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Sliding Neural Artificial Controller of Induction Motor Combined with NPC Five Level Inverter

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Abstract: Sliding mode is a robust approach used in nonlinear control; however, it can lead to high frequency chattering caused by the discontinuous control action. This phenomenon can become a significant issue, particularly when the system's state is near the sliding surface. To minimize the chattering phenomenon, we have replaced the discontinuous control with a neural artificial network. This has led to the development of a new controller, referred to as the sliding neural artificial controller, which is applied in speed control. This approach appears to effectively address these challenges while ensuring optimal control performance. Induction motors play a crucial role in the industry. To achieve speed variation, multi-level inverters are utilized due to their significant advantages. They enable operation in medium and high voltage as well as high-power applications while delivering improved voltage waveforms with low total harmonic distortion, making them ideal for electric machine applications. This article examines the Speed Sliding Neural Artificial (SM-ANN) controller employed to regulate the speed of an induction motor in combination with a Five Neutral Point Clamped inverter. The study focuses on evaluating the performance based on the physical parameters of the squirrel cage motor, such as speed, electromagnetic torque, and current, in comparison to the conventional speed sliding mode controller. Simulation results indicate significant improvements achieved by the SM-ANN controller, particularly in reducing ripple in the motor parameters. These simulations, conducted using Matlab/Simulink, effectively demonstrate the robustness and efficiency of the SM-ANN controller.

Keywords: Sliding mode controller (SMC), Artificial neural network (ANN), NPC five level inverter, Performance

Introduction

The induction motor is among the most commonly used machines in various variable-speed applications due to its several advantages, including ease of manufacturing and maintenance (Chuanguang et al., 2020 ; Mıloudı. et al., 2024; Bermakiet et al. 2023). It is also highly valued for its reliability and durability. However, while its mechanical structure is relatively simple, its mathematical model is highly complex, being multi-variable and non-linear in nature (Hakmiet, et al., 2024 ; Gourbi, et al., 2024).

Sliding mode control operates on the fundamental principle of directing the system's state trajectory toward a predefined surface, known as the sliding or switching surface, and ensuring it remains near this surface through a suitable switching mechanism. Designing a sliding mode controller involves two key steps : defining an appropriate switching surface and formulating the control law, which includes both the equivalent command and the discontinuous command. This control method provides desirable characteristics, such as robustness against parameter variations (Mendaz et al., 2023).

However, in SMC, when the system state is near the sliding surface, the high frequency chattering phenomena caused by the discontinuous control action is a serious issue (Chuanguang et al., 2020; Mendaz et al., 2023). We have used neural networks in place of discontinuous control to lessen the chattering phenomenon. The Sliding mode controller is included into the artificial neural network structure by the Sliding Artificial Neural Network (SANN) technique. The sliding mode controller is connected to an artificial neural network, which gives it structure and learning capabilities. Sliding Artificial Neural Network control is used to regulate the speed of induction motors.

Interesting benefits of multilevel inverters include the ability to operate in medium, high voltage, and high power applications and the provision of an improved voltage waveform (Miloudi et al., 2022). The speed sliding artificial neural network controller of the induction motor connected to the NPC five level is discussed in this paper. Matlab simulation results demonstrate the robustness and performance of this controller.

Method

Model Mathematic of Induction Motor

The mathematical model of induction motor is utilized to analyze its dynamic behavior (Miloudi, H. et al., 2024). Variations in the motor's dynamic behavior impact parameters like speed, torque, resistance, and flux, which are essential for evaluating the motor's performance (Chuanguang et al., 2020; Santos et al., 2025). The dynamic model of the squirrel cage motor is derived by converting three-phase quantities into two-phase direct and quadrature axis quantities using Park transformations. The mathematical equation of the induction motor, expressed in the rotating reference frame, is as follows :

$$\frac{d\Omega}{dt} = \frac{n_p L_m}{J L_r}\left(\varphi_{rd} I_{sq} - \varphi_{rq} I_{sd}\right) - \frac{1}{J} C_r - \frac{1}{J} f\Omega \quad (1)$$

