REWINDING OF 3 PHASE INDUCTION MOTOR DOUBLE SPEED

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ABSTRACT

A double-speed motor is a type of asynchronous AC motor designed with two or more windings. The presence of two separate windings causes three-phase double-speed motors to have a significantly larger physical size compared to three-phase single-speed motors of the same power rating. Numerous studies have investigated the impact of the rewinding process on the efficiency of single-speed induction motors. However, limited attention has been given to double-speed induction motors. Addressing this research gap, the present study focuses on two primary objectives: first, to analyze the impact of rewinding on the performance characteristics of double-speed induction motors; and second, to evaluate the operational performance of these motors after undergoing the rewinding process. In this study, the rewinding process utilized copper wire with a diameter of 0.50 mm, wound using a mold to create a total of 52 windings. Performance testing revealed the following results: under no-load conditions with slow rotation, the motor exhibited a current of 1.3 A, a frequency of 50.45 Hz, a power factor (cos φ) of 0.86, and a speed of 1515 RPM. When a load was applied under fast rotation, the motor demonstrated a current of 1.9 A, a frequency of 50.29 Hz, a power factor (cos φ) of 0.997, and a speed of 2949 RPM. The experimental results showed minimal variation in current and frequency between loaded and unloaded conditions, with significant differences primarily observed in rotational speed between slow and fast modes. This behavior is characteristic of double-speed motors, which are capable of operating at two distinct speeds. In fast rotation mode, the speed can reach approximately twice that of slow rotation, highlighting the design's capability to adapt to varying operational demands.

Keywords: *Dual speed motor, Rewinding, Phase, Induction motor, Double speed*

1. INTRODUCTION

AC motors are essential devices that convert electrical energy into mechanical energy. Similar to DC motors, AC motors consist of two primary components: the *stator* and the *rotor*. The stator is a stationary electrical component, while the rotor is the rotating part of the motor [1]–[4]. In induction motors, the stator houses a series of slots designed to accommodate conductive wires, forming the windings necessary for the motor's operation [5]–[11]. Electrical machines play a critical role in industrial production processes. They not only facilitate the implementation of production but also significantly reduce the time required for manufacturing, thereby increasing efficiency. However, the continuous operation of motors can lead to issues such as reduced performance and component failures, particularly in induction motors [12]. When motor windings become damaged, rewinding is a common repair method performed in industrial settings. Proper rewinding, done in accordance with the motor's nameplate specifications, can restore a motor to its original efficiency prior to disassembly. However, factors such as the rewinding technique, the quality of the winding material, insulation performance, and operating temperature can affect the motor's efficiency after rewinding [13].

Rewinding is a meticulous process aimed at repairing the stator windings of an induction motor, effectively restoring a damaged 3-phase induction motor to operational condition. A double-speed motor is a specific type of asynchronous AC motor designed with two separate windings [14], [15]. The inclusion of dual windings results in a

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larger motor size compared to single-winding 3-phase motors with similar power ratings. This motor type typically features a squirrel cage rotor configuration [16].

Double-speed motors, also referred to as pole-changing or two-speed motors, are multispeed induction motors where speed variation is achieved by altering the number of poles. This is accomplished by modifying the electrical connections within the motor. Depending on the configuration of the stator windings, these motors can operate with fixed or variable torque. The double-speed motor was first invented by Robert Dahlander (1870–1935), a Swedish engineer who worked for ASEA. By implementing pole-switching mechanisms, the motor's speed can be adjusted to meet specific operational requirements [17]–[19].

Numerous studies have investigated the impact of the rewinding process on the efficiency of induction motors, including notable research by [20] and[21]. These studies have primarily focused on assessing the effects of rewinding on key performance parameters, such as efficiency, energy losses, steady-state behavior, and harmonic distortion in three-phase induction motors. However, most of this research has been confined to single-speed induction motors, with limited exploration of the implications for double-speed induction motors. To address this gap, the present study aims to achieve two primary objectives. First, to analyze the impact of rewinding on the performance characteristics of double-speed induction motors, the second, to evaluate the operational performance of these motors following the rewinding process.

