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J. Electrical Systems 21-1 (2025): 38-49

Regular paper

Intelligent approach based on fuzzy logic applied to the speed controller for a three-phase induction motor

Journal of Electrical Systems

In this paper, we present the design of a fuzzy-based approach for monitoring the inversion of the rotational speed of an induction motor. Indeed, a robust vector control technique extended to fuzzy is presented. Direct torque control is known to produce fast and robust response in the AC drive system. However, in a steady state, a rapid and unexpected change in speed can occur and can be dangerous. Increasingly, the fuzzy logic control replaces the conventional control methods, when it appears useful for controlling the processes are very difficult to analyze conventional techniques. The present work proposes the ambition to give a general vision on the contribution brought by the fuzzy logic control field in an asynchronous machine, and to highlight the various beneficial aspects of this contribution. Direct torque control is known to produce quick and robust response in AC drive system. However, in the steady state, faults may occur. So, the performance of conventional PID regulators can be improved by implementing fuzzy logic techniques. First, the whole system including the capacitors, the induction generator, and the loads is modeled. The model is obtained using the Park transformation. This approach is applied on three-phase asynchronous motor (LS90Lz) in the Event of Rotational Speed Inversion. The results are compared with standard PID control and the results are very consistent. An appreciable rise time , a negligible excess, a good pursuit of the set-point,r and rejection of the disturbance.

Keywords: Fuzzy logic control, asynchronous motor, electric variables control, PID, Park transformation, vector control.

1. Introduction

The paper discusses the application of classical control methods in various industrial control problems, highlighting that while these methods have been effective, there are still unresolved issues that could potentially be addressed through fuzzy system approaches [1-2]. It presents a fuzzy-based technique designed for monitoring the inversion of rotational speed in induction motors. It introduces a robust vector control method enhanced by fuzzy logic, which is particularly beneficial in scenarios where conventional control techniques struggle to manage complex processes [3-6]. The study aims to provide a comprehensive overview of the contributions of fuzzy logic control in asynchronous machines, emphasizing its advantages over traditional PID controllers, especially in terms of performance during unexpected speed changes.

In this context, the asynchronous motor is modeled using the Park transformation, which replaces electrical quantities with their corresponding components, thereby simplifying calculations and representations [7-9]. To facilitate this modeling process, certain simplifying assumptions are made. Specifically, it is assumed that the eigen inductances

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remain constant [10-15], that mutual inductances vary as a function of the positions of their magnetic axes, and that rotor resistances are constant relative to the rotational velocity [16-20].

2. Asynchronous motor Modeling

Park transformation [13] allows control of only one flux component (axis d) instead of two components (axes d and q). The model is given by:

$$\begin{bmatrix} V_{ds} \\ V_{qs} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} (R_s + L_s\,S) & -\,L_s\omega_s & M\,S & -\,M\,\omega_s \\ L_s\omega_s & (R_s + L_s\,S) & M\,\omega_s & M\,S \\ M\,S & -\,\omega_{gl}\,M & (R_s + L_s\,S) & -\,\omega_{gl}\,L_r \\ \omega_{gl}\,M & M\,S & \omega_{gl}\,L_r & (R_r + L_r\,S) \end{bmatrix} \begin{bmatrix} I_{ds} \\ I_{qs} \\ I_{dr} \\ I_{qr} \end{bmatrix} \quad (1)$$

With:

$L_s = l_s - m_s$: Cyclic inductance of one phase of the stator.

$L_r = l_r - m_r$: Cyclic inductance of one phase of the rotor.

$M = 3/2\,M_{sr}$: Cyclic mutual between stator and rotor.

$\omega_{gl} = \omega_s - \omega_r$: Sliding pulse.

$[V_{ds}\ ,\ V_{qs}]$: Voltage component along the axes $[\,d, q]$.

$[I_{ds}\ ,\ I_{qs}\,]$: Component of the stator current along axes [d,q].

