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FIELD-ORIENTED CONTROL OF DUAL-STAR INDUCTION MACHINE WITH ENERGY QUALITY BASED ON FUZZY LOGIC

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Keywords: Dual star induction machine; Field oriented control; Fuzzy logic; Non-sequential components; Energy quality.

Power segmentation offers a solution to ensure service continuity and improve the quality of electrical energy. Multi-star machines powered by voltage inverters are subjected to non-sequential currents, which disturb the fundamental currents and thus deteriorate the quality of the energy supplied by these machines. In this work, a new field-oriented control (NFOC) based on a new mathematical model of the double-star induction machine (DSIM) is proposed. This new model separates the DSIM into two distinct parts (fundamental and secondary), enabling the elimination of these non-sequential currents using fuzzy logic. This also brings the control of the DSIM closer to that of classical three-phase induction machines, resulting in improved regulation and reduced computation time. The new model, along with its new control, has been validated through simulations in MATLAB/Simulink, yielding very interesting results compared to the classical DSIM field-oriented control (CFOC).

1. INTRODUCTION

Nowadays, no one can doubt the necessity of using AC machines in industry. Of course, classic three-phase machines used with power electronic converters are widely used in electrical energy conversion. For some applications, such as transport or renewable energy exploitation, it is necessary to ensure the reliability of the energy conversion chain while increasing power [1–3]. To achieve the required level of power and reliability, the polyphase machine appears to be a well-founded solution. These considerations have led researchers to study new electric drives consisting of multiphase induction machines powered by PWM inverters [4–6]. Modeling and vector control approaches are then developed. These first studies [7] have shown that, despite the machine being powered by voltage inverters, the non-sequential currents depend on the leakage inductance and degrade the energy quality and the electromagnetic torque, as they superimpose on the phase currents. Thanks to advances in power electronics and the speed of microprocessors, extensive research has been conducted on vector control of conventional AC machines [5]. Various vector control techniques have been studied, including rotor flux-oriented control, stator flux-oriented control, and magnetizing flux-oriented control [4–6]. Several control techniques are developed, with or without position sensors, and are associated with techniques for estimating physical quantities. In the high-power range, the segmentation of the latter is necessary. Increasing the number of phases also increases the torque per ampere for the same machine volume [8]. However, the application of these decoupled controls is insufficient for a double-star induction machine, as the quality of the energy conveyed within the machine is degraded by non-sequential currents generated by voltage harmonics [7]. A new rotor flux orientation control of the DSIM is presented in this work. The control is based on a new mathematical model of the DSIM, which decomposes the machine into two independent parts: a main part that participates in the conversion of energy and electromagnetic torque, and a secondary part that reflects the losses and parasites of the machine. The use of fuzzy logic takes its interest thanks to the uncertain behavior of non-sequential components; seven inference rules are used [8]. Further, a comparison between the classic rotor flux orientation control (CFOC) and the new control (NFOC) is undertaken.

2. MATHEMATICAL MODELING OF DSIM

The dual star induction machine (DSIM) is composed by a stator with two identical three-phase windings, the first denoted (a1, b1, c1) the second denoted (a2, b2, c2) and shifted by an electrical **angle** $\boldsymbol{\gamma = 30°}$ and a squirrel cage (Fig. 1). When the rotor denoted (ar, br, cr) rotates at different speeds, the rotor cage becomes the seat of a system for generating three phase electromotive forces, leading to induced rotor currents which manifest themselves by the development of a pair of electromagnetic forces on the rotor such that away speed is reduced [1–3].

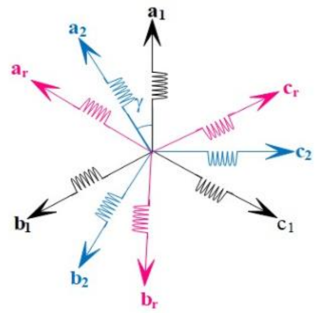

Fig.1 – Dual star induction machine winding representation.

The modeling approach is based on the following assumptions: magnetic saturation, hysteresis, eddy current, the temperature effect, and the effect of skin are neglected. The magneto-motive forces created by each phase of the two plates have a sinusoidal distribution. The inductances are constant; The mutual inductances between two windings are sinusoidal functions of the angle between their magnetic axes, and the machine has a balanced constitution.