2. RESEARCH METHODOLOGY

2.1 Research Flowchart

This chapter outlines the methods used in this study, which adopts a quantitative research approach. The focus of the research is the design and implementation of rewinding for a double-speed 3-phase induction motor. To achieve the research objectives, a systematic and structured workflow is essential. The overall research workflow is depicted in Figure 1. The first step is the literature review, which involves identifying and examining relevant sources that discuss double-speed motors. This review provides a foundation for understanding the operational principles, common issues, and design considerations of double-speed motors. Following this, a literature study is conducted to delve deeper into various theoretical frameworks and reference materials pertinent to the research. This stage includes an analysis of best practices for rewinding double-speed motors and highlights key factors influencing motor performance. Prior to disassembling the motor, critical data from the motor's nameplate must be recorded to ensure all specifications are documented. Once the nameplate data is collected, the motor is carefully disassembled for the rewinding process. The rewinding process is iterative and includes potential risks; it may either succeed or fail. In the event of failure, the guidelines for proper rewinding must be revisited to identify and correct errors. If the rewinding process is successful, the next step is to collect performance data from the motor. This data is then processed and analyzed to assess the impact of rewinding on the motor's performance. The analysis includes comparing the motor's efficiency, reliability, and other performance metrics before and after rewinding. Finally, the research concludes by synthesizing the findings to derive meaningful insights and validate the study's objectives.

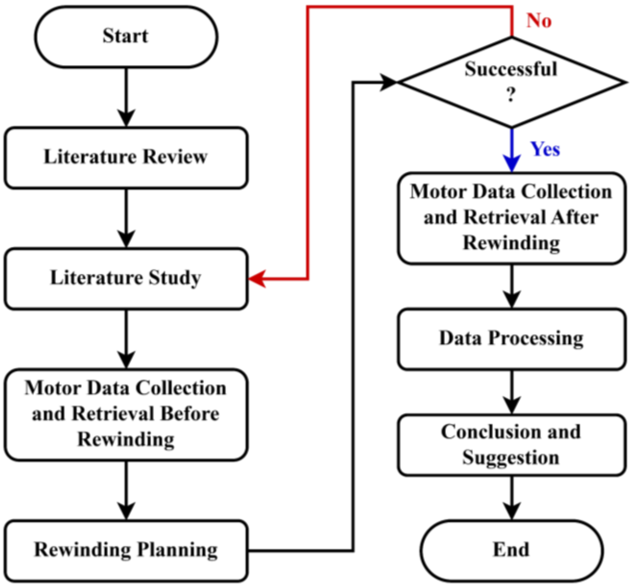

Figure 1. Research Flowchart

2.2 Data Collection and Research Stages

The technical data collection method used in this study is a direct review approach, conducted through on-site visits to gather the necessary data for the research process. This method ensures the acquisition of technical data related to the main components. The object of this study is a three-phase squirrel-cage induction motor with a power rating of less than 5 HP. The rewinding process was carried out in the LLK building, Tarakan. To achieve the research objectives, the study is divided into the following stages:

1. Preparation Stage
   During this stage, a three-phase squirrel-cage induction motor with identified burnt stator windings was selected. Data from the motor's nameplate, including specifications such as RPM limits, current, and the number of poles, were recorded. These data serve as a reference for the planned calculations and facilitate comparisons.
2. Disassembly Stage
   This stage involves dismantling the motor components, including the frame (housing), fan, pulley, and the stator windings, which are prepared for the rewinding process.
3. Design and Calculation Stage
   In this stage, the winding concept is designed and necessary calculations are performed to ensure the motor's functionality aligns with the desired specifications.
4. Testing and Data Analysis Stage
   Following the completion of the system design, this stage involves testing the motor and measuring its parameters. The collected data are then analyzed to evaluate the motor's performance post-rewinding.
5. Conclusion and Recommendation Stage
   In the final stage, conclusions are drawn based on the test results. Recommendations are provided to improve future implementations or resolve identified issues.

