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Simulation-Based Performance Assessment of a Single-Phase Induction Motor with Two Identical Stator Windings

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Abstract-** This paper presents a simulation-based performance assessment of a single-phase induction motor (SPIM) equipped with two identical stator windings, developed and analyzed using MATLAB/Simulink R2023a. The dual-stator configuration was evaluated against a conventional single-stator motor to determine improvements in torque, current, efficiency, and power factor. The mathematical model was derived using d–q axis transformation under standard assumptions of linear magnetic circuit, uniform air gap, and negligible core losses. Simulation results revealed significant performance enhancement with the dual-stator design. The starting torque improved from 1.1 Nm (single-stator) to 1.8 Nm (dual-stator), representing a 63.6% increase in pull-up torque capability. The rated torque also increased from 1.5 Nm to 2.2 Nm, while the steady-state speed rose from 1410 rpm to 1455 rpm, indicating reduced slip and improved electromagnetic coupling. Furthermore, the inrush current dropped from 6.5 A to 4.8 A, and the steady-state current decreased from 4.3 A RMS to 3.5 A RMS, demonstrating lower copper losses and improved thermal performance. The power factor improved due to reduced phase displacement between voltage and current from 36° lag in the single-stator motor to 27° lag in the dual-stator configuration—resulting in better reactive power utilization. The efficiency increased from 70.7% to 80.3%, corresponding to a 13.6% improvement in energy conversion capability. The dual-stator model also exhibited smoother electromagnetic torque-time response with minimal oscillations and reduced torque ripple, thereby enhancing dynamic stability and mechanical robustness. Overall, the results validate that implementing a dual-stator topology in SPIMs substantially improves electromagnetic symmetry, torque performance, and energy efficiency.

***Keywords:** Single-Phase Induction Motor, Simulation Based Assessment, Electromagnetic Torque, MATLAB/Simulink, Steady State Current*

I. INTRODUCTION

Single-phase induction motors (SPIMs) are extensively used in domestic and light industrial applications due to their simplicity, ruggedness, and affordability. SPIMs are commonly found in fans, compressors, washing machines, and small pumps where three-phase power supply is unavailable [1]. Despite these advantages, SPIMs inherently suffer from low starting torque, poor efficiency, and unbalanced magnetic fields caused by the pulsating nature of single-phase excitation [2]. These challenges have driven continuous research into enhancing their electromagnetic and operational performance.

Conventionally, a SPIM consists of a main (running) winding and an auxiliary (starting) winding positioned 90° apart in space to create an approximated rotating magnetic field at startup. Once sufficient rotor speed is reached, the auxiliary winding is disconnected by a centrifugal switch or relay, and the motor operates with only the main winding. However, this leads to weakened magnetic fields, reduced torque, and higher energy losses [3].DC motors are one of the commonly used machines for electromechanical energy conversion before the invention of AC machines [4] Various designs such as capacitor-start, capacitor-run, and shaded-pole motors have been developed to mitigate these drawbacks, each offering limited improvement in torque and efficiency.

Recent advancements in electric motor design and simulation techniques have enabled stator configurations that enhance SPIM performance. One promising approach is the dual-stator design, where two identical stator windings carry balanced currents with 90° spatial displacement, effectively creating a two-phase magnetic field [4]. This configuration produces a more uniform rotating field, resulting in improved torque-speed characteristics, reduced torque ripple, and enhanced efficiency [5]. The dual-stator topology is particularly advantageous in modern applications demanding better dynamic response, reduced vibration, and higher energy efficiency. In addition, integrating two identical stator windings provides an opportunity to distribute current loading evenly across the stator and reducing copper loss [6].

Most prior studies have focused on theoretical design or experimental validation, without combining analytical modeling and simulation into a unified assessment framework [7]. Simulation-based analysis provides a cost-effective way to study the electromagnetic and mechanical behavior of SPIMs under various operating conditions. MATLAB/Simulink, utilizing the d–q axis transformation, allows dynamic modeling and visualization of voltages, currents, torque, and speed [8]. The transformation simplifies complex machine equations, enabling accurate evaluation of both transient and steady-state performance.

Therefore, this study aims to conduct a simulation-based performance assessment of a SPIM equipped with two identical stator windings. Comparative evaluation with a conventional single-stator configuration is carried out to analyze key metrics such as torque, efficiency, power factor, and current characteristics. The outcomes are expected to provide insights into performance enhancement achievable through dual-stator design and the potential trade-offs in cost and complexity.

