Behavior of a doubly fed induction machine

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ARTICLE INFO

ABSTRACT

In this paper, we present the behavior of a doubly fed induction machine (DFIM) functioning in mode motor and of which the rotor and the stator are fed through the intermediary of a chain of conversion of AC/AC type. This last is composed of a converter AC/DC, an LC filter and a second converter DC/AC. So, we adopted a strategy of survey having for objective to make a servitude quickly of the DFIM while applying the vectorial order to flux oriented stator led then of a regulating PI, in the last part, of a fuzzy regulator.

1. Introduction

Currently, several studies are oriented towards the study of the doubly fed induction machine that has a solution for high power drives and variable speed operation and it ensures a very low speed (Khlifi et al., 2016; Khlifi and Alshammari, 2014; Abdelaziz et al., 2011). In addition, the variable speed drive is a multidisciplinary field of electrical engineering, which brings together diverse expertise in several sectors: electrical machinery, power electronics, control, etc., (Salah Saidi and Helmy, 2018; Abdelaziz and Mohammed, 2017; Khlifi, 2019). Thus, the association of double-fed asynchronous machines with static converters can provide different control strategies. However, order one of these machines remains a delicate operation, since it presents problems of command because of the strong coupling between the flux and torque. To overcome this problem, we came to the vector control which brings the behaviour of the MAS to that of a DC motor. Thus, regulators most commonly used for the purposes of this order are PI type with its simple implementation and ease of synthesis. Nevertheless, the limitation of performance offered by the regulator has encouraged researchers to find a replacement who found in artificial intelligence. Among the branches of this technique, we chose to work with fuzzy logic whose foundations were established by Zadeh (1965) at the University of California Berkeley, which introduced the concept of fuzzy set. In order to confirm the contribution of the use of a fuzzy controller compared to conventional PI, we represented the results of simulating the behavior of DFIM controlled stator flux oriented and conducted a fuzzy controller of speed.

2. Modeling of doubly fed induction machine

The use of DFIM in the field of variable speed drive uses the command, and to this end, a mathematical model of the process is then essential (Khlifi et al., 2016). Thus the determination of such a model allows us to simulate the behavior of the machine in transient and lead to an order following a control scheme (Baghli, 2005) we will study later.

The dynamic model of the DFIM is reflected in the Landmark Park, linked to the rotating field by the equations in what follows:

$$\Phi_{rd} = V_{rd} - \frac{R_r}{L_r}\Phi_{rd} + \frac{R_r}{L_r}\text{MI}_{sd} + (\omega_s - \omega)\Phi_{rq} \qquad (1)$$

$$\Phi_{rq} = V_{rq} - \frac{R_r}{L_r}\Phi_{rq} + \frac{R_r}{L_r}\text{MI}_{sq} - (\omega_s - \omega)\Phi_{rd} \qquad (2)$$

$$\text{I}_{sd} = \frac{1}{\sigma L_s}\Big[V_{sd} - I_{sd}\left(R_s + \frac{M^2}{L_r}\frac{R_r}{L_r}\right) + \sigma\omega_s L_s I_{sq} + \frac{M}{L_r}\frac{R_r}{L_r}\Phi_{rd} + \frac{M}{L_r}\omega\Phi_{rq}\Big] \qquad (3)$$

$$\text{I}_{sq} = \frac{1}{\sigma L_s}\Big[V_{sq} - I_{sq}\left(R_s + \frac{M^2}{L_r}\frac{R_r}{L_r}\right) - \sigma\omega_s L_s I_{sd} + \frac{M}{L_r}\frac{R_r}{L_r}\Phi_{rd} - \frac{M}{L_r}\omega\Phi_{rq}\Big] \qquad (4)$$

$$\Omega = \frac{pM}{J}\left(I_{sq}I_{rd} - I_{sd}I_{rq}\right) - \frac{C_r}{J} - \frac{f}{J}\Omega \qquad (5)$$

3. Strategy for the control of MADA

The structure of the double-fed asynchronous machine has the advantage of carrying out an order by several methods and structures, depending on the mode of operation, the variable order and the

