rotor wind turbine (DRWT), has two sets of rotor systems and is more efficient than the conventional single-rotor wind turbine (SRWT) from the energy extraction point of view [3]. Because most of the aerodynamic torque is generated from the tip portion of the blade, a relatively small auxiliary rotor which is positioned at the upwind location, would compensate for the less effective portion of the main rotor located downwind.

At the time of writing this paper, the authors could trace [4] as the only reference about the dynamic performance of the dual-rotor system. Multi-body dynamics is the employed approach. Although in this paper a model is provided to present the detailed procedures used to show the system dynamic and aerodynamic, however the authors did not compare the dynamic response of the dual-rotor wind turbine with a single-rotor wind turbine. According to [4], the commercial types of dual-rotor wind turbines are able to generate power up to 1 MW.

Even though at the same wind speed and environmental conditions the efficiency of the dual-rotor is higher, nevertheless it does not signify that the transient performance of DRWT is better than SRWT. Obviously, the transient behaviours of the dual-rotor and single-rotor wind turbines are different, because in the dual-rotor system the number, type and arrangement of the components are different.

The objective of this investigation is comparing synchronizing and damping torque introduced by DRWT and SRWT to the network. For getting to this stage both type of wind turbines have been set up in PSCAD software. Drive train method has been employed for modelling the mechanical system of DRWT and SRWT. The electrical characteristics of generator, transformer, transmission line and power system used for DRWT and SRWT are identical to have a fair comparison.

Synchronizing torque is mostly dominated by electromagnetic torque imposed by electrical side. Damping factor of generating

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Fig. 1. Dual-rotor wind turbine.

units is mostly influenced by their control system mode and natural damping characteristic, which is imposed by mechanical drive. To assess the transient response of DRWT and SRWT, when they are operating in constant speed mode, a temporary three phase short circuit is applied to the power system and post-fault fluctuations of the variable of interest are recorded and compared. To verify the validity of the time domain simulation, the control system is approximated by its speed droop characteristic and damping factors which are introduced by the control system are evaluated analytically.

To evaluate and compare the natural damping characteristic of DRWT and SRWT, the maximum short circuit period for which both generating units are able to keep their stability are checked while the controller are deactivated and both DRWT and SRWT are rotating at constant pitch angle. To verify the simulation results regarding natural damping response, eigenvalue analysis is employed using MATLAB software. The real portion of eigenvalues is a good criterion for assessing the system natural damping.

Additionally, in calculating the aerodynamic torque, the stream tube effect behind the auxiliary rotor disk is neglected in Ref. [4]. This simplification can affect the accuracy of the simulations negatively. In this paper, we have included the stream tube effect into the dual-rotor aerodynamic model which improves the exactness of the aerodynamic model to be more realistic.

This paper is organized as follows: In Section 2 mechanical models of different components of the DRWT and SRWT are presented; In section 3 state space equations of turbine generator set has been derived for eigenvalue analysis; Stream tube effect has been discussed in section 4; The effect of pitch angle control on damping torque is obtained analytically in section; 5 Computer simulation results are conducted in section 6. Although other configurations of DRWT are introduced to enhance the performance of this technology, however, the focus of this paper is on the T gearbox type of DRWT. The authors intend to extend the studies for other types of dual-rotor wind turbines. For example, one promising configuration is created if two rotors are directly coupled to an asynchronous electrical machine: one rotor to the induction windings and the other rotor to the induced ones.

2. Mechanical dynamic model

In this section, the dynamic models of different components of single and dual-rotor wind turbines are discussed. Fig. 2.a and Fig. 2.b shows the elements of the single and dual-rotor wind turbines, respectively.

2.1. Spur and bevel gears

Dynamic models for spur gearbox in SRWT and bevel gearbox employed in DRWT are presented in Fig. 3 and Fig. 4 respectively.

