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Dynamique Modeling and Simulation of a Triple-Star Induction Motor

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Abstract: The modeling of an electric motor is a fundamental stage in its development process. Advances in computer technology and software engineering have enabled the creation of highly accurate models, paving the way for the optimization of electrical machines. Modeling provides a quantitative understanding of the underlying physical phenomena, thereby guiding the design and development process. Furthermore, it serves as a valuable tool for both reproducing experimentally observed behaviors and predicting a wider range of machine operating conditions beyond those accessible through experimental investigation. The study of electrical machine modeling is of significant importance due to technical and economic requirements, which necessitate the design and operation of equipment close to their technological limits. In this work, a model of the Triple-Star Induction Motor (TSIM) is presented based on the solution of the dynamic equations governing its operation. In addition, the modeling of the power supply system is also developed to provide a comprehensive representation of the overall drive system.

Keywords: Modeling, Triple-Star Induction Motor TSIM, Simulation.

1. Introduction

Electric machines play a fundamental role in modern industry and constitute a key component of numerous industrial processes. They are employed in a wide variety of applications, ranging from industrial drives and transportation systems to power generation and energy conversion. Owing to their high efficiency, reliability, and versatility, electric machines have become indispensable in sectors such as manufacturing, mining, construction, and renewable energy production. Their widespread adoption has significantly enhanced productivity, improved energy utilization, and reduced operational costs. Furthermore, the growing demand for sustainable and renewable energy sources has increased the importance of electric machines, particularly in applications involving wind turbines, electric vehicles, and distributed generation systems. [1] [2]

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Among the various types of electric machines, the induction machine is one of the most extensively studied and widely used due to its numerous advantages. It is characterized by its robustness, reliability, low maintenance requirements, and simple construction. These features have made it the preferred choice for a broad range of industrial applications. In particular, the triple-star induction machine has attracted increasing attention because of its enhanced operating characteristics. This configuration provides improved current distribution, reduced harmonic content, increased fault tolerance, and enhanced service continuity, making it especially suitable for high-performance and demanding industrial environments. [3] [4]

Consequently, ongoing research and technological advancements in induction machine design, modeling, control, and optimization continue to drive innovation and contribute to the development of more efficient, reliable, and sustainable industrial systems.

2. Three-Phase Model of the Triple-Star Induction Machine

In order to perform a numerical simulation of the Triple-Star Induction Machine (TSIM), it is necessary to establish an accurate mathematical model of the system. By analyzing the topology of the electrical circuit, a set of independent differential equations governing the evolution of the currents is derived. These equations describe the dynamic behavior of the machine and constitute the basis for its numerical simulation and performance analysis under various operating conditions. [1] [5]

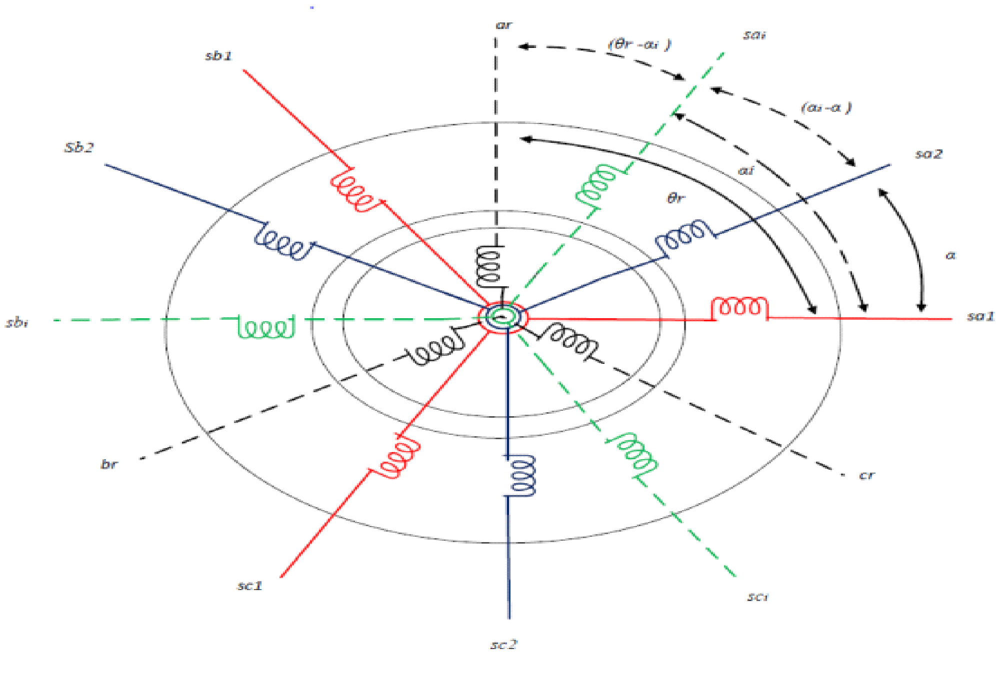

Figure 1: Schematic Diagram of the Stator and Rotor Windings of the Multi-Star Induction Machine (MSIM)