$[I_{dr}\ ,\ I_{qr}]$: Component of the rotor current along the axes [d,q].

Rotor and stator currents along the axes [d,q] are given:

$$I_{ds} = \frac{L_r}{L_s\,L_r - M^2}\,\Phi_{ds} - \frac{M}{L_s\,L_r - M^2}\,\Phi_{dr} \quad (2)$$

$$I_{qs} = \frac{L_r}{L_s\,L_r - M^2}\,\Phi_{qs} - \frac{M}{L_s\,L_r - M^2}\,\Phi_{qr} \quad (3)$$

$$I_{dr} = \frac{L_s}{L_s\,L_r - M^2}\,\Phi_{dr} - \frac{M}{L_s\,L_r - M^2}\,\Phi_{ds} \quad (4)$$

$$I_{qr} = \frac{L_s}{L_s\,L_r - M^2}\,\Phi_{qr} - \frac{M}{L_s\,L_r - M^2}\,\Phi_{qs} \quad (5)$$

The electromagnetic torque is given:

$$C_e = p\,\frac{M}{L_r}\left(\Phi_{dr}\,I_{qs} - \Phi_{qr}\,I_{ds}\right) \quad (6)$$

The motor model responses for a reference velocity of 150 rad/s are given below. The results show that when the motor is acted upon by resistive torque Cr=10N.m, the velocity (Figure. 1) exceeds the reference value and then decreases to 148 rad/s.

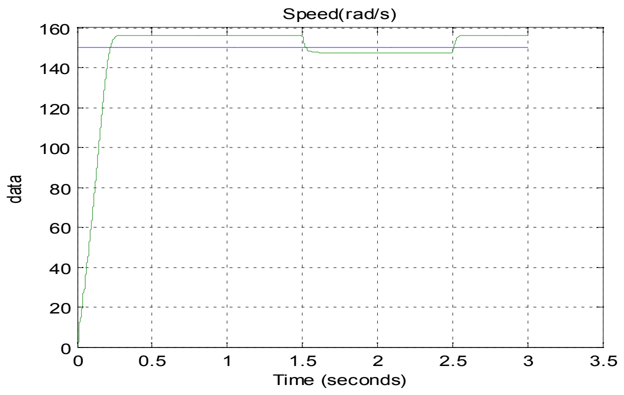

Figure. 1. Velocity response

The torque (Figure. 2) also increases until it reaches the value to drive the load.

