A new windings design for improving single-phase induction motor performance

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ABSTRACT

Single-phase induction (asynchronous) motors are widely used at home. These motors have two windings and usually operate at a lower performance than 3-phase asynchronous motors which have three windings. For this reason, this study aims to design a new winding of a single-phase asynchronous motor by increasing the number of phases in the motor windings in order to increase the performance of the motor. This research was focused on 36 slot capacitor-start capacitor-run asynchronous motor. The design used 4 non-identical windings in the motor, where three windings acted as auxiliary windings and one winding acted as main winding. The rated current of the designed motor winding was 2.74 A for the main winding and 3.15 A for the auxiliary winding. The performance of the designed motor compared to the traditional single-phase asynchronous motor with the same structure of stator, rotor, and rated current. A traditional single-phase asynchronous motor had data: 1 HP, 220 V, 8.3 A, 1440 RPM, 50 Hz, and 4 poles. The results of this study indicated that the designed motor operated with power factors almost close to unity and had higher output power, torque, and efficiency than the traditional single-phase asynchronous motors.

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1. INTRODUCTION

Single-phase induction motor (asynchronous motor) is the motor most used by the community, especially in domestic applications such as fans, and washing machines [1], [2]. The motor typically uses a single-phase power supply and operation at low-rated power [1], [2]. This motor differs from the three-phase asynchronous motor, where the single-phase asynchronous motor has only 2 windings, namely the auxiliary and main windings, which are powered by a single-phase system, while the three-phase asynchronous motor has 3 windings that are connected to a three-phase system [1], [2].

In general, induction motors have lower performance compared to DC or synchronous motors [3]–[16]. Several studies have been developed to improve motor performance, including operating a three-phase asynchronous motor from a single-phase power supply [17]–[30], making an optimal shape design on the rotor and stator slots [31], smooth rotor geometry design [32], using copper winding applications [33], using better ferromagnetic materials [33]–[44], and permanent magnets application in the rotor motors [3]–[16]. In general, the methods that have been developed involve significant additional costs to improve motor performance.

Given that in the domestic sector single-phase asynchronous motors are widely used, there is a need to improve the performance of single-phase asynchronous motors with low production costs. It is hoped that the single-phase asynchronous motor can be developed to operate with better performance but at a lower production cost so that household appliances using this motor can be produced with better performance and at a lower price.

Several studies have been conducted to improve the performance of asynchronous motors by increasing the number of motor windings phases [45]–[58] so that these motors can work with better performance. Therefore, research is also needed to develop the number of single-phase asynchronous motor windings to more than two windings in order for this motor to function with better performance. This study focuses on developing a 4-winding design for a single-phase asynchronous motor, that is similar to polyphase asynchronous motors, but the motor only operated on 1 phase power supply. Therefore, the single-phase asynchronous motor can be used with better performance without requiring costly additional costs. This study specifically focuses on the design of 4 windings not identical to a single-phase asynchronous motor, not like Anthony's method which applied 4 identical windings [59]. The study focuses on the power output, torque, efficiency, and power factor of a single-phase asynchronous motor having 36 slots in the stator.

2. METHOD

A single-phase asynchronous motor is an electric motor with two windings, with the main and auxiliary windings connected to the motor [2]. Single-phase capacitor-start capacitor-run asynchronous motor is a single-phase capacitor motor that has a higher power capacity than other single-phase motors. This motor normally uses 2 capacitors in its winding, namely, the starting capacitor and the running capacitor. Using the capacitors, the torque generated by the motor at the start is very high and the motors operate like a two-phase motor. The illustration of the motor winding is shown simply in Figure 1 [59].

From Figure 1, the motor has two windings, Y1 and Y2 for auxiliary windings, and X1 for X1 and X2 for main winding. The Cs in Figure 1 is the starting capacitor that only used at startup, and the Cr is the running capacitor used for both starting and running. The L and N are the line and neutral voltage sources of the single-phase power supply, and the S1 is the centrifugal switch of the motor.

Figure 2 presents a winding design of a traditional capacitor induction motor with 36 slots in the stator. In Figure 2 it can be seen that the two windings, the main and the auxiliary, are in the same slot. Therefore, careful planning is required to install the main and auxiliary windings with different cross-sections in the groove. The power developed by this motor generates by two windings.