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3. Electrical Equations

The voltage equations for all stator and rotor phases are derived as follows[1] [7]

$$\begin{cases} [V_{sa1}] = [R_{sa1}][I_{sa1}] + \dfrac{d}{dt}[\Phi_{sa1}] \\ [V_{sb2}][R_{sb2}][I_{sb2}] + \dfrac{d}{dt}[\Phi_{sb2}] \\ \vdots \\ [V_{si}] = [R_{si}][I_{si}] + \dfrac{d}{dt}[\Phi_{si}] \\ \vdots \\ [V_r] = [R_r][I_r] + \dfrac{d}{dt}[\Phi_r] \end{cases}$$

Where i=1,2,…, n identifies the i-the star-connected stator winding, and n is the number of star-connected winding sets in the stator.

For Star Set 1

$$\begin{pmatrix} V_{sa1} \\ V_{sb1} \\ V_{sc1} \end{pmatrix} = \begin{pmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{pmatrix} \begin{pmatrix} I_{sa1} \\ I_{sb1} \\ I_{sc1} \end{pmatrix} + \frac{d}{dt} \begin{pmatrix} \Phi_{sa1} \\ \Phi_{sb1} \\ \Phi_{sc1} \end{pmatrix}$$

For Star Set 2

$$\begin{pmatrix} V_{sa2} \\ V_{sb2} \\ V_{sc2} \end{pmatrix} = \begin{pmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{pmatrix} \begin{pmatrix} I_{sa2} \\ I_{sb2} \\ I_{sc2} \end{pmatrix} + \frac{d}{dt} \begin{pmatrix} \Phi_{sa2} \\ \Phi_{sb2} \\ \Phi_{sc2} \end{pmatrix}$$

For Star Set 3

$$\begin{pmatrix} V_{sa3} \\ V_{sb3} \\ V_{sc3} \end{pmatrix} = \begin{pmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{pmatrix} \begin{pmatrix} I_{sa3} \\ I_{sb3} \\ I_{sc3} \end{pmatrix} + \frac{d}{dt} \begin{pmatrix} \Phi_{sa3} \\ \Phi_{sb3} \\ \Phi_{sc3} \end{pmatrix}$$

For the rotor:

$$\begin{pmatrix} V_{ra} \\ V_{rb} \\ V_{rc} \end{pmatrix} = \begin{pmatrix} R_r & 0 & 0 \\ 0 & R_r & 0 \\ 0 & 0 & R_r \end{pmatrix} \begin{pmatrix} I_{ra} \\ I_{rb} \\ I_{rc} \end{pmatrix} + \frac{d}{dt} \begin{pmatrix} \Phi_{ra} \\ \Phi_{rb} \\ \Phi_{rc} \end{pmatrix}$$

As the rotor windings are short-circuited, all rotor phase voltages are assumed to be zero.

The application of the Park transformation to the previously derived equations leads to the following mathematical model.

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4. Association of the TSIM with the Voltage Source Inverters:

Figure (2) shows the configuration of the TSIM supplied by three three-phase voltage source inverters operating under PWM control [5] [6]