2.1 MODEL OF DSIM IN THE NATURAL FRAME

Knowing that the rotor and each star are considered as a three-phase winding each, the DSIM can then be considered as three magnetically coupled three-phase windings.

$$\begin{cases} v_{s1} = r_s[i_{s1}] + \frac{\mathrm{d}}{\mathrm{d}t}[\psi_{s1}], \\ v_{s2} = r_s[i_{s2}] + \frac{d}{dt}[\psi_{s2}], \\ v_r = r_r[i_r] + \frac{\mathrm{d}}{\mathrm{d}t}[\psi_r], \end{cases} \quad (1)$$

with:

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$$[v_{s1}] = [v_{as1} v_{bs1} v_{cs1}]^{\mathrm{T}},$$
$$[v_{s2}] = [v_{as2} v_{bs2} v_{cs2}]^{\mathrm{T}},$$
$$[v_r] = [v_{ar} v_{br} v_{cr}]^t, [i_{s1}] = [i_{as1} i_{bs1} i_{cs1}]^t,$$
$$[i_{s2}] = [i_{as2} i_{bs2} i_{cs2}]^{\mathrm{T}},$$
$$[i_r] = [i_{ar} i_{br} i_{cr}]^{\mathrm{T}},$$
$$[\psi_{s1}] = [\psi_{as1} \psi_{bs1} \psi_{cs1}]^{\mathrm{T}},$$
$$[\psi_{s2}] = [\psi_{as2} \psi_{bs2} \psi_{cs2}]^{\mathrm{T}},$$
$$[\psi_r] = [\psi_{ar} \psi_{br} \psi_{cr}]^{\mathrm{T}}.$$

The stator inductance matrix is as follows:

$$[L_{1,1}] = [L_{2,2}] = \begin{bmatrix} (l_{fs} + L_{ms}) & L_{ms}\cos(\frac{2\pi}{3}) & L_{ms}\cos(\frac{4\pi}{3}) \\ L_{ms}\cos(\frac{4\pi}{3}) & (l_{fs} + L_{ms}) & L_{ms}\cos(\frac{2\pi}{3}) \\ L_{ms}\cos(\frac{2\pi}{3}) & L_{ms}\cos(\frac{4\pi}{3}) & (l_{fs} + L_{ms}) \end{bmatrix}$$

The rotor inductance matrix is as follows:

$$[L_{r,r}] = \begin{bmatrix} (l_{fr} + L_{mr}) & L_{mr}\cos(\frac{2\pi}{3}) & L_{mr}\cos(\frac{4\pi}{3}) \\ L_{mr}\cos(\frac{4\pi}{3}) & (l_{fr} + L_{mr}) & L_{mr}\cos(\frac{2\pi}{3}) \\ L_{mr}\cos(\frac{2\pi}{3}) & L_{mr}\cos(\frac{4\pi}{3}) & (l_{fr} + L_{mr}) \end{bmatrix}$$

The mutual inductance matrix between the two stator stars is as follows:

$$[L_{1,2}] = \begin{bmatrix} L_{ms}\cos(\gamma) & L_{ms}\cos(\gamma + \frac{2\pi}{3}) & L_{ms}\cos(\gamma + \frac{4\pi}{3}) \\ L_{ms}\cos(\gamma - \frac{2\pi}{3}) & L_{ms}\cos(\gamma) & L_{ms}\cos(\gamma + \frac{2\pi}{3}) \\ L_{ms}\cos(\gamma - \frac{4\pi}{3}) & L_{ms}\cos(\gamma - \frac{2\pi}{3}) & L_{ms}\cos(\gamma) \end{bmatrix}$$

The mutual inductance matrix between the rotor and each stator star is written as follows:

$$[L_{i,r}] = L_{sr}\begin{bmatrix} \cos(\theta - (i-1)\gamma) & \cos(\theta + \frac{2\pi}{3} - (i-1)\gamma) & \cos(\theta + \frac{4\pi}{3} - (i-1)\gamma) \\ \cos(\theta - \frac{2\pi}{3} - (i-1)\gamma) & \cos(\theta - (i-1)\gamma) & \cos(\theta + \frac{2\pi}{3} - (i-1)\gamma) \\ \cos(\theta - \frac{4\pi}{3} - (i-1)\gamma) & \cos(\theta - \frac{2\pi}{3} - (i-1)\gamma) & \cos(\theta - (i-1)\gamma) \end{bmatrix}$$

with $i = 1$ for the first star et $i = 2$ for the second star.