2.3 Identification and Rewinding Process of a 3-Phase Induction Motor

The initial stage in planning the rewinding of a 3-phase induction motor is the identification process. This begins with examining the nameplate data affixed to the motor's body, which provides critical information such as RPM, voltage, current, and the number of poles. These parameters are essential for determining the motor's operational limitations and for guiding the calculations required in the rewinding process. Rewinding a 3-phase induction motor with burnt or damaged windings requires a structured approach. The process includes several preparatory steps to ensure accurate estimation of the motor's capacity for rewinding. These steps are as follows:

1. Remove all motor covers.
2. Count the number of stator slots.
3. Determine the winding step for each phase or slot group.
4. Calculate the number of poles for each phase.
5. Count the number of turns in each slot.
6. Measure the dimensions of the existing copper wire.
7. Calculate the specifications for the replacement copper wire.

Once these preliminary steps are completed, the rewinding stage begins. This stage is critical and must be executed with precision and adherence to established procedures. The rewinding process involves:

1. Installing copper wire into the stator slots.
2. Coating the installed copper with varnish (sirlak) to secure the windings and provide insulation.
3. Connecting the windings to the motor's terminals, ensuring proper configuration for desired rotational speed (fast or slow).

After completing these steps, the rewound motor undergoes functional testing. If the motor fails to operate as expected, the rewinding process is re-evaluated to identify and rectify errors. Key equations in the rewinding process shown below:

a. Synchronous speed (ns)

$$ns = \frac{120 \times f}{p} \tag{1}$$

where f is the supply frequency, and p is the number of poles.

b. Slip occurs between the stator and rotor (s):

$$s = \frac{ns - nr}{ns} \times 100\% \tag{2}$$

where *nr* is the rotor speed.

c. Number of phase turns (*Nph*):

$$Nph = \frac{V \times 86000}{RPM \times B \times D \times L} \tag{3}$$

where *V* is the operating voltage, *B* is a constant, *D* is the stator core diameter, and *L* is the stator slot length.

d. Copper wire cross-sectional area (*q*):

$$q = \frac{1}{4} \times \pi \times d^2 \tag{4}$$

where *d* is the diameter of the existing copper wire.

e. Slot pitch (*Yg*)

$$Yg = \frac{G}{p} \tag{5}$$

where *G* is the total number of stator slots and *p* is the number of poles.

f. Motor power (*P*)

$$P = V \times I \times cos\varphi \times \sqrt{3} \tag{6}$$

g. Stator resistance (*R1*)

$$R1 = \frac{Vdc}{2 \times Idc} \tag{7}$$

h. Rotor resistance (R2), stator reactance (X1), and rotor reactance (X2):

$$R_2 = \frac{P_{Br}}{3 \times I_{Br^2}} - R_1 \tag{8}$$

$$\mathrm{X}_1 + \mathrm{X}_2 = \sqrt{\frac{V_{Br^2}}{I_{Br^2}} - (\mathrm{R}_1 + \mathrm{R}_2)^2} \tag{9}$$

$$\mathrm{X}_1 = 0.4\,(\mathrm{X}_1 + \mathrm{X}_2) \tag{10}$$

$$\mathrm{X}_2 = 0.6\,(\mathrm{X}_1 + \mathrm{X}_2) \tag{11}$$

i. Core loss resistance (*Rc*) and magnetizing reactance (*Xm*)

At no-load conditions:

$$I_C = I_{nl} \times Cos\,\varphi \tag{12}$$

$$Rc = \frac{Vphase}{I_C} \tag{13}$$

where *V-phase* is the phase voltage, and *Ic* is the core loss current

$$Xm = \frac{Vphase}{I_{nl}} - \mathrm{X}_1 \tag{14}$$

where *Inl* is the no-load current.