$$\frac{dI_{sd}}{dt} = -\lambda\, I_{sd} + w_s I_{sq} + \frac{K}{\tau_r}\varphi_{rq} + w_r\, K\varphi_{rd} + \frac{1}{\sigma L_s} v_{sd} \quad (2)$$

$$\frac{dI_{sq}}{dt} = -w_s I_{sd} - \lambda\, I_{sq} - w_r\, K\varphi_{rd} - \frac{K}{\tau_r}\varphi_{rq} + \frac{1}{\sigma L_s} v_{sq} \quad (3)$$

$$\frac{d\varphi_{rd}}{dt} = \frac{L_m}{\tau_r} I_{sd} - \frac{1}{\tau_r}\varphi_{rd} + (w_s - w_r)\varphi_{rq} \quad (4)$$

$$\frac{d\varphi_{rq}}{dt} = \frac{L_m}{\tau_r} I_{sq} - (w_s - w_r)\varphi_{rd} - \frac{1}{\tau_r}\varphi_{rq} \quad (5)$$

Speed Sliding Control

The motor speed Ω should track a specific reference speed Ω_{ref} with presence of load torque. The system controlled in such a way that the error $e(t) = \Omega_{ref} - \Omega$ and its rate of change always move towards a sliding surface. We take n = 1, the speed control manifold equations can be obtained as equation "(7)" presents the sliding surface and "(8)" represents the derivative of the surface which is used to calculate the equivalent control (Mendaz et al., 2023).

$$\frac{d\Omega}{dt} = \frac{n_p\, L_m}{J\, L_r}\left(\varphi_{rd} I_{sq} - \varphi_{rq} I_{sd}\right) - \frac{1}{J}\,T_l - \frac{1}{J}\, f\Omega \quad (6)$$

$$S(\Omega) = \Omega_{ref} - \Omega \quad (7)$$

$$\frac{dS(\Omega)}{dt} = \frac{d\Omega_{ref}}{dt} - \frac{d\Omega}{dt} \quad (8)$$

Where the equivalent control is:

$$I_{sq}^{eq} = \left(\frac{d\Omega_{ref}}{dt} + \frac{1}{J} T_l + \frac{1}{J} f\Omega\right)\frac{J L_r}{n_p L_m}\frac{1}{\varphi_{rd}} \quad (9)$$

The correction factor (discontinuous command) gives by flowing equation (Boukhnifer et al .,2006), (Mendaz et al., 2023) :

$$I_{qn} = K_{q1} sat(S(\Omega)) \quad (10)$$

Where:

$$sat\big(S(\Omega)\big) = \begin{cases} \frac{1}{\varepsilon}\, S(\Omega) & if|S(\Omega)| \le \varepsilon \\ sgin\, S(\Omega) & if|S(\Omega)| > \varepsilon \end{cases} \qquad (11)$$

NPC Five Level Inverter Structure

The neutral-point-clamped (NPC) topology is one of the most commonly used configurations. In a neutral-point-clamped inverter, the DC link is divided into multiple smaller voltage levels through a series of bulk capacitors connected in a bank. This structure enables the inverter poles to connect to any of these voltage levels, producing a multi-level voltage waveform at the output (Mendaz, et al., 2022). The NPC five-level converter topology utilizes clamped diodes to ensure equal voltage distribution among the switches, there by enhancing their reliability (Elamri et al., 2022). A three-phase N-level diode-clamped inverter requires (N-1) capacitors, 3(N-1)(N-2) clamped diodes, and 6(N-1) active switches for its operation (Boukhnifer et al, 2006).

A three-phase, five-level NPC converter is designed with a common DC bus. It comprises eight switches arranged in series, six clamping diodes, and four capacitors connected to a single DC voltage source. Each switch includes an IGBT and an antiparallel diode to support its functionality (Mendaz et al., 2022 ; Elamri et al., 2022). The switches must not open or close at the same time to prevent a short circuit in the DC input source of the inverter or the disruption of the inductive circuit in its load (Bermaki et al., 2022 ; Boukhnifer et al.,2006). The floating diodes, six per arm, play a crucial role in enabling the output of varying voltage levels for each arm. The continuous input bus is composed of four capacitors (C1, C2, C3 and C4), making it possible to create a set of three capacitive middle points. The total voltage of the DC bus isV_{dc}; under normal operating conditions, it is uniformly distributed over the four capacitors, which then have a voltage$\frac{V_{dc}}{4}$ at their terminals.

