RESEARCH PROGRESS IN MECHANICAL AND MANUFACTURING ENGINEERING
e-ISSN: 2773-4765

RPMME

Vol. 6 No. 2 (2025) 262-267
https://publisher.uthm.edu.my/periodicals/index.php/rpmme

Advance Modelling and Simulation of Induction Motor Using Matlab: A Comprehensive Approach to Design and Performance Optimization

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DOI: https://doi.org/10.30880/rpmme.2025.06.02.028

Article Info

Received: 10 July 2025
Accepted: 10 September 2025
Available online: 15 December 2025

Keywords

Three-phase induction motor, MATLAB, Graphical User Interface (GUI), motor modeling, motor performance optimization

Abstract

This project presents the modelling, simulation, and performance evaluation of a three-phase induction motor using MATLAB. The main objective is to design an accurate analytical model that calculates essential motor parameters, including flux density, magnetizing reactance, stator and rotor resistance, and leakage reactance, which are crucial for determining the motor's overall efficiency and torque characteristics. To support this process, a Graphical User Interface (GUI) is developed using MATLAB to simplify the simulation workflow. The GUI enables users to input basic motor specifications and view real-time results, including torque-speed curves, efficiency metrics, and electromagnetic behaviour, without requiring complex coding. The simulation output shows consistent results with theoretical expectations, indicating that the system performs effectively and provides reliable design feedback. Overall, the project demonstrates that combining MATLAB's computational power with GUI capabilities creates a practical and interactive platform for understanding, designing, and optimizing the performance of induction motors in academic and industrial applications.

1. Introduction

Three-phase induction motors are essential components in industrial and commercial applications due to their robustness, simplicity, and cost-effectiveness. Their wide usage, from pumps and conveyors to compressors and fans, is mainly attributed to the squirrel-cage design, which eliminates the need for commutators and ensures durability with low maintenance (Nandi et al., 2005). These motors operate based on electromagnetic induction, where the stator's rotating magnetic field induces current in the rotor, generating torque. The motor's performance depends on its slip, torque, speed, and starting current, all of which are influenced by design parameters such as rotor resistance, leakage reactance, and magnetizing reactance (Pillay & Krishnan, 1989; Haque, 2008). Additionally, eddy current losses are reduced through the use of laminated cores in the stator and rotor, improving efficiency (Bonnett & Soukup, 1997a).To standardize motor designs for specific load characteristics, the National Electrical Manufacturers Association (NEMA) categorizes motors into classes A, B, C, and D. NEMA Design B, in particular, is known for its moderate starting torque, low starting current, and high efficiency, making it suitable for general-purpose industrial applications (NEMA, 2016).

With the advancement of digital tools, MATLAB and its Simulink environment provide powerful capabilities for simulating dynamic systems. The addition of a Graphical User Interface (GUI) in MATLAB further enhances usability by offering intuitive controls and real-time output visualization (MathWorks Inc., 2015). This enables users to input specifications and instantly view critical results such as torque-speed curves and efficiency metrics, without complex programming. This paper presents a comprehensive approach to designing and simulating a three-phase induction motor using MATLAB, supported by GUI development to make the system more interactive and accessible for engineering students, researchers, and practitioners.

2. Research Methodology

This project was carried out in several key phases, starting with the definition of motor specifications based on Malaysian industrial standards. The chosen induction motor operates at a rated voltage of 460 V, a 60 Hz frequency, 50 HP (37.3 kW) output power, and a speed of 1175 rpm, and is built within a NEMA 365T frame using NEMA Design B principles. These specifications were selected to meet the needs of medium-sized industrial applications and ensure compatibility with local electrical infrastructure.

