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A winding design for improving 3-phase induction motor performance

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ABSTRACT

One of the most popular electric motors used today is the 3-phase induction motor, which has a sturdy design, is less expensive, and is simple to use. Improvements to the materials used in the rotor or stator of induction motors, raising the number of motor phases, and employing a 3-phase induction motor for 1-phase power are just a few of the ways the motor is now being developed to perform better. These studies are all pricey, though. The goal of this study is to determine how to enhance the motor's performance at a reasonable cost. The suggested remedy was to create a 3-phase induction motor winding with a 1-layer design that resembled a symmetrical 6-phase winding. The primary study topics were the motor's rotor speed, mechanical torque, efficiency, and winding current when it was powered by a three-phase power source. The results of the study show that, although consuming less winding current, the 3-phase induction motor with a new winding design outperforms a traditional 3-phase induction motor in terms of rotor speed, mechanical torque, and efficiency.

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1. INTRODUCTION

The most popular alternating current electric motor utilized as a driving force nowadays is the 3-phase induction motor due to its sturdy design, ease of usage, and lower cost compared to other electric machines [1]–[3]. When compared to other alternating current motors, this motor still has drawbacks, including lower starting torque, a lower power factor, and lower efficiency [4]–[6]. Many previous studies have made various attempts to enhance the performance of this motor so that it can operate with better performance, including improving the materials used in the rotor or stator of induction motors [5]–[12], developing more phases of induction motors [13]–[37], and operating the motors on a single-phase power supply [38]–[40] to improve motor performance. The results of the research show that 3-phase induction motors can operate with better performance, but the cost of producing or operating the motor goes up. Therefore, additional research and efforts are still required to enhance the motor's performance so that it can operate more efficiently without requiring expensive additional costs for the motor.

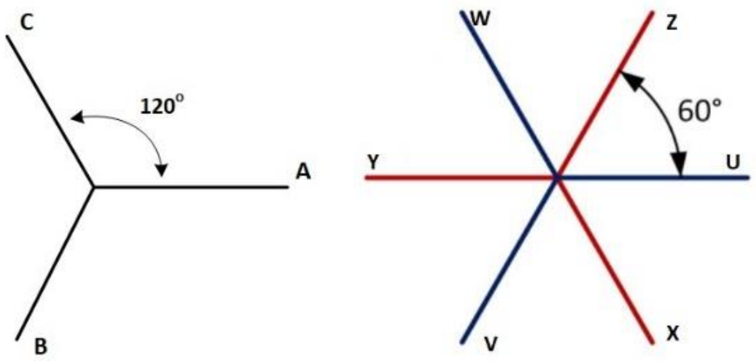
According to research [38]–[40], by using a 1-phase electric power source, a 3-phase induction motor can be run with a higher beginning torque and a power factor that is almost equal to one. These methods require several capacitors and a redesign of the motor control circuit so that the motor can operate properly on a 1-phase system. However, these methods add to the cost of running the motor because it costs more to create a motor control and add capacitors to the motor. According to research [5]–[12], enhancing the quality of the materials used in motors can also enhance motor performance. The type of application that is suitable for usage is largely influenced by the type and composition of materials used in a motor. The performance of the motor improves with material quality, but at a higher cost, which raises the cost of motor production.

Research on increasing the number of phases of 3-phase induction motors [13]–[37] was carried out through winding design in induction motors that were designed for more than 3-phases, such as 5-phase to 12-phase designs. To run more efficiently, this motor needs to be powered by an electric power source that has the same number of phases as the motor winding. When the winding of the motor has more phases, it will run more efficiently. However, as the number of phases in the motor winding increases, so does the cost of creating a new power source with the same number of phases as the motor winding design [13]–[37]. Additionally, if the motor being used has a higher power capacity, creating a new power source to power the motor will cost more money.