Table1. Switching states of five level NPC inverter States of switches voltages level.

States of switches								Voltages level
K1	K2	K3	K4	K'1	K'2	K'3	K'4	
on	on	on	on	off	off	off	off	$\frac{V_{dc}}{4}$
off	on	on	on	on	off	off	off	$\frac{V_{dc}}{2}$
off	off	on	on	on	on	off	off	0
off	off	off	on	on	on	on	off	$-\frac{V_{dc}}{4}$
off	off	off	off	on	on	on	on	$-\frac{V_{dc}}{2}$

The "Fig. 1" shows the speed sliding mode control of induction motor.

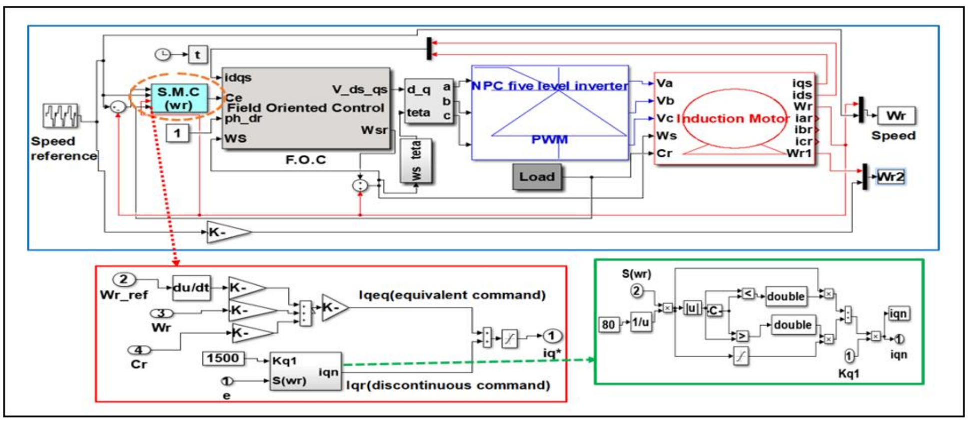

Figure 1. Speed sliding mode control of induction motor combined NPC five level inverter

Speed Sliding Neural Control

One notable drawback of sliding mode control is the chattering phenomenon caused by the discontinuous control command. To enhance the performance of SMC, numerous advancements have been proposed, particularly through the integration of Artificial Neural Networks (ANN) (Szoke.et al.,2025; Venkatesan et al.,2020). In this context, the objective is to substitute the discontinuous control command with artificial neural networks. Figure 2 illustrates the speed control of an asynchronous motor using a hybrid controller that combines sliding mode control and artificial neural networks, referred to as the Sliding Artificial Neural Network Controller (SANN).