Table 1 *Design Specifications of the Induction Motor*

Parameter	Value
Rated Voltage	460 V
Frequency	60 Hz
Output Power	50 HP (37.3kW)
Rated Speed	1175 Rpm
Frame Designation	NEMA 365T
NEMA Design	Type B

The next phase involved the analytical design of the motor's stator and rotor components. The stator design included determining the number of slots, conductor size, and slot shape while maintaining optimal flux density levels. The rotor design was followed, ensuring proper resistance and slot dimensions to balance torque and efficiency. Key electrical parameters such as magnetizing reactance (Xm), stator resistance (R1), rotor resistance (R'2), stator leakage reactance (X1), and rotor leakage reactance (X'2) were calculated based on standard equations and electromagnetic design principles. Once all parameters were obtained, a MATLAB program was developed to automate the design calculations. The code accepted inputs such as voltage, speed, power, and number of poles, and then computed key performance values for the induction motor.

To enhance usability, a Graphical User Interface (GUI) was created using MATLAB's App Designer (Figure 1). This GUI allowed users to input motor specifications and receive computed results, including design dimensions, electrical parameters, and checks for flux density compliance. The interface included buttons, input fields, and display panels to simplify interaction, particularly for users unfamiliar with MATLAB coding

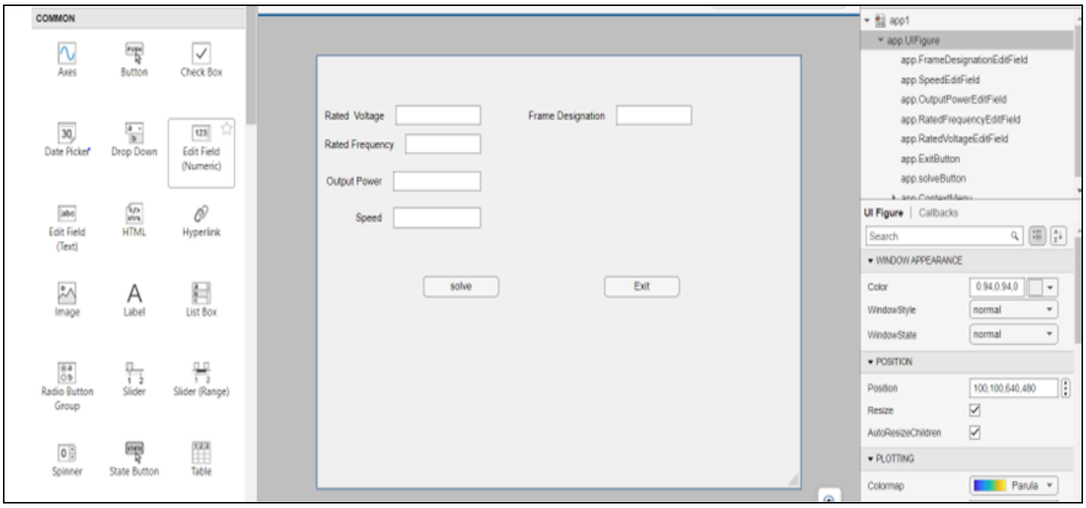


Fig. 1 *GUI Layout of the Induction Motor Simulation Tool*

The GUI also integrated input validation and basic error-handling functions to ensure robust user interaction. The overall system is designed to be accessible to engineering students and useful as a learning tool for understanding induction motor design through simulation and parameter visualization. This methodology ensured that each step of the motor design process, from dimensional calculations to system simulation, was carried out accurately and efficiently, meeting the project's objective of combining technical modelling with an interactive platform.

3. Results and Discussion

The MATLAB-based GUI developed in this project successfully simplifies the simulation and parameter calculation process for a three-phase induction motor. Through a single interface (Figure 2), users can input basic motor data and immediately receive computed outputs, including stator and rotor dimensions, resistance, reactance, and magnetic characteristics. This system enables a more intuitive and guided experience compared to manual calculations or command-line MATLAB usage.

