ECHAHID HAMMA LAKHDAR UNIVERSITY - EL-OUED
Under the Supervision of the DGRSDT and in collaboration with the CRTI
International Pluridisciplinary PhD Meeting (IPPM'20)
23-26, 2020 1st Edition, February
Theme: Modern Technology and Fineness Life

4 à 5 pages

Fuzzy-Direct Torque Control of Double-Star Induction Motor

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Abstract

In this paper, direct torque control (DTC) is applied to a double star induction motor (DSIM) using the fuzzy logic controller. This control technique can be considered as an alternative to conventional methods of control by pulse width modulation (PWM) and by field oriented control (FOC), the DTC found by Takahashi offers high performance in terms of simplicity in control and fast electromagnetic torque response. The fuzzy logic controller (FLC) is insensitive to parametric variations, in contrast, the PID classic regulator is sensitive to variations parametric of the system controlled, we tested the performance of the system under different operating conditions, and by using MatLab/Simulink the simulation results are presented and analyzed.

Keywords: Double star induction motor (DSIM), direct torque control (DTC), fuzzy Logic control (FLC), oriented control (FOC), pulse width modulation (PWM).

1. Introduction

In recent years, the double star induction motors has largely replaced asynchronous machines, whose were predominant in the industry [1], [2], indeed, this priority due to numerous factors such as great power, power segmentation, minimizing torque ripples, high reliability, ruggedness, low cost and minimal loss...etc [3], [4].This type of machines is constituted by the two windings shifted between them by an angle of 30 degrees. These windings are usually fed by a six-phase inverter supply in variable speed. Their main benefits of DSIM are higher torque density, higher efficiency, reduced harmonic content of the DC link voltage [5].

Currently, several moderns control techniques has been proposed to control the double star induction motors. Among this techniques, direct torque control, feedback control, vector control, adaptive control …etc [6].Takahashi and Depenbrock are the first two proposed the direct torque control (DTC) in 1985 which considered a solution for the problems of vector control [6]. This technique does not look the voltages to be applied to the machine, but the best switching state of the inverter to satisfy the user's requirements [7].The method supplies direct control of the stator flux and torque and gives a systematic solution to improve the operating characteristics of the motor and the voltage source inverter. Direct torque control allows fast and efficient control of the stator flux and torque by optimal selection of the inverter switch states in each sampling period. The additional inverter is available for multiphase machines, allows greater flexibility in their selection and therefore more narrow adjustment of stator flux and torque. The control is realized by only eight possible inverter states in three phases on the other hand at several of inverter states means that a more elaborate selection criterion is required. For this reason, a small research was presented on switching-table-based direct torque control of multiphase drives [7]. Due to the parametric sensitivity of PID regulator, minimal research has been done to avoid this inconvenient such as in [8], [9], [10], among them the fuzzy logic which considered one of the artificial intelligence technique.

The aim of this paper is to solve the problem of the parametric sensitivity of the control applied using the fuzzy logic regulator. The performance and the robustness of the system are tested under different operating conditions, and by using MatLab/Simulink the results of simulation are presented and analyzed.

This paper is organized as follows: The DSIM model will be presented in the next section. The control method by DTC and fuzzy logic will be discussed in section three. Moreover, in the fourth section the simulation results are discussed on Matlab/Simulink for the proposed control schemes. Finally, a general conclusion summarizes this work.

2. Modelling of the DSIM

The DSIM dynamic equations in the reference d-q are established in [11].

3. Direct torque control (DTC) of DSIM

In [12], TAKAHACHI proposed the classical DTC wich based on the following algorithm:

- Divid the time domain into period of short duration.
- Measure line currents and phase voltages of the DSIM for each clock struck.
- Through the measurement of line current and stator flux the stator flux composants and the electromagnetic torque have been estimated.
- Input of the used three level hysteresis comparator is the error between the estimated torque and the reference one, this comparator generates at its output the value of +1 to increase the flux and 0 to reduce it and thus increasing the torque -1, it reduce this flux and 0 to keep it constant in a band.
- For the two levels of the hysteresis comparator, its input is the error between the estimated stator flux magnitudes; its output gives the value +1 to increase the flux and 0 to reduce it.
- The state of the switches to determine the operating sequences of the inverter is selected through the switching table.