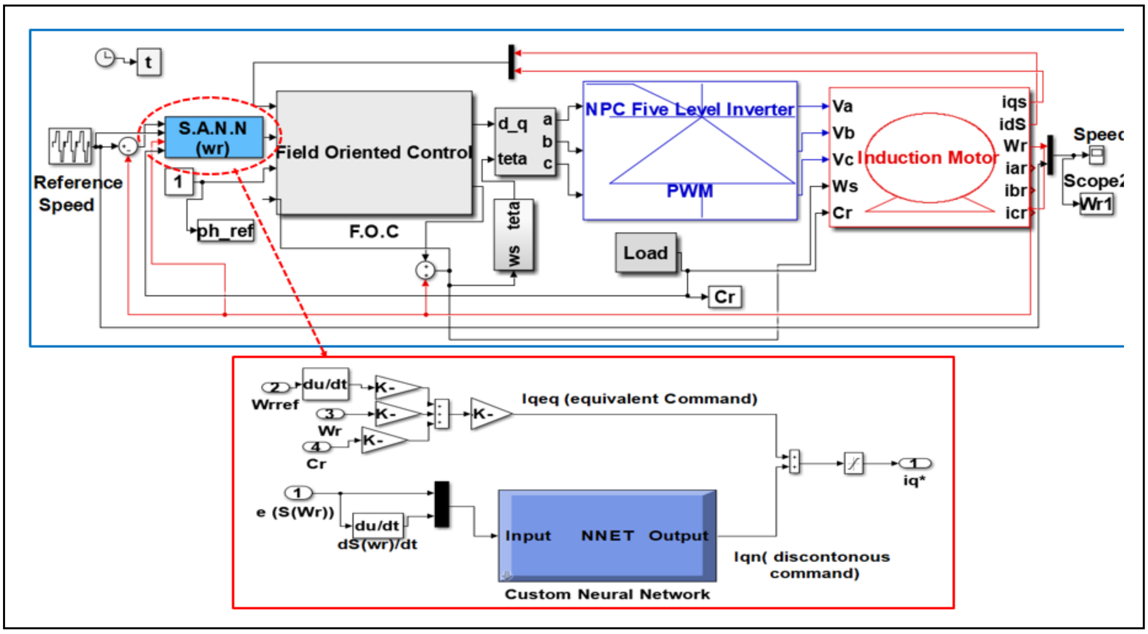

Figure 2. Speed sliding artificial neural networks (SANN) control of induction motor combined NPC five level inverter

The Figure.3 shows the architecture of speed sliding artificial neural networks (SANN) controller.

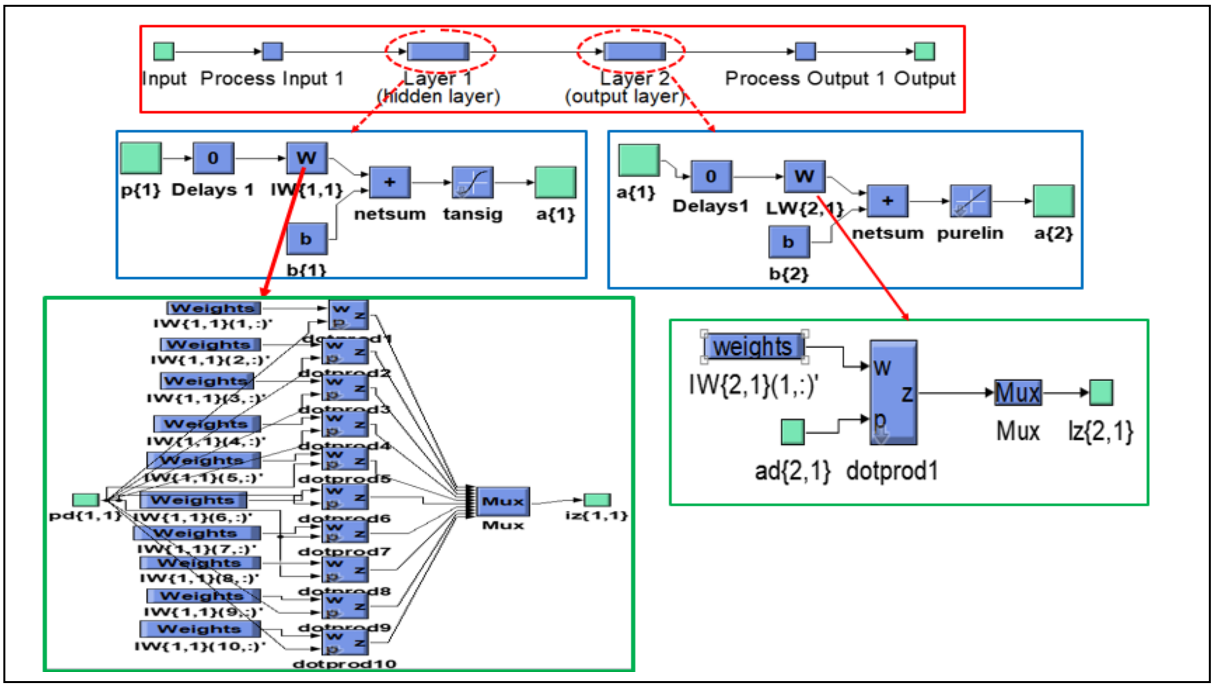

Figure 3. The architecture of speed sliding artificial neural networks (SANN) controller

