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Comparison of 5th order and 3rd order machine models for doubly fed induction generator (DFIG) wind turbines

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Abstract

With increasing concern over climate change, a number of countries have implemented new renewable energy targets, which require significant amounts of wind generation. It is now recognized that much of this new wind generation plant will be variable speed type using doubly fed induction generators (DFIG). In order to investigate the impacts of these DFIG installations on the operation and control of the power system, accurate models are required. A fifth order and reduced order (3rd) machine models are described and the control of the wind turbine discussed. The capability of the DFIG for voltage control (VC) and its performance during a network fault is also addressed.

Keywords: Machine models; DFIG; Wind turbines

1. Introduction

The exploitation of the wind as a source of renewable energy continues to increase with some 25 GW of wind turbine capacity installed worldwide. In some countries the penetration of wind energy is such that already it is a significant fraction of generation capacity and projections of future installations indicate that the number of wind turbines will increase rapidly over the next 10 years. Hence, wind farms must be included in computer simulations to study both the development and operation of the power system.

At present variable speed operation of wind turbines, using doubly fed induction generators (DFIG), is emerging as the preferred technology. This is due mainly to the reduced mechanical loads on the wind turbines that arise from variable speed operation [1]. However, a secondary advantage is the increased possibilities of control of both real and reactive power to allow easier integration of wind turbines into the power system.

In comparison to conventional synchronous generation, wind power is developed in relatively small units. Typical wind turbine ratings vary between 800 kW and 3 MW with wind farms ranging from 1 to 200 MW. Thus it is important to determine the simplest possible models of wind turbines that give an accurate representation in the various studies that are undertaken on the power system. In this paper a comparison is made between a 5th order model of the DFIG wind turbine and a 3rd order representation where the stator transients are neglected. The development of the models is described and it is shown that for dynamic modeling the 3rd order model is adequate. For detailed representation of fault current contribution, the 5th order model provides better resolution although it must be recognized that the behavior of the converter control systems is likely to have a dominant effect on fault currents.

2. Doubly fed induction generator (DFIG)

DFIG wind turbines utilize a wound rotor induction generator, where the rotor winding is fed through back-to-back variable frequency, voltage source converters. A

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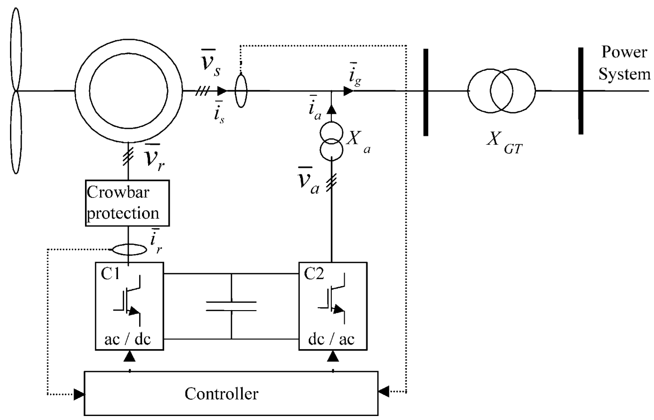

Fig. 1. Basic configuration of a DFIG wind turbine.

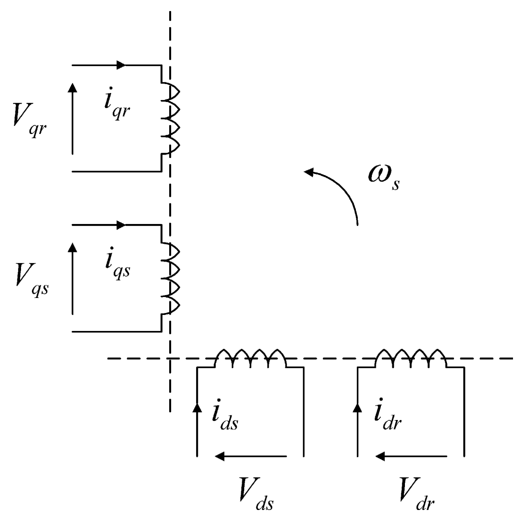

Fig. 2. Direct (d) and quadrature (q) representation of induction machine.

typical configuration of a DFIG based wind turbine is shown schematically in Fig. 1. The converter system enables variable speed operation of the wind turbine by decoupling the power system electrical frequency and the rotor mechanical frequency. A more detailed description of the DFIG system together with its control and protection circuits can be found in [2–4].