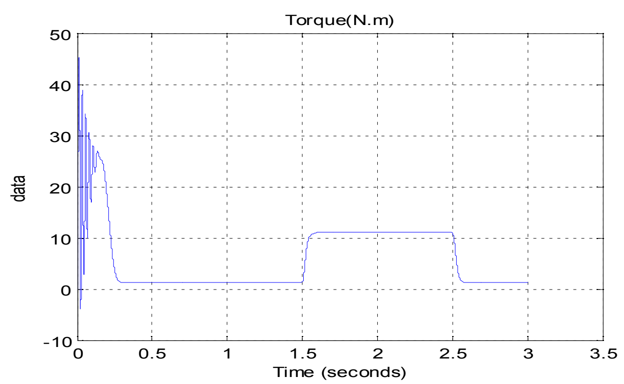

Figure.2. Torque response

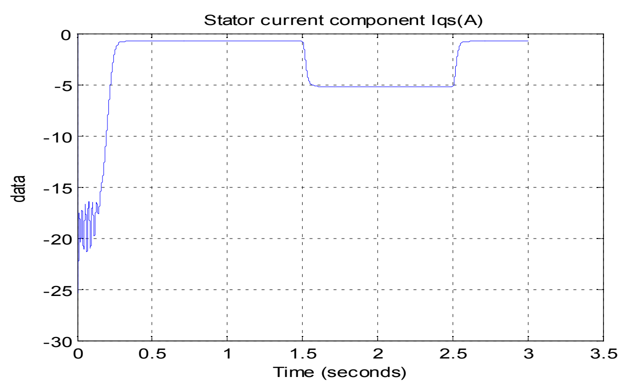

Figure. 3. Stator current component Iqs response

The stator current increases to its nominal value and the stator current (Figure.3) following axis Iqs, decreases and stabilizes at −5.2 A and the rotor fluxes (Figure. 4) and (Figure. 5) increase and stabilize respectively at −0.15 Wb and 0.1 Wb. Input variables are mostly error ‘e’ and the change-of-error ‘de’ regardless of complexity of controlled plants. Alternatively, the change of control input is used as its output variable.

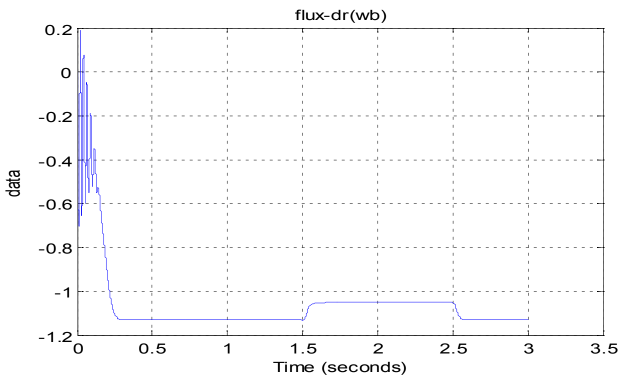

Figure. 4. Flux-dr response

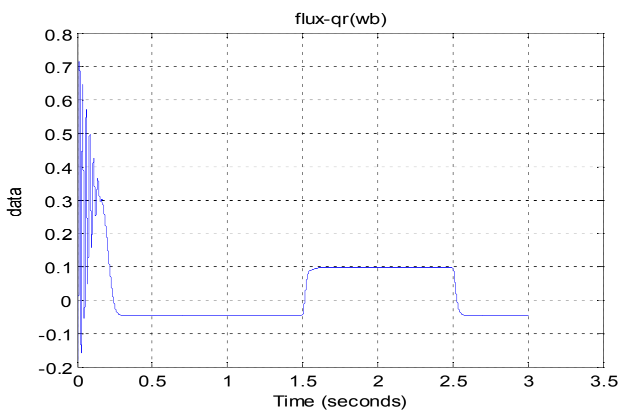

Figure. 5. Flux-qr response

4. Fuzzy Control Design

The fuzzy controller takes its place in the control chain as shown in (Figure. 6).

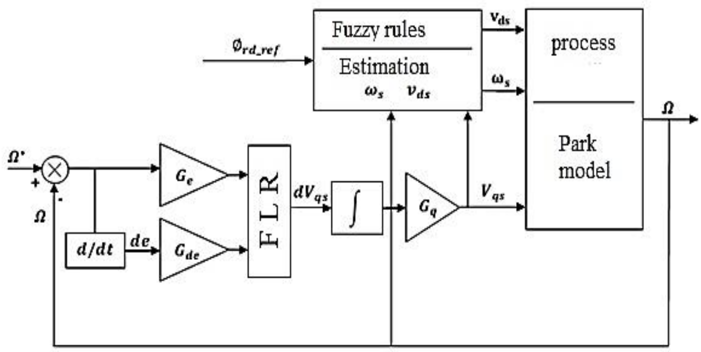

Figure. 6. Fuzzy-logic control topology

The output is calibrated to allow it to vary in the domain accepted by the system. To construct a Mamdani fuzzy inference system, triangular membership functions are used (see Figure. 7, Figure. 8 and Figure. 9) and the Regulator control surface (Fiure.10).