Since all stator/rotor mutual inductance matrices depend on θ, the electromagnetic torque equation is derived from the co-energy's partial derivative relative to θ , and it can be simplified as follows:

$$\Gamma_{em} = P([i_{s1}]^{\mathrm{T}}\frac{\partial}{\partial\theta}[L_{1,r}] + [i_{s2}]^{\mathrm{T}}\frac{\partial}{\partial\theta}[L_{2,r}])[i_r]. \qquad (2)$$

P is the umber of pole pairs of the machine.

2.2 DSIM MODEL IN THE ROTATING FRAME SYSTEM D_1 Q_1 D_2 Q_2

To simplify the control, and to linearize the instructions of the latter, the mathematical model of the DSIM is extrapolated from the natural frame to a rotating frame (dq), For this, the transformations of eq. (4) are applied to the system of eq. (1). A model of the DSIM in Park's frame is obtained.

$$[P(\theta)] = \sqrt{\frac{2}{3}}\begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin(\theta) & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \qquad (3)$$

For second star: Just replace θ by $(\theta - \gamma)$ to obtain the transformation that will be applied to the second star.
The following voltage system is obtained:

$$\begin{cases} v_{ds1} = r_1 i_{ds1} + \frac{d}{dt}\psi_{ds1} - \omega_s\psi_{qs1}, \\ v_{qs1} = r_1 i_{qs1} + \frac{d}{dt}\psi_{qs1} + \omega_s\psi_{ds1}, \\ v_{ds2} = r_2 i_{ds2} + \frac{d}{dt}\psi_{ds2} - \omega_s\psi_{qs2}, \\ v_{qs2} = r_2 i_{qs2} + \frac{d}{dt}\psi_{qs2} + \omega_s\psi_{ds2}, \\ v_{dr} = r_r i_{dr} + \frac{d}{dt}\psi_{dr} - \omega\psi_{qr}, \\ v_{qr} = r_r i_{qr} + \frac{d}{dt}\psi_{qr} + \omega\psi_{dr}, \end{cases} \qquad (4)$$

where $\omega = \omega_s - \omega_r$. The flux equations are given as follow:

$$\begin{cases} \psi_{ds1} = L_{fs} i_{ds1} + L_m(i_{ds1} + i_{ds2} + i_{dr}), \\ \psi_{qs1} = L_{fs} i_{qs1} + L_m(i_{qs1} + i_{qs2} + i_{qr}), \\ \psi_{ds2} = L_{fs} i_{qs2} + L_m(i_{ds1} + i_{ds2} + i_{dr}), \\ \psi_{qs2} = L_{fs} i_{ds2} + L_m(i_{qs1} + i_{qs2} + i_{qr}), \\ \psi_{dr} = L_{fr} i_{dr} + L_m(i_{ds1} + i_{ds2} + i_{dr}), \\ \psi_{qr} = L_{fr} i_{qr} + L_m(i_{qs1} + i_{qs2} + i_{qr}). \end{cases} \qquad (5)$$

And by applying transformation (3) to eq. (2), the electromagnetic torque becomes:

$$\Gamma_{em} = PL_m(i_{dr}(i_{qs1} + i_{qs2}) - i_{qr}(i_{ds1} + i_{ds2})). \qquad (6)$$

2.3 DSIM MODEL IN NEW FRAME D^+ Q^+ D^- Q^-

From eq. (6), the electromagnetic torque is expressed as a function of the sum of the currents (i_{ds}, i_{qs}), then this model can be rewritten through a change of variables using the sum of these currents. And for reasons of bijectivity, a normalization transformation is integrated:

$$\begin{bmatrix} X_{ds}^+ \\ X_{qs}^+ \\ X_{ds}^- \\ X_{qs}^- \end{bmatrix} = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \end{bmatrix}\begin{bmatrix} X_{ds1} \\ X_{qs1} \\ X_{ds2} \\ X_{qs2} \end{bmatrix}, \qquad (7)$$

$r_1 = r_2 = r_s$. Two identical stars.