Fig.1 illustrates the synoptic diagram of the DTC of DSIM.

The flux and torque is controlled by two hysteresis comparators at 2 and 3 levels, respectively [9].

The expression of the stator flux is given by the following equations:

$$\begin{aligned}\phi_{s\alpha 1,2} &= \int_0^t (V_{s\alpha 1,2} - R_s i_{s\alpha 1,2})dt \\ \phi_{s\beta 1,2} &= \int_0^t (V_{s\beta 1,2} - R_s i_{s\beta 1,2})dt\end{aligned} \qquad (1)$$

4.DSIM Fuzzy Logic Control

The main characteristic of fuzzy logic controllers (initiated by Mamdani and Assilian based on Fuzzy set theory suggested by Zadeh in 1965) is that linguistic imprecise knowledge of human experts is used [13], [14].

The schematic diagram of the FLC speed control of DSIM based on DTC is illustrated in fig. 2.

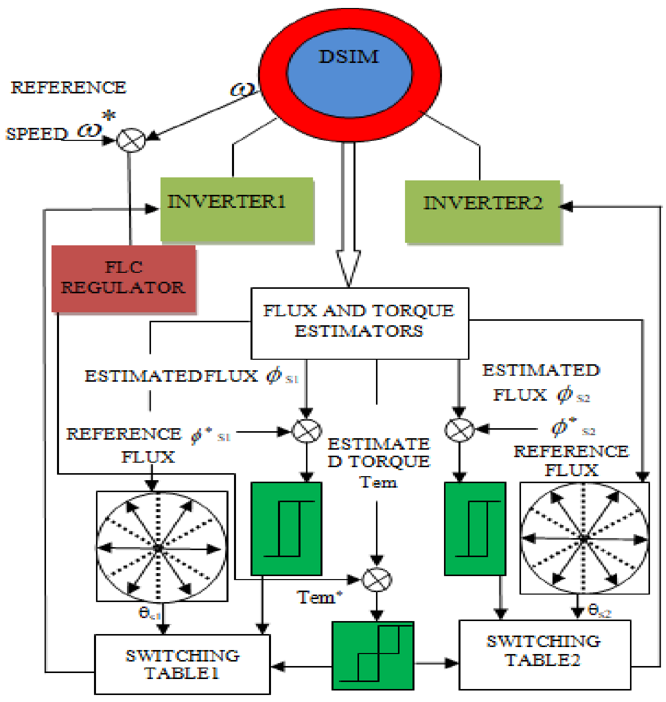

Fig.1. Block diagram of DSIM speed FLC under DTC

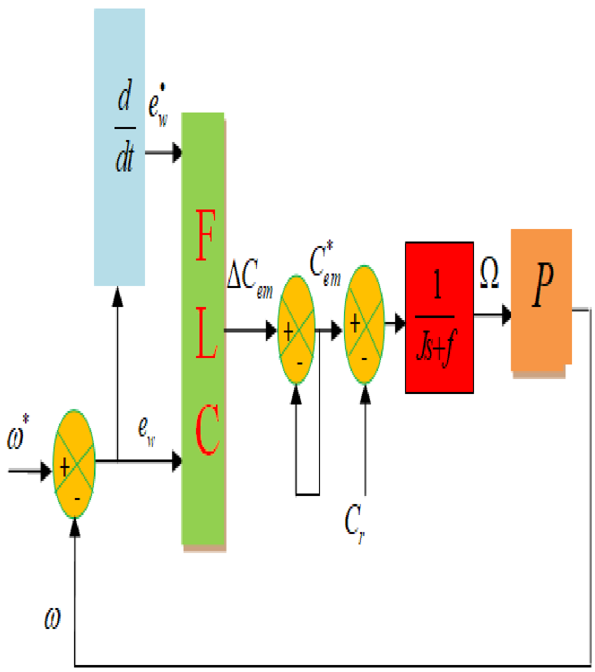

Fig. 2. Speed FLC Controller.

