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Evaluation of Control Strategies for Induction Motors in EVs: A Focus on DTC, and Fuzzy Logic DTC

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Abstract
The escalating emphasis on environmentally sustainable transportation, driven by an increasing awareness of climate change, is accelerating the adoption of electric vehicles (EVs). A critical technical challenge in this context is the precise control of induction motors (IMs), which serve as the primary propulsion mechanism for these vehicles. Traditional control methodologies, including Field Oriented Control (FOC) and Direct Torque Control (DTC), are hampered by limitations such as susceptibility to motor parameter variations and substantial torque fluctuations, which compromise overall performance. This research seeks to address these constraints by introducing a Fuzzy DTC method, designed to enhance the control of IMs in EVs.
Keywords: *Induction Motor (IM), Electric Vehicles (EVs), Direct Torque Control (DTC), Fuzzy Logic*

1. Introduction
The burgeoning global awareness of climate change and the imperative for sustainable transportation solutions have positioned electric vehicles (EVs) as a viable alternative to traditional gasoline-powered vehicles, offering enhanced efficiency and reduced environmental impact. However, a critical challenge lies in achieving precise control of the electric motor to ensure consistently high performance in real-time. Conventional control methodologies, including Field Oriented Control (FOC) and Direct Torque Control (DTC), are limited by their susceptibility to parameter variations and significant torque ripple, which compromise efficiency and operational quality, potentially resulting in increased maintenance costs.[1][2][3] In response to these limitations, advanced control techniques have been explored, including neural network-based, fuzzy rule-based, and model predictive speed control. This research proposes the application of a Fuzzy DTC scheme for induction motor (IM) drives in EVs, aiming to leverage the benefits of fuzzy logic control to improve switch control and reduce torque ripple. The primary contribution of this work lies in the development and implementation of a Fuzzy DTC scheme for automotive IM drives, with the objective of achieving improved speed control precision, increased efficiency, and decreased torque ripple. [4][5] Induction motors are widely utilized in EVs due to their reliability and low cost. However, their control presents significant challenges, necessitating the development of advanced control techniques. The proposed Fuzzy DTC scheme offers a promising solution, with the potential to improve the overall performance and efficiency of EVs. The validity and superiority of the proposed methodology will be demonstrated through simulation and experimental results, providing a comprehensive evaluation of its effectiveness in addressing the challenges associated with IM control in EVs. [6][7][8]

2. Methodology

2.1. Direct Torque Control (DTC)
Direct Torque Control (DTC) is a widely employed methodology for the control of Induction Motor (IM) drives, distinguished by its direct regulation of stator flux and torque. Unlike alternative control strategies that manipulate current, DTC operates within the torque-flux plane, thereby facilitating an accelerated transient response and enhanced dynamic performance. The fundamental principle of DTC involves the acquisition of voltage and current measurements supplied to the motor, enabling the determination of the instantaneous motor torque and stator flux. [9] Subsequently, a comparison is made between the actual motor torque and stator flux,

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derived from estimations, and their respective reference values. Based on the resulting error signals, appropriate switching actions for the inverter are selected to maintain the torque and flux at the desired levels. This constitutes a controllable closed-loop system that enables rapid and decoupled control of both torque and speed. The DTC scheme's ability to directly regulate stator flux and torque allows for improved dynamic performance and faster transient response, making it a popular choice for IM drive control applications. [10] Shown in Figure 1 Block Diagram of Conventional Method of DTC.

