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Indirect vector control of a squirrel cage induction generator wind turbine

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ABSTRACT

The paper deals with a squirrel cage induction generator connected to the grid through a back-to-back converter driven by vector control. The stator-side converter controls the generator torque by means of an indirect vector control scheme. In order to reduce the system dependance from the mechanical system behavior, a torque loop is used in the current reference calculations. Moreover, a torque control is included in the stator-side control in order to overcome a voltage dip fault. The grid-side converter controls the DC bus voltage and the reactive power in order to accomplish the grid codes. The proposed control strategy is evaluated by the simulation of different scenarios such as variable wind speed and different levels of voltage sags by means of Matlab/Simulink®.

1. Introduction

Wind power is one of the most promising renewable energy sources due to the progress experienced in the last decades. The increasing penetration level of wind energy (Denmark 20%, Portugal 15%, Spain 14% and Germany 9% [1]) has led to the establishment of grid codes. Among these requirements, voltage sag ride through capability is mandatory [2–5].

Wind farms can be composed of fixed-speed or variable-speed generators, and also by induction (doubly-fed and squirrel-cage) or synchronous machines (permanent magnets and wound rotor). Squirrel cage induction generators (SCIG) have been used as fixed-speed generators, or for micro-generation [6,7]. However, they can also be implemented as a variable-speed generators, introducing full rate power converter between grid and generators [8]. The main advantages of using squirrel cage generator topology are low cost, good reliability and robustness. Its main drawback compared to permanent magnets synchronous generators (PMSG) is the difficulty to build a multipolar squirrel cage induction generator.

SCIG control can be implemented using different approaches: scalar or vector control, direct or indirect field orientation, rotor or stator field orientation [9–11]. Scalar control [12] is simple to implement, but easily unstable. A better performance is obtained with direct vector control, requiring sensed flux values to define and control the field orientation references. This however means that it is necessary to use hall-effect sensors, which, in practise, is problematic, and expensive, [13,14]. The indirect field-orientation method is more sensitive to the machine parameters but removes the necessity of direct flux sensing [15,16].

This paper proposes an indirect vector control strategy less sensitive from the machine parameters than the conventional scheme [8]. Voltages are referred to a q–d synchronous frame, aligned with the rotor flux vector, for the stator-side converter.

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Nomenclature

Symbols

λ	Flux linkage
Γ	Torque
θ	Angle
$\dot{\theta}$	Angular velocity
s	Slip
r	Resistance
L	Inductance
M	Mutual inductance

Superscripts

$*$	Set point
e	Synchronism reference

Subscript

s	Stator
l	Grid-side converter
z	Grid
d	d-axis
q	q-axis

The grid-side converter is controlled by means of vector control strategy decoupling active and reactive power. The article also analyzes the response of the system during faults, where the fault ride through is achieved.

This paper is organized as follows. In Section 2, the studied global system under study is described and analyzed. The control scheme is presented in Section 3. The torque regulation, in order to overcome the fault ride through, is explained in Section 4. In Section 5, the proposed control is validated by means of different simulation. Conclusions are summarized in Section 6.

2. Squirrel cage induction generator with full power converter

The system being analyzed can be seen in Fig. 1. It is important to point out that there are more elements, e.g. a transformer and a wind farm grid, which are not included in the present paper.

The squirrel cage induction generator (SCIG) is attached to the wind turbine by means of a gearbox. The SCIG stator windings are connected to a back to back full power converter.

The wind turbine is responsible for transforming wind power into kinetic energy. Wind Turbine power can be determined by using,

$$P_{wt} = \frac{1}{2} \cdot c_p \cdot \rho \cdot A \cdot v_w^3. \tag{1}$$

The gearbox provides speed and torque conversions from a rotating power source to another device, using gear ratios. In the analyzed system, it is described by means of a one mass model which complies with:

$$\begin{aligned} &\frac{d}{dt}\omega_{gen} = \frac{\Gamma_g - \Gamma_t'}{J_{tot}} \\ &\Gamma_t' = \frac{\Gamma_t}{K_{gear}} \\ &\omega_t = K_{gear} \cdot \omega_{gen} \end{aligned} \tag{2}$$

where ω_t and ω_{gen} are the turbine and generator angular speeds, respectively.

For the machine equations, assuming that the stator and rotor windings are sinusoidal and symmetrical [17,18], the relation between voltage and currents on a synchronous reference qd can be written as:

$$\begin{bmatrix} v_{sq} \\ v_{sd} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} L_s & 0 & M & 0 \\ 0 & L_s & 0 & M \\ M & 0 & L_r & 0 \\ 0 & M & 0 & L_r \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_{sq} \\ i_{sd} \\ i_{rq} \\ i_{rd} \end{bmatrix} + \begin{bmatrix} r_s & L_s\omega_e & 0 & M\omega_e \\ -L_s\omega_e & r_s & -M\omega_e & 0 \\ 0 & sM\omega_e & r_r & sL_r\omega_e \\ -sM\omega_e & 0 & -sL_r\omega_e & r_r \end{bmatrix} \begin{bmatrix} i_{sq} \\ i_{sd} \\ i_{rq} \\ i_{rd} \end{bmatrix} \tag{3}$$