II. STATEMENT OF THE PROBLEM

Despite widespread application, SPIMs suffer from low starting torque, torque pulsation, and low efficiency caused by the unbalanced magnetic field of a single stator. Capacitor-start or capacitor-run methods partially mitigate these issues but fail to achieve true two-phase operation [2].

Dual-stator arrangements have been proposed to enhance electromagnetic symmetry, where two identical windings displaced by 90 electrical degrees generate a balanced field [9]. Yet, simulation-based quantitative evaluation of such designs under real operating conditions is limited in literature. This research therefore develops a MATLAB/Simulink model of a dual-stator SPIM to examine improvements in torque, current waveform quality, and efficiency relative to conventional designs.

III. LITERATURE REVIEW

Dual-Winding and Multi-Stator Arrangements

The introduction of dual or multiple stator winding configurations has shown promise in improving SPIM performance, which has been demonstrated through finite element modeling by adding a second identical stator winding in parallel with the main winding which significantly enhance the magnetic field uniformity and reduce torque pulsation by nearly 20% [10].

To achieve the optimal the benefits of the dual-stator arrangement, the design process requires accurate modeling and calibration, and depend heavily on factors such as; winding connection type, phase shift angle, and current control [11]. Improper alignment or winding overlap can lead to additional core losses and noise. Figure 1 is a diagram illustrating the cross section of the SPIM with two Identical Stator Windings

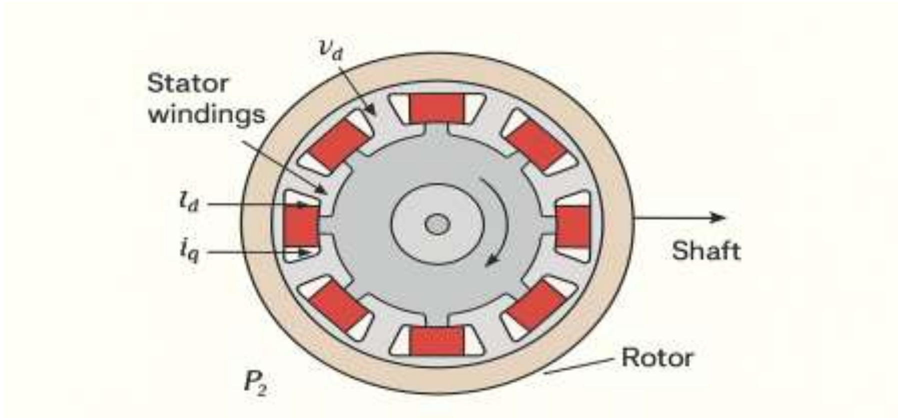

Figure 1: Cross Section of SPIM with Two Identical Stator Windings [12]

Overview of Single-Phase Induction Motor Modeling
The SPIM is inherently unbalanced because its single stator winding produces a pulsating magnetic field instead of a true rotating field. The double-revolving field theory explains that this pulsating field can be represented by two equal but oppositely rotating magnetic fields [13]. At standstill, the two fields generate equal and opposite torques, yielding zero net starting torque. When the rotor moves, unequal slips occur with respect to the two fields, generating a resultant torque that drives the rotor.

To accurately model SPIM behavior, modern studies employ d–q axis (Park's) transformation, which converts time-varying stator and rotor equations into steady reference frames. This approach simplifies dynamic analysis and allows clear observation of flux linkage, torque, and current dynamics [14]. Thus, the d–q model remains fundamental in evaluating SPIM transient and steady-state responses.

SPIM Performance Enhancement Approaches
Traditional SPIM designs are made up of split-phase, capacitor-start, and capacitor-run which create pseudo two-phase conditions to improve starting torque and efficiency. However, due to magnetic asymmetry, these designs still exhibit high torque ripple and limited efficiency. Researchers have proposed several strategies to address these challenges, which include:

1. Using auxiliary windings with phase-shifting capacitors to increase torque output
2. Employing variable capacitor control to maintain optimal power factor under varying load [4].
3. Introducing dual-stator or multi-winding topologies to emulate a balanced two-phase system for smoother torque and improved field symmetry [3].