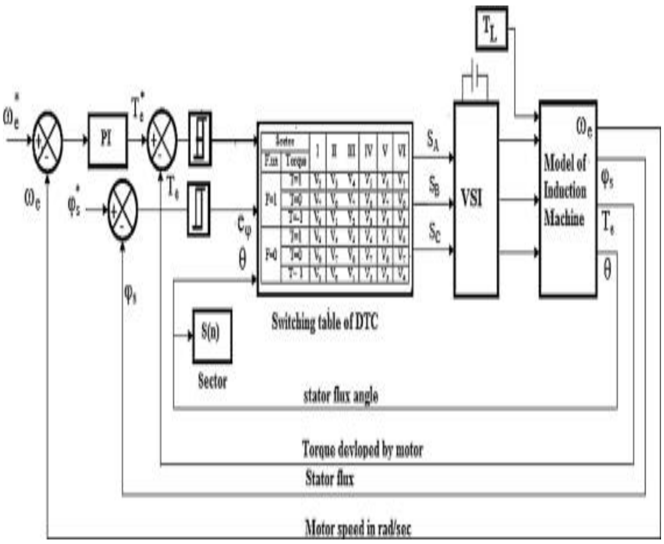

Figure 1 Block Diagram of Conventional method of DTC

The proposed Direct Torque Control (DTC) scheme will be implemented based on an effective estimation of the electromagnetic flux and torque of the induction motor. This estimation will be facilitated through a Simulink dynamic simulation model of the induction motor, which captures the motor's dynamics through a set of coupled differential equations. The induction motor's characteristics can be transformed from a 3-phase stationary reference frame to a 2-phase reference frame, with the α-β stationary reference frame being a more optimal choice. This transformation enables a more efficient and accurate estimation of the motor's electromagnetic flux and torque, which is essential for the effective implementation of the DTC scheme.[11],[12]

2.2. CDTC Control Principle

The voltage vector is generated based on the flux error, the torque error, and the calculated flux angle. This vector is strategically oriented to rotate the stator flux, thereby producing the desired electromagnetic torque (Te), where |ψs| represents the calculated stator flux amplitude and θs denotes the stator flux angle. To maintain the flux within defined boundaries, a double-level hysteresis band control is implemented. This method generates a binary error signal based on the deviation of the actual flux from the predetermined upper and lower limits. Furthermore, the stator flux space is divided into six sectors, each spanning 60°, to facilitate the selection of the appropriate voltage vector.[13]

2.3. Fuzzy Logic-Based Direct Torque Control

2.3.1. (FLDTC) of Induction Motor

Conventional Direct Torque Control (DTC) methodologies are plagued by significant flux and torque ripple, as well as limitations in low-speed transient response. To address these shortcomings, a novel approach integrating fuzzy logic into the DTC framework is proposed. This Fuzzy Direct Torque Control (FDTC) method employs a Fuzzy Logic Switching Controller (FLSC) to determine the optimal switching state, thereby replacing the traditional hysteresis bands and switching logic table. The FLSC receives inputs comprising the torque error, flux error, stator flux angle, and the number of switching updates, which are then utilized to ascertain the most suitable switching configuration. The fuzzy logic controller is based on a Mamdani Fuzzy Inference System (FIS), wherein the input variables are associated with fuzzy sets through triangular and trapezoidal membership functions. Notably, the fuzzy controller output utilizes seven distinct switching states, each represented by a crisp triangular membership function. The specific membership function distributions for the torque error, stator flux error, and stator flux angle error are illustrated in Figures 2(a), 3(b), and 3(c), respectively. These membership functions facilitate a more gradual and refined control output, enabling the fuzzy controller to select one of seven switching states as its output, as depicted by a crisp triangular membership function in Fig. 3. This innovative approach aims to mitigate the limitations of conventional DTC methodologies and provide a more

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effective and efficient control solution.[14]

Table 1 Fuzzy Switching Logic Rule Base

θ / e_T	e_ϕ	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8	θ_9	$\theta10$	$\theta11$	$\theta12$
PL	P	V_1	V_2	V_2	V_3	V_3	V_4	V_4	V_5	V_5	V_6	V_6	V_1
	Z	V_2	V_2	V_3	V_3	V_4	V_4	V_5	V_5	V_6	V_6	V_1	V_1
	N	V_2	V_3	V_3	V_4	V_4	V_5	V_5	V_6	V_6	V_1	V_1	V_2
PS	P	V_1	V_2	V_2	V_3	V_3	V_4	V_4	V_5	V_5	V_6	V_6	V_1
	Z	V_2	V_3	V_3	V_4	V_4	V_5	V_5	V_6	V_6	V_1	V_1	V_2
	N	V_3	V_3	V_4	V_4	V_5	V_5	V_6	V_6	V_1	V_1	V_2	V_2
ZE	P	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0
	Z	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0
	N	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0
NS	P	V_6	V_6	V_1	V_1	V_2	V_2	V_3	V_3	V_4	V_4	V_5	V_5
	Z	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0
	N	V_4	V_5	V_5	V_6	V_6	V_1	V_1	V_2	V_2	V_3	V_3	V_4
NL	P	V_6	V_6	V_1	V_1	V_2	V_2	V_3	V_3	V_4	V_4	V_5	V_5
	Z	V_5	V_6	V_6	V_1	V_1	V_2	V_2	V_3	V_3	V_4	V_4	V_5
	N	V_5	V_5	V_6	V_6	V_1	V_1	V_2	V_2	V_3	V_3	V_4	V_4