Given the above-mentioned circumstances, it seems that a novel approach is still required to enhance the performance of 3-phase induction motors without necessitating significant additional expenditures for the motor. Thus, the goal of this study was to offer a simple method for enhancing a 3-phase induction motor's performance without having to buy expensive extra parts for the motor. The work of Anthony *et al.* [41]–[43], who developed a 1-phase induction motor winding design with 3-phase and 4-phase winding designs to enhance the motor's performance, served as the foundation for this investigation. Therefore, the solution proposed in this study was to develop a design for the 3-phase induction motor winding from 3 coils to 6 coils, similar to the design of a symmetrical 6-phase winding. It is expected that this design will increase the flux density of a three-phase induction motor, resulting in improved motor performance when powered by a three-phase source. The goal of this project was to build a 3-phase induction motor using a symmetrical 6-phase winding design that included 36 stator slots and a 1-layer, 50 Hz, 2-pole winding. The winding connections were arranged in such a way that the magnetic flux produced in the motor windings can make the motor operate with better performance without requiring expensive additional costs for the motor. Rotor speed, mechanical torque, effectiveness, and motor coil current were the main topics of the study. It is envisaged that by using the study's findings, a new, more affordable 3-phase induction motor with improved performance can be developed.

2. THE COMPREHENSIVE THEORETICAL BASIS

Three identical windings spaced around 120 degrees apart form a three-phase induction motor. For optimal performance, a 3-phase induction motor is often powered by a three-phase electric power source with a phase difference of 120 degrees. To enable it to run at the necessary speed, this three-phase induction motor's winding is built with a predetermined number of poles [44]. In contrast to a three-phase induction motor, a symmetrical six-phase induction motor typically has six identical windings spaced about 60 degrees apart and is powered by a six-phase electric power supply with a phase difference of 60 degrees. Figure 1 [44] displays a vector representation of the winding distance shape for both designs, where Figure 1(a) is an image of the phase angle difference between each phase for a 3-phase source that differs by 120 electrical degrees, and Figure 1(b) is an image of the phase angle difference between each phase. for a 6-phase source that differs by 60 electrical degrees.



(a) (b)

Figure 1. The symmetrical winding configurations for the three and six phases are represented in vector form: (a) depiction of vectors in three-phase system; and (b) depiction of vectors in six-phase systems

Figure 2 depicts a typical 3-phase induction motor winding with a 2-pole configuration and 36 slots overall. Figure 2 shows that U1 indicates the winding's entering point at phase 1, and U2 indicates its exit. V1 is Phase 2's initial winding entry, while V2 is Phase 2's ultimate exit. Phase 3 begins with a winding entry at W1 and concludes with an exit at W2. The three-phase power system may supply power to the terminals U1, V1, and W1. Figure 3 depicts a 6-phase symmetrical induction motor winding with a 2-pole configuration and 36 slots overall. Figure 3 shows that U1 indicates the winding's entering point at phase 1, and U2 indicates its exit. V1 is phase 2's initial winding entry, while V2 is phase 2's ultimate exit. Phase 3 enters in a winding manner from W1 and leaves at W2. The first winding entry into phase 4 is X1, while the exit from phase 4 is X2. Phase 5 enters windingly at Y1 and leaves at Y2. Phase 6 begins with a winding entry at Z1 and ends with an exit at Z2. The terminals U1, V1, W1, X1, Y1, and Z1 can receive power from a 6-phase power system.

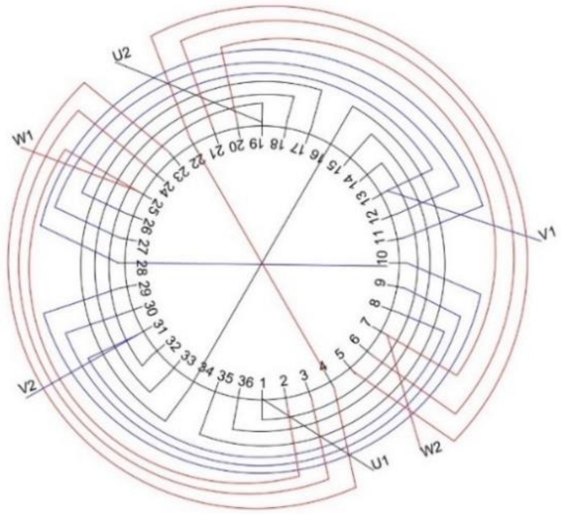


Figure 2. A 3-phase induction motor's winding arrangement contains two poles and 36 slots