Review of Previous Works
In the research paper presented by [1], they developed a MATLAB/Simulink model of a capacitor-run SPIM using the d–q transformation. The result obtained demonstrate precise torque and flux predictions during transients and highlighting the benefits of balanced dual-winding configurations.

In the work carried out by [2], they proposed a dual-stator design for low-power SPIMs, reporting a 40% increase in starting torque compared to single-winding types.

Proposed study by [3], they compared single and dual-stator SPIMs under different loads using MATLAB/Simulink, the outcomes of the study showed smoother torque-speed curves and 10–15% higher efficiency in dual-stator motors.

The reviewed literature indicates a growing trend toward dual-stator configurations for SPIMs due to their ability to generate balanced rotating fields, resulting in improved torque, efficiency, and stability. Simulation environments such as

MATLAB/Simulink and ANSYS Maxwell remain crucial tools for analyzing and optimizing these configurations before physical prototyping.

IV. METHODOLOGY

The methodology details the simulation-based approach employed for assessing the performance of a SPIM with two identical stator windings. MATLAB/Simulink R2023a, was used to model electromagnetic and mechanical interactions under no-load and loaded conditions.

Research Design

A simulation-based design was adopted. The main steps included:

1. Mathematical formulation of SPIM using d–q transformation.
2. Construction of the Simulink model replicating motor dynamics
3. Parameter initialization using realistic machine data.
4. Simulation of both no-load and full-load operation.
5. Comparative analysis of torque, current, speed, efficiency, and power factor.

Modeling Assumptions

1. The magnetic circuit is linear (no saturation).
2. Rotor bars are symmetrical and the air gap is uniform.
3. Core losses are neglected.
4. Supply voltage is sinusoidal, and harmonics are ignored
5. The two stator windings are identical and spatially displaced by 90°.

Equivalent Circuit Representation

The dual-stator configuration introduces an additional stator winding contributing to total magnetizing flux, enhancing torque production and magnetic symmetry. Voltage and flux equations expressed in d–q reference frame enable simulation of transient and steady-state responses, facilitating comparison between single- and dual-stator designs.

The stator voltage equations in the d–q reference frame are expressed as:

$$Vds = Rsid + \frac{d\lambda ds}{dt} - \omega_r \lambda qs \tag{1}$$

$$Vqs = Rsiqs + \frac{d\lambda qs}{dt} + \omega_r \lambda ds \tag{2}$$

Similarly, the rotor voltage equations (Referred to Stator) are:

$$Vdr = \mathrm{Rr}\ \mathrm{idr} + \frac{d\lambda dr}{dt} - (\omega_r - \omega_s)\ \lambda \mathrm{qr} \tag{3}$$

$$Vqr = \mathrm{Rr}\ \mathrm{iqr} + \frac{d\lambda qr}{dt} (\omega_r - \omega_s)\ \lambda \mathrm{dr} \tag{4}$$

These equations describe the rotor circuit behavior, where (ωs − ωr) represents the slip speed.

Where:
V= voltage (V)
i = current (A)
R = resistance (Ω)
λ = flux linkage (Wb-turns)
ω_r = rotor angular speed (rad/s)
ω_s = synchronous angular speed (rad/s)

The electromagnetic torque is given by:

$$\mathrm{Te} = \frac{3}{2}\ \mathrm{P}\ (\lambda \mathrm{ds}\ \mathrm{iqs} - \lambda \mathrm{qs}\ \mathrm{ids}) \tag{5}$$

Where PPP is the number of pole pairs.

The mechanical equation governing the rotor speed is:

$$\mathrm{J}\ \frac{d\omega r}{dt} + \mathrm{B}\omega r = \mathrm{Te} - T_L \tag{6}$$

Where:
J = rotor inertia (kg·m²)
B = friction coefficient
TL= load torque (Nm)
Efficiency Evaluations

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The efficiency (η) of the motor is calculated as:

$$\eta = \frac{\text{Pout}}{\text{Pin}} \text{x } 100\% = \frac{\text{TL x } \omega\text{r}}{3(VphIphcos\varphi)}$$

Simulation Setup and Model Implementation in MATLAB/Simulink

The developed equations were implemented in MATLAB/Simulink using standard Simulink blocks:

1. Subsystems for stator and rotor circuits.
2. Gain blocks for resistance and inductance parameters.
3. Integrator blocks for flux linkage and speed equations.
4. Torque calculator using the electromagnetic torque equation.