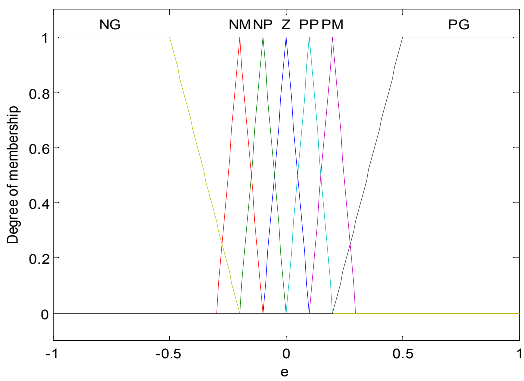

Figure. 7. Input 'e' membership functions

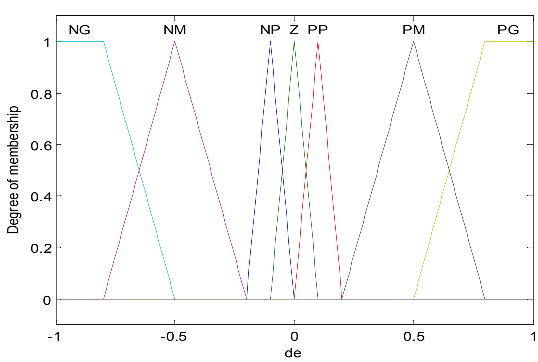

Figure. 8. Input 'de' membership functions

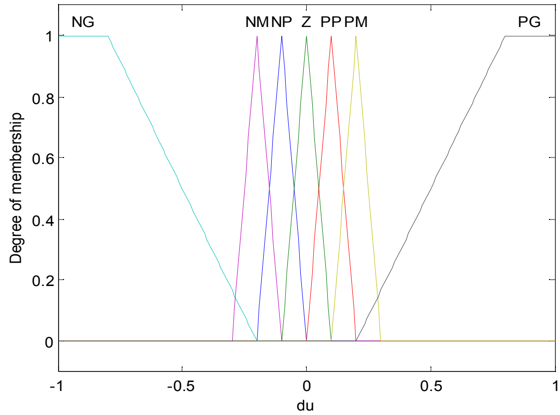

Figure. 9. Output du' membership functions

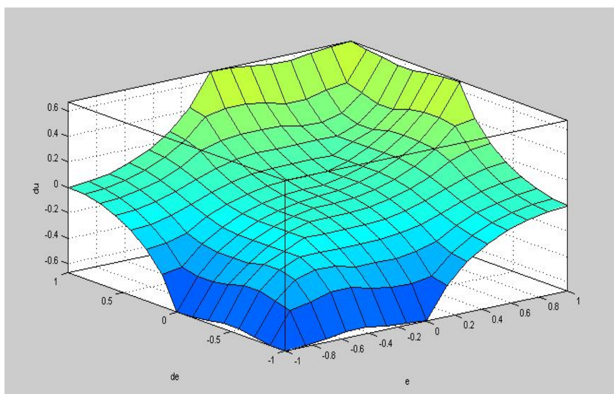

Figure. 10. Regulator control area

5.Case study

After Park transformation [13] allows control of only one flux component (axis d) instead of two components (axes d and q). The characteristics of the asynchronous machine are shown in Table 1.

Table1.machine characteristics

Parameter	Value	Unit
Nominal power	$P_n = 1500$	W
Synchronous speed	$N = 1420$	tr / min
Nominal load torque	$C_r = 10$	$N.m$

Voltage	$V = 220/380$	V
Nominal current	$I = 6.31/3.64$	A
Synchronous frequency	$f_s = 50$	Hz
Efficiency	$\eta = 0.78$	%
Flux	$\Phi = 0.7$	Wb
Number of pole pairs	$p = 2$	

The fuzzy controller results are given in figures below.