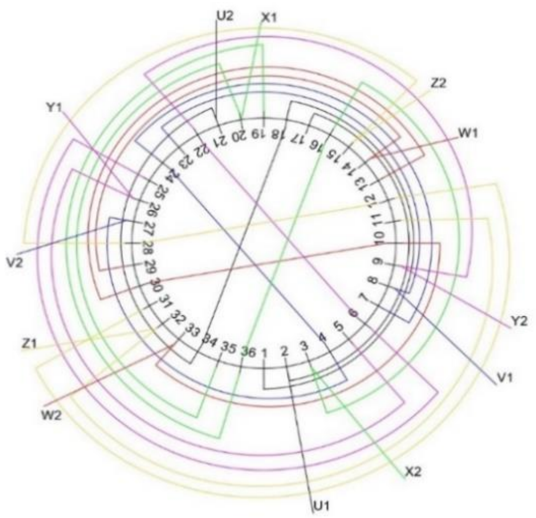


Figure 3. The design of two poles and 36 slots makes up the 6-phase winding architecture of the induction motor

When a three-phase induction motor runs on a three-phase system, the stator magnetic field rotates with speed (N_s), slip (s), and rotational speed of the rotor (N_r), as shown by (1) to (3) [44].

$$N_s = 120 \,.\, f/p \tag{1}$$

$$s = (N_s - N_r)/N_s \tag{2}$$

$$N_r = N_s\,(1 - s) \tag{3}$$

If we refer to the relationship between flux density (B), magnetic force (F), and mechanical torque (T_m) produced by the stator winding to rotate the rotor, it can be made as [44]:

$$F = B.I.l \tag{4}$$

$$T_m = F.r \tag{5}$$

where:

$$B = \mu.H \tag{6}$$

μ is permeability, H is magnetic field intensity (A turn/m), I is electric current (A), l is axial length of rotor (m), r is rotor radius (m). The formulas (7) to (12) can be used to compute the motor's rotational velocity (ω_r), mechanical power (P_m), mechanical torque (T_m), output power (P_{out}), input power (P_{in}), and efficiency (E_{ff}) [44].

$$\omega_r = 2.\pi.Nr/60 \tag{7}$$

$$P_m = T_m.\omega_r \tag{8}$$

$$T_m = P_m/\omega_r \tag{9}$$

$$P_{out} = P_m - P_{rot} \tag{10}$$

$$P_{in} = \sqrt{3}\,.V_{LL}.I_L.Cos\,\varphi \tag{11}$$

$$E_{ff} = (P_{out}\,/P_{in})x100\% \tag{12}$$

3. METHOD

The investigation was carried out in the Electrical Engineering Laboratory of the Institute of Technology Padang. The traditional three-phase induction motor, which serves as a comparison motor, and the newly built three-phase induction motor have the same design and parts. Both motors have the same structure: rated current, rotor, and stator. 380 V, 1 HP, 2,880 RPM, Y connector, 36 slots, 1.5 A, and 50 Hz were the induction motor data used for this design. Figure 2 depicts a typical 3-phase induction motor with a 1-layer construction and a 3-phase winding configuration. The new 3-phase induction motor with a 1-layer, 6-phase winding architecture is depicted in Figure 3. The entire connection form for the motor winding under study is shown in Figure 4. The ends of the windings are linked to the R, S, and T phases of a three-phase power supply at terminals U1, W1, and Y1 in Figure 4. The two motors were run under varying load conditions using a three-phase power source.