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application domain (Elbia, 2009). In our work, we studied the structure of which the DFIG is controlled from two inverters: one to the other stator and the rotor. Each of these two converters is powered by its own rectifier through an LC filter. Fig. 1 presents this structure.
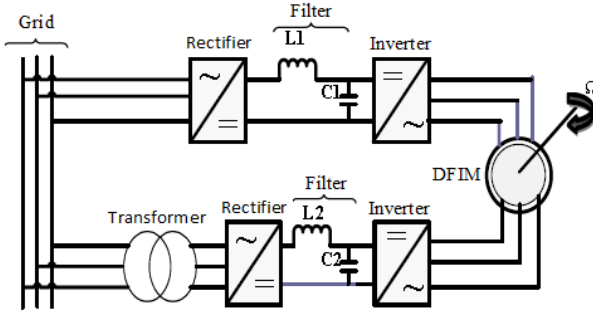

Fig. 1: General diagram of a DFIM commanded by two inverters

To improve the performance of the inverter, use the pulse width modulation (PWM). This control technique allows to define the instants of the switches (Abdelaziz and Chokri, 2012; Baghli, 2005). Its principle consists in regulating the amplitude and fundamental frequency signal and the rejection of harmonics whose amplitude is important. Of MLI techniques, the best known are:

- PWM control strategy with current or hysteresis current modulation.
- PWM with carrier-modulation or natural.
- Vector PWM.
- PWM with harmonic-criteria.

In our study, we focus on the modulation hysteresis current. This control strategy is simple and effective because it allows us to both maintain the current close to their references in a band known as hysteresis tolerance band whose role is to impose the real ripple currents, and control the switches of the inverter and control the currents in the stator phases of the machine.

4. Vector control

It is important to remember that the difficulty of controlling a MAS is prompted by the fact that the electromagnetic torque from the interaction between charged currents in the stator windings and currents induced in those rotor. The application of vector control introduced by Blaschke (1972) was a breakthrough in controlling the induction machine. It leads us to decouple the rotor and the stator frame (Nemmour, 2002).

The principle of vector control is then in fact bring the behaviour of the MAS to the MCC with a decoupling between flux and torque, is existing in nature. This is illustrated in Fig. 2.

The vector control can be classified into two types according to the method of flow direction (direct or indirect):

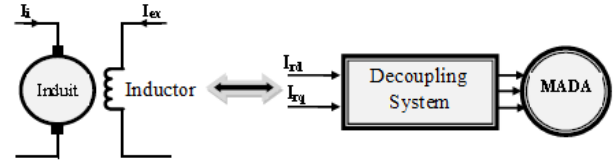- Vector control directly.
- Vector control indirectly.

Fig. 2: Representative diagram of the analogy between the MCC and the DFIM

The indirect method can be considered as the easiest to implement and widely used (Pietrzak-David and De Fornel, 1992). In this work, use this method, given its huge advantage in the fact that the amplitude does not flow, but only its position. Specifically, we will focus on the orientation of stator flux. Stator flux orientation along the axis line is used to write:

$$\Phi_{sd} = \Phi_s \text{ and } \Phi_{sq} = 0 \tag{6}$$

We get to write the electromagnetic torque as given by Eq. 7.

$$C_{em} = \frac{pM}{L_s}\Phi_s I_{rq} \tag{7}$$

Thus, the shape of the torque obtained is similar to a couple MCC. It should be noted that in the expression, already established, the two components of rotor current and intercede with the first (IRD) controls the flow and the other (I_{rq}) controls the torque. This means that there are two action variables (Azaizia, 2008) and the couple DFIM becomes similar to that of MCC. The voltage equation of stator phase is given by:

$$v_s = R_s i_s + \frac{d\Phi_s}{dt} \tag{8}$$

For a machine of high or medium power, and stator flux oriented, we get:

$$V_{sd} = 0 \tag{9}$$
$$V_{sq} = v_s = \omega_s \Phi_s \tag{10}$$

Taking into account Eqs. 9 and 10, the active power and reactive that are given by the two Eqs. 11 and 12.

$$P_s = V_{sq} I_{sq} \tag{11}$$
$$Q_s = V_{sq} I_{sd} \tag{12}$$

By choosing to work with a stator power factor very close to unity, it will be mandatory to have a zero reactive power to the stator (Baghli, 1999).