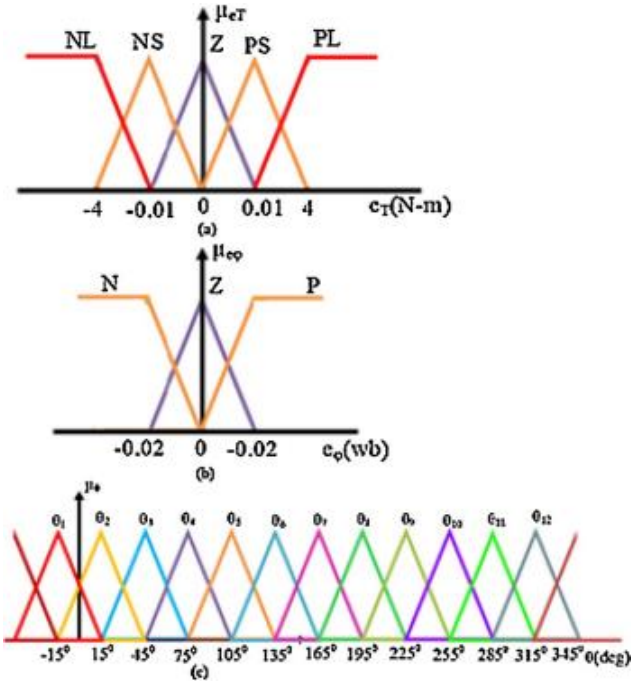

Figure 2 (a), (b) & (c). Membership Functions of Inputs Flux Error, Torque Error and Sector

3. Simulations, Results and Discussion

The MATLAB simulation is carried out for induction motor having ratings listed below:
Power: 102 kW (137 hp) Voltage(RMS):312 V, Frequency:50 Hz,Ploe:4, Stator Resistance:0.903 Ω, Rotor Resistance:2.13 Ω,Rated Speed:1440 RPM Torque base:671.5 Nm Base Torque at 50 % Load=335.75 Nm,Base Torque at 120% Load=805.8 Nm. Torque Reference signal is given at 0.5 s. Speed reference signal is given at 0.1s. Shown in Figure 3 to Figure 14.

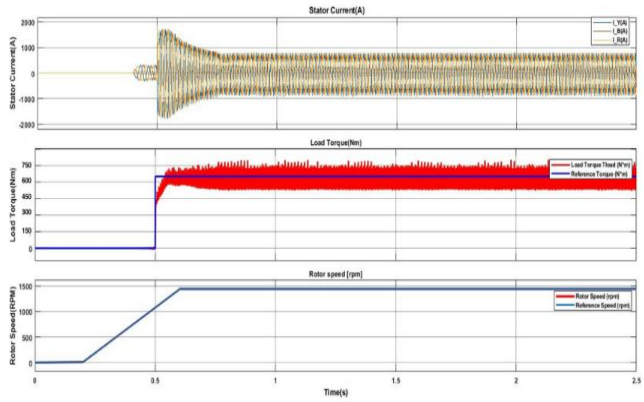

Figure 3 Stator Current, Torque Speed in DTC Control Scheme at 100% load and 100% Speed

