absolute error; *ISE*: integral squared error.

For quantitative comparison between two regulators, *ITAE, IAE* and *ISE* are used as the criterion. Table.3 shows the *ITAE*, *IAE* and *ISE* values of direct torque control using two regulators (T1FLC and T2FLC).

This comparison shows clearly that the T2FLC gives good performances and it's more robust than T1FLC.

7. CONCLUSION

In this paper, we presented control the doubly star induction machine by direct torque control using a type-2 fuzzy logic regulator. We established a mathematical model of the machine to study static behavior and dynamic of this machine.

The complete dynamic model of the Direct Torque Control system is developed and simulated by using MATLAB-SIMULINK. Then, we have continued to improve the direct torque control by the application of type-2 fuzzy logic. The simulation results show that the DTC-T2FLC present a good dynamics performance and his robustness with speed and load torque variation.

REFERENCES

[1] Tir Z, Soufi Y, Hashemnia MN, Malik OP, Marouani K. (2016). Fuzzy logic field oriented control of double star induction motor drive. Electrical Engineering, 1-9. https://doi.org/10.1007/s00202-016-0377-2

[2] Zhao Y, Lipo TA. (1995). Space vector PWM control of dual three phase induction machine using vector space decomposition. IEEE Transactions on Industry Applications 31: 1100-1109. https://doi.org/10.1109/28.464525

[3] Hadiouche D, Razik H, Rezzoug A. (2000). Study and simulation of space vector PWM control of double star induction motors. Power Electronics Congress, 42-47.

[4] Layadi N, Zeghlache S, Benslimane T, Berrabah F. (2017). Comparative analysis between the rotor flux oriented control and backstepping control of a double star induction machine (DSIM) under open-phase fault. AMSE Journals, Series Advances C 72(4): 292-311.

[5] Takahashi I, Noguchi T. (1986). A new quick-response and high efficiency control strategy of an induction motor. IEEE Transactions on Industry Applications 22(5): 820-827. https://doi.org/10.1109/TIA.1986.4504799

[6] Ghalem B, Bendiabdellah A. (2010). Six-Phase matrix converter fed double star induction motor. Acta Polytechnica Hungarica 7(3).

[7] Radhwane S. (2012). Indirect rotor field-oriented control (IRFOC) of a dual star induction machine (DSIM) using a fuzzy controller. Acta Polytechnica Hungarica 9(4).

[8] Hellali L, Belhamdi S. (2018). Direct torque control of doubly star induction motor using fuzzy logic speed controller. IAES International Journal of Artificial Intelligence (IJ-AI) 7(1): 42-53.

[9] Casadei D, Profumo F, Serra G, Tani A. (2002). FOC and DTC: Two viable schemes for induction motors torque control. IEEE Transactions on Power Electronics 5(17): 779-787. https://doi.org/10.1109/TPEL.2002.802183

[10] Brod MD, Novotny WD. (1985). Current control of VSI-PWM inverters. IEEE Transactions on Industry Applications IA-21(3): 562-570. https://doi.org/10.1109/tia.1985.349711

[11] Mendel JM. (1985). Uncertain rule-based fuzzy logic systems: Introduction and new directions. Prentice-Hall.

[12] Khouidmi H, Massoum A, Meroufel A. (2011). Dual star induction motor drive: Modeling, supplying and control. International Journal of Electrical and Power Engineering 5(1): 28-34.

[13] Wu D, Tan WW. (2006). Genetic learning and performance evaluation of type-2 fuzzy logic controllers. Engineering Applications of Artificial Intelligence 19(8): 829-841. https://doi.org/10.1016/j.engappai.2005.12.011

[14] Hagras H. (2007). Type-2 FLCs: A new generation of fuzzy controllers. IEEE Compute Intelligence Magazine 2(1): 30-43. https://doi.org/10.1109/mci.2007.357192

[15] Wu D, Tan WW. (2006). A simplified type-2 fuzzy controller for real-time control. ISA Transactions 15(4): 503-516. https://doi.org/10.1016/S0019-0578(07)60228-6

[16] Zaimeddine R, Berkouk EM. (2007). A novel DTC scheme of double-star induction motors using three-level Voltage source inverter. Journal of Engineering and applied Sciences 2(1): 136-142.

[17] Belhamdi S, Goléa A. (2015). Direct torque control for induction motor with broken bars using fuzzy logic type-2. AMSE Journals, Series Advances C 70(1-2): 15-28.

[18] Castillo O, Melin P. (2008). A, type-2 fuzzy logic, theory and applications. Granular Computing 223. https://doi.org/10.1007/978-3-540-76284-3

Appendix

Table 4. Machine parameters [7]

DSIM Mechanical Power	4.5 kW	Stators 1,2 self inductances	0.022 H
Nominal voltage	220 V	Rotor inductance	0.006 H
Frequency	50 Hz	Mutual inductance	0.3672 H
Pole pair number	1	Moment of inertia	0.0625Nms^2/rad
Stators 1,2 resistances	3.72 Ω	Friction coefficient	0.001Nms/rad
Rotor resistance	2.12 Ω		

List of abbreviations and symbols

Abbreviations	**Designation**
DSIM	Doubly Star Induction Motor
DTC	Direct Torque Control
T2FLC	Type-2 Fuzzy Logic Controller
T1FLC	Type-1 Fuzzy Logic Controller
VSI	Voltage Source Inverter
Ω_r	the rotor angular speed
T_{em}	Electromagnetic torque
K_f	Friction coefficient
J	Moment of inertia
P	Number of pole pairs
T_r	Load torque