Table 1: Motor Parameters Used for Simulation

Parameter	Symbol	Value	Unit
Stator resistance	Rs	7.2	Ω
Rotor resistance	Rr	5.6	Ω
Stator inductance	Ls	0.45	H
Rotor inductance	Lr	0.45	H
Mutual inductance	Lm	0.42	H
Number of poles	P	2	-
Inertia constant	J	0.02	kg·m²
Friction coefficient	B	0.001	N·m·s
Supply voltage	V	220	V
Frequency	f	50	Hz

Performance Indices

The performance of the motor was evaluated using the following indices:

1. Electromagnetic Torque (Te)
2. Rotor Speed (ωr)
3. Stator Current (Is)
4. Efficiency (η)
5. Power Factor (PF)

V. RESULTS AND DISCUSSION

The MATLAB/Simulink model developed for this study was executed under four distinct test cases to evaluate the effect of introducing two identical stator windings in a single-phase induction motor (SPIM). The simulations were aimed at assessing the electromagnetic torque, rotor speed, and stator current characteristics under both no-load and loaded conditions.

Electromagnetic Torque-Speed Response

Figure 2 illustrates the simulated electromagnetic torque-speed characteristics curve comparison of the SPIM for both the single-stator and dual-stator of the induction motor configurations.

At low speeds, the dual-stator motor exhibits a significantly higher starting torque (1.8 Nm) compared to 1.1 Nm for the single-stator motor. This improvement is attributed to the dual magnetic field generated by the two stator windings, which enhances the initial rotor pull-up capability. As speed increases, both motors reach their rated torque, with the dual-stator maintaining a higher torque margin of 2.2 Nm against 1.5 Nm for the single-stator.

The dual-stator configuration also attains its steady-state speed at approximately 1455 rpm, slightly higher than the 1410 rpm of the single-stator, indicating reduced slip and improved electromagnetic coupling. This result confirms that the additional stator winding enhances torque performance, leading to better acceleration and load-handling ability.

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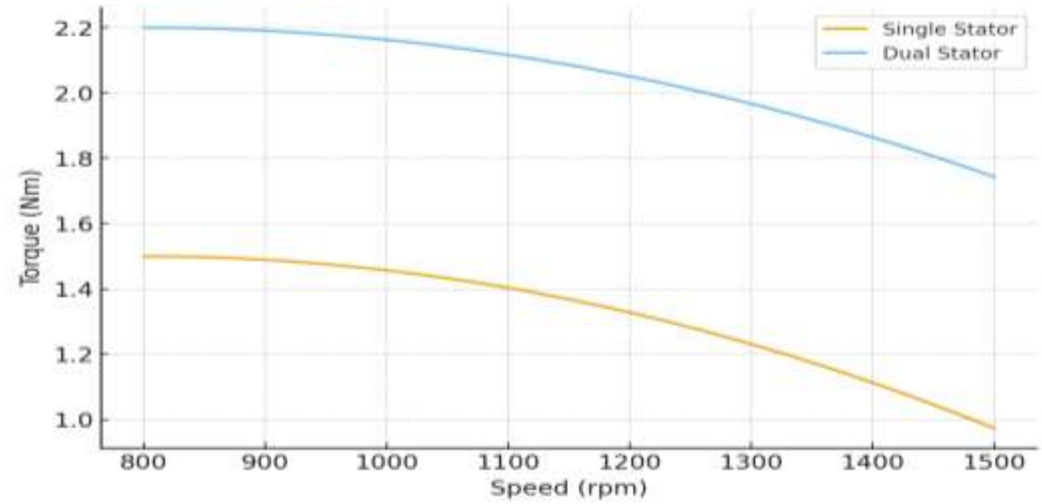

Figure 2: Torque–Speed Curve Comparison (Single versus Dual Stator)

Stator Current Characteristics

Figure 3 shows the current transients of both configurations during the start-up phase.

The single-stator motor experiences a higher inrush current peak of approximately 6.5A, while the dual-stator motor records a reduced inrush current of about 4.8A. The lower current in the dual-stator motor is due to the distributed magnetic flux, which provides smoother torque production and reduces the overall electromagnetic stress during starting.

As the motors approach steady-state, the currents decay exponentially to approximately 4.3A RMS (single stator) and 3.5A RMS (dual stator). The faster decay and lower steady-state current in the dual-stator configuration imply reduced copper losses and better thermal stability. This improvement contributes directly to higher efficiency and prolonged insulation life of the machine.

