PERFORMANCES OF TORQUE TRACKING CONTROL FOR DOUBLY FED ASYNCHRONOUS MOTOR USING PI AND FUZZY LOGIC CONTROLLERS

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Abstract: *In this paper a performances of torque tracking control for Doubly Fed Asynchronous Motor (DFAM) using PI and fuzzy logic controllers is proposed. First, a mathematical model of the doubly-fed asynchronous motor written in an appropriate d-q reference frame is established to investigate simulations. In order to control the rotor currents of DFAM, a torque tracking control law is synthesized using PI controllers, under conditions of the stator side power factor is controlled at unity level. The performances of fuzzy logic controller (FLC) which is based on the torque tracking control algorithm are investigated and compared to those obtained from the PI controller. Results obtained in Matlab/Simulink environment show that the FLC is more robust, superior dynamic performance and hence found to be a suitable replacement of the conventional PI controller for the high performance drive applications.*

Keywords: *Doubly-Fed asynchronous motor (DFAM), Torque Tracking Control, Fuzzy logic control.*

Nomenclature

V_{ds} ,V_{qs} , V_{dr} , V_{qr} : Two-phase statoric and rotoric voltages.
i_{ds} , i_{qs} , i_{dr} , i_{qr} : Two-phase statoric and rotoric currents.
Ψ_{ds} , Ψ_{qs} , Ψ_{dr} , Ψ_{qr} : Two-phase statoric and rotoric fluxes.
T_L : Mechanical load.
U_m : Stator (line) voltage amplitude.
ω_s : Angular frequency.
θ_s, θ_r, Ω : Statoric flux position, mechanical rotoric position and mechanical speed.
T_m T_e : Prime mover and electromagnetic torque.
R_s , R_r : Stator and rotor resistances respectively.
L_s , L_r : Stator and rotor inductances respectively.
M : mutual inductance.
J, f : Inertia and friction coefficient.
p : Number of pole pairs.

1. Introduction

A Doubly-Fed asynchronous motor (DFAM) is an electrical asynchronous three-phases machine with open rotor windings which can be fed by external voltages. The typical connection scheme of this machine is reported in Fig. 1. The stator windings are directly connected to the line grid, while the rotor windings are controlled by means of an inverter,[1,2]. This solution is very attractive for all the applications where limited speed variations around the synchronous velocity are present, since the power handled by the converter at rotor side will be a small fraction (depending on the slip) of the overall system power,[2].

The DFAM control issues are traditionally handled by fixed gain proportional integral (PI) controllers. However, the fixed gain controllers are very sensitive to parameter variations, cannot usually provide good dynamic performance, etc. So, the controller parameters have to be continually adapted. The problem can be solved by several adaptive control techniques such as model reference adaptive control (MRAC), sliding mode control (SMC),[3] etc. The design of all of the above controllers depends on the exact system mathematical model.

Fuzzy control technique does not need accurate system modelling. It employs the strategy adopted by the human operator to control complex processes and gives superior performance than the conventional proportional-integral (PI) control. The fuzzy algorithm is based on human intuition and experience, and can be regarded as a set of heuristic decision rules,[4,5].

In this paper torque tracking control strategy is achieved by adjusting rotor currents and using stator voltage vector oriented reference frame. The performances of fuzzy logic controller (FLC) which is based on the torque tracking control algorithm are investigated and compared to those obtained from the PI controller. Results obtained show that the FLC is more robust and superior dynamic performance.

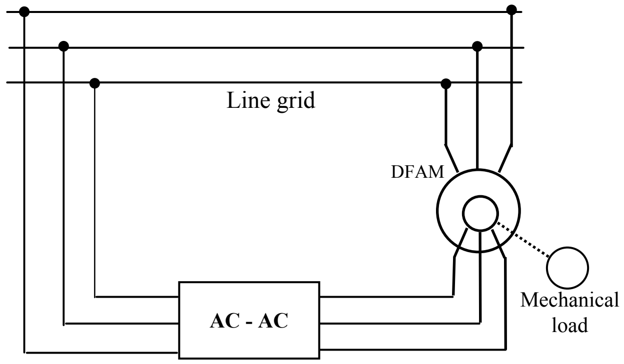

Fig. 1. The typical connection scheme of DFAM

2. Mathematical model of the DFAM

The equivalent two-phase model of the symmetrical DFAM is represented in stator voltage-vector oriented frame (d-q) is, [6,7]:

$$J\frac{d\omega}{dt}=[p\mu(\Psi_{qs}\cdot i_{dr}-\Psi_{ds}\cdot i_{qr})-T_L-f\omega] \qquad (1)$$

$$\frac{d\Psi_{ds}}{dt}=-\alpha_s\Psi_{ds}+\omega_s\Psi_{qs}+\alpha_s Mi_{dr}+V_{ds} \qquad (2)$$

$$\frac{d\Psi_{qs}}{dt}=-\alpha_s\Psi_{qs}-\omega_s\Psi_{ds}+\alpha_s Mi_{qr}+V_{qs} \qquad (3)$$

$$\frac{di_{dr}}{dt}=-\gamma_r i_{dr}+\omega_r i_{qr}+\alpha_s\beta\Psi_{ds}-\beta p\omega\Psi_{qs}-\beta V_{ds}+\frac{1}{\sigma_r}V_{dr} \qquad (4)$$

$$\frac{di_{qr}}{dt}=-\gamma_r i_{qr}-\omega_r i_{dr}+\alpha_s\beta\Psi_{qs}+\beta p\omega\Psi_{ds}-\beta V_{qs}+\frac{1}{\sigma_r}V_{qr} \qquad (5)$$

$$\dot{\theta}=\omega \qquad (6)$$

Positive constants related to DFAM electrical parameters are defined as:

$\alpha_s=R_s/L_s$; $\sigma_r=L_r(1-M^2/L_sL_r)$; $\beta=M/(L_s.\sigma_r)$; $\mu=3M/2L_s$; $\gamma_r=R_r/\sigma_r+(R_sM^2)/L_s^2\sigma_r$

3. Torque tracking control algorithm for DFIG

In this paper we present a stator voltage vector oriented reference frame instead of the stator flux oriented. Specifically, the torque tracking, stator-side unity power factor control problem are considered, with the requirement to achieve stable rotor current and stator flux error dynamics, independently of speed behaviour. Conditions of stator flux field orientation and line voltage orientation are equivalent if the stator side power factor is controlled at unity level,[7,8]. Under such condition the stator flux modulus is not a free output variable but it is a function of the produced electromagnetic torque,[7]. This last is a positive trapezoidal torque reference.

The reactive component of the stator current is practically equal to zero as it is the given working condition of DFAM control algorithm, [8].

Under this reference frame, the flux errors are defined as:

$$\tilde{\Psi}_{ds}=\Psi_{ds}\,,\ \tilde{\Psi}_{qs}=\Psi_{qs}-\Psi^*\,,$$

$$V_{ds}=U_m=V_s\,,\ V_{ds}=0,\ i_{qs}=0.$$

where Ψ^* is the flux level reference trajectory.

The setting of different vectors and transformation angle is represented on Fig 2.

Fig. 3 shows the control diagram of power factor.

The complete equations of the vector control of the doubly fed asynchronous motor are given by,[10]:

Stator flux vector controller:

$$i_{qr}^*=\frac{1}{\alpha_s M}\left(\alpha_s\Psi^*+\dot{\Psi}^*\right) \qquad (7)$$

$$\Psi^*=\frac{-U_m-\left(U_m^2-4(2/3)\omega_s R_s T_g^*\right)}{2\omega_s} \qquad (8)$$

Torque controller:

$$i_{dr}^*=\frac{T_e^*}{\mu\Psi_{qs}^*} \qquad (9)$$

Rotor current controller:

$$\begin{aligned}U_{dr}&=\sigma_r[\gamma_r i_{dr}^*-\omega_r i_{qr}^*+\beta\omega\Psi^*+\beta U_m+\frac{di_{dr}^*}{dt}+kp\tilde{i}_{dr}+x_d]\\U_{qr}&=\sigma_r[\gamma_r i_{qr}^*+\omega_r i_{dr}^*-\beta\alpha_s\Psi^*+\frac{di_{qr}^*}{dt}-kp\tilde{i}_{qr}+x_q]\end{aligned} \qquad (10)$$

