Global Journal of
Computer Sciences:
Theory and Research

Volume 07, Issue 1, (2017) 31-37

www.gjcs.eu

Direct control of active and reactive power of a doubly fed induction machine

Amel Ourici*, Electrical Engineering Institute, Badji Mokhtar University of Annaba, Annaba, Algeria.
Wafa Tourab, Electrical Engineering Institute, Badji Mokhtar University of Annaba, Annaba, Algeria.
Merabet Leila, Electrical Engineering Institute, Badji Mokhtar University of Annaba, Annaba, Algeria.

Suggested Citation:

Ourici, A., Tourab, W. & Leila, M. (2017). Direct control of active and reactive power of a doubly fed induction machine. *Global Journal of Computer Sciences: Theory and Research. 7*(1), 31-37.

Received December 16, 2016; revised February 28, 2017; accepted April 17, 2017.
Selection and peer review under responsibility of Prof. Dr. Dogan Ibrahim, Near East University, North Cyprus.

Abstract

This paper proposes a direct power control for doubly fed induction machine for variable speed wind power generation. It provides decoupled regulation of the primary side active and reactive power and is suitable for both electric energy generation and drive applications. In order to control the power flowing between the stator of the doubly fed induction generator and the network, a decoupled control of active and reactive power is synthesised using PI controllers. The obtained simulation results show the feasibility and effectiveness of the suggested method.

Keywords: Doubly fed induction machine, decoupled power control, vector control, active and reactive power, PWM inverter.

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* ADDRESS FOR CORRESPONDENCE: **Amel Ourici,** Electrical Engineering Institute, Badji Mokhtar University of Annaba, Annaba, Algeria. *E-mail address*: amel.ourici@hotmail.com

1. Introduction

Wind energy systems using a doubly fed induction generator (DFIG) have a number of advantages due to variable speed operation and four-quadrant active and reactive power capabilities compared with fixed speed induction. Investigations using predictive functional controller [1] and internal mode controller [2, 3] have shown satisfactory power response compared with the power response of PI, but it is difficult to implement due to the predictive functional controller and internal mode controller formulation. Another possibility for doubly fed power control can be made using fuzzy logic [4, 5]. These strategies have satisfactory power response although they involve relatively complex transformation of voltages, currents and control outputs among the stationary, rotor and synchronous reference frames. Direct power control was applied to the DFIG power control, and it is presented in [6–8]. This scheme calculates the required rotor controlling voltage directly based on the estimated stator flux, active and reactive power and their errors. In [6], the principles and implementation of DPC are made with hysteresis controllers and variable switching frequency. In [7] and [8], the principles of this method are described in detail and the simulations results are presented with variable and constant switching frequency, respectively. Moreover, the conventional DPC complicates the AC filter design because of its variable switching frequency. An alternative to direct power control is the power error vector control [9]. This strategy is less complex and obtains results similar to direct power control. To improve the power response, eliminate the torque ripple and protect rotor-side converter under grid voltage sags, a proportional control with anti-jamming control was proposed in [10]. This control has satisfactory power response and eliminates the rotor current overshoot in voltage sags when the loop of torque control is applied, although power and rotor currents results were shown only in fixed speed operation. We present in this paper a direct power control, it results in good decoupling control between active and reactive power and achieves high accuracy and fast dynamic power response.

2. Description and Modelling of DFIM

The proposed system is shown in Figure 1, and is constituted of two pulse-width modulation (PWM) inverters supplying the stator and the rotor of the machine separately [11].

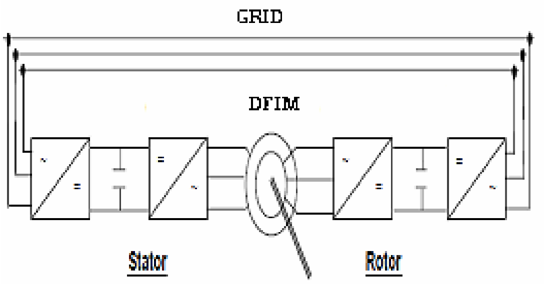

Figure 1. DFIM supplied by two PWM inverters

We choose a three-level PWM for both stator and rotor inverters, which constitutes three arms; each arm has four switches formed by a transistor and a diode, as shown in Figure 2.