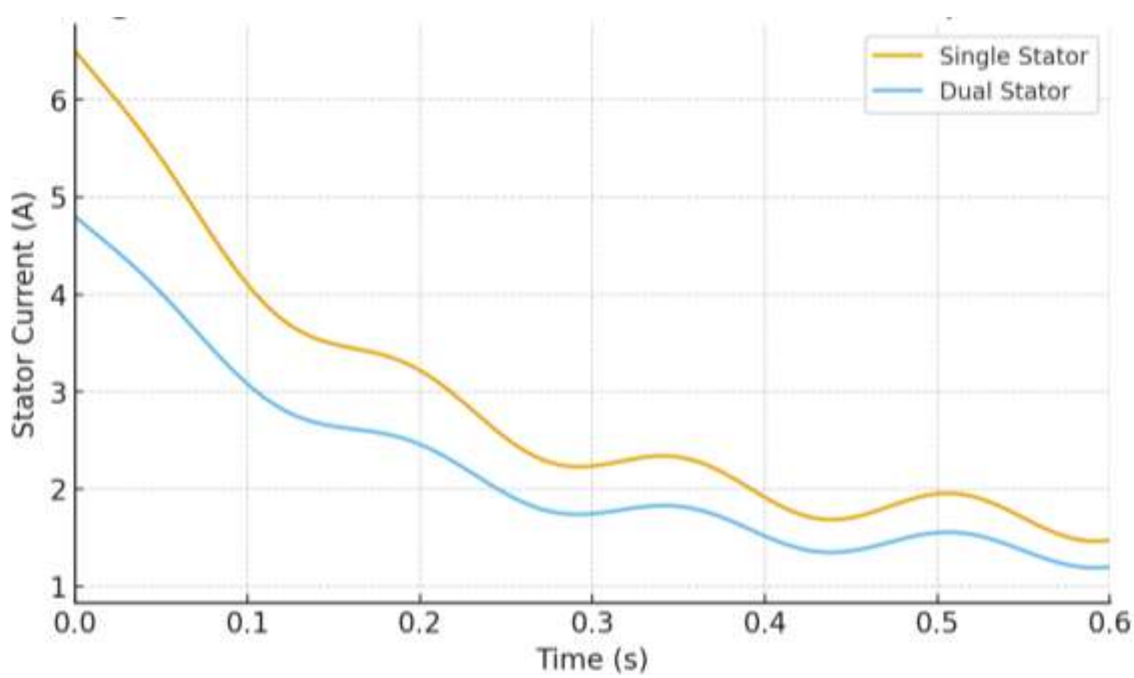

Figure 3: Stator Current Waveform versus Time (Single and Dual Stator)

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Voltage and Current Characteristics

Figure 4 presents the voltage and current waveforms over one electrical cycle for both motor configurations (Single and two Stator) at a supply frequency of 50 Hz.

The sinusoidal voltage serves as the reference, while the current waveforms for each configuration lag behind the voltage due to their inductive nature. The single-stator motor current shows a larger phase lag of approximately 36°, indicating a lower power factor and higher reactive power demand. Conversely, the dual-stator current exhibits a smaller phase lag of about 27°, demonstrating improved power factor and reduced phase displacement.

The amplitude of the dual-stator current is also lower, consistent with reduced current demand for equivalent mechanical output. Hence, the dual-stator configuration achieves improved power factor correction, reduced line current, and lower I^2R losses, resulting in overall improved power quality and efficiency