For comparison the PID controller responses are also represented. The design of the PID controller is presented on (Figure. 11). The PID parameters are given by:

$$\boldsymbol{K_d = P.\frac{M}{L_r}.\Phi^*, K_p = \frac{2.\varepsilon.\omega_n.J + F}{Ke} \ and \ K_i = \frac{\omega_N^2.J}{Kp.Ke}}$$

(Kp=9.25, Kd=0 and Ki=6.25) ($\boldsymbol{\omega_n = 16\,rd}$: proper pulsation, $\boldsymbol{\varepsilon = 0.7}$: damping factor).

During start-up and in the transient state, the velocity increases and evolves with a rise time of 0.2 s, at t = 0.3 s (start of the steady state), it stabilizes at a value close to the set point velocity (156.7 rad/s) (Figure. 12).

We observe a perfect continuation of the reference velocity, an insensitivity and rapid rejection of the disturbance (0.88%).

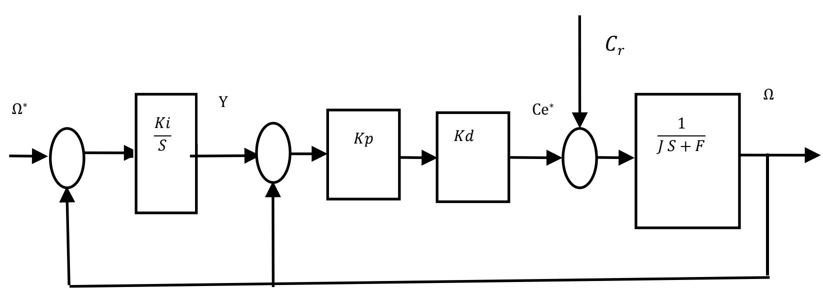

Figure. 11. PID control topology

The torque oscillation reaches the maximum value of the order of 4.5 times the nominal torque (rises to more than 45.27 N·m). This is due to noises generated by mechanical parts.

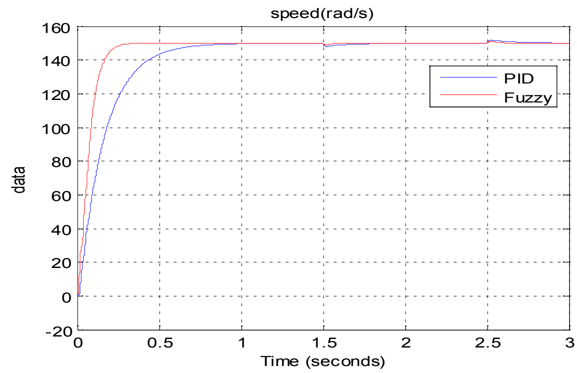

Figure. 12. Velocity response

After the disappearance of the transient regime which lasts 0.16s, the torque decreases almost linearly from 26.9 N · m and tends towards zero. The minimum value is 0.314 N · m, it is due to friction (Figure. 13). These results show that the two types of control demonstrate good performance for Flux_dr (Figure. 14), Flux_qr (Figure. 15) and stator current component Iqs (Figure. 16).

We find almost the same situation with the only difference in response time of speed; the response time of the PI controller is always the same under all conditions, but that of the fuzzy controller depends on the set-point.Let us now consider the case where the motor is in the final position and an unknown disturbance at some frequency is applied to the motor shaft.