Applying this transformation to the system of electrical equations, the following model is obtained:

$$\begin{cases} \psi_{ds^+} = L_{fs} i_{ds^+} + \sqrt{2}L_m(i_{ds^+} + i_{dr}), \\ \psi_{qs^+} = L_{fs} i_{qs^+} + \sqrt{2}L_m(i_{qs^+} + i_{dr}) \\ \psi_{ds^-} = L_{fs} i_{ds^-}, \\ \psi_{qs^-} = L_{fs} i_{qs^-}, \\ \psi_{dr} = L_{fr} i_{dr} + L_m(i_{ds^+} + i_{dr}), \\ \psi_{qr} = L_{fr} i_{qr} + L_m(i_{qs^+} + i_{qr}). \end{cases} \qquad (8)$$

This transformation, applied to the voltage equations, yields:

$$\begin{cases} v_{ds^+} = r_s i_{ds^+} + \frac{\mathrm{d}}{\mathrm{d}t}\psi_{ds^+} - \omega_s \psi_{qs^+}, \\ v_{qs^+} = r_s i_{qs^+} + \frac{\mathrm{d}}{\mathrm{d}t}\psi_{qs^+} + \omega_s \psi_{ds^+}, \\ v_{ds^-} = r_s i_{ds^-} + \frac{\mathrm{d}}{\mathrm{d}t}\psi_{ds^-}, \\ v_{qs^-} = r_s i_{qs^-} + \frac{\mathrm{d}}{\mathrm{d}t}\psi_{qs^-}, \\ v_{dr} = r_r i_{dr} + \frac{\mathrm{d}}{\mathrm{d}t}\psi_{dr} - \omega \psi_{qr}, \\ v_{qr} = r_r i_{qr} + \frac{\mathrm{d}}{\mathrm{d}t}\psi_{qr} + \omega \psi_{dr}. \end{cases} \tag{9}$$

Applying this transformation to the electromagnetic torque equation given by eq. (6), it becomes:

$$\Gamma_{em} = \sqrt{2} P L_m \left(i_{dr} i_{qs^+} - i_{qr} i_{ds^+} \right). \tag{10}$$

The major advantage of this model is represented in the equivalent diagram of Fig. 2; it is the decoupling between a principal part, which contributes to the creation of the torque, and a second part, which is the image of the losses due to parasitic currents (non-sequential components).

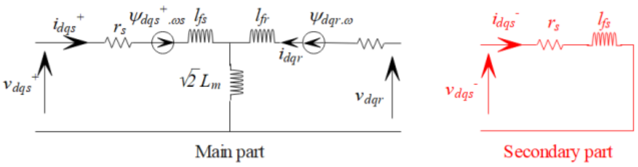

Fig. 2 – Electric scheme of the new DSIM model.

3. NEW FIELD-ORIENTED CONTROL OF DSIM

The DSIM model separates the machine into two parts: a principal part that contributes to the energy conversion and a second part that represents the parasites and losses of the machine. By taking into consideration, the non-sequential components of currents (i_{ds^-}, i_{qs^-}), they will be regulated to zero; given their uncertain behaviour, the use of fuzzy logic finds all its interest. This new model, therefore, makes it possible to bring the control of the DSIM back to that of the classic machine.

Non-sequential components have uncertain behavior, varying frequencies and amplitudes, which make their filtering in the transient regime via classical filters (low pass, high pass) difficult and sometimes impossible. The solution that the author proposed in [9] consists of placing filters in series with the stator windings of the machine; the latter are connected in a prescribed manner so that they add negligible impedances for the fundamental current, but they add a considerable impedance for the rest of the harmonics. This solution is not only cumbersome but also very limited since it is only valid in the permanent regime. In this work, the filtering of these currents and their minimization via fuzzy logic are presented. Starting with the development of the new field-oriented control (NFOC) for the DSIM, then integrating fuzzy logic for the minimization of non-sequential components [8].