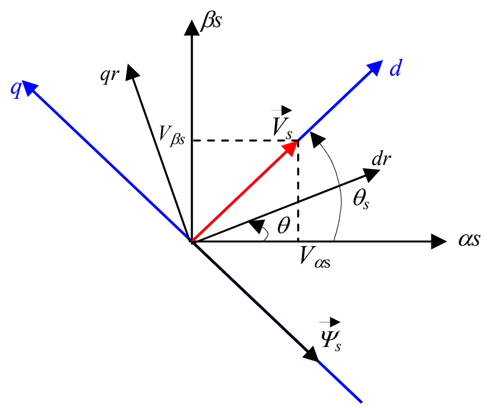

Fig. 2. Setting of vectors oriented and Transformation angles

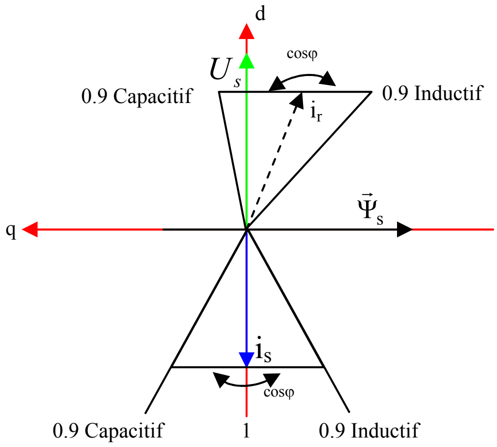

Fig. 3. Control diagram of power factor

where: $\dot{x}_d = -ki \cdot \tilde{i}_{dr}$; $\dot{x}_q = -ki \cdot \tilde{i}_{qr}$; $\tilde{i}_{dr} = i_{dr} - i^*_{dr}$; $\tilde{i}_{qr} = i_{qr} - i^*_{qr}$.

where i^*_{dr}, i^*_{qr} are rotor current references in (d-q) reference frame; k_p and k_i are positive proportional and integral gains of the rotor current controllers; Ψ^* is stator flux reference; x_d, x_q are integral components of current controllers.

Under such condition, the stator side active and reactive powers are given by:

$$P_s = -\frac{3}{2} U_m i_{ds} \tag{11}$$

$$Q_s = \frac{3}{2} U_m i_{qs} \tag{12}$$

The study, that we present, consists in using a motor where the rotor is supplied through a converter. This latter is based on PWM control algorithm,[11], operating at 2 KHz switching frequency.

4. **Fuzzy controllers design**

For the proposed FLC, The inputs to the direct- and quadrature-axis rotor current fuzzy controllers are the d- and q-axis rotor current errors $e_{i_{dr}}(n) = i^*_{dr}(n) - i_{dr}(n)$ and $e_{i_{qr}}(n) = i^*_{qr}(n) - i_{qr}(n)$, and their changes in error $\Delta e_{i_{dr}}(n) = e_{i_{dr}}(n) - e_{i_{dr}}(n-1)$, $\Delta e_{i_{qr}}(n) = e_{i_{qr}}(n) - e_{i_{qr}}(n-1)$.

The outputs of the two fuzzy controllers are U_{dr} and U_{qr}. The block diagram of FLC system is shown on fig.4.

The input and output linguistic variables of the two fuzzy controllers have been quantised in the following seven fuzzy subsets:

Negative big (NB); Negative medium (NM); Negative small (NS); Zero (ZE); Positive small (PS); Positive medium (PM); Positive big (PB).

The universes of discourse of both input and output fuzzy variables of each controller have been normalised in the interval [-1;1]. For sake of simplicity, a distribution of the membership functions has been adopted, as Fig. 5 shows, and the triangular membership functions are used for all the fuzzy sets except the fuzzy set NG and PB of the inputs and output linguistic variables, [12]. The trapezoidal and the triangular membership functions are used to reduce the computation for on-line implementation.

The set of the linguistic control rules for the proposed regulators is summarised in table I.

In this work, the center of gravity defuzzification is used [12].

The block diagram of the proposed controller is shown in Fig. 6.

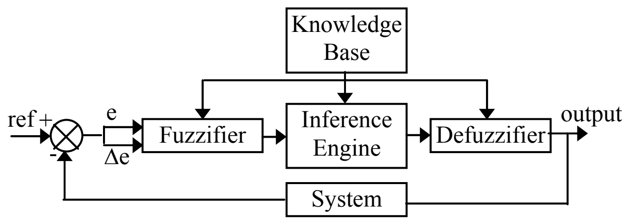

Fig. 4. Block diagram of FLC system

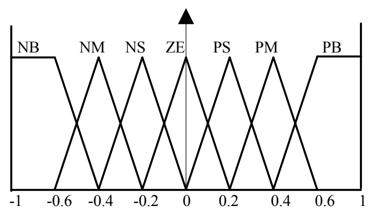

Fig. 5. Membership functions distribution for inputs and output variables.