Results and Discussion

In Figure.4, the machine is applied with a load torque of 10 Nm in a time interval [0.31, 0.5] s and [1.21, 1.5] s; the direction of rotation of the machine is reversed from 157 rad/s to -50 rd/s in time 1.64s and diminution of speed to -157rd/s in time 2.1s . When the motor started with the reference speed 50 rd/s in the time interval [0, 0.01] s, the sliding artificial neural (SANN) control show that the speed returns to its reference during the transient regime compared to the sliding mode (SM) regulator, which shows that there is a gap between the motor speed and its reference. When the direction of rotation reversed, two controllers show that the speed follows its reference in the steady state. The load torque application has not effect on speed response. According to the speed results, we observe that SANN control gives a perfermant result, which is in the reduction of ripples in the speed and torque signal compared to the SMC, which shows an increase in ripples on the speed, and torque signal that created by the discontinuous control. Therefore, the combination between SM and ANN control, which replaces the discontinuous control, improves the performance of this regulator wish observed in the reduction of ripples then it is the reduction of the chattering effect. The simulation results show that the speed sliding artificial neural control (SANNC) is robust to the variation of the reference speed, since the speed follows the reference speed at start-up as well as the reversal of the direction of rotation, in a very satisfactory way, the application of load torque does not influence the speed response. In the Fig. 4 the speed sliding control (SMC) ensures the robustness of this technique to high and low speed variations as well as the application of load torque (Tl=10Nm) in time interval [0.26, 0.75] s and [0.91, 2.3] s .

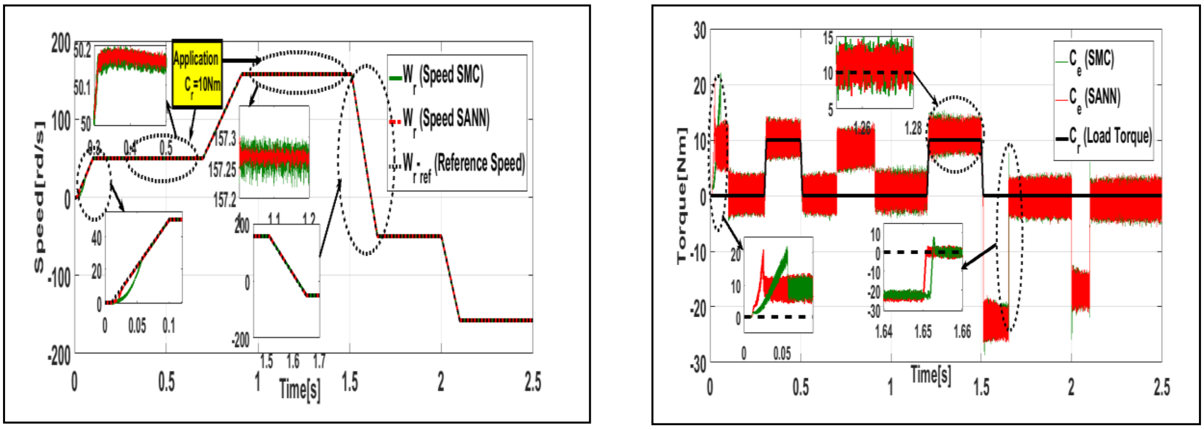

Figure 4. Speed and torque result of speed sliding mode control and speed sliding artificial neural networks (SANN) controller of induction motor combined NPC five level inverter

We show that the harmonic spectrum of one phase stator current of induction motor combined with NPC five level inverter obtained using Fast Fourier Transform (FFT) technique for the two controllers (Figure5 and Figure6). It can be clear observed that the total harmonic distortion (THD) is reduced for SANN (THD = 0.48%) compared to SMC (THD = 0.75%). Therefore, the proposed controller (SANN) has proven effective in reducing the value of the total harmonic distortion.