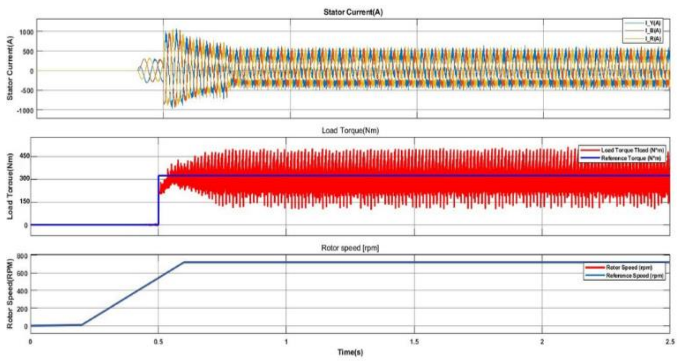

Figure 4 Stator Current, Torque Speed in DTC Control Scheme at 50% load and 50% Speed

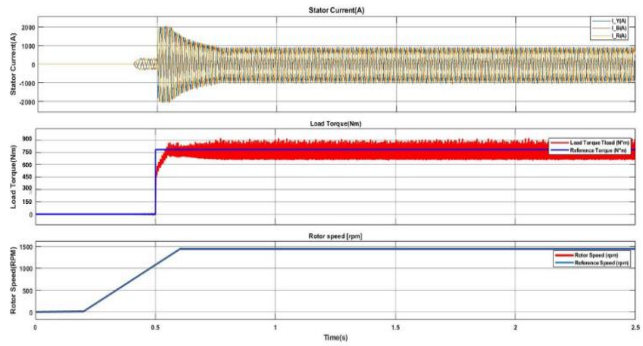

Figure 5 Stator Current, Torque Speed in DTC Control Scheme at 120% load and 100% Speed

The MATLAB simulation is carried out for induction motor having ratings listed below:
Power:2.2 kW(3 HP), Voltage(RMS):220 V, Frequency:50 Hz, Ploe:4, Stator Resistance:1.91 Ω,

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Rotor Resistance:4.47 Ω,Rated Speed:1440 RPM Torque base:14.5 Nm

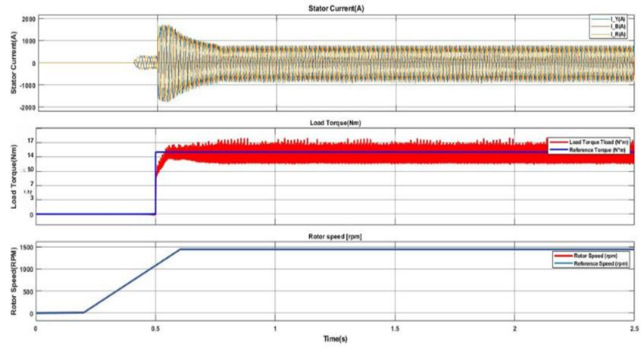

Figure 6 Stator Current, Torque Speed in DTC Control Scheme at 100% load and 100% Speed

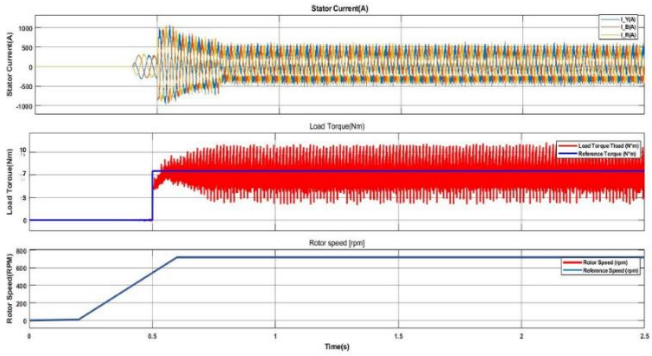

Figure 7 Stator Current, Torque Speed in DTC Control Scheme at 50% load and 50% Speed

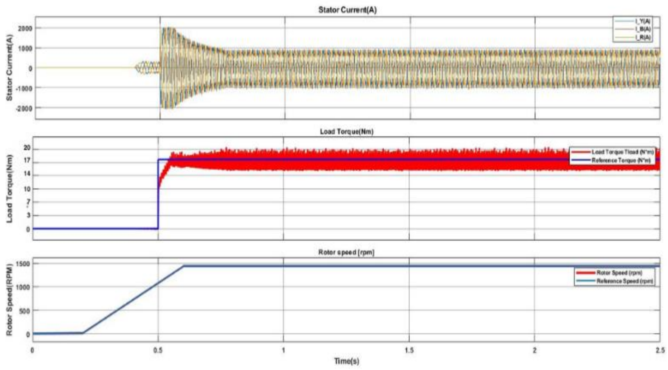

Figure 8 Stator Current, Torque Speed in DTC Control Scheme at 120% load and 100% Speed