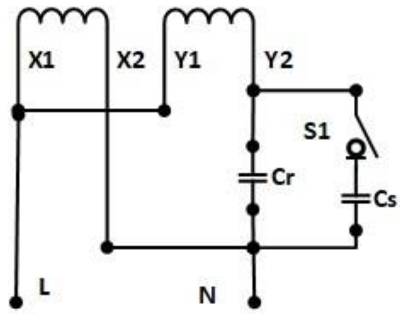

Figure 1. Winding design with capacitors installed in a capacitor-start capacitor-run asynchronous motor

This study aims to reveal an attractive winding design for a 36-slot capacitor motor that can improve motor performance. This study focused on a capacitor-start capacitor-run asynchronous motor. The motor was designed with four windings, three windings acted as auxiliary windings and one winding acted as the main winding. In this design, it is hoped that greater torque will be produced on the motor to improve motor performance. The motor was designed so that the cross-sections of the main and auxiliary windings are 0.65 mm^2 and 0.75 mm^2, respectively. To operate the motor with the same current density, the main and auxiliary windings were rated at 2.74 A and 3.15 A, respectively. The motor was equipped with Cs=20 µF and Cr=25 µF. The auxiliary windings are 15% larger than the main windings and the capacitors are installed in series with these windings. The capacitance of the capacitors used in the present study is calculated using (1) through (4). Figure 3 illustrates the proposed design of the motor winding with the capacitors installed on the motor.

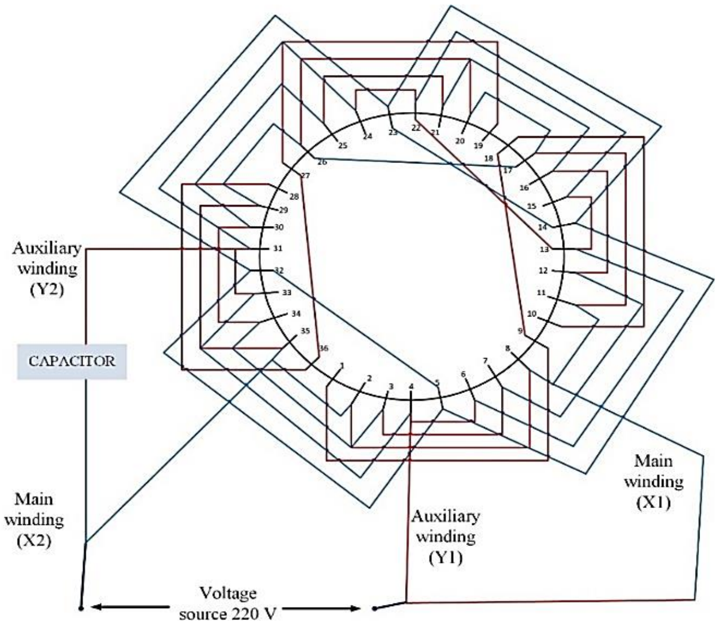

Figure 2. Winding structure of a traditional capacitor motor with 36 slots in the stator

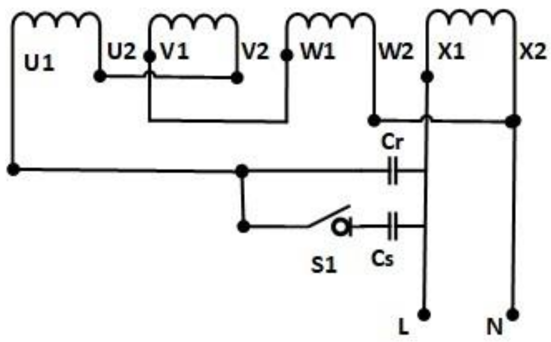

Figure 3. A Four-phase winding design of a capacitor motor in the proposed method

In this study, a traditional single-phase asynchronous motor was used as a comparable motor, whose stator and rotor design are identical to that of the proposed motor. The main and auxiliary windings of the traditional single-phase asynchronous motor had cross-sections of 0.65 mm^2 and 0.9 mm^2 respectively. The motor main winding was rated at 2.74 A, the same as the proposed motor. The traditional single-phase asynchronous motor had the following data: 1 HP, 220 V, *Cs*=200 µF, *Cr*=30 µF, 8.3 A, 4 poles, 1440 RPM, 50 Hz.