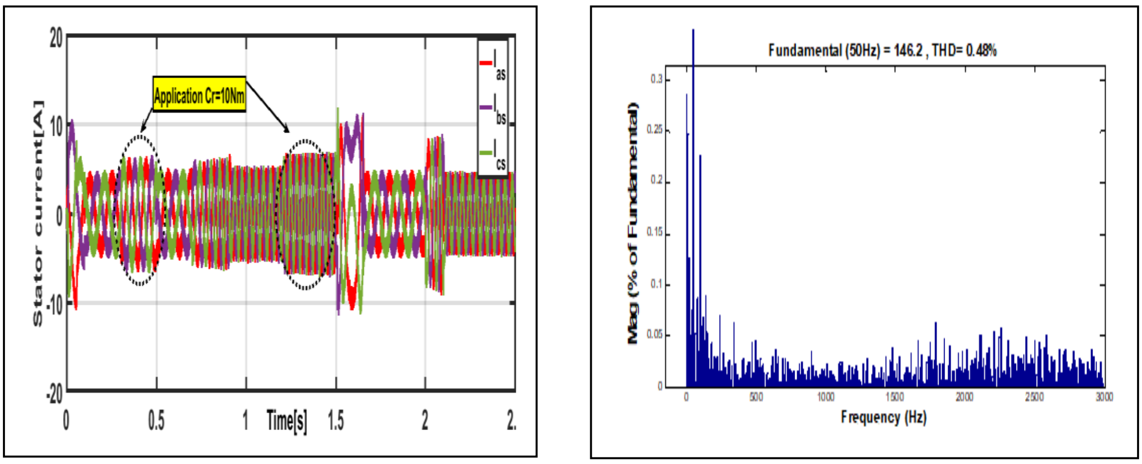

Figure 5. Stator current result of speed sliding artificial neural networks (SANN) controller of induction motor combined NPC five level inverter and spectrum harmonic of one phase stator current for SANN.

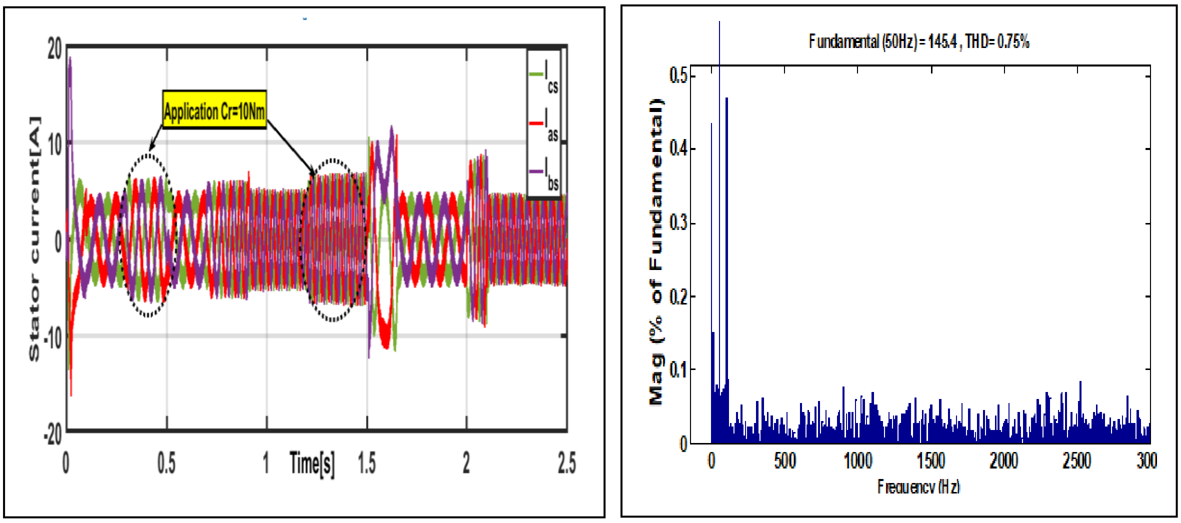

Figure 6. Stator current result of speed sliding mode (SMC) controller of induction motor combined NPC five level inverter and Spectrum harmonic of one phase stator current for SMC.