Rotor flux orientation control consists of decoupling the generating quantities of the electromagnetic torque and the rotor flux. This can be done by coinciding the rotor flux with the "*d*" axis of the reference frame linked to the rotating field. Thus, by acting on the variables i_{ds^+} and i_{qs^+}, the quantities ψ_r and Γ_{em} are controlled separately.

$$\begin{cases} \Lambda L_s \frac{\mathrm{d}}{\mathrm{d}t} i_{ds^+} = -\left(r_s + \frac{L_m^{\,2}}{L_r^{\,2}} r_r \right) i_{ds^+} + \Lambda L_s \omega_s i_{qs^+} + V_p, \\ V_p = \frac{L_m}{T_r L_r}\psi_{dr} + \frac{L_m}{L_r}\omega_r \psi_{qr} + v_{ds^+}, \\ \Lambda L_s \frac{\mathrm{d}}{\mathrm{d}t} i_{qs^+} = -\left(r_s + \frac{L_m^{\,2}}{L_r^{\,2}} r_r \right) i_{qs^+} - \Lambda L_s \omega_s i_{ds^+} + V_h, \\ V_h = \frac{L_m}{T_r L_r}\psi_{qr} - \frac{L_m}{L_r}\omega_r \psi_{dr} + v_{qs^+}, \\ \frac{\mathrm{d}}{\mathrm{d}t}\psi_{dr} = \frac{L_m}{\sqrt{2} T_r} i_{ds^+} + \omega \psi_{qr} - \frac{1}{T_r}\psi_{dr}, \\ \frac{\mathrm{d}}{\mathrm{d}t}\psi_{qr} = \frac{L_m}{\sqrt{2} T_r} i_{qs^+} - \omega \psi_{dr} - \frac{1}{T_r}\psi_{qr}, \\ \Gamma_{em} = \sqrt{2} P \frac{L_m}{L_r}\left(\psi_{dr} i_{qs^+} - \psi_{qr} i_{ds^+} \right), \\ \mathrm{J}\frac{\mathrm{d}}{\mathrm{d}t}\Omega_r = \Gamma_{em} - \Gamma_r - f\Omega_r. \end{cases} \tag{11}$$

where $T_r = L_r / r_r$, $L_r = (l_{fr} + L_m)$,$T_s = L_s / r_s$ and $L_s = (l_{fs} + L_m)$ and $\Lambda = 1 - \frac{\sqrt{2} L_m^{\,2}}{2 L_r L_s}$.

Vector control by orientation of the rotor flux requires the following condition: $\psi_{dr} = \psi_r$, $\psi_{qr} = 0$, which allows us to simplify the machine model as follows:

$$\begin{cases} v_{ds} = \left(r_s + \frac{L_m^{\,2}}{L_r^{\,2}} r_r \right) i_{ds^+} + \Lambda L_s \frac{\mathrm{d}}{\mathrm{d}t} i_{ds^+} - H_d, \\ H_d = \Lambda L_s \omega_s i_{qs^+} - \frac{L_m}{T_r L_r}\psi_r, \\ v_{qs} = \left(r_s + \frac{L_m^{\,2}}{L_r^{\,2}} r_r \right) i_{qs^+} + \Lambda L_s \frac{\mathrm{d}}{\mathrm{d}t} i_{qs^+} + H_q, \\ H_q = \Lambda L_s \omega_s i_{ds^+} + \frac{L_m}{L_r}\omega \psi_r, \\ \frac{\mathrm{d}}{\mathrm{d}t}\psi_r = \frac{L_m}{T_r} i_{ds^+} - \frac{1}{T_r}\psi_r, \\ \omega = \omega_s - \omega_r = \frac{L_m}{T_r \psi_r} i_{qs^+}, \\ \Gamma_{em} = \sqrt{2} P \frac{L_m}{L_r}\psi_r i_{qs^+}, \\ \mathrm{J}\frac{\mathrm{d}}{\mathrm{d}t}\Omega = \Gamma_{em} - \Gamma_r. \end{cases} \tag{12}$$

The rotor flux and electromagnetic torque can be estimated from the i_{ds} and i_{qs} currents, which are stator quantities that can be obtained by measuring the actual stator currents, provided that the Park transformation is applied.

$$\begin{cases} \psi_r^* = \frac{\sqrt{2} L_m}{1 + s T_r} i_{ds^+}, \\ \Gamma_{em}^* = P \frac{\sqrt{2} L_m}{L_r} i_{qs^+} \psi_r^*, \\ \theta^* = \int \left(P\Omega + \frac{\sqrt{2} L_m i_{qs^+}}{T_r \psi_r^* + \varepsilon} \right) \mathrm{d}t. \end{cases} \tag{13}$$

Equation (13) outlines the employed estimator, which performs the estimation of electromagnetic torque, rotor angle (θ), and rotor flux.