Figure 4 shows in detail the distribution of windings installed in the grooves of the proposed motor. According to Figure 4, winding U (from U1 to U2), winding V (from V1 to V2), and winding W (from W1 to W2) are connected in series and are called auxiliary winding. The X winding (from X1 to X2) is called the main winding. For better motor performance, the total capacitor capacity (*Cst*) in Figure 3 can be calculated as in (1) [59].

$$Cst = \frac{0.1757(I_N)}{(V_{LN}).(f)}(Farad) \tag{1}$$

The running capacitor capacitance (*Cr*) can be determined in Figure 3 as (2):

$$Cr = 1.25\frac{I_{ph}}{(A_Z).(2.\pi.f)(V_{LN})}(Farad) \tag{2}$$

where [59]:

$$A_Z = \frac{N_U + N_V + N_W}{N_X} \tag{3}$$

where, f = power supply frequency (Hz), V_{LN} = phase voltage (V), I_{ph} = rated motor winding current (A), N_U = total number of slots occupied by U windings, N_V = total number of slots occupied by V windings, N_W = total number of slots occupied by W windings, and A_Z = Zuriman Anthony's constanta.

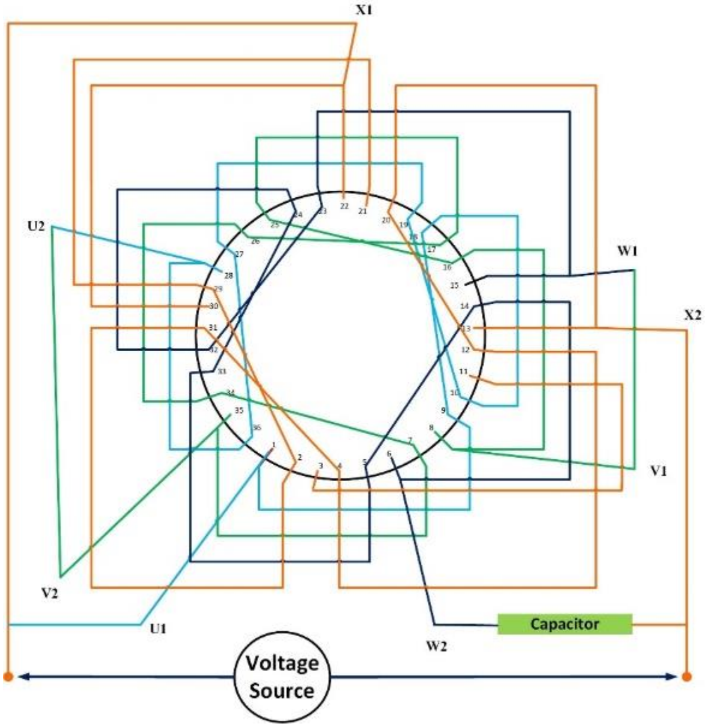

Figure 4. Winding design for capacitor motor with 36 slots of the proposed method

The capacitance of the starting capacitor (Cs) in Figure 3 can be determined using (4) [59].

$$Cs = Cst - Cr(Farad) \tag{4}$$

The voltage (*Vc*), apparent power (*S*) and the reactive power (*VARc*) of the run capacitor can be determined by the following formulas [59].

$$V_C = (V_{LN}).(A_Z) \tag{5}$$

$$S = VARc = (V_C)^2.(Cr).(\omega) = (V_{LN}.A_Z)^2.(Cr).(\omega) \tag{6}$$

The motor line current (I_L) can be determined as [59].

$$I_L = \frac{S}{V_{LN}} \tag{8}$$

If the proposed motor rotates at standard speed, power factor of the motor will become close to unity (between 0.96 and 0.97). Therefore, the power factor (*PF*) then can be set as (8).

$$PF = Cos(\varphi) = 0.96 \tag{8}$$

Then the motor input power (*Pin*) can be determined by the formulas (9) [59].

$$Pin = S.Cos(\varphi) \tag{9}$$

3. RESULTS AND DISCUSSION

Both motors, the proposed motor with 4 non-identical winding constructions and the traditional single-phase asynchronous motor were tested in the electrical laboratory of the Institute of Technology Padang. The study focuses on the motors' power output, torque, efficiency, and power factor. Both properties of the motors are compared to be evaluated in the following way.

3.1. Output power characteristic

Figure 5 shows the power output curve of the motors as a result of laboratory tests. It can be seen from Figure 5 that the designed motor (Pout-M1P4) performed better than traditional single-phase induction motors (Pout-M1C), where the output power of the designed motor is always higher than the traditional single-phase asynchronous motor. Therefore, the proposed motor design is superior to traditional single-phase asynchronous motors in terms of output power characteristics.