Each equation plays a crucial role in ensuring the accuracy and success of the rewinding process, from determining stator and rotor parameters to validating motor performance after rewinding.

3. RESULTS AND DISCUSSIONS

Data collection is conducted after ensuring that the motor operates according to the desired design concept and has been successfully fabricated. Furthermore, the motor must be capable of supporting the data collection process, which will subsequently be analyzed to draw conclusions. In planning the rewinding of an induction motor stator, several preliminary stages must be completed. These stages are recording the motor specifications as listed on the nameplate, disassembling the motor to determine the number of stator slots, designing the stator winding concept based on calculation results, and conducting motor testing to validate the rewinding process.

The identification process serves as the foundational step in the rewinding of an induction motor. Its primary purpose is to provide a comprehensive overview, facilitating the development of an accurate calculation framework for the stator winding design. This process ensures alignment with the parameters specified on the motor's nameplate. Tabel 3 shown the motor specifications before rewinding.

3.1 Stator Winding Calculation and Rewinding Process

After determining the number of stator slots, the next step involves calculating the number of windings per slot. The motor specifications include a stator diameter of 9.7 cm, stator length of 8 cm, and an operating voltage of 380 V. The calculation for the number of turns per phase (*Nph*) is based on equation (3) below:

$$Nph = \frac{V \times 86000}{RPM \times B \times D \times L}$$

$$Nph = \frac{380 \times 86000}{1500 \times 0{,}45 \times 9{,}8 \times 8}$$

$$Nph = \frac{18.620.000}{52{,}380}$$

$$Nph = 623{,}9$$

The number of turns per slot is calculated by dividing (*Nph*) by the total number of slots. Turn per slot is 623,9/12 = 51.9 turn (52 rounded to 52 turns per slot).

The size of the copper wire required for the rewinding process is calculated using equation (4):

$$q = \frac{1}{4} \times \pi \times d^2$$

$$q = \frac{1}{4} \times 3{,}14 \times 0{,}8^2$$

$$q = 0{,}5\ mm$$

The slot pitch, which determines the step between adjacent winding slots, is calculated using equation (5):

$$Yg = \frac{G}{p}$$

$$Yg = \frac{36}{4}$$

$$Yg = 9$$

Based on the calculated parameters and design, the winding is installed on the stator. The stator consists of three-phase windings labeled as R (red), S (black), and T (green). The rewinding process involves translating the design calculations into the physical winding of copper coils onto the stator slots. Schematic of stator winding depicted in Figure 2.

Based on the design drawing, the winding can be wound on the available stator which is a three-phase R (red), S (black) and T (green) winding. The rewinding process represents the culmination of calculations and planning conducted earlier. This step ensures that the theoretical design is translated into a functional system, ready for testing and evaluation in the final stage. The rewinding process involves multiple sequential stages to ensure precise installation and optimal motor functionality. The detailed process is illustrated in Figure 3, which provides a visual representation of the winding installation.