For the minimization of non-sequential currents, a classical fuzzy controller is used. Seven linguistic variables are defined and detailed below:

NL : negative large ; **NM** :negative medium; **NS** :negative small; **Z**: zero; **PS**: positive small; **PM**: positive medium; **PL**: positive large ;

Figures 3 and 4 illustrate, respectively, the evaluation rules of the corrector as well as the surface of the regulator. Narrowing the domain of the variable Z allows for better system responsiveness when the static error is low. The input variables of this regulator are the error E and the error variation dE. A "fuzzy PI" is therefore used. It is possible to choose a large number of inference tables. The one presented in Table 1 has been chosen.

Table 1

Rules of inference.

E | dE	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NM	NM	NS	NS	Z
NM	NL	NM	NM	NS	NS	Z	PS
NS	NM	NM	NS	NS	Z	PS	PS
Z	NM	NS	NS	Z	PS	PS	PM
PS	NS	NS	Z	PS	PS	PM	PM
PM	NS	Z	PS	PS	PM	PM	PL
PL	Z	PS	PS	PM	PM	PL	PL

All parameters of this regulator have been adjusted using several simulations. The algorithmic cost is very high, but the rejection of disturbances is effective. In addition, this regulator can do without compensation algorithms.

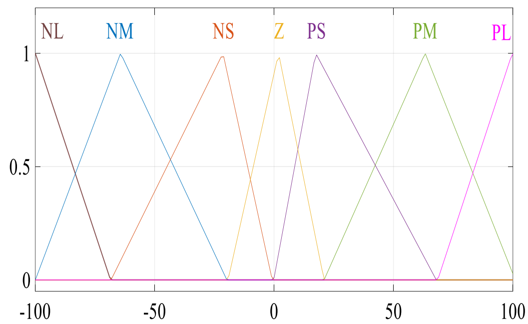

Fig. 3 – Corrector's evaluation rules.

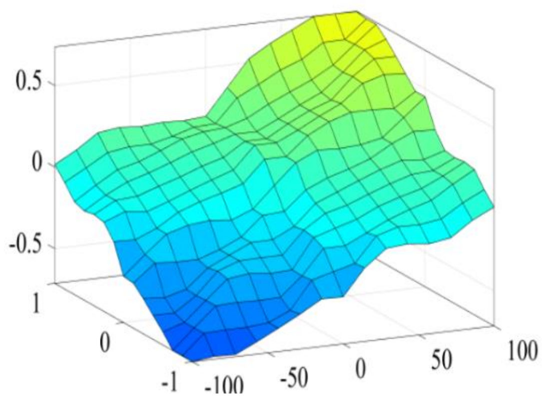

Fig. 4 – Regulator surface.

The complete schematic of the new direct vector control of the DSIM fed through a two-level PWM inverter is given in Fig. 5.