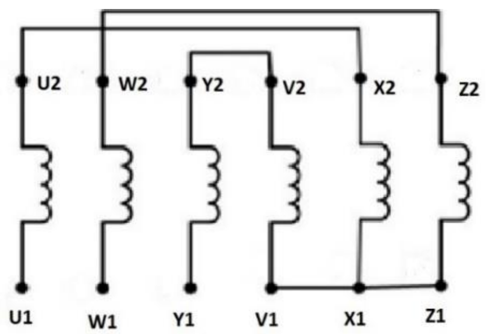
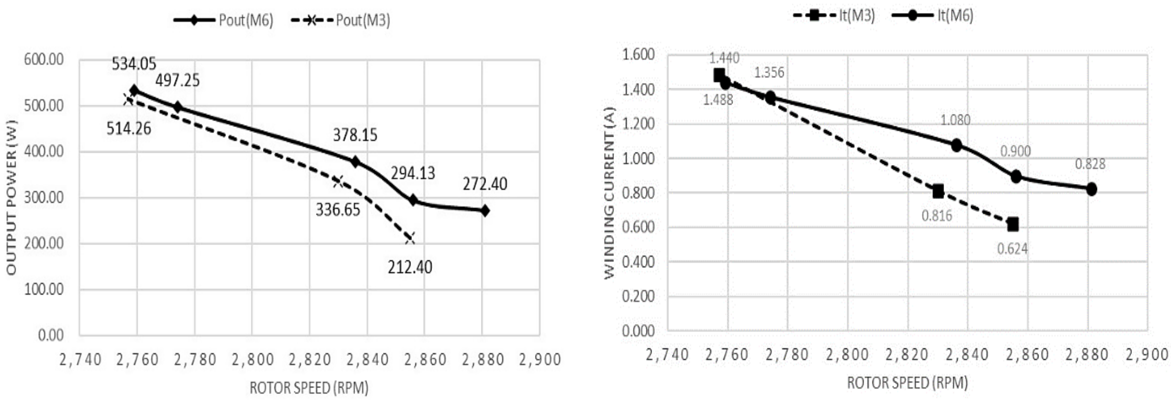


Figure 4. The motor winding design's full connecting form, as shown in Figure 3

4. RESULTS AND DISCUSSION

The characteristics of the output power and winding current of both motors are displayed in Figure 5. From Figure 5(a), it can be explained that the output power of the newly developed 3-phase induction motor "Pout (M6)" is greater than the output power of the conventional 3-phase induction motor "Pout (M3)." From Figure 5(a), it can be seen that the "Pout (M3)" of a conventional 3-phase induction motor is only 514.26 W, while the "Pout (M6)" of the newly developed induction motor is 534.05 W. When compared with a traditional 3-phase induction motor, newly designed induction motors often have a larger “output power” and faster "speed,” as illustrated in Figure 5(a). This is because the new 6-phase winding design for induction motors produces a flux density for the motor in the 60 electrical degree range, which is superior to the flux density for a traditional 3-phase induction motor, which is in the 120 electrical degree range. A better flux density (B) increases the magnetic field strength around the rotor, as seen in (4), thus increasing the rotor speed while at the same time increasing the motor's output power, as seen in (8) to (10), and increasing the motor's efficiency, as seen in (12). The image of the current characteristics of the two motors is shown in Figure 5(b). As can be observed by comparing Figures 5(a) and 5(b), the newly created motor's output power, or "Pout (M6)," is 534.05 W in Figure 5(a), yet the current flowing through the winding is only 1.440 A, as seen in Figure 5(b). In comparison, the conventional three-phase induction motor in Figure 5(b) has a higher winding current of 1.488 A but a smaller output power, or "Pout (M3)," of only 514.26 W, as seen in Figure 5(a).