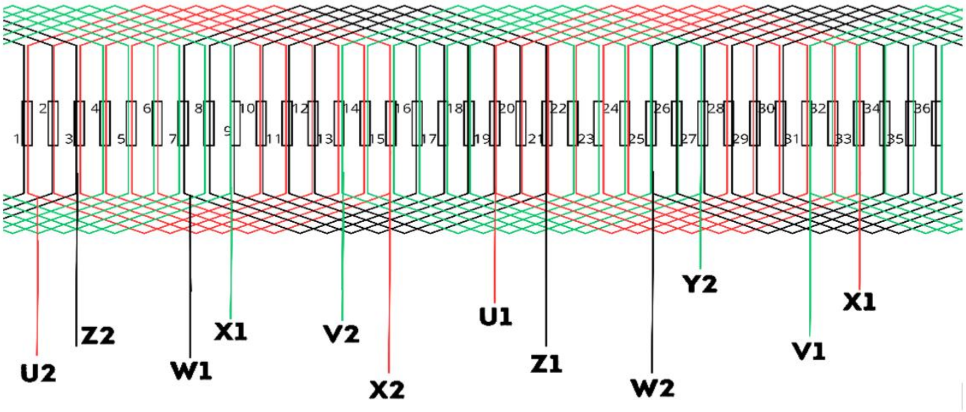

Figure 2. Schematic of Stator Winding

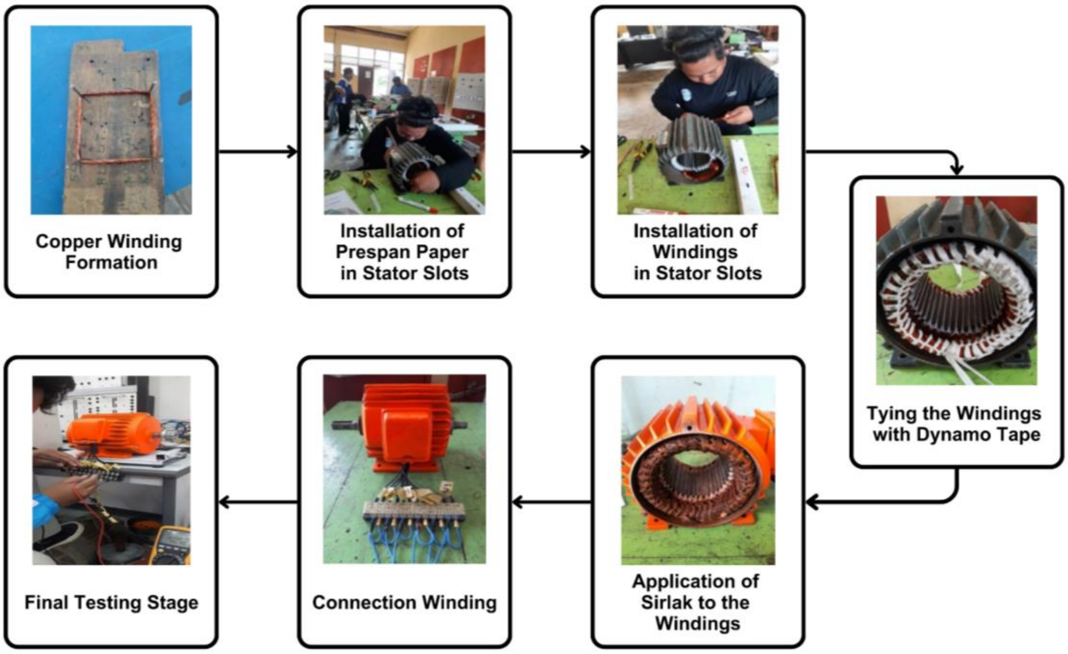

Figure 3. Rewinding Process Overview

As illustrated in Figure 3, the winding process begins with rolling the enamel-coated copper wire according to the calculated specifications for the induction motor. The wire is shaped to fit the stator slot dimensions, which are 9.7 cm in length and 8 cm in width. This process ensures that the windings are uniform and consistent with the design parameters. Next, prespan paper with a thickness of 0.2 mm, is installed in the stator grooves to provide insulation between the windings and the stator core. This insulation prevents short circuits caused by potential enamel damage on the copper coils and ensures electrical safety.

The prepared windings are then inserted into the stator slots based on the calculated data, ensuring proper alignment and distribution for optimal electrical and magnetic properties. After insertion, dynamo tape is applied to secure the windings. This step achieves three key objectives which consist of ensuring the windings are neat and well-organized, compacting the windings tightly to maintain structural integrity, and preventing short circuits between the windings and the motor body. Following this, sirlak a heat-resistant insulating varnish, is applied to the windings. Sirlak provides protection against environmental factors such as dust, moisture, and chemical exposure, potential damage from high temperatures, which could otherwise cause short circuits or corrosion, and the effects of acid, base, or solvent accumulation due to operational wear and tear.