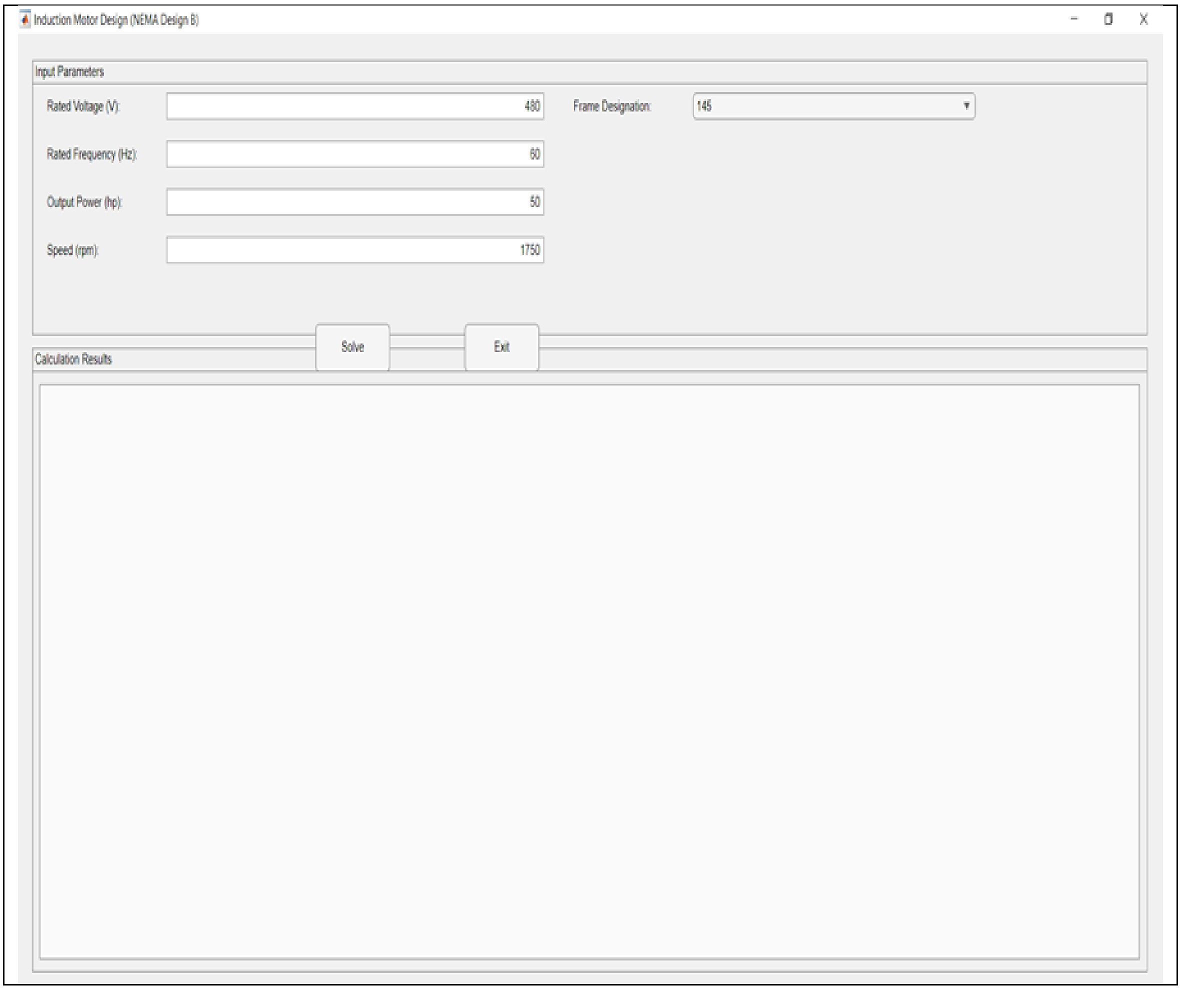
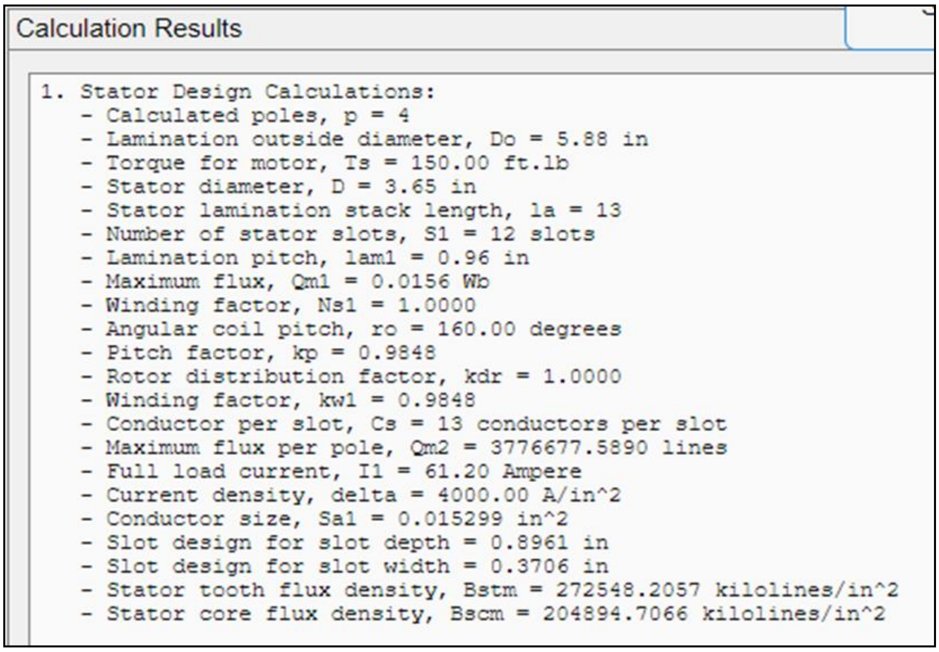