The most used controller has two inputs: the error and the derivative of the error with respect to a defined reference signal, and one output, which is usually the command: e= Ω*- Ωr; this error and the change in error Δe (k) = e (k) – e (k -1) are used as the inputs of the FLC

4.1. Fuzzyfiction

According to the prescribed membership functions the precise entry variables has been transformed to fuzzy variables by the fuzzification interface and also gives the degree of each crispy input belongs to the corresponding fuzzy set [15].

In this paper, five linguistic values are adapted and membership function of trapezoidal type is adopted as illustrated in Fig. 3 and outputs membership functions are illustrated in fig 4. The linguistic variables are presented in Table 2.

4.2. Inference table

Inference rules for one output variable are shown in Table 3.

TABLE 2. Member ship functions

Positive Big	PB
Positive Small	PS
Zero Environ	ZE
Negative Small	NS
Negative Big	NB

TABLE 3. Inference rules for fuzzy control

		Δe_N				
ΔT_{em}		NB	NS	ZE	PS	PB
e_N	NB	NB	NB	NS	NS	ZE
	NS	NB	NS	NS	ZE	PS
	ZE	NS	NS	ZE	PS	PS
	PS	NS	ZE	PS	PS	PB
	PB	ZE	PS	PS	PB	PB

4.3. Defuzzification

The used method in this paper is MIN operation for calculate the degree of μ(ΔTem) associated with every rule, used expression is:

$\mu(\Delta T_{em})$=MIN ($\mu(e)$, $\mu(e_c)$).

In the defuzzification stage, a crisp value of the electromagnetic torque is calculated by the normalized output function as [16]:

$$du=\frac{\sum_{j=1}^{m}\mu(\Delta T_{emj})T_{emj}}{\sum_{j=1}^{m}\mu(\Delta T_{emj})} \quad (2)$$

Where: m is the total number of rules (5*5), μ(ΔTem) is the membership grade for the n rules, ΔTem is the position of membership functions in n rules

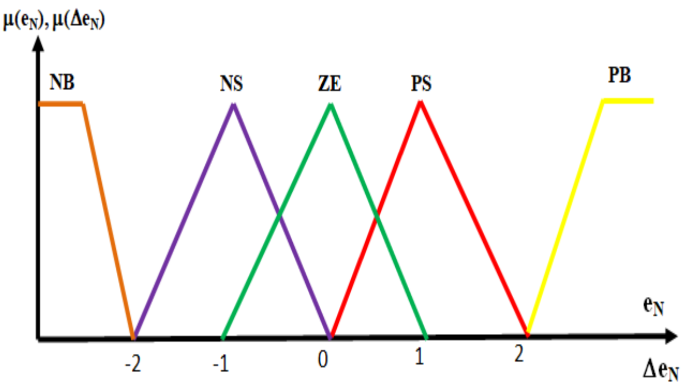

Fig. 3. Inputs membership functions

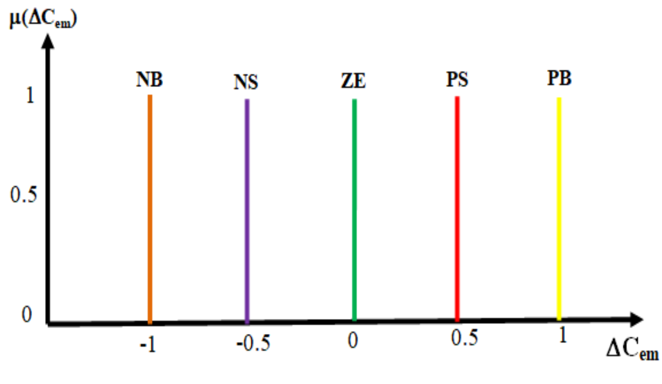

Fig. 4. Outputs membership functions.

5. Simulation results and discussion

The control of the drive system has been tested by simulation under DTC scheme using FLC controller; the results are performed in this paper by using MATLAB/SIMULINK.. The used double star induction motor has the following parameters, the nominal power Pn is 4.5kw, Nominal voltage Vn is 220V, stator resistances Rs1 and Rs2 are 3.72 Ohm, rotor resistance

Rr is 2.12 Ohm, Mutual inductance Lm is 0.3672H, Rotor inductance Lr is 0.006H, moment of inertia J is 0.0662kg.m2, and friction coefficient Kf is 0.001.All simulation results have been obtained for two tests conditions.