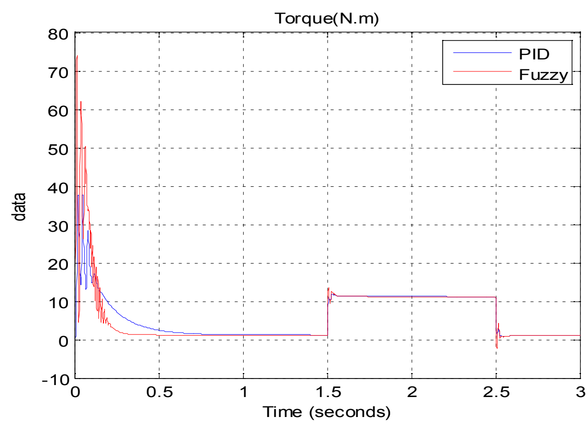

Figure. 12. Torque response

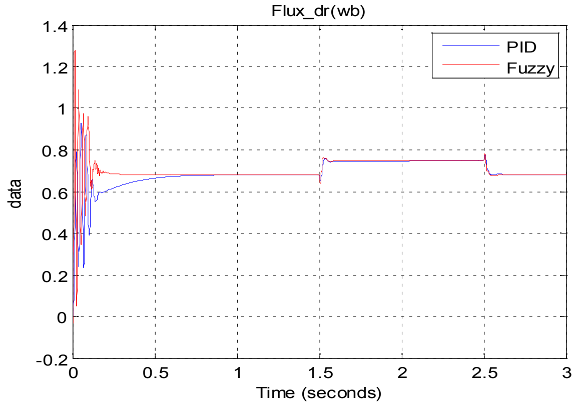

Figure. 14. Flux_dr response

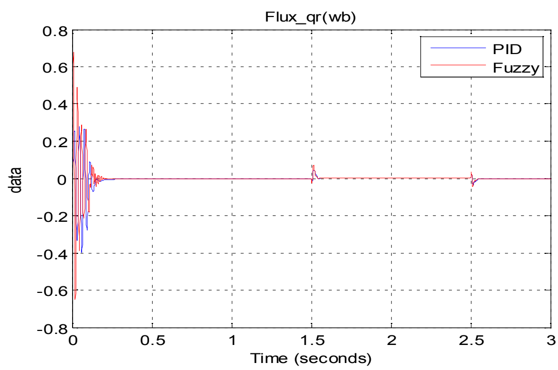

Figure 15. Flux_qr response

In transient mode, mains supply shows a high current demand of 27.06 A. After its disappearance, the steady state is reached.

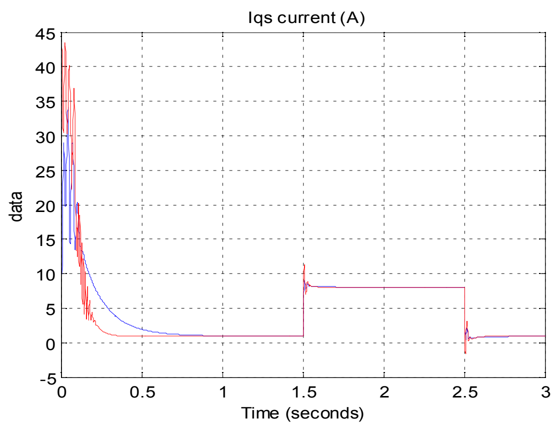

Figure. 16. Stator current component Iqs response

An inversion of the rotational reference velocity considered as a defect is applied after 1 s and a disturbance of 10 N·m at 2 s from the start. The output (Figure. 17) has a good follow-up of the set-point, current Iqs (Figure. 18) does not have an overshoot during this inversion.

Considering all these results, the response time, the fuzzy logic extended vector control gave a faster, less oscillatory response.