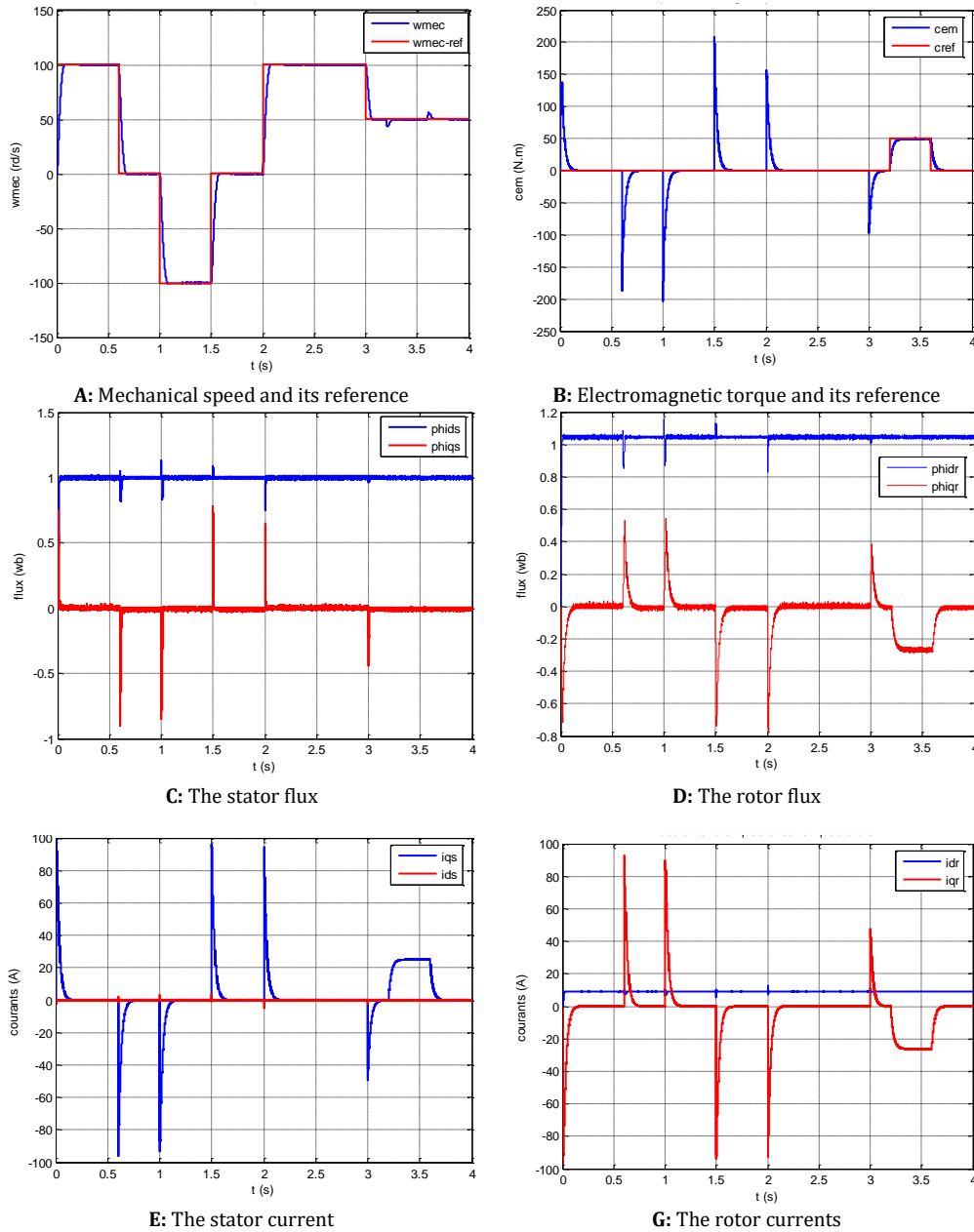This amounts to imposing a stator reference current I_{sd} zero.

$$I_{sdref} = 0. \tag{13}$$

We arrive at the instruction set of the electromagnetic torque.

$$C_{emref} = pMI_{rdref}I_{sqref} \qquad (14)$$

from where:

$$I_{sqref} = \frac{C_{emref}}{pMI_{rdref}} \qquad (15)$$

with,

$$I_{rdref} = \frac{\Phi_{sref}}{M}. \qquad (16)$$

As for the current I_{rq} reference, it can be written in this form:

$$I_{rqref} = \frac{-L_s}{M}I_{sqref}. \qquad (17)$$

From Eqs. 13, 15, 16, and 17, we then come to find references to different currents needed to control hysteresis inverters. The speed control will be provided by a PI controller responsible for providing the electromagnetic torque reference. Fig. 3 implements the block diagram of the speed control of the DFIM stator flux oriented controlled. This command is mainly based on the loop speed control. The latter gives us, at its output, the torque (EMC ref) to calculate the reference current (I_{sq} ref).

