Journal for Maritime in Community Service and Empowerment ISSN:
Vol. xx, No xx, Month-year

Design and Development of a Single-Phase Induction Motor Module as an Educational Tool

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Abstract: *In the field of education, particularly in marine electrical engineering, knowledge of single-phase capacitor motors is essential. To equip students with a solid understanding of the principles and operation of single-phase capacitor AC motors, appropriate infrastructure and learning tools, such as trainer kits, are required. A trainer kit functions as a basic educational tool that enhances comprehension of single-phase capacitor induction motors, which is crucial for students studying specialized courses in electrical motors. This tool enables various practical experiments, such as measuring the insulation resistance of motor windings, reversing the motor's rotation, testing the starting process of capacitor motors, and analyzing the power factor of capacitor motors. Additionally, a single-phase induction motor with a capacitor start can be used as a split-phase motor. The starting current in a split-phase motor is higher compared to a capacitor-start induction motor because the capacitor increases the starting power, resulting in a smaller current compared to the split-phase motor.*

Keyword: *Marine electrical engineering, Trainer kits, Induction motors, Capacitor-start motors*

Introduction

In both the industrial and maritime sectors, electric motors play a crucial role, often serving as the driving force behind the production of specific goods, whether through manual or automated processes [1]. Similarly, in the field of education, especially within the discipline of marine electrical engineering, a comprehensive understanding of single-phase induction motors is of significant importance [2][3]. To equip students with a thorough understanding of the principles and operational mechanics of these motors, proper infrastructure and educational tools commonly known as trainer kits are essential [4]. These tools provide hands-on learning experiences that are fundamental for students pursuing specialized courses in electrical motors.

A single-phase induction motor is a type of electric motor that operates on the principle of electromagnetic induction [5]. It consists of two main components: the stator and the rotor. The stator, the stationary part of the motor, receives electrical power, while the rotor, the moving part, is induced by the electromagnetic field generated in the stator through an air gap. This electromagnetic interaction gives rise to the term "induction motor." In industrial applications, single-phase induction motors are used in various systems such as compressors, pumps, main drive units for production processes or mills, and workshop machinery like drills, grinders, and cranes.

Due to the essential role of single-phase induction motors in both industry and education, as well as the limitations of existing trainer kits in the Electrical Engineering Laboratory at the Surabaya State Shipbuilding Polytechnic, this final project aims to develop a trainer kit designed to enhance students' understanding of single-phase induction motors [6][7]. The trainer kit will enable students to conduct a range of experiments, such as measuring insulation resistance of motor windings, reversing the direction of rotation, and testing the starting process of capacitor motors [8][9]. This hands-on tool will allow students to explore key aspects of motor functionality, equipping them with practical skills and a deeper understanding of electrical motor systems.

In the context of community service, this educational tool has the potential to extend beyond the classroom. The development of such training equipment aligns with the broader goal of empowering local communities by providing accessible and practical learning resources. By creating tools that support hands-on learning, the project not only contributes to the academic development of students but also facilitates the skill-building of individuals in local industries, improving their knowledge and technical expertise in electrical engineering.

Methodology

The research methodology serves as the primary approach to achieving the objectives of the study. The selection of the appropriate methodology should be aligned with the goals and nature of the research[10]. In the context of this project, the methodology focuses on the design and development of an educational tool that addresses the practical learning needs of students and empowers local communities through technical education[11]. Furthermore, the research methodology outlines the various stages of the project, including the design phase, the construction of the single-phase induction motor module, and the subsequent implementation of the tool in educational settings[12][14]. The steps involved in the research process, from data collection and testing to finalizing the tool and preparing the report, will be thoroughly detailed to ensure transparency and replicability in community-oriented educational projects.