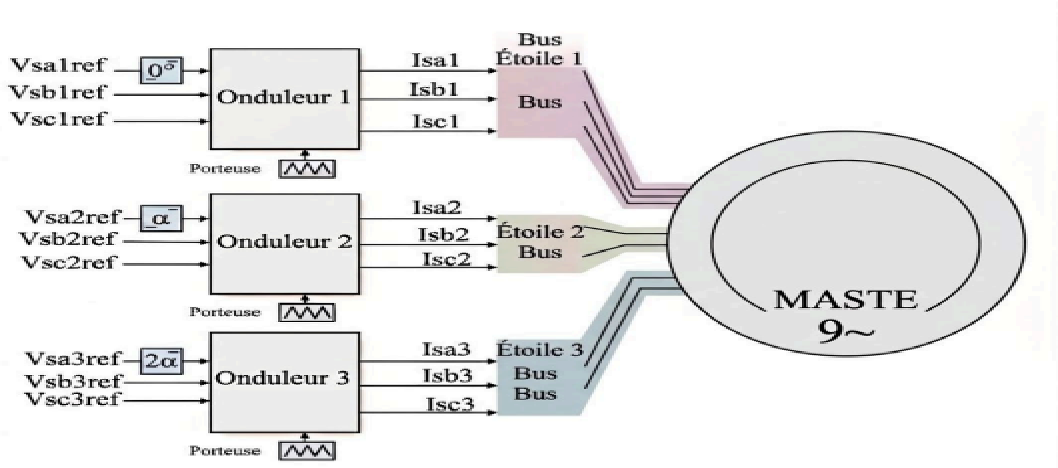


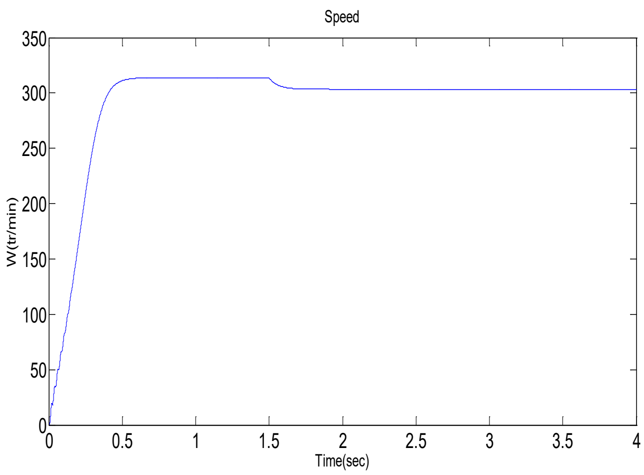
Figure 2: Association of the TSIM with Three PWM Inverters.

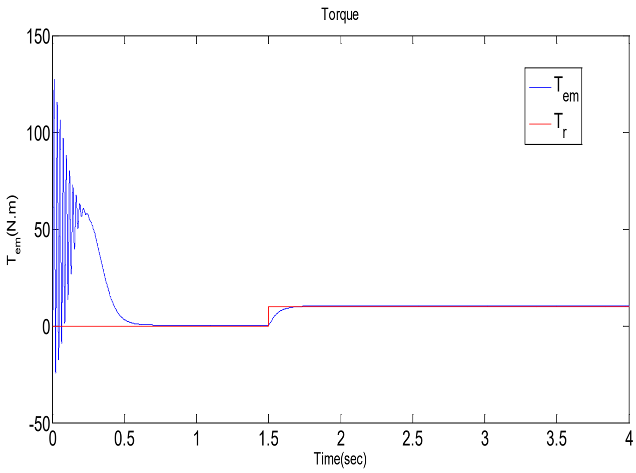
5. Simulation and Result Interpretation of the TSIM

- **Load Test**

For the simulation, it is sufficient to implement the electrical model of the Triple-Star Induction Machine in the MATLAB/Simulink environment

The following figures illustrate the performance of the Triple-Star Induction Machine under load conditions, where a load torque of Cr=10 Nm.