Power: 102 kW (137 hp) Voltage(RMS):312 V,. Frequency:50 Hz, Ploe:4, Stator Resistance:0.903 Ω, Rotor Resistance:2.13 Ω Rated Speed:1440 RPM,Torque base:671.5 Nm. Base Torque at 50 % Load=335.75 Nm. Base Torque at 120% Load=805.8 Nm. Torque Reference signal is given at 0.5 s. Speed reference signal is given at 0.1s

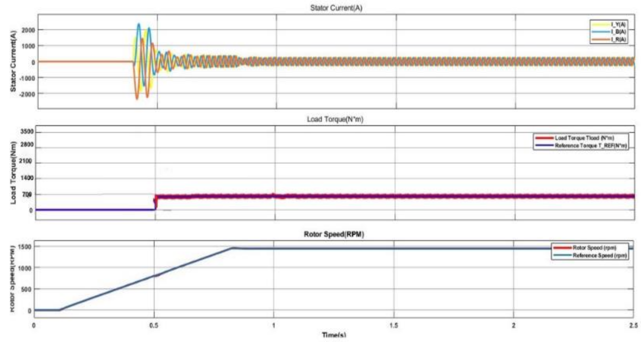

Figure 9 Stator Current, Torque Speed in FLC-DTC Control Scheme at 100% load and 100% Speed

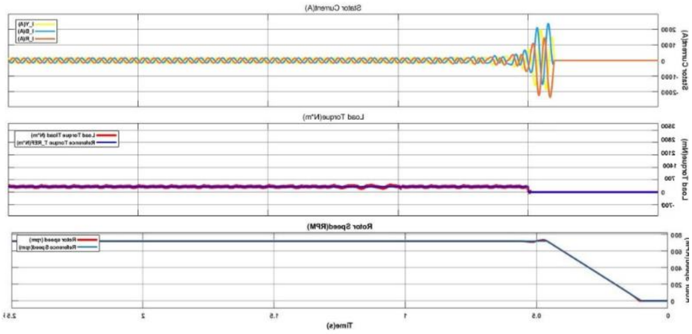

Figure 10 Stator Current, Torque Speed in FLC-DTC Control Scheme at 50% load and 50% Speed

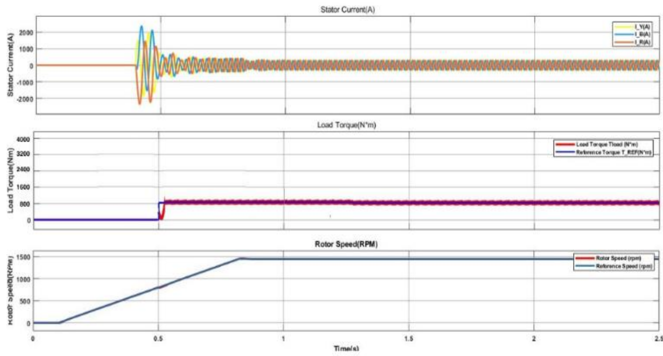

Figure 11 Stator Current, Torque Speed in FLC-DTC Control Scheme at 120% load and 100% Speed

The MATLAB simulation is carried out for induction motor having ratings listed below: Power:2.2 kW(3 HP), Voltage(RMS):220 V, Frequency:50 Hz, Ploe:4, Stator Resistance:1.91 Ω, Rotor Resistance:4.47 Ω Rated Speed:1440 RPM, Torque

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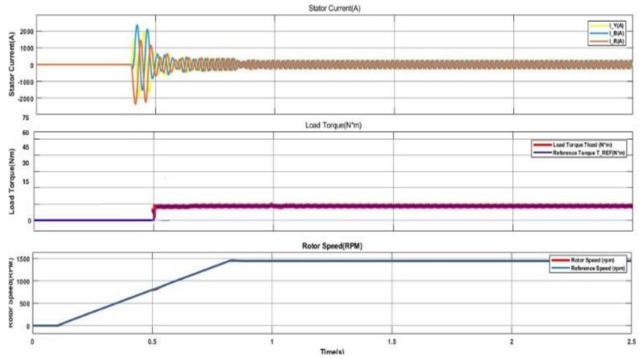