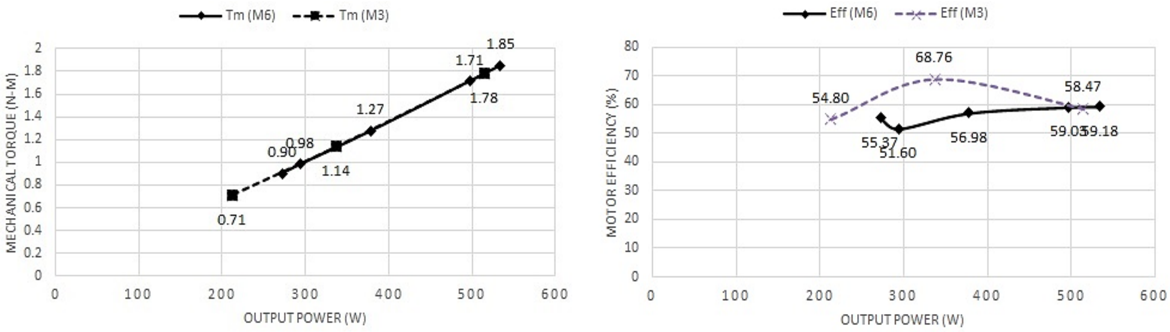


(a) (b)

Figure 5. Properties of the output power and winding current of both motors: (a) output power vs. rotor speed and (b) winding current vs. rotor speed

The characteristics of the mechanical torque and efficiency of the motors are displayed in Figure 6. By focusing especially on Figure 6(a), it can be shown that the mechanical torque "Tm (M6)" of a 3-phase induction motor with a 6-phase winding design is 1.85 Nm, higher than the mechanical torque of a conventional 3-phase induction motor "Tm (M3)", which is only 1.78 Nm. A thorough examination of Figure 6(b) reveals that the efficiency "Eff (M6)" of a 3-phase induction motor with a 6-phase winding design is 59.18%, higher than the efficiency "Eff (M3)" of a conventional 3-phase induction motor, which is only 58.47%. This is due to a rise in flux density, which has led to an increase in the motor's mechanical torque, output power, and efficiency. The pertinent link between an increase in flux density and a rise in mechanical torque, speed, power, and motor efficiency can be seen in (4) to (12). The innovative winding design of the three-phase induction motor suggested in this study is clearly better than the conventional design, as can be seen from the data above. Table 1 presents specific performance accomplishments for both motors.

Their equal manufacturing costs are made possible by the fact that both motors-the traditional design and the new design-use the same structure, including the same number of slots and windings per slot. So, there are no additional costly expenses for the new motor. Specific performance achievements for both motors are listed in Table 1. According to Table 1, the proposed motor's performance was enhanced by increasing the rotor speed by 0.07%, the mechanical torque by 7%, and the efficiency by 1.22%, but decreasing the winding current by -3.23%. Based on the findings of this study, it can be concluded that this study's motor winding design can be employed as a 3-phase induction motor winding design, allowing the motor to work better without requiring additional costly expenses.



(a) (b)

Figure 6. Properties of the mechanical torque and efficiency of both motors: (a) mechanical torque vs. output power and (b) motor efficiency vs. output power

Table 1. The performances of the motors

Object	Conventional design	New design	Enhancement (%)
Number of Poles	2	2	0
Number of windings per slot	70	70	0
Number of Slots	36	36	0
Output power (W)	514.26	534.05	3.85
Rotor speed (r/min)	2757	2759	0.07
Mechanical torque (Nm)	1.78	1.85	7
Efficiency (%)	58.47	59.18	1.22
Current (A)	1.488	1.440	-3.23

5. CONCLUSION

The goal of the study was to develop an affordable technique for raising a three-phase induction motor's performance. The suggested remedy was to create a motor's 1-layer winding architecture that resembled a symmetrical 6-phase winding. The freshly built three-phase induction motor is built using the same parts and construction as the traditional three-phase induction motor, which serves as a benchmark. Both motors have the same structure, rotor, stator, and rated current. The study's primary focus was on the motor's efficiency, winding current, mechanical torque, and rotor speed. The study's findings demonstrate that a three-phase induction motor with a new winding design performs better than a traditional three-phase induction motor, increasing efficiency (1.22%), mechanical torque (7%), and rotor speed (0.07%), but with a lower winding current (-3.23%). In order to improve motor performance without adding significant additional costs to the motor, it is therefore advised that the proposed design be used with standard 3-phase induction motors.

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