By considering a zero backlash for the transmission system, the spur gearbox dynamic model which is the interface between two parallel shafts, is considered to be as follows [5]:

$$\begin{aligned} J_1 . \ddot{\theta}_1 + r_1 K_{12}[r_1\theta_1 + r_2\theta_2] + r_1 d_{12}\left[r_1\dot{\theta}_1 + r_2\dot{\theta}_2\right] &= T_1 - d_1 \cdot \dot{\theta}_1 \\ J_2 . \ddot{\theta}_2 + r_2 K_{12}[r_1\theta_1 + r_2\theta_2] + r_2 d_{12}\left[r_1\dot{\theta}_1 + r_2\dot{\theta}_2\right] &= T_2 - d_2 \cdot \dot{\theta}_2 \end{aligned} \tag{1}$$

where the definitions of parameters in Fig. 3 are as follows: J gear inertia; r gear radius; d damping coefficient between the gears; K contact points stiffness; T torque at the connection; θ rotational angle of gears;

Through comparing Figs. 3 and 4 there are number of dissimilarities between the gearboxes used in single and dual-rotor wind turbines. The differences are due to two main reasons. The major cause is the difference between the numbers of the equipment which are connected through the gearboxes and the minor one is related to the structure unlikeness of the spur and bevel gears such as gear teeth formation [6]. Therefore, the dynamic model of gearboxes employed in dual-rotor and single-rotor systems are different.

Referring to Fig. 4, we have derived the bevel gearbox dynamic model, which links three shafts, as follows:

$$\begin{aligned} & J_1 \cdot \ddot{\theta}_1 + r_1 \cdot K_{12}[r_1 \cdot \theta_1 + r_2 \cdot \theta_2] + r_{av1} d_{12}\left[r_1 \cdot \dot{\theta}_1 + r_2 \cdot \dot{\theta}_2\right] \\ & \quad = T_1 - d_1 \cdot \dot{\theta}_1 \\ & J_2 \cdot \ddot{\theta}_2 + r_3 K_{12}[r_1\theta_1 + r_2\theta_2] + r_3 \cdot d_{12}\left[r_1 \cdot \dot{\theta}_1 + r_3\dot{\theta}_3\right] \\ & \qquad + r_3 K_{23}[r_2\theta_2 + r_3\theta_3] + r_3 d_{32}\left[r_2\dot{\theta}_2 + r_3\dot{\theta}_3\right] = T_2 - d_2 \cdot \dot{\theta}_2 \\ & J_3 \ddot{\theta}_3 + r_3 K_{23}[r_3\theta_3 + r_2\theta_2] + r_3 d_{23}\left[r_3\dot{\theta}_3 + r_2\dot{\theta}_2\right] = T_3 - d_3 \cdot \dot{\theta}_3 \end{aligned} \tag{2}$$

Stiffness of the contact point is a time variable quantity depending on the number of teeth which are engaged to each other. The stiffness variation for each cycle can be considered with a minimum value when one pair of teeth are engaged and

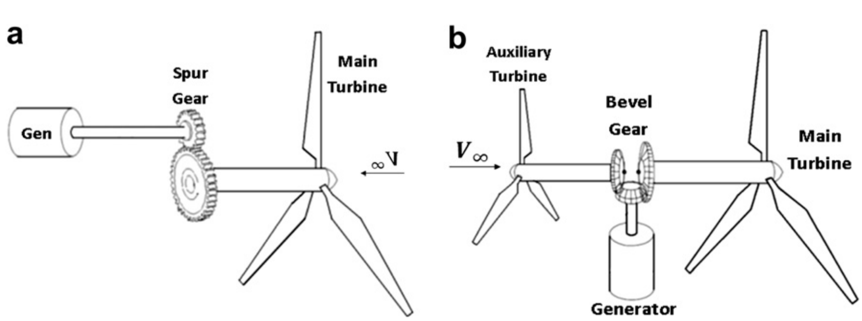

Fig. 2. a. Single-rotor wind turbine, b. Dual-rotor wind turbine.