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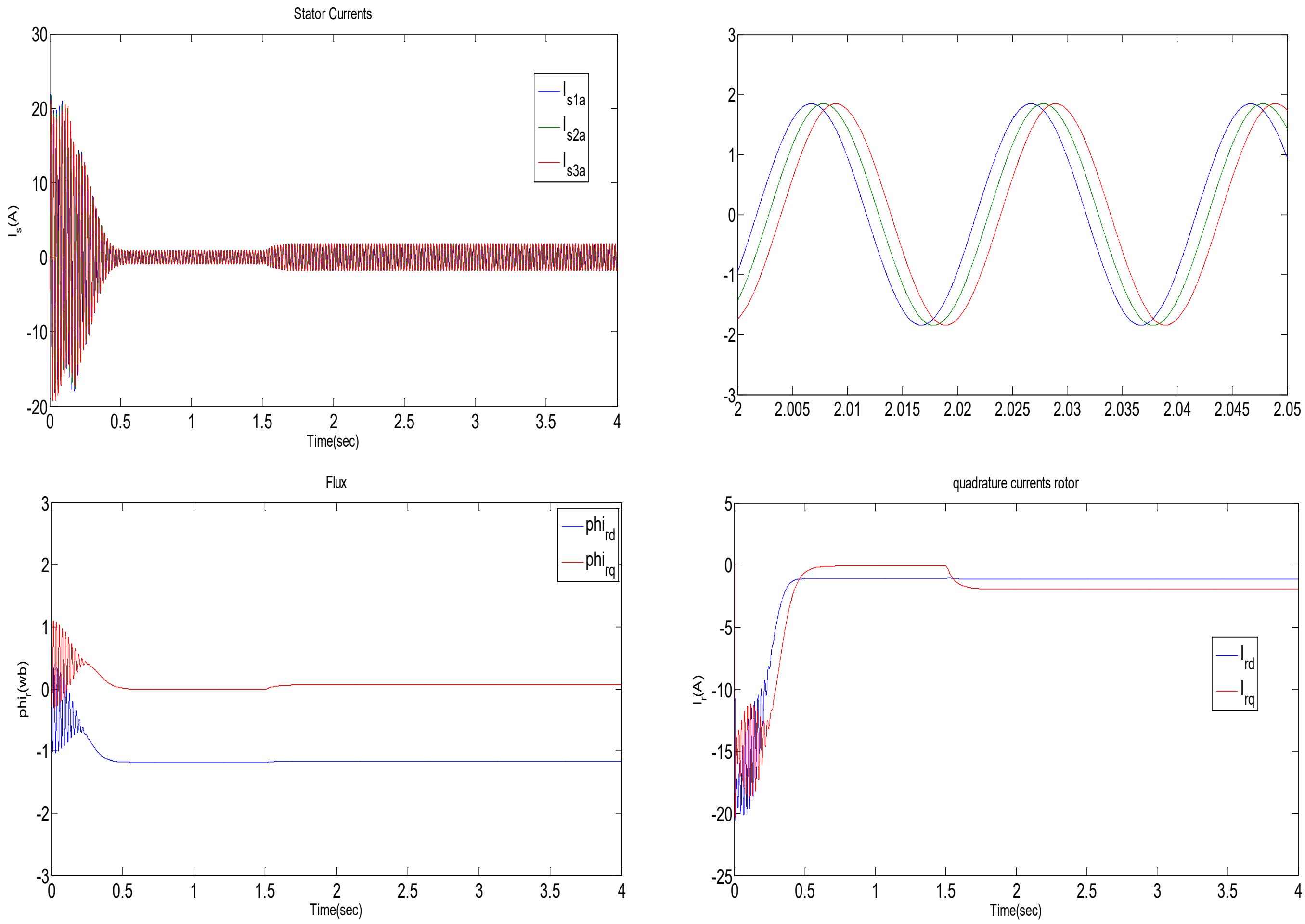

Figure 3 Evolution of the characteristics of the Triple-Star Induction Machine under load conditions.

- **Interpretation of Results**

Figure (3) illustrates the evolution of the speed, electromagnetic torque, stator phase currents (star 1, star 2, and star 3), rotor current, as well as the stator flux (star 1, star 2, and star 3) and rotor flux of the TSIM supplied directly by a three-phase grid. The machine operates under no-load conditions and a load is applied at t=1.5s. The following observations can be made:

- The speed curve shows a linear increase during the transient regime, reaching its nominal value of 313.84 rad/. At t=1.5 s, a decrease in speed is observed, reaching 303.41 rad/ s.
- The electromagnetic torque exhibits significant oscillations with a peak value of approximately 127.28 N m. At t=1.5 s, the torque settles to a value corresponding to the applied load (10.3 Nm).
- The stator and rotor fluxes stabilize around −1.18 Wb.during steady-state operation, and a slight decrease is observed after the application of the load.

6. Case of the Triple-Star Induction Machine Model with Inverter

- **Load Test**

The following figures illustrate the performance of the Triple-Star Induction Machine under a load condition where a load torque of Cr=10 Nm is applied at t=1.5s. This load corresponds to the nominal operating condition of the machine.