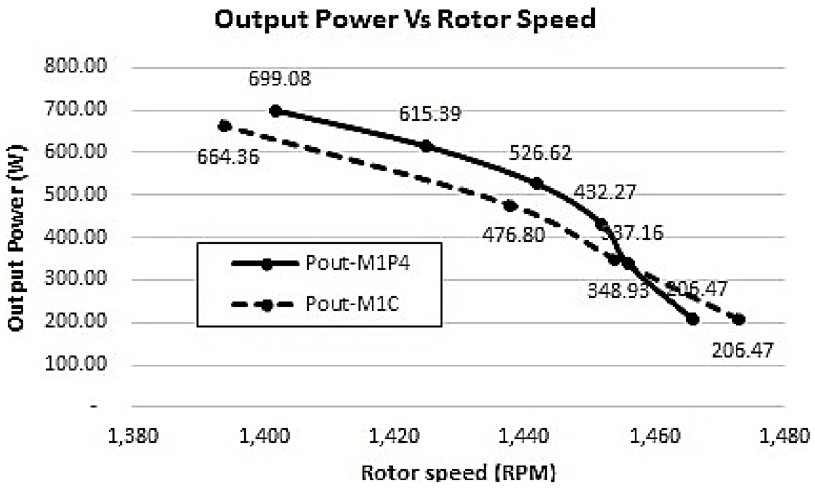

Figure 5. Output power characteristic of the motors

3.2. Torque characteristic

Figure 6 presents the torque curve of the motors as a result of laboratory tests. It can be seen in Figure 6 that the designed motor (TM-1P4) had a better performance than the traditional single-phase asynchronous motors (TM-1C), where the torques of the designed motor are always greater than of the traditional asynchronous motor, so the power the mechanical output of the designed motor will also be higher than that of the traditional single-phase asynchronous motor as given in Figure 5.

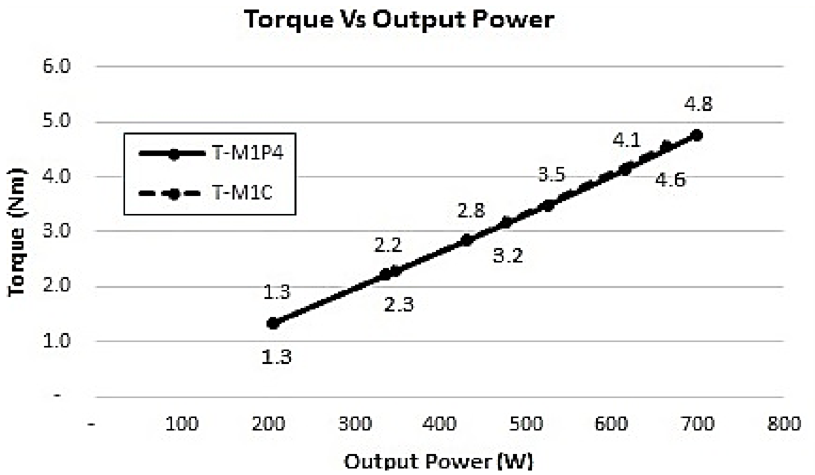

Figure 6. Torque characteristics of motors

3.3. Power factor characteristic

Figure 7 presents the power factor characteristics of motors as a result of testing from a laboratory. Figure 7 shows that the proposed motor power factor (PF-M1P4) is nearly identical to that of a traditional asynchronous motor (PF-M1C). The maximum power factor of the proposed asynchronous motor and traditional asynchronous were 96.1% and 97.8%, respectively. Both power factor characteristics of the motors are almost close to unity. Thus, it can be said that for the power factor characteristics, both motors are almost the same.