Figure 12 Stator Current, Torque Speed in FLC-DTC Control Scheme at 100% load and 100% Speed

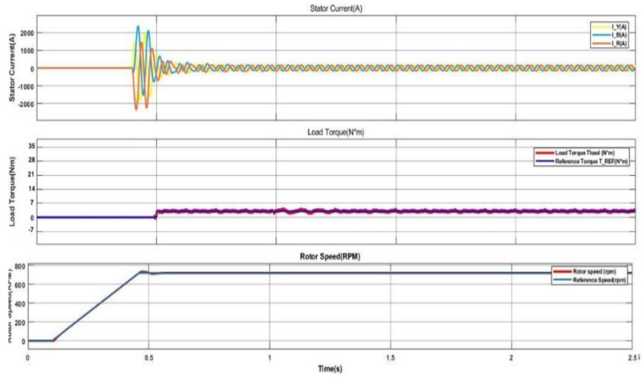

Figure 13 Stator Current, Torque Speed in FLC-DTC Control Scheme at 50% load and 50% Speed

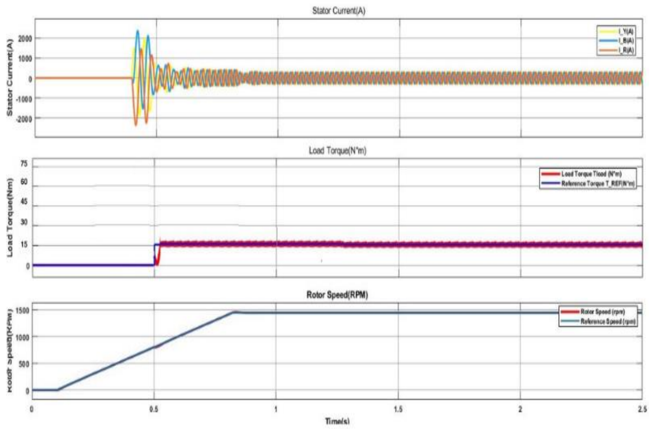

Figure 14 Stator Current, Torque Speed in FLC-DTC Control Scheme at 120% load and 100% Speed

The comparison of two DTC method with normal loading condition is carried out and below table shows the comparison of torque ripple, Shown in Table 2.

Table 2 Torque Ripple Comparison

Sr Number	Method Name	Motor Rating	Minimum - T(Nm)	Avg. T(Nm)	Max. T(N.m)	Torque Ripple(%)
1	DTC	102 kw(137 hp)	620	671.5	751	19.5
2	DTC	2.2 kW(3 hp)	13.1	14.5	15.9	19.1
3	FLC -DTC	102 kw(137 hp)	664	671.5	678	2.1
4	FLC -DTC	2.2 kW(3 hp)	14.35	14.5	14.65	2.1

Conclusion

This paper has presented a comprehensive investigation into the implementation of a fuzzy logic-based Direct Torque Control (DTC) strategy for induction motor (IM) drives in electric vehicles (EVs). The proposed Fuzzy DTC methodology seeks to address the inherent limitations of conventional DTC techniques, particularly the issue of high torque ripple, through the integration of fuzzy logic within the control framework. The simulation results demonstrate that the proposed Fuzzy DTC effectively achieves accurate and resilient speed control across a range of EV operating conditions. By optimizing switching decisions based on fuzzy rules, this approach yields enhanced performance in comparison to traditional DTC methods. The proposed Fuzzy DTC scheme offers several advantages, including reduced torque ripple, improved efficiency, enhanced dynamic performance, and a more refined driving experience. These findings suggest that the Fuzzy DTC methodology has the potential to provide a more effective and efficient control solution for IM drives in EVs.

References

[1]. M. L. De Klerk and A. K. Saha, “A Comprehensive Review of Advanced

Traction Motor Control Techniques Suitable for Electric Vehicle Applications," IEEE Access, vol. 9, pp. 125080–125108, 2021, doi: 10.1109/ACCESS.2021.3110736.