TABLE. I: Linguistic control rules

e \ Δe	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

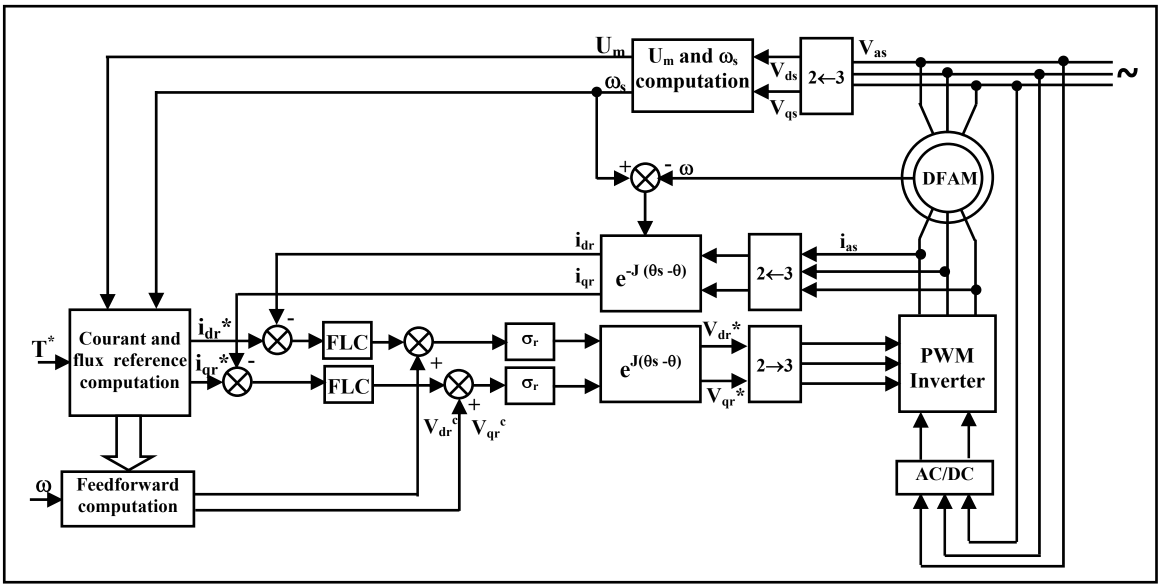

Fig. 6. Block diagram of the DFAM torque tracking control

5. Simulation results

The results, reported in Figs. 7 to 14 were performed to investigate system behaviour during torque tracking. The sequence of operation during this test is shown in Fig. 7. The DFAM, already connected to the line grid, is required to track a trapezoidal torque reference, which starts at t = 0.2s from zero initial value and reaches the rated value of 10 Nm at t = 0.3 s. Note that flux value, required to track torque trajectory with unity power factor at stator side is not a constant. The rotor current i_{as} is sinusoidal as shown in Fig. 14. Waveforms of the rotor reference currents i^*_{dr} and i^*_{qr} are shown in Fig. 9.

Fig.10 and Fig.13 show the results of rotor currents responses using PI and FLC controller, respectively.

The stator power P_s follows the current i^*_{qr} as shown in Fig. 11. This results in unity power factor on the grid as the stator reactive power Q_s is zero. Rotor current errors are controlled at zero level. The reactive component of the stator current i_{qs} is almost equal to zero during all the time. As result, the stator phase current, reported in Fig. 14, has a same phase angle to the line voltage indicating that the rotor power is supplied by the grid.

In order to test the robustness of the two controllers, the value of the rotor resistance R_r is augmented by +50% (from 5.3 Ω to 7.95Ω) at t=0.5s.

Figs.15 to 18 show the effect of rotor resistance variation on the motor response for the two controllers respectively.

This robustness test shows that in the case of a PI regulator, the time response is strongly altered whereas it remains unmodified when the FLC is used.