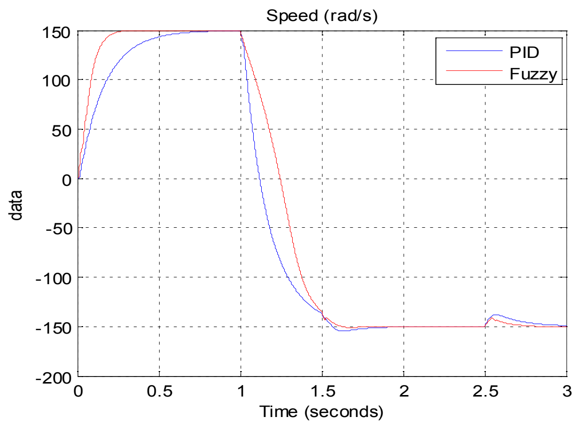

Figure. 17. Velocity response

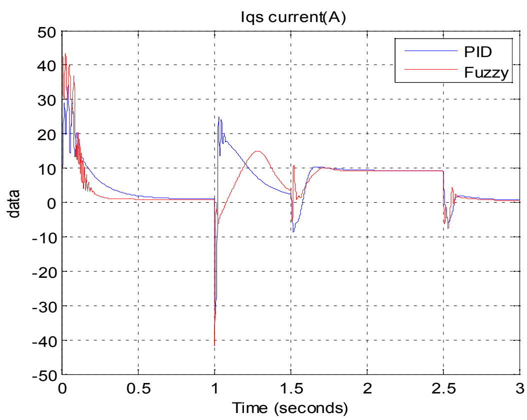

Figure18. Iqs current response

The control strategy with the fuzzy logic has been applied to the AM, and the results of simulation have proved the efficiency of control of the system whose required performance indicators were fully met, namely:

- An appreciable rise time.
- A negligible excess.
- A good pursuit of the set-point.
- Rejection of the disturbance.

- The speed of reversal of the direction of rotation.

Fuzzy control greatly improves the behavior and the efficiency of the vector control and thus allows obtaining a high-performance variable speed drive which is justified by the results obtained by comparing the vector control with conventional PI regulators and by fuzzy logic controllers. The fuzzy controller improves the robustness of the vector control; the simulations show that the errors converge towards negligible static values which give good control results.

The results of this fault-tolerant control based on field-oriented control and fuzzy logic regulator are very conclusive if they do not differ too much from the results already seen with the same regulator if the engine parameters do not vary. However, we see a slightly higher response time.

5. Conclusion

In this paper, we have presented the results obtained applying fuzzy control, which greatly enhances the behavior and the efficiency of the vector control.

The P.I.D control can often display low performance. Overshoot and rising times are tightly coupled, making gain adjustments difficult.

Fuzzy logic extended vector control provides a diagnosis approach to significantly decoupling the overshoot and rise time, allowing for easy set-up and very high disturbance rejection characteristics. The study presented improves the transient response time and servo system accuracy. An inversion of the rotational reference velocity is considered, and the results are very consistent.

Considering these results, we find a perfect continuation reference speed, insensitivity and rapid rejection of disturbances, as well as decoupling of d-q axes that is not Influenced by regime applied to the machine. The command fuzzy improves the behavior and efficiency of vector control and thus allows obtaining a variable speed drive more stable and robust to faults. Analysis of machine parameter variations such as electromagnetic torque, the stator and rotor current in the Park frame allows detecting the presence of defects. The developed command adapts to the abrupt behavioral change such as reversal of speed.

References

[1] I.Mehidi, SAAD, N.Magzoub, M.Abdelkafi, and al, “Simulation analysis and experimental evaluation of improved field-oriented controlled induction motors incorporating intelligent controllers”. IEEE Access, 2022, vol. 10, p. 18380-18394 Design and Simulation of Neuro-Fuzzy Controller for Indirect Vector-Controlled Induction Motor Drive | SpringerLink

[2] A. Roose, S. Yahya, and H. Al-Rizzo, “Fuzzy-logic control of an inverted pendulum on a cart” Computers & Electrical Engineering, Elsevier, 2017.

[3] A. Roose, S. Yahya, and H. Al-Rizzo, “Comparative study between sliding mode and Neuro-fuzzy controllers for a water pump drive supplied by multi-level converters” J. Electrical Systems 20-4, 433-450, 2024.

[4] B. M. Badr, A. M. Eltamaly, and A. I. Alolah, “Fuzzy controller for three phases induction motor drives”, in IEEE Vehicle Power and Propulsion Conference, Sept. 2010. https://doi.org/10.1109/VPPC.2010.5729080

[5] F. Khan, E. Sulaimanandand and Z. Ahmad, “Review of Switched Flux Wound-Field Machines Technology,” IETE Technical Review, 2016.