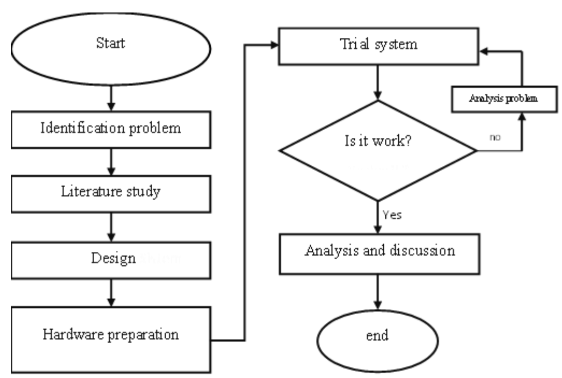

Figure 1. Flowchart

The issue began with the damage of the single-phase induction motor trainer kit in the electrical engineering laboratory at PPNS Polytechnic. This trainer kit, which was a crucial teaching tool for students, was no longer functional, hindering practical learning activities. The primary objective of this project was, therefore, to develop and design a new educational tool specifically a trainer kit or learning module that could be used effectively for student practical sessions at PPNS. The goal was to address the gap created by the damaged equipment and to improve the overall learning experience by providing students with an accessible and efficient tool for understanding single-phase induction motors.

In line with the development of the single-phase induction motor trainer kit, this final project aims to build upon the work whose previous project had some limitations [13][15]. The updated version of the trainer kit incorporates several key improvements. Notably, three additional measuring instruments were included: a voltmeter to measure voltage, an ampermeter to measure current, and an RPM meter to monitor the rotational speed of the motor[16]. These enhancements are designed to provide students with a more comprehensive understanding of the motor's operational characteristics[17].

$$Ns = 120.f / p :$$

With:

• Ns : stator rotation field speed (rpm).

• f : frequency (Hz).

• p : number of poles.

Then, for the formula for calculating the amount of slip in an induction motor (cage rotor), you can use the following equation[18] [19]:

$$S = \frac{\mathrm{Nr - Ns}}{Nr}\,100\%$$

With:

• S: motor slip.

• Nr: rotor rotation speed (rpm).

Next, to calculate the value of mechanical power and torque in an induction motor, we can use the equation below[20]:

Power Mechanic:

$$Pmek = I_2^{\,2}.R_2\ \frac{(1-s)}{s}$$

Torque:

$$T = \frac{\mathrm{Pmek}}{\omega r}$$

Efficiency:

$$\eta = \frac{P_{out}}{P_{in}}\ x\ 100\ \%$$

With :

• Prot: power on the rotor.

• Pmek = Pout: rotor mechanical power.

• T: torque.

• I2: current in the rotor.

• R2: resistance on the rotor.

• η : efficiency.

Furthermore, an important addition to this project is the inclusion of a test to convert the capacitor-start induction motor into a split-phase motor. This conversion experiment will allow students to directly observe and understand the differences in motor performance, specifically in terms of starting currents and efficiency, providing a more practical insight into the application of single-phase induction motors in real-world scenarios.

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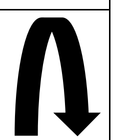
Results and Discussions

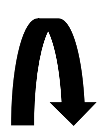
Each component has undergone testing and comparison with conventional measuring instruments commonly used in the field. The results of the comparison for the readings of each component and measuring instrument are presented in the table below:

Table 1. Experiment result motor induction 1

Voltage (UL)	Current (IL)	Start current (Is)	Rotation (RPM)	Capacitor (μf)	Direction
200 v	3.6	18.90	1497	Non	
200 v	3.6	17.59	1497	100	
200 v	3.5	17.60	1499	300	
200 v	3.59	17.95	1500	400	

The motor was tested with the rotation set to the right, and the results demonstrated consistent performance. The rotational speed matched the expected values, with minimal deviation observed during the trials. This indicates that the motor operates efficiently in a clockwise direction, providing smooth and stable motion under the given test conditions.

Table 2. Experiment result motor induction 2

Voltage (UL)	Current (IL)	Start current (Is)	Rotation (RPM)	Capacitor (μf)	Direction
220 v	4.2	18.90	1496	Non	
220 v	4.1	17.70	1500	100	
220 v	4	17.65	1497	300	
220 v	4	17.80	1498	400	

During the clockwise rotation tests, the motor exhibited stable performance with predictable speed and torque outputs. The data confirmed that the motor maintained reliable operation when turning to the right, ensuring consistent mechanical stability and validating the effectiveness of the implemented capacitor.