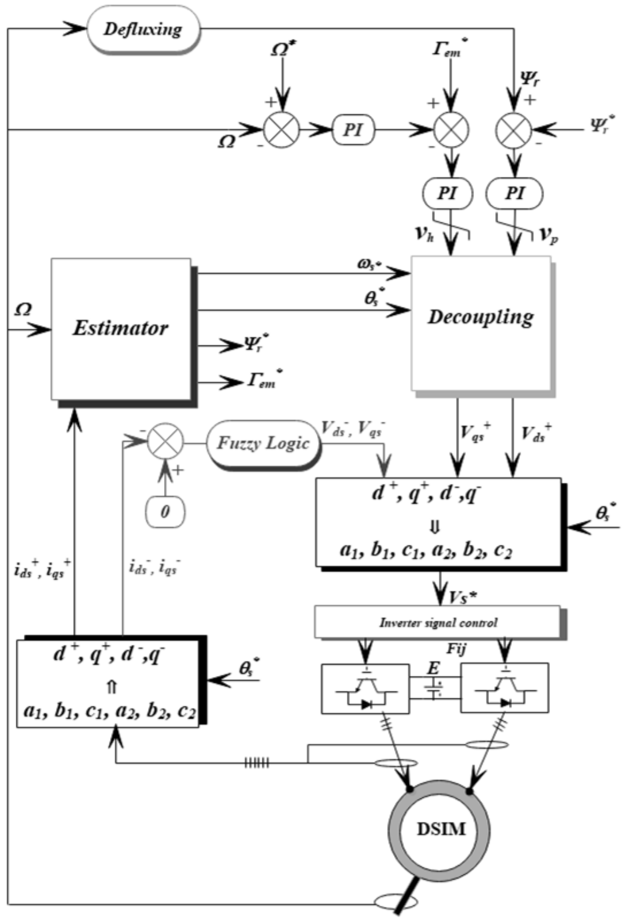

Fig.5 – Complete schematic of the new direct vector control of the DSIM.

4. SIMULATION RESULTS AND DISCUSSION

The control technique is developed under MATLAB /Simulink, a speed profile is adopted as seen in Fig. 6, a good speed tracking with good robustness when applying a load torque $\Gamma_{\text{load}} = 15\ \text{N.m}$ in the interval $t = [1.3\ \text{s}, 2\ \text{s}]$ is noted. It is also shown on the same figure a comparison between NFOC and CFOC; the results of the NFOC are smoother with fewer ripples. Figure 7 shows a comparison of the electromagnetic torque of the two drives; the decrease in the ripples of the electromagnetic torque is very distinct, which is the result of the improvement in the quality of the currents as seen in Fig. 8. This is due to the minimization of the non-sequential components of the current as seen Fig. 9 thanks to the use of fuzzy logic. In this figure, a perfect minimization is evident. Figure 10 shows that the electromagnetic torque is the image of the current i_{qs}^{+} (quadratic current of the main part) and that the rotor flux Fig. 11 is the image of the current i_{ds}^{+} which is proof of the decoupling of the machine. This figure shows the variation in flux with load application. A summary of the comparison between NFOC and CFOC is given in Table 2. A gain in the number of regulators and energy quality is noted. In addition, the new control is very simple and is similar to that of the classic three-phase machine.

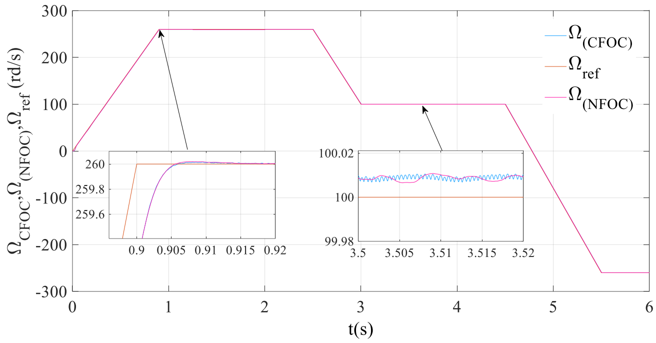

Fig. 6 – Mechanical speed.

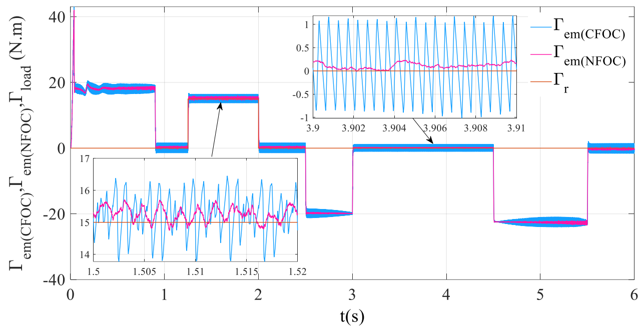

Fig. 7 – Electromagnetic torque.