[2]. A. Karki, S. Phuyal, D. Tuladhar, S. Basnet, and B. P. Shrestha, "Status of pure electric vehicle power train technology and future prospects," Appl. Syst. Innov., vol. 3, no. 3, pp. 1–28, 2020, doi: 10.3390/asi3030035.

[3]. L. Chapman, "Transport and climate change: a review," J. Transp. Geogr., vol. 15, no. 5, pp. 354–367, 2007, doi: 10.1016/j.jtrangeo.2006.11.008.

[4]. J. A. Sanguesa, V. Torres-Sanz, P. Garrido, F. J. Martinez, and J. M. Marquez-Barja, "A review on electric vehicles: Technologies and challenges," Smart Cities, vol. 4, no. 1, pp. 372–404, 2021, doi: 10.3390/smartcities4010022.

[5]. K. T. Chau, "Electric vehicle machines and drives: Design, analysis and application," Electr. Veh. Mach. Drives Des. Anal. Appl., pp. 1–400, 2015, doi: 10.1002/9781118752555.

[6]. G. K. Nisha and Z. V Lakaparampil, "Induction Machine Characteristics Control in Field Weakening Region for Propulsion Application BT - Power Electronics and High Voltage in Smart Grid," 2022, pp. 283–297.

[7]. I. M. Alsofyani, N. R. N. Idris, and K.-B. Lee, "Dynamic Hysteresis Torque Band for Improving the Performance of Lookup-Table-Based DTC of Induction Machines," IEEE Trans. Power Electron., vol. 33, no. 9, pp. 7959–7970, 2018, doi: 10.1109/TPEL.2017.2773129.

[8]. N. El Ouanjli et al., "Modern improvement techniques of direct torque control for induction motor drives-A review," Prot. Control Mod. Power Syst., vol. 4, no. 1, 2019, doi: 10.1186/s41601-019-0125-5.

[9]. N. El Ouanjli, S. Mahfoud, A. Derouich, S. El Daoudi, and M. El Mahfoud, "Speed Sensorless Fuzzy Direct Torque Control of Induction Motor Based MRAS Method," Lect. Notes Networks Syst., vol. 455 LNNS, no. May, pp. 779–790, 2022, doi: 10.1007/978-3-031-02447-4_80.

[10]. A. Ghamri, R. Boumaaraf, M. T. Benchouia, H. Mesloub, A. Goléa, and N. Goléa, "Comparative study of ANN DTC and conventional DTC controlled PMSM motor," Math. Comput. Simul., vol. 167, pp. 219–230, 2020, doi: https://doi.org/10.1016/j.matcom.2019.09.006

[11]. Darshan U. Thakar, Dr Rakeshkumar A. Patel, Comparative Analysis of Induction Motor Speed Control Methods for Electric Vehicles Application Journal of Electrical Systems. ISSN No:1112-5209, Vol. 20 No. 10s (2024), 6485 – 6495

[12]. [Darshan U. Thakar, Dr Rakeshkumar A. Patel,"COMPARISON OF ADVANCE AND CONVENTIONAL MOTORS FOR ELECTRIC VEHICLE APPLICATION" at 2019 3rd International Conference on Recent Developments in Control, Automation & Power Engineering (RDCAPE)

[13]. Darshan U. Thakar, Dr Rakesh A. Patel,"Conventional and Artificial Intelligence based Control Techniques for Induction Motor Drive,",IJCRT Vol-6-1

[14]. Darshan U. Thakar, Dr Rakesh A. Patel," Fuzzy based Direct Torque Control of Induction Motor for Electric Vehicles",

[15]. A. Ghezouani, B. Gasbaoui, and J. Ghouili, "Modeling and Sliding Mode DTC of an EV with Four In-Wheel Induction Motors Drive," in 2018 International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM), 2018, pp. 1–9. doi: 10.1109/CISTEM.2018.8613379.

[16]. C. Fahassa, M. Akherraz, and A. Bennassar, "Sensorless DTC of an induction motor based on intelligent dual observer and ANN based selector table," WSEAS Trans. Syst. Control, vol. 13, pp. 390–400, 2018.