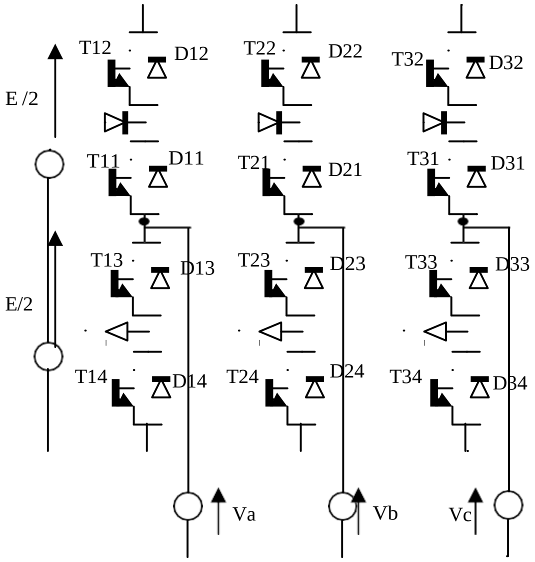

Figure 2. General diagram of a three-level PWM inverter

The simple voltages are obtained starting from the following conditions:

If (Vréf = Vp) and (Vréf > 0)

$$= > V_K = + E/2$$

If (Vréf = Vp) and (Vréf < 0)

$$=> V_K = -E/2$$

$$\psi ds = LsIds = MIdr$$

$$\psi qs = LsIqs + MIqr$$

$$\psi dr = LrIdr + MIds$$

$$\psi qr = LrIqr + MIqs$$

If $V_{\text{réf}} = V_p = > V_K = 0$

The mechanical equation is given as

$$Cem = Cr + J\frac{d\wedge}{} + f\wedge d$$

with

$V_{\text{réf}}$ as the reference voltage standard; Vp the carrying voltage and

V_K is the potential of the node K.

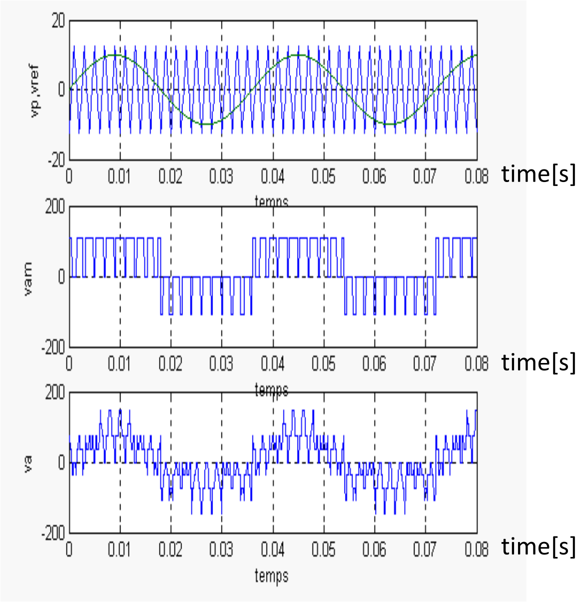

Figure 3. Carrying voltage, simple voltage and phase voltage

Stator and rotor voltages of the machine after Park transformation are given in [12]

$$\begin{aligned} Vds &= RsIds + \frac{d\psi ds}{dt} - \frac{d\theta s\psi qs}{dt} \\ Vqs &= RsIqs + \frac{d\psi qs}{dt} - \frac{d\theta s\psi ds}{dt} \end{aligned} \tag{1}$$

$$\begin{aligned} Vdr &= RrIdr + \frac{d\psi dr}{dt} - \frac{d\theta r\psi qr}{dt} \\ Vqr &= RrIqr + \frac{d\psi qr}{dt} - \frac{d\theta s\psi dr}{dt} \end{aligned} \tag{2}$$

Stator and rotor fluxes are given as

3. Control Strategies

By orienting rotor flux towards *d*-axis, and stator flux towards *q*-axis, conventionally, the *d*-axis remains reserved to magnetise axis and *q*-axis to torque axis, we obtain

$$\begin{gathered} \psi sq = \psi s, \\ \psi rd = \psi r, \\ \psi sd = \psi rq = 0 \end{gathered} \tag{3}$$

Then the developed torque can be written as

$$\text{Cem} = Dc\psi s\psi r,\ Dc = pM/\sigma LsLr \tag{4}$$

Vector diagrams before and after flux orientation are shown as follows [13]:

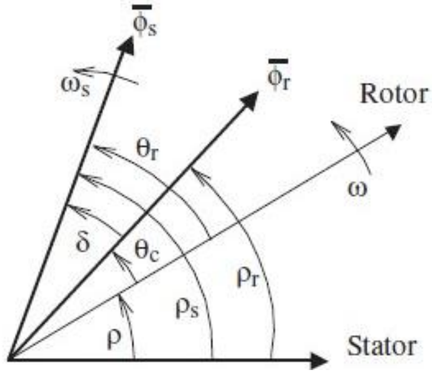

Figure 4. DFIM flux relative armature position

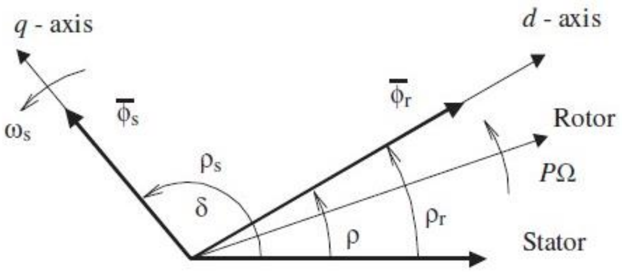

Figure 5. DFIM vector diagram after orientation

The stator active and reactive powers can be written as

$$P = V_{ds} \cdot I_{ds} + V_{qs} I_{qs}$$

$$Q = V_{qs} I_{ds} - V_{ds} I_{qs}$$

After all calculations we can draw up this plan.