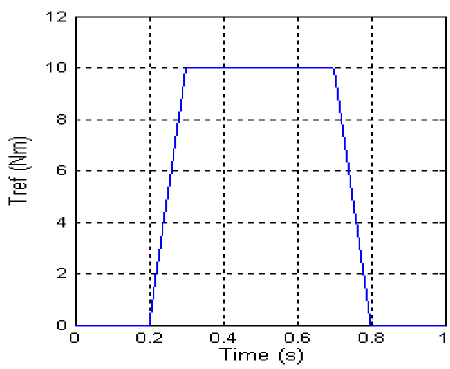

Fig. 7. Torque reference

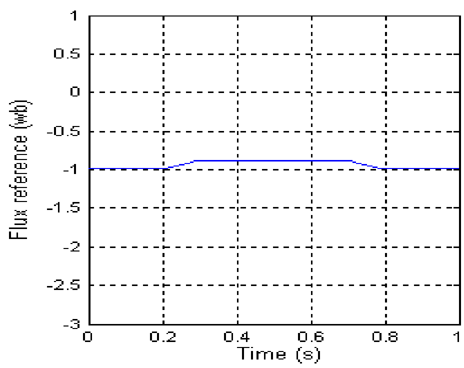

Fig. 8. Flux reference

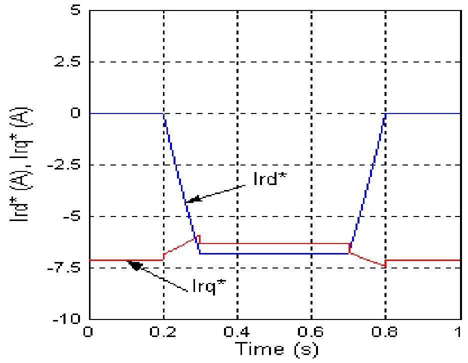

Fig. 9. Rotor reference currents Ird* and Irq*

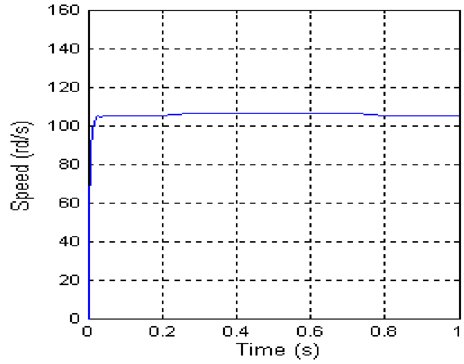

Fig. 12. Speed

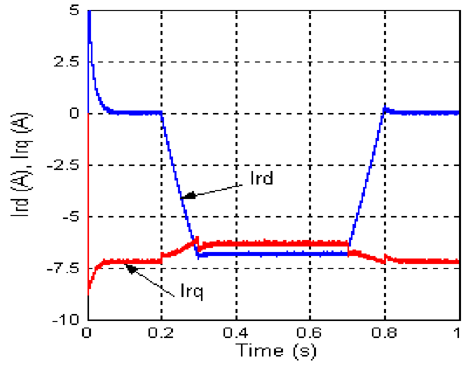

Fig. 10. Rotor Currents responses Ird and Irq with PI controllers

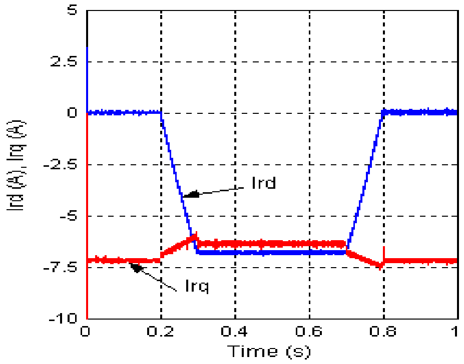

Fig. 13. Rotor Currents responses Ird and Irq with FLC

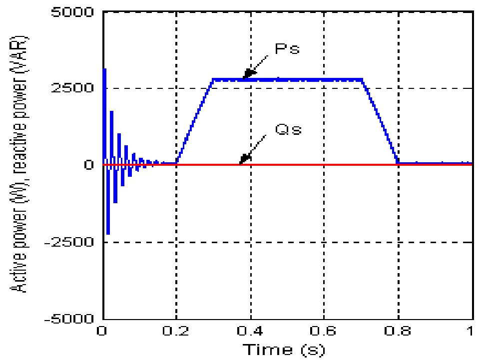

Fig. 11. Stator active power P_s and reactive power Q_s

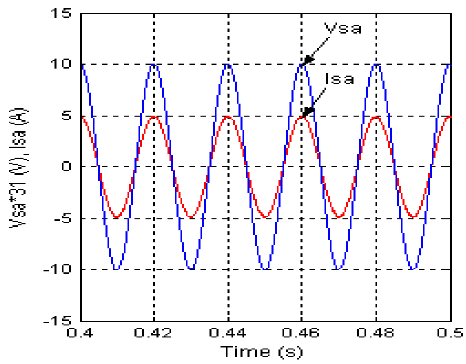

Fig. 14. Stator voltage and current

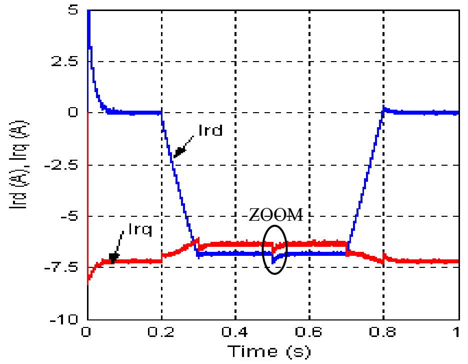

Fig. 15. Response to a rotor resistance variation with PI controllers

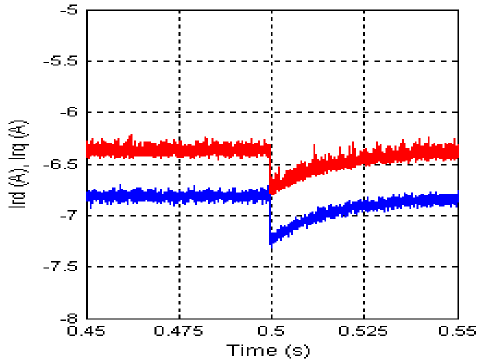

Fig. 16. Zoom of response to a rotor resistance variation with PI controllers

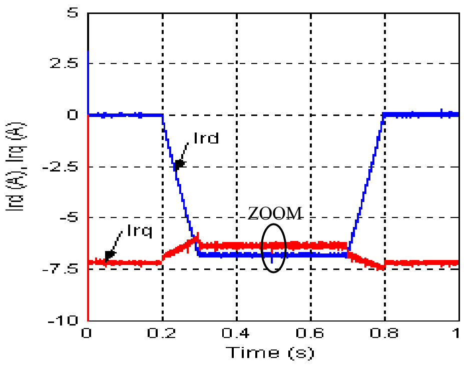

Fig. 17. Response to a rotor resistance variation with FLC

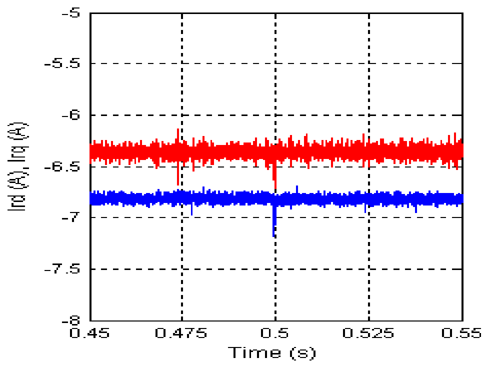

Fig. 18. Zoom of response to a rotor resistance variation with FLC

Machine parameters

Stator resistance	$R_s = 4.7\ \Omega$
Rotor resistance	$R_r = 5.3\ \Omega$
Stator inductance	$L_s = 0.161$ H
Rotor inductance	$L_r = 0.161$ H
Mutual inductance	M = 0.138 H
Rated current	$I_r = 5.2$ A
Rated voltage	220/380 V
Rated torque	15 Nm
Rated speed	880 rev/min
Number of pole pair	p = 3.
Friction coefficient	f = 0.45

7. Conclusion

In this paper, performances of torque tracking control for Doubly Fed Asynchronous Motor using PI and fuzzy logic controllers have been proposed. Torque tracking control strategy has been achieved by adjusting rotor currents and using stator voltage vector oriented reference frame. The performances of fuzzy logic controller which is based on the torque tracking control algorithm has been investigated and compared to those obtained from the PI controller. Simulations results have shown that the FLC is more robust, efficient and more robust under parameters variations of the DFAM (for example rotor resistance in our study).

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