[6] N. Ananthamoorthy and K.Baskaran, “Velocity and torque control of permanent magnet synchronous motor using hybrid fuzzy proportional plus integral controller”, Journal of Vibration and Control , SAGE Publications, pp. 20–29, 2013.

[7] A. Aissaoui and M. Abid, “A fuzzy logic controller for synchronous machine,” Journal of Electrical Engineering, pp. 285–290, 2007.

[8] Y. Bharathi et. al., “Multi-input fuzzy logic controller for brushless DC motor drives”, Defence Science Journal, vol. 58, no. 1, pp. 147–158, 2008. https://doi.org/10.14429/dsj.58.1632

[9] J. Faiz, M. Manoochehri, and G. Shahgholia, “Performance improvement of a linear permanent magnet synchronous drive using fuzzy logic controller”, in Proceedings of IEEE International Conference on Power System Technology, Oct. 2010. https://doi.org/10.1109/POWERCON.2010.5666041

[10] A. Soundarajan and A. Sumathi, “Fuzzy based intelligent controller for power generating stations”, Journal of Vibration and Control, vol. 17, pp. 214–227, 2011. https://doi.org/10.1177/1077546310371347

[11] N. Ozturk and E. Celik, “Educational Tool for the Genetic Algorithm-Based Fuzzy Logic Controller of a Permanent Magnet Synchronous Motor Drive”, International Journal of Electrical Engineering Education, SAGE Publications, 2014. https://doi.org/10.7227/IJEEE.51.3.4

[12] Y. Bharathi et.al., “Multi-input fuzzy logic controller for brushless DC motor drives”, Defence Science Journal, vol. 58, no. 1, pp. 147–158, 2008. https://doi.org/10.14429/dsj.58.1632

[13] J. Ruiz, A. Espinosa and L. Romeral, “An introduction to fault diagnosis of permanent magnet synchronous machines in master’s degree courses”, Comput. Appl. Eng. Educ., published online, 2010.

[14] E. Siavashi, R. Pahlavanhoseini and A. Pejmanfar, “Using Clonal Selection Algorithm to optimize the Induction Motor Performance”, Canadian Journal on Electrical and Electronics Engineering, vol. 2, no. 9, 2011.

[15] F. Zidani and R. Nait Said, “Direct Torque Control of Induction Motor with Fuzzy Minimization Torque Ripple”, Journal of Electrical Engineering, vol. 56, no. 7–8, pp. 183–188, 2005.

[16] F. Ameur, “Application of Fuzzy Logic for a Ripple Reduction Strategy in DTC Scheme of a PWM Inverter fed Induction Motor Drives,” Journal of Electrical Systems, no.1, pp. 13–17, 2009.

[17] S. M. Gadoue, D. Giaouris and J. W. Finch, “Artificial intelligence-based speed control of DTC induction motor drives: A comparative study”, Electric Power Systems Research, vol. 79, no. 1, pp. 210–219, 2009. https://doi.org/10.1016/j.epsr.2008.05.024

[18] S. Liu, M. Wang, Y. Chen and S. Li, “A Novel Fuzzy Direct Torque Control System for Three-level Inverter-fed Induction Machine,” International Journal of Automation and Computing, vol. 7, no. 1 pp. 78–85, 2010. https://doi.org/10.1007/s11633-010-0078-7

[19] M. Pasamontes et. al., “Learning switching control: A tank level-control exercise,” IEEE Trans. Educ., vol. 55, no. 2, pp. 226–232, 2012. https://doi.org/10.1109/TE.2011.2162239

[20] U. Guven, Y. Sonmez and S. Birogul, “A computer based educational tool for fuzzy logic-controlled DC-DC converters” J. Polyt., vol. 10, pp. 339–346, 2007. controller for a three-phase induction motor