The first test is the no load start then under load and variation of rotor and stator resistance of 50% from t=2sec with load torque is Tr= 14 N.m and reference speed is wref=100rd/sec.

The second test is the no load start with inversion of reference speed from 100rd/sec to -100rd/sec, for all tests reference flux is 1wb.

Fig.5 and 6 respectively present differents responses of electromagnetic torque, speed, stator flux and stator current for the first test and the second test

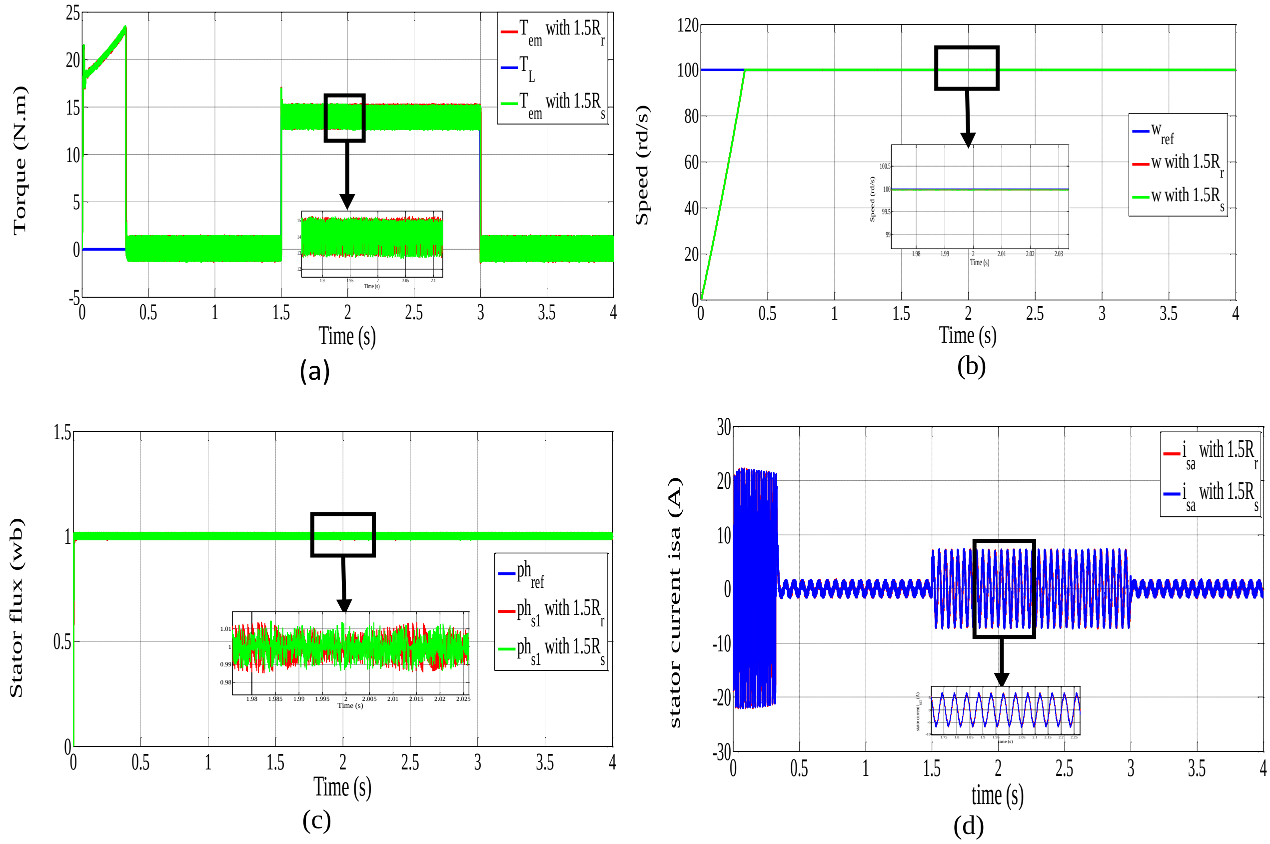

Figure 5. Torque, speed, stator flux and current responses for the first test.