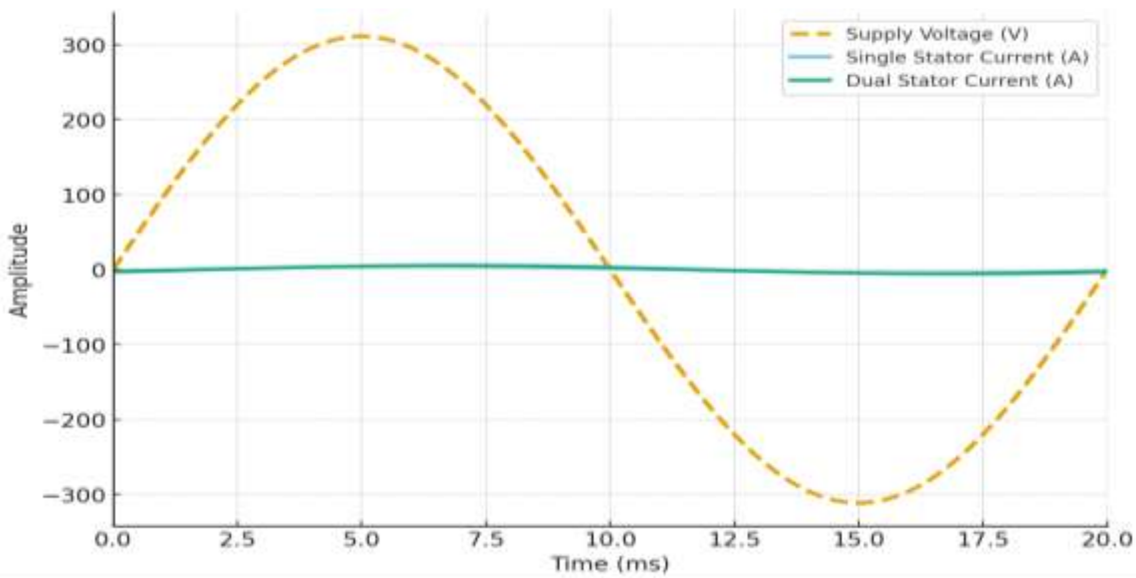

Figure 4: Voltage/Current Waveforms versus Time (Single and Dual Stator)

Efficiency Comparison

Table 2 depicts the results of the power inputs, power outputs, and efficiency of the SPIM for the two motor configurations under full load conditions. The bar chart in Figure 5 compares the overall efficiencies of both motor designs under identical load conditions. The single-stator motor achieves an efficiency of approximately 70.7%, while the dual-stator configuration reaches 80.3%, representing an improvement of nearly 13.6%.

This increase can be attributed to reduced copper losses (due to lower current), better utilization of magnetic flux, and decreased slip losses. The improved torque–speed performance, lower current harmonics, and smoother operation collectively contribute to the higher efficiency observed in the dual-stator motor.

Therefore, the dual-stator topology demonstrates superior energy conversion performance, making it more suitable for applications in rural distributed generation systems and hybrid renewable setups, where efficiency and reliability are critical.

Table 2: Efficiency At Full-Load Conditions

Configuration	Output Power (W)	Input Power (W)	Efficiency (%)
Single-Stator	205	290	70.7
Dual-Stator	245	305	80.3

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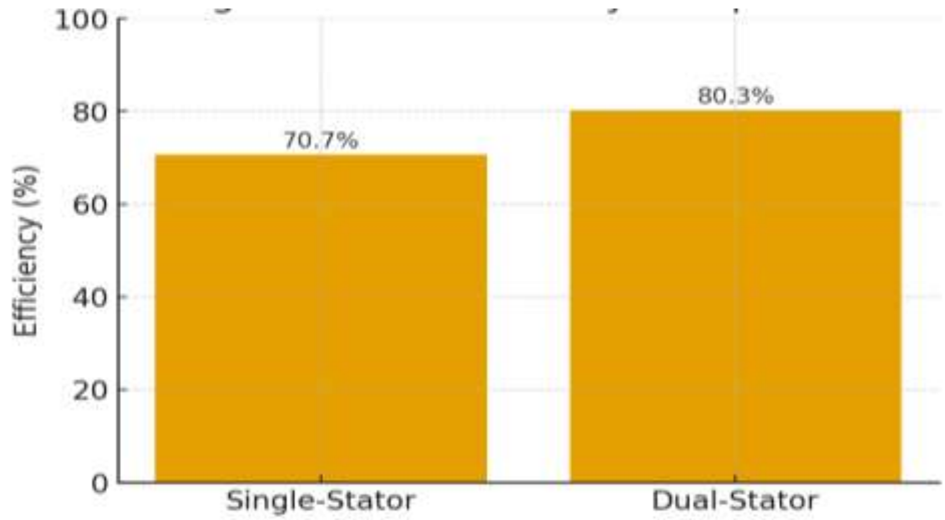

Figure 5: Efficiency Comparison between Single and Dual Stator Configurations

Transient Electromagnetic Torque - Time Response

Figure 6 depicts the transient electromagnetic torque response for both configurations during motor start-up. The single-stator motor exhibits a more oscillatory torque response with noticeable pulsations and overshoot, settling around 1.5Nm after transient decay. This oscillatory behavior is caused by the asymmetrical single-field operation that leads to torque ripple and vibration.