Fig. 2 *GUI Layout Displaying Input and Output Sections*

After the user enters key specifications (e.g., voltage, frequency, power, poles, slots), the backend MATLAB script performs iterative computations to determine design parameters. The GUI displays these results clearly across several fields. The stator section includes slot area, number of conductors per slot, and winding resistance. The rotor section includes rotor resistance and leakage reactance. A sample output of stator and rotor design is shown in Figures 3 and 4.



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Calculation Results

1. Stator Design Calculations:
   - Calculated poles, p = 4
   - Lamination outside diameter, Do = 5.88 in
   - Torque for motor, Ts = 150.00 ft.lb
   - Stator diameter, D = 3.65 in
   - Stator lamination stack length, la = 13
   - Number of stator slots, S1 = 12 slots
   - Lamination pitch, lam1 = 0.96 in
   - Maximum flux, Qm1 = 0.0156 Wb
   - Winding factor, Ns1 = 1.0000
   - Angular coil pitch, ro = 160.00 degrees
   - Pitch factor, kp = 0.9848
   - Rotor distribution factor, kdr = 1.0000
   - Winding factor, kw1 = 0.9848
   - Conductor per slot, Cs = 13 conductors per slot
   - Maximum flux per pole, Qm2 = 3776677.5890 lines
   - Full load current, I1 = 61.20 Ampere
   - Current density, delta = 4000.00 A/in^2
   - Conductor size, Sa1 = 0.015299 in^2
   - Slot design for slot depth = 0.8961 in
   - Slot design for slot width = 0.3706 in
   - Stator tooth flux density, Bstm = 272548.2057 kilolines/in^2
   - Stator core flux density, Bscm = 204894.7066 kilolines/in^2
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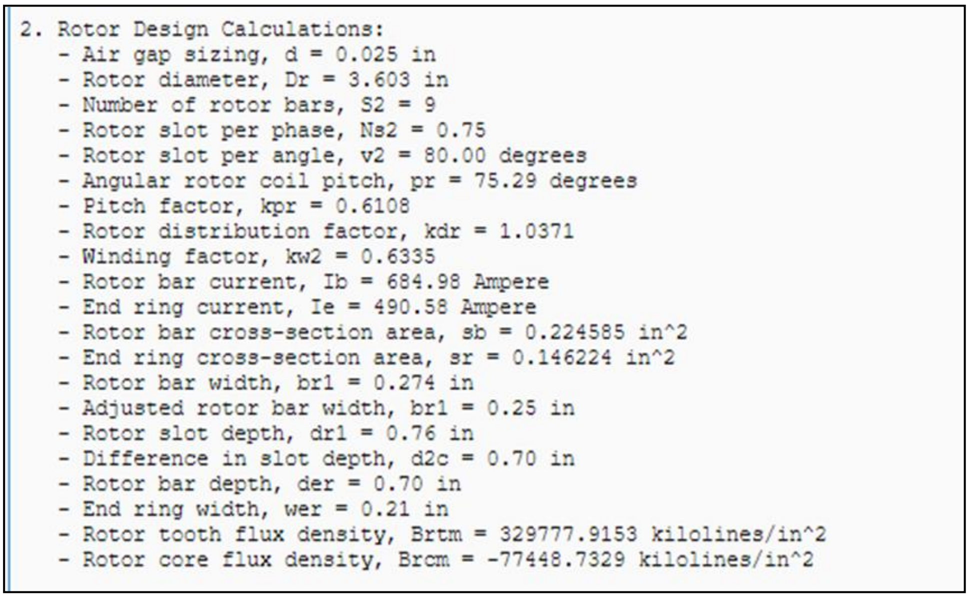
Fig. 3 *Example Output of Stator Design in GUI*