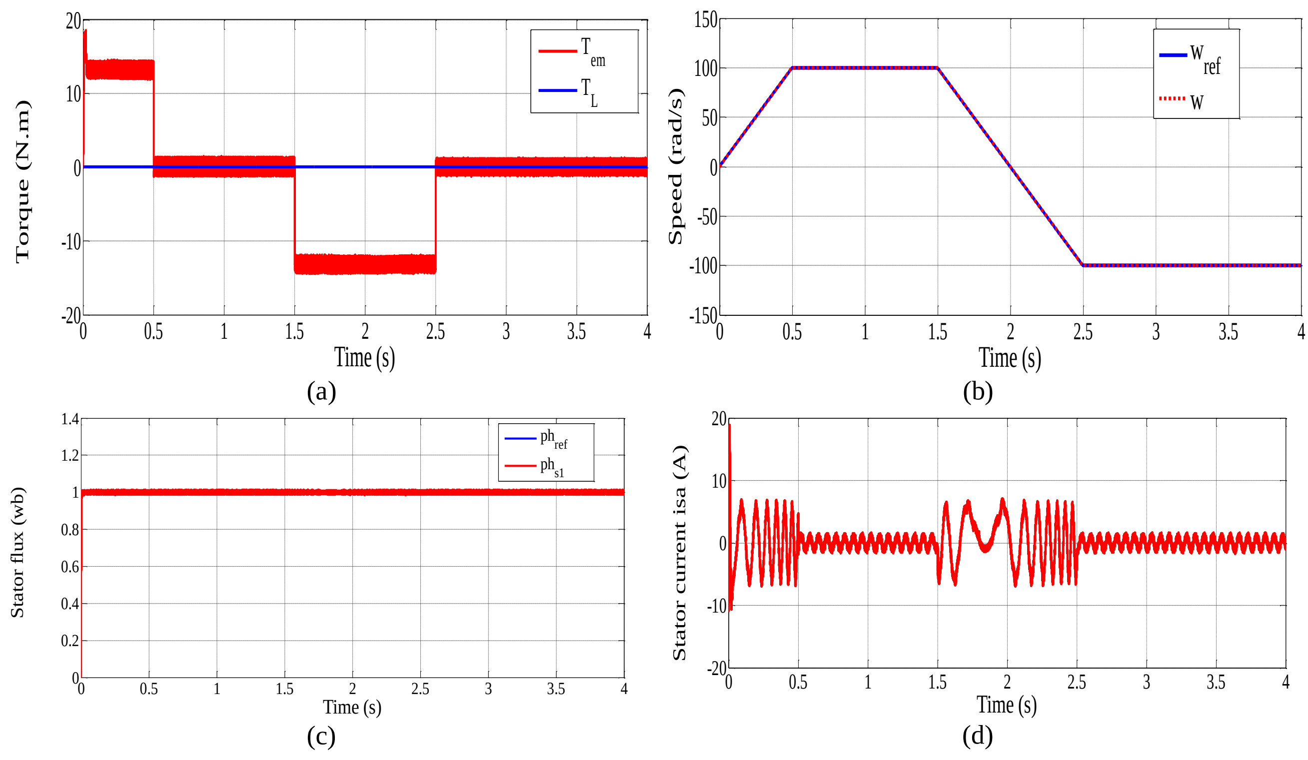

Figure 6. Torque, speed, stator flux and current responses for the second test

Figure 5 illustrated the simulation results of the first test, the electromagnetic torque have the same form of the load torque wich shows that it compensates the load torque and the friction in the established regime fig 5(a), the speed reaches the reference speed at t=0.3s and follows it perfectly, it also noticed that the speed controller rejects the load disturbance quickly fig 5(b), the stator current has a peak value at the start up of 21A, in the presence of load its peak value is 7A and 1.5A in the absence of theme (no load) fig 5(d), results of this test showed that the sensitivity of torque, speed, flux and stator current due to the stator and rotor resistance variation, is not apparent.

Figure 6 represented the simulation results of the second test, the speed follows its reference and reverses such as it reaches the value -100rd/s at t=2.5s fig 6(b), the reversal of direction of rotation leads to a negative electromagnetic torque of about -14N.m fig 6(a), when reversing the direction of rotation from t=1.5s to t=2.5s the stator current amplitude is similar to that the start up fig 6(d), in all the two tests the stator flux tracked its reference perfectly fig 5(c) and 6(c).