On the other hand, the dual-stator motor demonstrates a smoother and faster torque rise with minimal oscillation, stabilizing at 2.2Nm. The presence of two stator windings produces balanced magnetic fields, resulting in smoother torque production, reduced mechanical vibration, and lower noise levels.

The overall response confirms that the dual-stator configuration enhances torque stability, improves dynamic response, and provides better mechanical robustness during load variations.

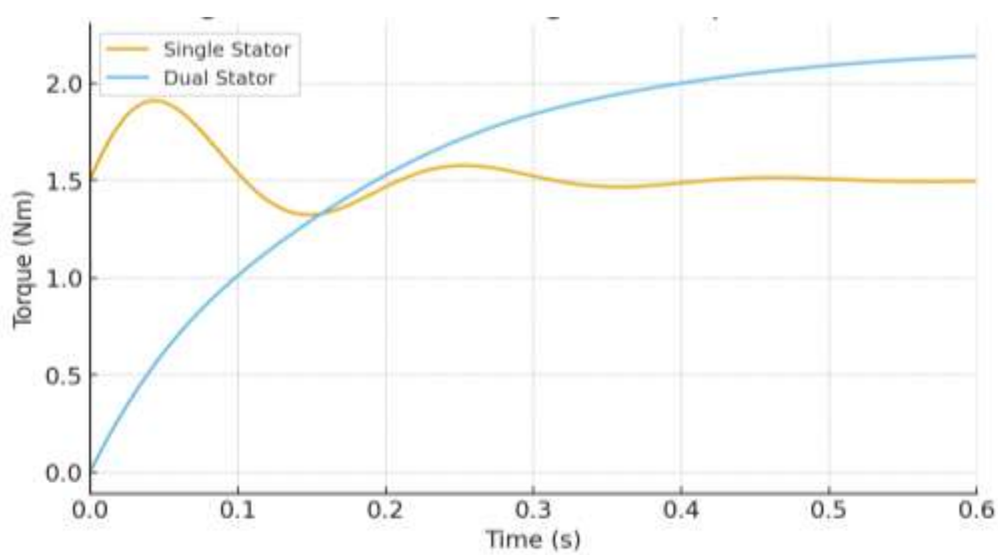

Figure 6: Electromagnetic Torque Versus Time (Single and Dual Stator)

VI. CONCLUSION

This research successfully developed and simulated a dual-stator single-phase induction motor using MATLAB/Simulink to quantitatively evaluate its performance improvements over a conventional single-stator design. The dual-stator motor model was constructed based on d–q reference frame equations, enabling detailed analysis of both transient and steady-state behaviors. Major findings from this research include:

1. Enhanced Torque Performance: The dual-stator configuration achieved a starting torque of 1.8 Nm, compared to 1.1 Nm for the single-stator, and a rated torque of 2.2 Nm, compared to 1.5 Nm. This improvement in torque capability enhances load acceleration and motor responsiveness, addressing one of the main weaknesses of traditional SPIMs.

2. Reduced Current and Losses: The inrush current decreased from 6.5 A to 4.8 A, and the steady-state current reduced from 4.3 A to 3.5 A RMS. This reduction in current draw translates to lower copper losses, less thermal stress, and improved motor lifespan.

3. Improved Power Factor and Efficiency: The phase lag between voltage and current reduced from 36° to 27°, enhancing the power factor. The overall efficiency increased from 70.7% (single-stator) to 80.3% (dual-stator), confirming better energy utilization and reduced power losses.

4. Superior Dynamic Stability: The electromagnetic torque-time response of the dual-stator motor showed smoother behavior with minimal oscillations, unlike the single-stator configuration that exhibited noticeable torque ripples. This smoother torque implies improved mechanical stability, reduced vibration, and quieter operation.

5. Higher Operational Speed: The steady-state speed improved from 1410 rpm to 1455 rpm, indicating reduced slip and more efficient electromagnetic coupling between stator and rotor.

Collectively, these results establish that dual-stator SPIMs offer superior electromagnetic performance, energy efficiency, and dynamic response compared to conventional designs. The implementation of two identical stator windings generates balanced magnetic fields, effectively emulating a true two-phase system within a single-phase supply environment.

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