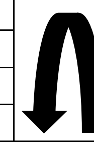
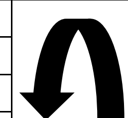
Voltage (UL)	Current (IL)	Start current (Is)	Rotation (RPM)	Capacitor (μf)	Direction
200 v	3.59	18.90	1496	Non	
200 v	3.5	17.59	1500	100	
200 v	3.4	17.60	1497	300	
200 v	3.4	17.95	1498	400	

Table 3. Experiment result motor induction 3

When the motor was tested for counterclockwise rotation, it showed a steady and reliable performance. The rotational speed was within the expected range, and the motion remained smooth throughout the trials. This suggests that the motor is well-suited for operation in a leftward direction under similar conditions.

Table 4. Experiment result motor induction 4

Voltage (UL)	Current (IL)	Start current (Is)	Rotation (RPM)	Capacitor (μf)	Direction
220 v	4.2	18.90	1496	Non	
220 v	4.1	17.70	1500	100	
220 v	4	17.65	1497	300	
220 v	4	17.80	1498	400	

The motor's performance during counterclockwise operation was evaluated, revealing stable speed and effective torque delivery. The test data confirmed that the motor functioned efficiently when set to rotate left, demonstrating consistent electrical and mechanical characteristics during operation.

Discussion

Based on the test results for each capacitor, whether 100, 300, or 400 microfarads or without a capacitor, there were noticeable differences compared to using a capacitor, even though the variations in capacity did not significantly impact the results. This is because the primary function of a capacitor is to enhance motor torque and reduce the current in the motor.

For cases without a capacitor, the differences were quite pronounced. Without a capacitor, the starting current became much larger, resulting in less smooth initial rotations. This demonstrates the critical role of capacitors in stabilizing the motor's performance during startup.

The test results also highlighted differences in motor current (IL) depending on the supply voltage. The variations in voltage supply influenced the current drawn by the motor, emphasizing the interplay between voltage, current, and motor performance.

Regarding rotational speed, the data indicated that there was no significant difference in speed between the motor's clockwise and counterclockwise rotations. This suggests that the rotational characteristics remain consistent irrespective of direction.

In conclusion, the tests demonstrate the importance of capacitors in improving motor efficiency and reducing the starting current, while also highlighting that rotational speed is largely unaffected by direction but dependent on the capacitor's presence and capacity.

Conclusion

The development of the trainer kit has been successfully completed. A single-phase induction motor with a capacitor-start configuration can be utilized as a split-phase motor, provided that the resistance of the main winding is lower than that of the auxiliary winding.

In split-phase motors, the starting current is higher compared to capacitor-start induction motors. This difference occurs because the capacitor in the capacitor-start motor enhances the starting power, which reduces the current required during the startup phase. In contrast, split-phase motors lack this capacitor support, leading to a higher starting current.

This finding underscores the functional distinction between capacitor-start and split-phase motors, highlighting the capacitor's critical role in optimizing startup efficiency and reducing current demand. The trainer kit facilitates these insights, making it an effective educational tool for understanding these motor types.

In short:

- Completion of Trainer Kit Development: The trainer kit has been fully developed and is ready for practical and educational use. It provides a hands-on platform to study and analyze single-phase induction motors.

- Dual Functionality: The motor can function as a capacitor-start motor or be adapted to operate as a split-phase motor. For the motor to work as a split-phase motor, the resistance of the main winding must be lower than that of the auxiliary winding.

- Starting Current Comparison: in Split-Phase Motors: Split-phase motors require more current during startup compared to capacitor-start motors. In capacitor-start motors, the capacitor enhances the starting power, reducing the current demand during startup. Without the capacitor, as in split-phase motors, the startup current is significantly higher.

- Importance of the Capacitor in Motor Performance: The capacitor ensures efficient motor startup by increasing torque and minimizing initial current draw. Reduced startup current leads to less strain on the motor, potentially extending its lifespan.

- Educational Value of the Trainer Kit: The trainer kit enables users to study and compare the behavior of capacitor-start and split-phase motors in detail. It provides a comprehensive platform for students and professionals to grasp the critical role of capacitors and winding configurations in motor performance.

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