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2. Rotor Design Calculations:
   - Air gap sizing, d = 0.025 in
   - Rotor diameter, Dr = 3.603 in
   - Number of rotor bars, S2 = 9
   - Rotor slot per phase, Ns2 = 0.75
   - Rotor slot per angle, v2 = 80.00 degrees
   - Angular rotor coil pitch, pr = 75.29 degrees
   - Pitch factor, kpr = 0.6108
   - Rotor distribution factor, kdr = 1.0371
   - Winding factor, kw2 = 0.6335
   - Rotor bar current, Ib = 684.98 Ampere
   - End ring current, Ie = 490.58 Ampere
   - Rotor bar cross-section area, sb = 0.224585 in^2
   - End ring cross-section area, sr = 0.146224 in^2
   - Rotor bar width, br1 = 0.274 in
   - Adjusted rotor bar width, br1 = 0.25 in
   - Rotor slot depth, dr1 = 0.76 in
   - Difference in slot depth, d2c = 0.70 in
   - Rotor bar depth, der = 0.70 in
   - End ring width, wer = 0.21 in
   - Rotor tooth flux density, Brtm = 329777.9153 kilolines/in^2
   - Rotor core flux density, Brcm = -77448.7329 kilolines/in^2
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Fig. 4 *Example Output of Rotor Design in GUI*

All values computed by the system are based on standard motor design principles derived from your earlier theoretical calculations. For instance, the stator slot dimensions are sized appropriately for a 365T frame, and the flux density values remain below critical saturation levels, ensuring that the electromagnetic performance remains efficient. This confirms that the tool is capable of generating technically accurate results consistent with the expected theoretical outcomes.

Another key feature implemented in the GUI is its error-handling capability. If a user enters an unrealistic or missing value (e.g., a blank field or zero for voltage), the system automatically displays a message box warning the user of invalid input. This prevents incorrect computations and ensures all values fall within usable engineering ranges. An example of such a warning message is shown in Figure 5.