As to current guidelines, they allow the current control of two inverters (side stator and rotor). By accessing the inverse Park transformation, one arrives at the reference currents in the natural landmark that represent the instructions provided to the PWM stage. This stage PWM hysteresis role is to provide controls the switches of each inverter. With regard to the speed control used, it should determine the electromagnetic torque reference in order to maintain speed to its reference (Nemmour, 2002). To do this, it takes as input the speed reference and the measured one. In our work, we used a PI controller due to its simplicity and speed of handling it offers. The transfer function of such a controller is given by the following equation:

$$H(p) = k_p + \frac{K_I}{p} \qquad (18)$$

Fig. 3: Diagram bloc of the regulation of speed of the MADA to flux oriented stator

5. Application of the vector control conducted a PI controller for DFIM

When simulating the behaviour of the DFIM stator flux oriented and using a PI controller for speed, we obtained the results shown in Fig. 4.

The analysis of these results shows that the response speed of 0.196 is delayed about every time we vary the set point during start unloading. During the phase of insertion torque, the actual speed of the machine moves away from its reference of considerable value. In addition to changes in set point speed cause large peaks (coming up to 200Nm) for the electromagnetic torque.

Let's notice, by examining the curves representing the variation of the quadrature

component of stator current and the rotor current, these two quantities undergo unwanted peaks during the transition phases of the reference speed. For the behaviour of the machine magnetic point of

view, we find the response of the rotor flux on the axis "q" peaks seen on the quadrature component of the current frame.

A: Mechanical speed and its reference

B: Electromagnetic torque and its reference

C: The stator flux

D: The rotor flux

E: The stator current

G: The rotor currents

Fig. 4: Evolution of various quantities of MADA (implementation of vector control using a conventional PI controller)

As for the stator flux on the same axis, he says the direction vector applied to the MADA, however, he sustained peak varies very fast when the reference speed. Thus, there is also the impact of torque on the magnetic state of the machine. This can be judged from the evolution curve of Φ_{rq} In conclusion, the curves representing the evolution of electrical, magnetic and mechanical ones, we can conclude the lack of the use of PI (especially point of view dynamic performances).

6. Conclusion

Within this article, we performed a study on the vector control by stator flux orientation of the MADA with emphasis on the improvement made by a fuzzy

controller, capable of handling the imprecise, the uncertain, the wave and the non-linear models, the performance of this machine compared to a conventional PI controller which can lose its strength vis-à-vis an external perturbation.

List of abbreviations

Acronym	Meaning
MAS	Asynchronous machine
DFIM	doubly fed induction machine
MCC	DC machine
PI	Proportional Integral
MLI	Pulse width modulation
FOC	Field Oriented Control

List of symbols

Symbol	Designation
R_s	Stator resistance per phase
R_r	Rotor resistance per phase
L_s	Stator cyclic inductance
L_r	Rotor cyclic inductance
M	Mutual inductance between stator and rotor
$I_{sd,sq}$	Stator currents
$I_{rd,rq}$	Rotor currents
$V_{sd,sq}$	Stator voltages
$V_{rd,rq}$	Rotor voltages
$\Phi_{sd,sq}$	Stator flux
$\Phi_{rd,rq}$	Rotor flux
v_s	Instantaneous voltage stator
C_{em}	Electromagnetic torque
C_r	Load torque
K_e	Gain error of fuzzy controller
K_{de}	Gain variation of the error of fuzzy controller
K_{du}	Gain variation control output
K_p	Coefficient of proportionality
K_I	Integration coefficient
μ	Function or degree of membership
Ω	Mechanical speed of rotation
σ	Dispersion coefficient of Blondel

Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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