Conclusion

Sliding mode control is widely recognized as a robust control method. However, its primary drawback is the chattering phenomenon, which results from high-frequency switching near the sliding surface due to the discontinuous control law used during sliding mode design and interactions with parasitic dynamics. To address this issue, the discontinuous control is replaced with a neural network, incorporating artificial intelligence (ANN) into the sliding mode methodology. Neural networks have been integrated into sliding mode control for several purposes, such as improving controller performance and eliminating chattering effects. The proposed controller employs a speed sliding neural network (SANN) for an induction motor paired with an NPC five-level inverter, delivering enhanced performance outcomes. This setup effectively reduces ripples in the physical parameters of the induction motor, including speed, electromagnetic torque, as well as stator and rotor currents. Simulation results clearly demonstrate the superior performance of speed sliding neural control. The response characteristics reveal its excellent capability for mitigating oscillations and improving overall system performance.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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References

Bermaki, M. H., Miloudi, H., Miloudi, M., Gourbi, A., & Bendaoud, A. (2023). High-frequency differential mode modeling of universal motor's windings. *International Journal of Electrical and Electronics Research, 11*, 1057-1064.

Boukhnifer, M., & Chaib, S. (2006). Control for induction motor fed by five level inverter with sliding mode observer. *2006 IEEE International Conference on Control Applications (CCA),* Munich, Germany.

Chuanguang, C., & Haisheng, W. (2020). Backstepping sliding mode control of induction motor based on disturbance observer. *IET Electric Power Applications, 14*(12), 2537-2546.

Elamri, O., Oukassi, A., El Bahir, L., & El Idrissi, Z. (2022). Combined vector and direct controls based on five-level inverter for high performance of IM drive. *World Electric Vehicle Journal, 13*(1), 2-16.

Gourbi, A., Miloudi, M., Miloudi, H., & Bermaki, M. H. (2024). Comparative analysis of differential-mode impedance in single-phase induction motors. *WSEAS Transactions on Circuits and Systems, 23*, 261-273.

Hakmi, Y., Miloudi, H., Miloudi, M., Bendaoud, A., Mendaz, K., & Bermaki, M. H. (2024*)*. A novel experimental approach for predictive high frequency modeling of differential-mode impedance in three-phase induction motors (Paper presentation). *3rd International Conference on Advanced Electrical Engineering*, Sidi-Bel-Abbes, Algeria.

Mendaz, K., & Flitti, M. (2023). Input-output linearization control based on the sliding mode of the squirrel cage motor. *Revue Roumaine des Sciences Techniques – Série Électrotechnique et Énergétique, 68*(2), 176-181.

Mendaz, K., Flitti, M., Benhadda, Y., Attou, A., & Bendaoud, A. (2022). Effect of defective five levels inverter on input output linearization control for induction motor. *Electrotehnica, Electronica, Automatica (EEA), 70*(4), 30-45.

Mendaz, K., Miloudi, H., & Younes, K. (2023). Sliding input output control of squirrel cage motor based NPC five level inverter. *Periodica Polytechnica Electrical Engineering and Computer Science, 67*(4), 458-468.

Miloudi, H., Miloudi, M., Ardjoun, A. M., Mahmoud, M. M., Telba, A. A., Denaï, M., Khaled, U., & Ewias, A. M. (2024). Electromagnetic compatibility characterization of start-capacitor single-phase induction motor. *IEEE Access, 12*, 2313-2316.

Miloudi, H., Miloudi, M., Gourbi, A., Bermaki, M. Z., Bendaoud, A., & Zeghoudi, A. (2022). A high-frequency modeling of AC motor in a frequency range from 40 Hz to 110 MHz. *Electrical Engineering & Electromechanics Journal, 6*, 3-7.

Santos, V. F., Frosini, L., & Sotelo, D. M. (2025). Diagnosis of rotor asymmetries in induction motors: A steady state approach using rotating frame references. *e-Prime - Advances in Electrical Engineering, Electronics and Energy, 12*(1), 1-12.

Szoke, E., Szabo, C., & Pintilie, N. P. (2025). Artificial intelligence-based sensorless control of induction motors with dual-field orientation. *Applied Sciences, 15*(16), 2-24.

Venkatesan, S., Premkumar, K., & Vishnupriya, M. (2020). Speed control of permanent magnet synchronous motor using neural network model predictive control. *Journal of Energy Systems, 4*(2), 71-87.

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