[17]. Q. A. Tarbosh et al., "Review and Investigation of Simplified Rules Fuzzy Logic Speed Controller of High Performance Induction Motor Drives," IEEE Access, vol. 8, pp. 49377–49394, 2020, doi:

10.1109/ACCESS.2020.2977115.

[18]. N. El Ouanjli, S. Motahhir, A. Derouich, A. El Ghzizal, A. Chebabhi, and M. Taoussi, “Improved DTC strategy of doubly fed induction motor using fuzzy logic controller,” Energy Reports, vol. 5, pp. 271–279, 2019, doi: https://doi.org/10.1016/j.egyr.2019.02.001.

[19]. S. El Daoudi, L. Lazrak, N. El Ouanjli, and M. Ait Lafkih, “Sensorless fuzzy direct torque control of induction motor with sliding mode speed controller,” Comput. Electr. Eng., vol. 96, p. 107490, 2021, doi: https://doi.org/10.1016/j.compeleceng.2021.107490.

[20]. S. H., K. S.F., and S. B., “Improvements in direct torque control of induction motor for wide range of speed operation using fuzzy logic,” J. Electr. Syst. Inf. Technol., vol. 5, no. 3, pp. 813–828, 2018, doi: https://doi.org/10.1016/j.jesit.2016.12.015.

[21]. S. El Daoudi and L. Lazrak, “Comparison between PI-DTC-SPWM and fuzzy logic for a sensorless asynchronous motor drive,” Prot. Control Mod. Power Syst., vol. 6, no. 1, p. 34, 2021, doi: 10.1186/s41601-021-00216-9.

[22]. R. Tidke and A. Chowdhury, “Quasi ZSI-Fed Sliding Mode Control-based Indirect Field-Oriented Control of IM Using PI-Fuzzy Logic Speed Controller,” Electrica, vol. 22, no. 1, pp. 70–83, 2022, doi: 10.5152/electrica.2021.21081.

[23]. A. Ammar, A. Bourek, and A. Benakcha, “Sensorless SVM-Direct Torque Control for Induction Motor Drive Using Sliding Mode Observers,” J. Control. Autom. Electr. Syst., vol. 28, no. 2, pp. 189–202, 2017, doi: 10.1007/s40313-016-0294-7.

[24]. M. Zamani, M. Karimi-Ghartemani, N. Sadati, and M. Parniani, “Design of a fractional order PID controller for an AVR using particle swarm optimization,” Control Eng. Pract., vol. 17, no. 12, pp. 1380–1387, 2009, doi: https://doi.org/10.1016/j.conengprac.2009.07.005.

[25]. A. Rajasekhar, R. Kumar Jatoth, and A. Abraham, “Design of intelligent PID/PIλDµ speed controller for chopper fed DC motor drive using opposition based artificial bee colony algorithm,” Eng. Appl. Artif. Intell., vol. 29, pp. 13–32, 2014, doi: https://doi.org/10.1016/j.engappai.2013.12.009.

[26]. I. Podlubny, “Fractional-order systems and PI/sup /spl lambda//D/sup /spl mu//-controllers,” IEEE Trans. Automat. Contr., vol. 44, no. 1, pp. 208–214, 1999, doi: 10.1109/9.739144.

[27]. X. S. Wang, R. R. Wang, and Y. H. Cheng, “Safe Reinforcement Learning: A Survey,” Zidonghua Xuebao/Acta Autom. Sin., vol. 49, no. 9, pp. 1813–1835, 2023, doi: 10.16383/j.aas.c220631.

[28]. D. Gu, H. Hu, and L. Spacek, “Learning fuzzy logic controller for reactive robot behaviours,” in Proceedings 2003 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 2003), 2003, vol. 1, pp. 46–51 vol.1. doi: 10.1109/AIM.2003.1225070.

[29]. W. D. Smart and L. P. Kaelbling, “Effective reinforcement learning for mobile robots,” in Proceedings 2002 IEEE International Conference on Robotics and Automation (Cat. No.02CH37292), 2002, vol. 4, pp. 3404–3410 vol.4. doi: 10.1109/ROBOT.2002.1014237.

[30]. R. C. Arkin, Behavior-based Robotics. MIT Press, 1998. [Online]. Available: https://books.google.co.in/books?id=mRWT6alZt9oC