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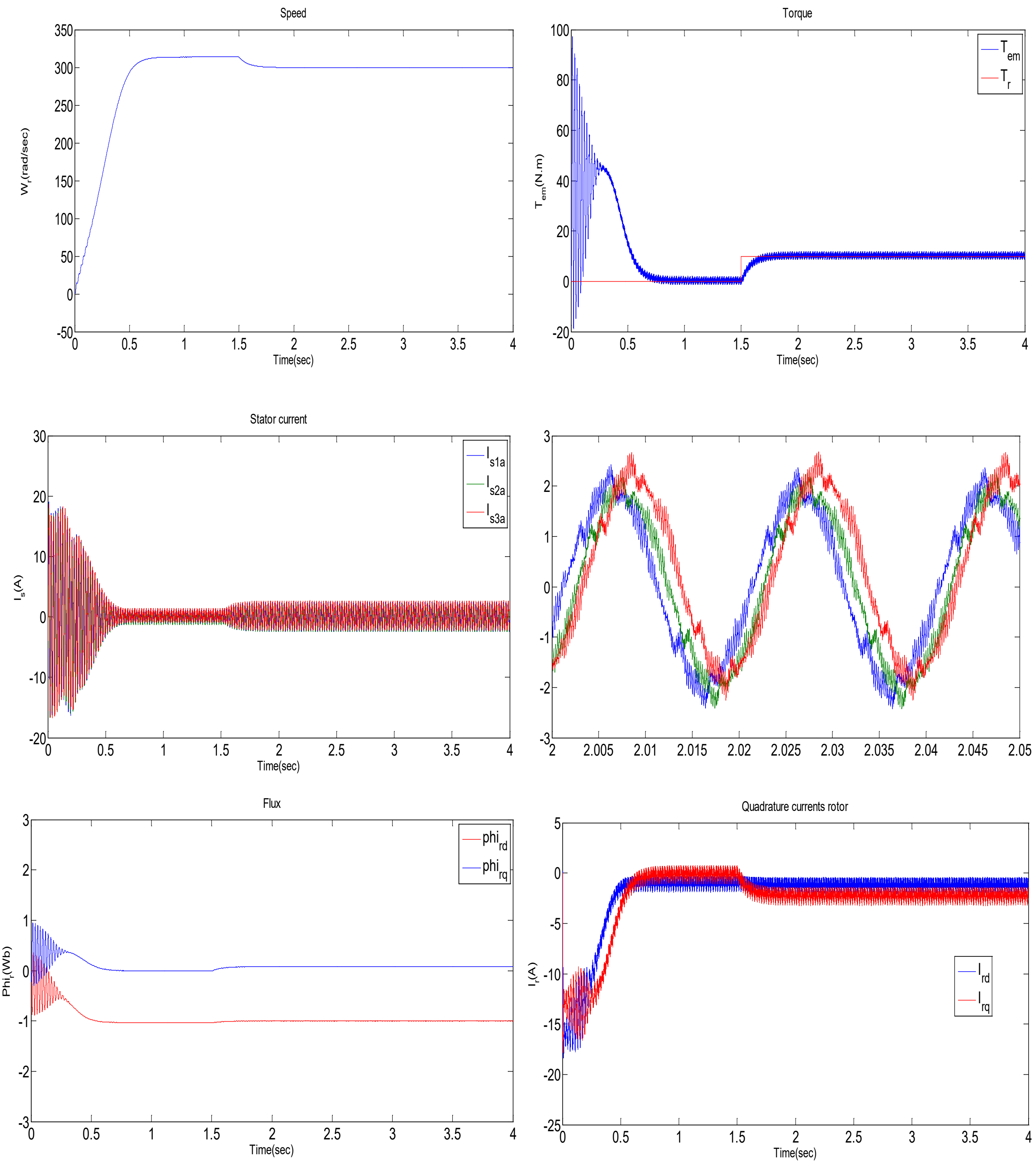

Figure 4. Simulation results of the triple-star induction machine with inverter

- **Interpretation of Results**

The examination of the curves in Figure (4) shows that:

- The stator currents increase to a higher value due to the rise in load torque demand.

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- A slight decrease in speed is observed as a consequence of the applied mechanical load.
- The electromagnetic torque tends to follow and stabilize around the load torque value.
- The ϕdr flux exhibits oscillations in the negative region and stabilizes around −1.17Wb, whereas the ϕqr flux shows oscillations mainly in the positive region and tends toward an approximately zero value in steady-state operation.

7. Conclusion

This work focused on the modeling of the Triple-Star Induction Machine (TSIM) supplied by three voltage source inverters. In the first part, the TSIM model was developed within the framework of Park's theory by transforming the original three-phase system into an equivalent two-phase system, thereby reducing its complexity through several simplifying assumptions.

The second part of this chapter dealt with the power supply of the TSIM using two-level voltage source inverters controlled by a sinusoidal PWM (sinus-triangular) technique. Finally, the obtained simulation results made it possible to analyze the behavior of the TSIM under different operating conditions and supply sources.

To improve the dynamic performance of the machine when subjected to disturbances, further advanced control strategies can be implemented

Conflicts of interest

The authors declare no conflict of interest

Author contributions

B.S. conceived and designed the study. H.A. collected the data. B.S. analyzed the data. H.A wrote the first draft of the manuscript. All authors reviewed and approved the final version.

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