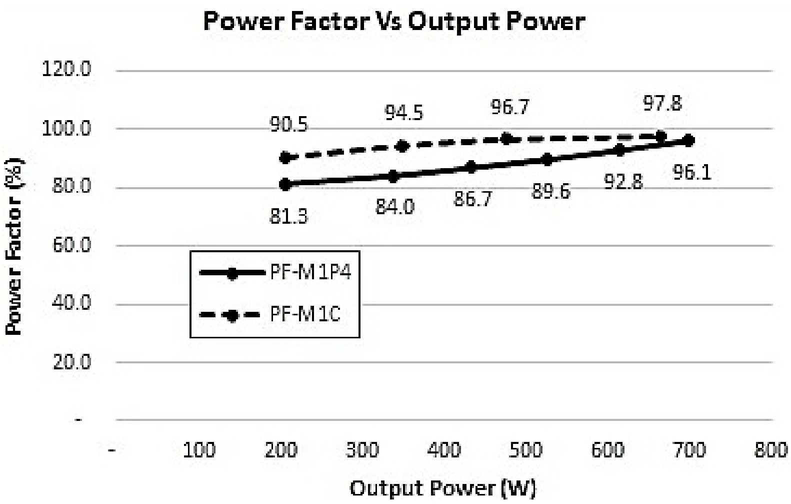

Figure 7. Power factor characteristics of motors

3.4. Efficiency characteristic

Figure 8 shows the efficiency characteristics of motors as a result of testing from a laboratory. Figure 8 presents that the efficiency of the designed motor (Eff-M1P4) had better performance than that of the traditional single-phase asynchronous motor (Eff-M1C). The maximum efficiency range of the designed asynchronous motor and the traditional asynchronous motor was 66.3% and 63.3%, respectively. So, it can be concluded that for the efficiency characteristics, the designed motor is also better than the traditional single-phase asynchronous motor. From the results of all characteristics displayed by the two motors can be concluded the maximum characteristics of both motors as shown in Table 1.

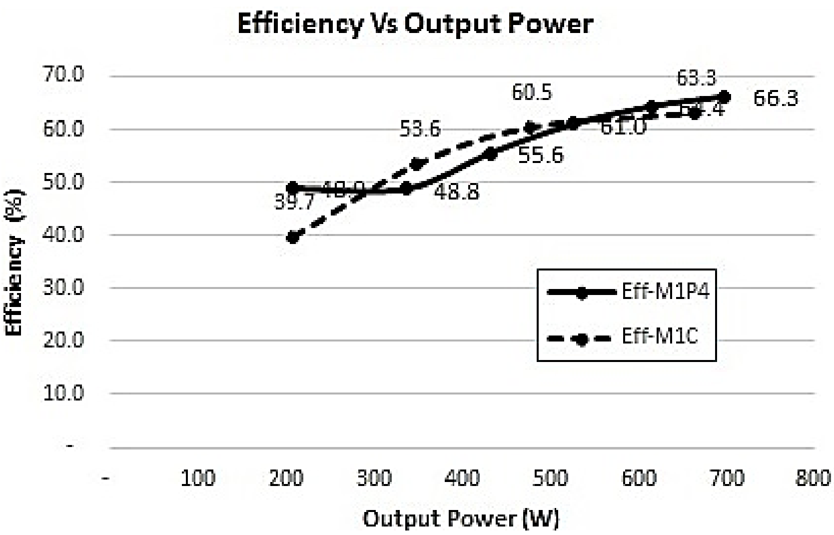

Figure 8. Efficiency characteristics of motors

In Table 1 it can be seen that the proposed motor with 4 non-identical windings has a better performance than the traditional single-phase asynchronous motor. Referring to (2) and (4), the capacitance values of the capacitors used in the designed motor are Cr=25 µF and Cs=20 µF. These values are lower than the capacitance value of the capacitor used by that the conventional single-phase induction motor that uses Cr=30 µF and Cs=200 µF. From the condition, it can be seen that the capacitor capacitance value of the proposed motor is saved, thereby saving the cost of producing the motor.

Table 1. Maximum characteristics of the motors

No	Object	Motor design of proposed	Conventional motor design
1	Output power (W)	669.08	664.36
2	Rotor speed (RPM)	1402	1394
3	Torque (Nm)	4.8	4.6
4	Power factor (%)	96.1	97.8
5	Efficiency (%)	66.3	63.3

4. CONCLUSION

This study focused on the design of 4 non-identical winding designs for a capacitor-start capacitor-run induction motor. The designed motor had 4 windings, but not identical. The performance of the designed motor was compared with that of a traditional single-phase asynchronous motor of the same construction as the stator, rotor, and rated current. The result of this study shows that the performances of the designed motor were better than those of traditional single-phase asynchronous motors. The designed motor can also be operated using a capacitor lower capacity than the capacitor used on a traditional single-phase asynchronous motor so that the cost of the designed motor is lower than that of conventional single-phase motors. Therefore, the designed winding design can be recommended for application to new single-phase asynchronous motors.

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