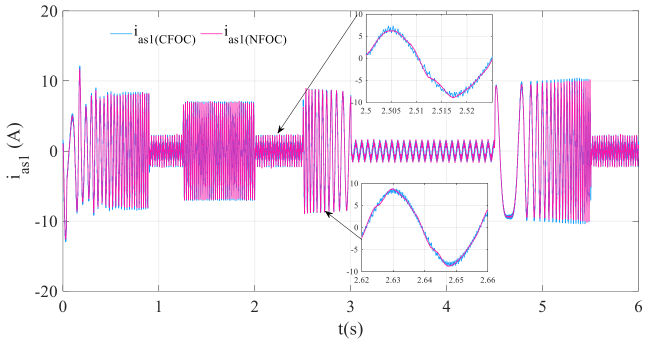

Fig. 8 – First stator current (main part current).

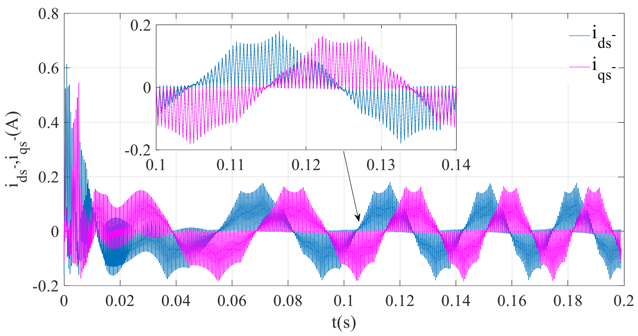

Fig. 9 – Current secondary part (non-sequential current).

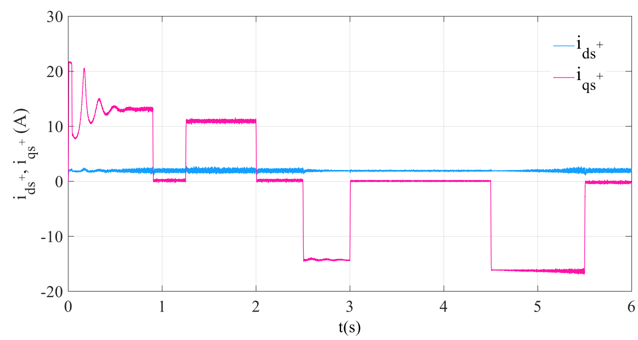

Fig. 10 – Direct and quadratic currents (main part).

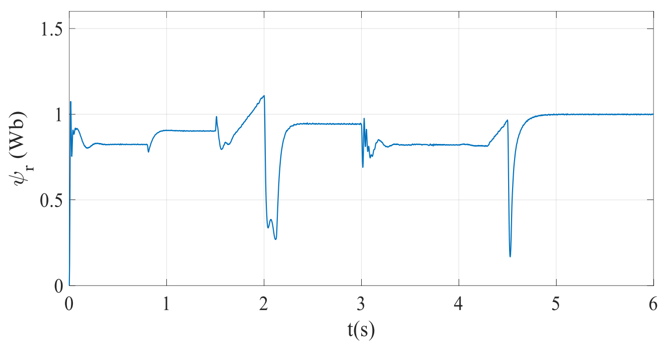

Fig. 11 – Rotor flux.

Table 2

Summary of the comparison between NFOC and CFOC

Control	Regulator number	Currents THD in %
NFOC	4	4.24 %
CFOC	5	5.49 %

5. CONCLUSION

The new DSIM model in the new reference frame $d^+q^+d^-q^-$ developed in this paper makes it possible to distinguish two parts: the first 'main' part, which is responsible for electromagnetic torque production, and the second 'secondary' part, representing the non-sequential machine currents caused by the voltage inverter supply. This new model also enabled the development of the new Rotor Flux-Oriented Control (NFOC), which allows for the elimination of non-sequential current components. This new oriented rotor flux control (NFOC) of the DSIM showed better performance than the classic one (CFOC), the fuzzy logic minimization of the non-sequential component leads to the improvement of the energy quality of the DSIM. The results obtained demonstrate the severity of the NFOC with a simplification and a gain in regulator and calculation cost. This method can be extrapolated for all multi-star or so-called asymmetric induction machines, thus making their control similar to that of the classic three-phase machine. As a perspective for this work, a reduction in the number of inverter arms can be done via vector control, thus making the podium for the multi-phase machine.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Iffouzar Koussaila: Conceptualization, methodology, formal analysis, original draft preparation, and development of the DSIM model and NFOC control strategy.
Damak Tarek: Software implementation and review of the manuscript.

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