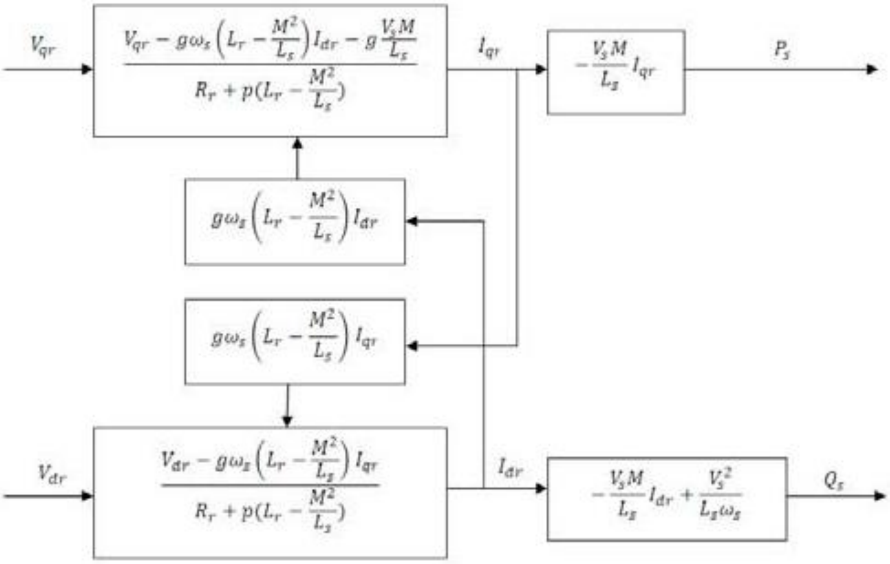

Figure 6. Block diagram of the DFIG

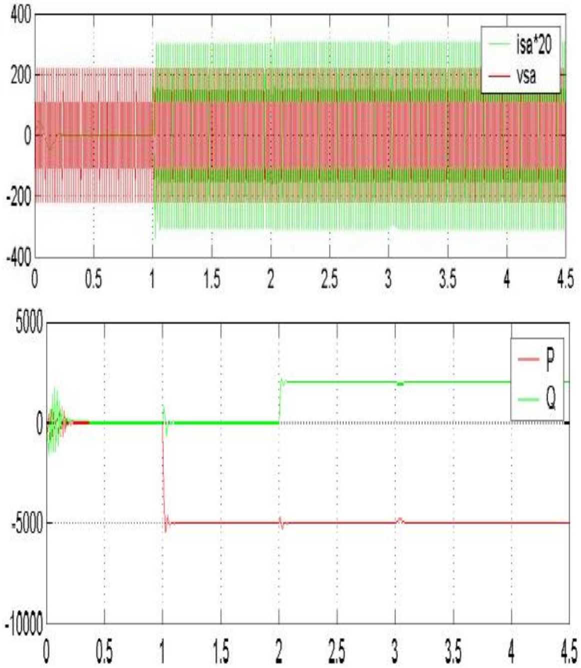

Figure 7. Stator voltage and current, active and reactive power

4. Results Analysis

Figure 3 shows the carrying voltage, simple voltage and phase voltage of the three-level inverters used. Figure 4 presents speed, stator current and rotor current in the start-up of the machine; till 0.8 s the machine starts with rotor in short circuit, after the rotor is fed by the inverter. In Figure 8, we can see stator voltage and current, and active and reactive power. At time equal to 1 s, when we forced the active power to −5 Kw, the reactive power did not react; also, when we give a level of 2 KVA to the reactive power, the active one did not react. Hence, we can conclude that we have made effective decoupling between both the powers. It can be said that this strategy in addition to its simplicity shows good results.

5. Conclusion

We present in this paper simulation of a doubly fed induction machine fed with two PWM inverters, based on *d-q* modelling. Access to the stator and rotor windings is one of the advantages of the wound rotor induction machine compared to the conventional squirrel-cage machine; consequently, the doubly fed induction machine offers several possible combinations for its control. A double flux orientation was presented. Since the fluxes are used like control variables, the machine fluxes must be maintained at the acceptable level, especially during the transient regimes. In addition, we successfully decoupled the active and reactive power. This control development enabled us to highlight several interesting aspects for further study on wind power production. It is obvious that the direct method is easier to implement than the indirect one.

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