Table 1. DC Inject and Block Rotor Measurements

Vdc (Volt)	Idc (Ampere)	Pbr (Watt)	Ibr (Ampere)	Vbr (Volt)
Test at High Speed				
28	1,93	127	1,98	49,7
Test at Low Speed				
20	1,53	173	2,03	68,3

The last step is the final testing stage. The rewound motor undergoes a running test to evaluate its performance and ensure its operational feasibility. This test includes measuring key parameters such as speed, current, voltage, frequency, and power factor under no-load and load conditions. For double-speed motors, the number of poles influences rotational speed. For fast rotation (2 poles) on the motor, the connection is (U2- Y1, Z1-V2, and X1-W2) then for slow rotation (4 poles) it is (U1- X2, W1- Z2, and V1-W2). These connections are made in parallel, and their configuration determines the motor's rotational characteristics.

3.2 Calculation and Analysis of Motor Parameters

By connecting the output of each winding, specific values essential for analysis can be determined. During motor testing with a DC source, the test produces a DC voltage of 28 V and a DC current of 1.93 A. The results of DC injection and blocked rotor measurements are shown in Table 1. These measurements are used to calculate the stator resistance (*R1*) using equation (7):

$$R1 = \frac{Vdc}{2 \times Idc}$$

$$R1 = \frac{28}{2 \times 1{,}93}$$

$$R1 = 7{,}25\ \Omega$$

Once R1 (stator resistance) is obtained, the rotor resistance (*R2*), as well as the reactances *X1*, *X2*, and *Xm*, can be determined using equations (8-14). The power loss in the blocked rotor test (P_{Br}) is recorded as 127 W, and the blocked rotor current (I_{Br}) is measured at 1.98 A. These values are used in the following calculations:

$$R2 = \frac{127}{3\ x\ 1{,}98^2} - 7{,}25$$

$$R2 = 3{,}54\ \Omega$$

$$\mathrm{X}_1 + \mathrm{X}_2 = \sqrt{\frac{49{,}7^2}{1{,}98^2} - (7{,}25 + 3{,}54)^2}$$

$$X1 = 0{,}4 \times (22{,}66)$$

$$X1 = 9{,}04\ \Omega$$

$$X2 = 0{,}6 \times (22{,}66)$$

$$X2 = 13{,}59\ \Omega$$

These values represent the stator and rotor reactance, which are further utilized to calculate other parameters. The core loss current (*Ic*), core loss resistance (*Rc*) and magnetizing reactance (*Xm*) are derived as follows:

$$Ic = 1{,}13 \times 0{,}96$$

$$Ic = 1{,}08\ \mathrm{A}$$

$$Rc = \frac{234}{1{,}08}$$

$$Rc = 216\ \Omega$$

$$Xm = \frac{234}{1{,}13} - 9{,}04$$

$$Xm = 198{,}08\ \Omega$$

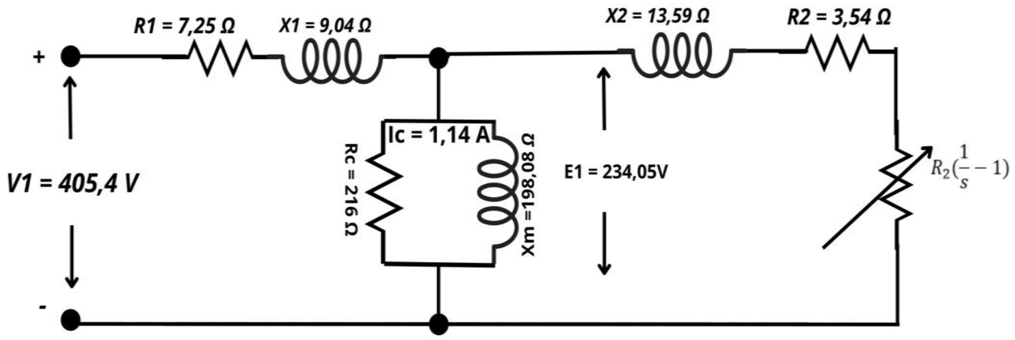

Figure 4. Equivalent Circuit

Table 2. Results of Measurements from Double-Speed Motor Testing

Current (Ampere)	Voltage (Volt)	Frequency (Hz)	Cos φ	Speed (Rpm)
No-load Testing at Slow Turns				
1,33	405,4	50,45	0,86	1515
No-load Testing at Fast Turns				
1,13	405,4	50,50	0,95	3010
Testing with Load at Slow Turns				
1,55	405,4	50,35	0,975	49,7
Testing with Load at Fast Turns				
1,90	405,4	50,29	0,99	68,3

After obtaining *R1*, *R2*, *X1*, and *X2*, these values are used to obtain the supporting parameters required for constructing the motor's equivalent circuit. The equivalent circuit represents the motor operation under no-load conditions and is used to evaluate its performance. The equivalent circuit from this motor is depicted in Figure 4. The operation of an induction motor is analogous to a transformer, as both are based on the principle of electromagnetic induction. However, in the case of an induction motor, the secondary circuit rotates.

The measurement results in Table 2 confirm that the motor operates as designed, featuring two distinct speed settings corresponding to its dual-pole configuration. These operational results have been validated through detailed calculations, as outlined above. Upon successfully completing the rewinding process, the motor's updated performance characteristics were compiled to create a new nameplate for the three-phase, double-speed induction motor. This new nameplate reflects the improved specifications and operational capabilities of the motor after rewinding.

Table 3. Specifications of the Motor Before and After the Rewinding Process

Parameter	Before	After
Manufacturer	Indonesia	Indonesia
Type	ORK Frame 90L	ORK Frame 90L
Serial Number	5854-03105Y165	5854-03105Y165
Voltage	200/220 V	380 V
Power	1500 W	1,3 kW
Current	5,7/6,5 A	1,33/1,9 A
Number of Slots (G)	36	36
Stator Core Diameter (D)	9,7 cm	9,7 cm
Stator Core Length	8 cm	8 cm
Speed	1430/1730 rpm	1511/2949 rpm
Power Factor (Cos φ)	-	0,86/0,99
Conductor Diameter	0,85 mm	0,50 mm
Frequency	50/60 Hz	50 Hz
Efficiency	-	88,72%

The Table 3 presents a comparison of the motor's specifications before and after the rewinding process, highlighting the effectiveness of the rewinding procedure in restoring and optimizing the motor's performance. This improvement is evident in the increase in motor speed, which rose from the initial value of 1430/1730 rpm to 1511/2949 rpm after rewinding. Additionally, the rewound induction motor achieved a power factor (Cos φ) of 0.86/0.99 and an efficiency of 88.72%, demonstrating significant enhancements in operational performance and energy efficiency.

4. CONCLUSION

The conclusion of this final project research focuses on analyzing the rewinding of a 3-phase double speed induction motor. From this research, the following conclusions can be drawn: In this research using a 3-phase induction motor which is converted into a double speed type motor, with an old copper diameter of 0.8 mm. Then in this rewinding it is not possible to use the same copper size. If you use the same size, the motor will heat up quickly or be damaged. Therefore, for the new copper size, it uses 0.5 mm and 52 turns.

After planning the new winding for the 3-phase induction motor, 36 grooves and 4 poles are obtained, 104 turns per groove, which means the total number of turns is 3,744 turns. If the coil winding direction is reversed, the magnetic level of the motor will be greatly affected. Tests were conducted on a three-phase induction motor that had been re-planned for its coil winding. The test results show that with the design that has been made, the three-phase induction motor can rotate as desired.

At the time of the experiment using a load or no load does not have a big difference, only at its speed there is a big difference between slow and fast rotation. In slow rotation the speed can reach 1511 rpm and in fast rotation it can reach 2949 rpm. This is because the double speed motor is a motor that has 2 speeds, which at the time of the fast rotation the result is 2x the slow rotation.

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