3. Fifth order model of the DFIG

Three-phase stator and rotor windings of an induction machine can be represented by two sets of orthogonal fictitious coils. Appendix B shows the transformation from three-phase to two-phase fictitious coils which are placed in direct (d) and quadrature (q) axes [5,6]. A generalized fifth order machine model was then developed by considering the following conditions and assumptions:

a) The stator current was assumed positive when flowing towards the machine.
b) The equations were derived on the synchronous reference.
c) The q-axis was assumed to be 90° ahead of the d-axis with respect to the direction of rotation.
d) The q component of the stator voltage was selected as the real part of the busbar voltage and d component was selected as the imaginary part.

Machine equations can be represented in terms of the machine variables or in terms of arbitrary reference frame variables. However, for power system studies it is desirable to use a per unit (pu) representation. This enables the conversion of the entire system to pu quantities on a single power base. The voltage equations for the fictitious coils were normalized as shown in Appendix C. Fig. 2 shows the dq representation of the machine.

The voltage equations for the induction generator are given below, where all quantities except the synchronous speed are in pu:

$$\begin{cases} \bar{v}_{ds} = \bar{R}_s \times \bar{i}_{ds} - \bar{\lambda}_{qs} + \dfrac{1}{\omega_s}\dfrac{d}{dt}\bar{\lambda}_{ds} \\ \bar{v}_{qs} = \bar{R}_s \times \bar{i}_{qs} + \bar{\lambda}_{ds} + \dfrac{1}{\omega_s}\dfrac{d}{dt}\bar{\lambda}_{qs} \end{cases} \tag{1}$$

$$\begin{cases} \bar{v}_{dr} = \bar{R}_r \times \bar{i}_{dr} - s \times \bar{\lambda}_{qr} + \dfrac{1}{\omega_s}\dfrac{d}{dt}\bar{\lambda}_{dr} \\ \bar{v}_{qr} = \bar{R}_r \times \bar{i}_{qr} + s \times \bar{\lambda}_{dr} + \dfrac{1}{\omega_s}\dfrac{d}{dt}\bar{\lambda}_{qr} \end{cases} \tag{2}$$

where,

$$\begin{cases} \bar{\lambda}_{ds} = \bar{L}_{ss} \times \bar{i}_{ds} + \bar{L}_m \times \bar{i}_{dr} \\ \bar{\lambda}_{qs} = \bar{L}_{ss} \times \bar{i}_{qs} + \bar{L}_m \times \bar{i}_{qr} \end{cases} \tag{3}$$

$$\begin{cases} \bar{\lambda}_{dr} = \bar{L}_{rr} \times \bar{i}_{dr} + \bar{L}_m \times \bar{i}_{ds} \\ \bar{\lambda}_{qr} = \bar{L}_{rr} \times \bar{i}_{qr} + \bar{L}_m \times \bar{i}_{qs} \end{cases} \tag{4}$$

From equation (4):

$$\bar{i}_{dr} = \left(\frac{\bar{\lambda}_{dr} - \bar{L}_m \times \bar{i}_{ds}}{\bar{L}_{rr}}\right) \quad \text{and} \quad \bar{i}_{qr} = \left(\frac{\bar{\lambda}_{qr} - \bar{L}_m \times \bar{i}_{qs}}{\bar{L}_{rr}}\right) \tag{5}$$

Substituting from Eq. (5) into Eq. (3) and with $\bar{X}_1 = [\bar{L}_{ss} - \frac{\bar{L}_m^2}{\bar{L}_{rr}}]$:

$$\bar{\lambda}_{ds} = \bar{X}_1 \times \bar{i}_{ds} + \left(\frac{\bar{L}_m}{\bar{L}_{rr}}\right) \times \bar{\lambda}_{dr} \quad \text{and} \quad \bar{\lambda}_{qs} = \bar{X}_1 \times \bar{i}_{qs} + \left(\frac{\bar{L}_m}{\bar{L}_{rr}}\right) \times \bar{\lambda}_{qr} \tag{6}$$

In order to obtain a voltage behind a transient model