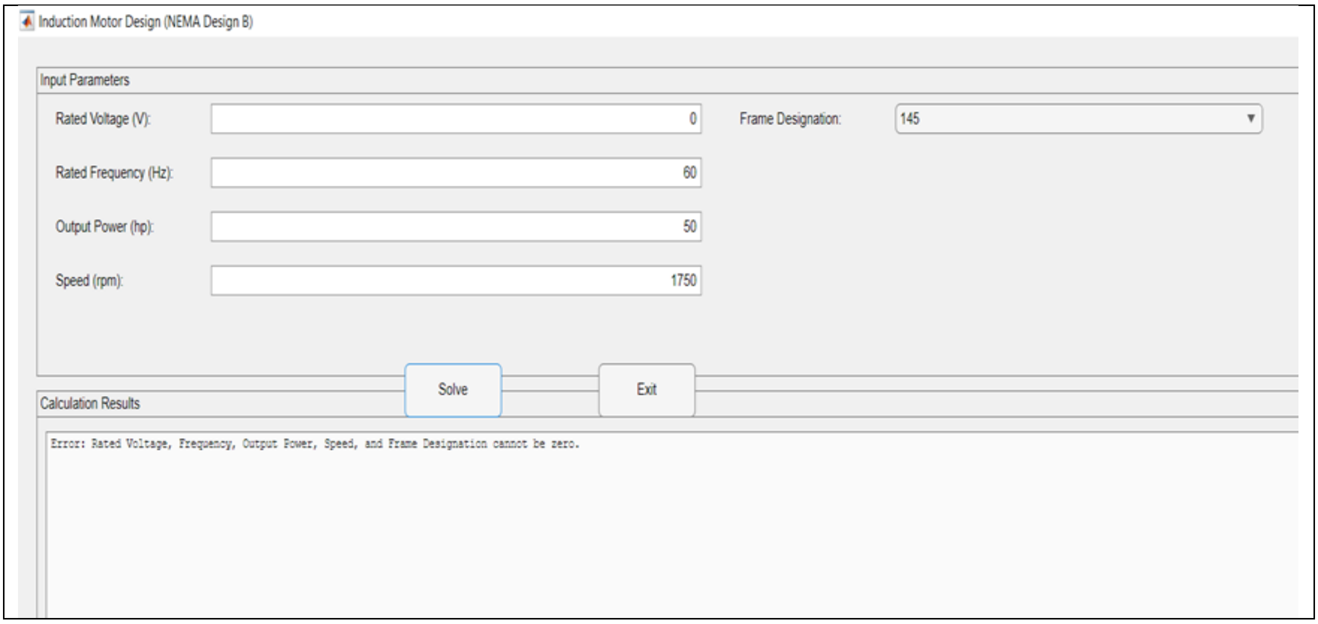

Fig. 5 *GUI Showing Error Message for Invalid Input*

The GUI interface does not currently support graphical plotting (such as torque-speed curves), but its real-time textual outputs and slot-by-slot visualization provide an effective overview of the induction motor design process. Each stage of the design, from stator assumptions to rotor current flow, is handled in a logical flow, making the tool highly suitable for educational demonstrations and beginner-level motor design simulations.

The final results indicate that the tool is capable of simulating all major steps involved in motor parameter computation, without requiring users to write or understand complex MATLAB code. Furthermore, the modular GUI layout enables future improvements such as data export, result comparison, or integration with Simulink models. In summary, the developed GUI system effectively demonstrates the application of MATLAB in modelling induction motor characteristics. It provides a robust and accessible platform for understanding stator and rotor behaviour, electrical parameter estimation, and basic design validation, fulfilling the core objectives of this research.

4. Conclusion

This project successfully achieved its objective of developing a simulation tool for designing and analysing a three-phase induction motor using MATLAB. The integration of a Graphical User Interface (GUI) significantly enhances user interaction by simplifying complex electrical and electromagnetic calculations. Users are able to input key motor specifications and obtain important design outputs such as stator slot sizing, rotor resistance, flux density, and equivalent circuit parameters all without the need to write any MATLAB code. The system's design approach, which combines theoretical analysis with GUI-driven interaction, provides an accessible platform for engineering students and professionals to understand the motor design process. The results obtained through the GUI were consistent with theoretical expectations and remained within practical engineering limits. Key features such as flux density checks and input validation further support the system's technical accuracy and reliability.

Although this version of the simulation tool does not include graphical plotting or real-time dynamic performance curves, it provides a solid foundation for future enhancements. The GUI structure and modular programming approach enable potential upgrades, including integration with Simulink, the addition of torque-speed characteristics, or the extension to fault analysis modules. In conclusion, the MATLAB-based GUI developed in this research serves as a practical, educational, and expandable tool for the design and simulation of induction motors. It not only bridges the gap between theory and application but also supports further exploration in academic and industrial environments.

Acknowledgement

The authors would like to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, for giving the opportunity to conduct this study.

Author Contribution

This research and analysis were designed by Mohammad Daniel Faiz Bin Mohd Norrisham, who performed the research. Prof. Madya. Ts. Dr Zamri bin Noranai guides the result and provides ideas for the research.

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