6. Conclusion

In this paper the double star induction motor has been controlled by the direct torque control (DTC) based on the fuzzy logic approach, for prove the insensitivity of FLC due to variation parametric two test has been performed via Matlab/Simlink, as can be seen from the simulation results of the system under different conditions with fuzzy controller, the robustness in terms of stability and performance is reached. An excellent stability and disturbances rejection with high performance are offered.

References

1. Y.Zahao, T. A . Lipo, "Space vector PWM control of dual thri-phase induction machine using vector space decomposition," IEEE Trans. on industry applications, 31(5), 1995 pp. 1100–1109, doi:10.1109/28.464525.
2. Hammache, H, Moussaoui, D, . Marouani, K,. Hamdouche, T, "Magnetic properties in double star induction machine," 2008 18th.
3. Azib, A., Ziane, D., Rekioua, T., & Tounzi, A. (2016). Robustness of the direct torque control of double star induction motor in fault condition. In Rev. Roum. Sci. Techn.-Electrotechn. et Energ (Vol. 61, No. 2, pp. 147-152).
4. Hamidia, F., Abbadi, A., & Boucherit, M. S. (2015, December). Direct torque controlled dual star induction Motors (in open and closed loop). In 2015 4th International Conference on Electrical Engineering (ICEE) (pp. 1-6). IEEE.
5. Youb, L., Belkacem, S., Naceri, F., Cernat, M., & Pesquer, L. G. (2018). Design of an Adaptive Fuzzy Control System for Dual Star Induction Motor Drives. Advances in Electrical and Computer Engineering, 18(3), 37-44.
6. H. Lazreg, D. Moussaoui, K. Marouani, T. Hamdouche, "Sensorless Speed Control of Double Star Induction MachineWith Five Level DTC Exploiting Neural Network and Extended Kalman Filter," Irania journal of electrical and electronic engeniring.
7. Zheng, L., Fletcher, J. E., Williams, B. W., & He, X. (2010). A novel direct torque control scheme for a sensorless five-phase induction motor drive. IEEE Transactions on Industrial Electronics, 58(2), 503-513.
8. Lekhchine, S., Bahi, T., & Soufi, Y. (2014). Indirect rotor field oriented control based on fuzzy logic controlled double star induction machine. International Journal of Electrical Power & Energy Systems, 57, 206-211.
9. Boukhalfa, G., Belkacem, S., Chikhi, A., & Benaggoune, S. (2018). Direct torque control of dual star induction motor using a fuzzy-PSO hybrid approach. Applied Computing and Informatics.
10. Y. Yuntao, L. Yan, “A Novel Sensorless Fuzzy Sliding-Mode Control of Induction Motor”, International Journal of Control and Automation, 8 (9), pp. 1-10, 2015.
11. L, Noureddine, Z, Samir, B, Fouad, et al. Comparative Study between Sliding Mode Control and Backstepping Control for Double Star Induction Machine (DSIM) under Current Sensor Faults,

    International Journal of Information Technology and Electrical Engineering, Vol 6, Issue 6 Dec 2017.
12. Takahashi, I., & Noguchi, T. (1986). A new quick-response and high-efficiency control strategy of an induction motor. IEEE Transactions on Industry applications, (5), 820-827.
13. L. A. Zadeh, "Fuzzy Setes. In: Information and Control, " vol. 8, pp.338-343, 1965.
14. E. H. Mamdani and S. Assilian, "An experiment in linguistic synthesis with a fuzzy logic controller,” Internat. J. Man-Machine Stud, vol. 7, pp. 1-13.
15. Zaidi, E., Marouani, K., Mabrek, A. E., Merabet, E., & Bentouhami, L. (2018, October). Fuzzy Logic Control of Multi-Phase Induction Machine Drives Based on Cascaded Hybrid Multi-level Inverters. In 2018 International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM) (pp. 1-6). IEEE.
16. Z. Tir, O.P. Malik, A.M. Eltamaly, Fuzzy logic based speed control of indirect field oriented controlled double star induction motors‘‘ connected in parallel to a single six-phase inverter, Electric Power Syst. Res. 134 (1) (2016) 126–133.