

# Single Phase Induction Motor with 4 Windings Design and Current Control in Auxiliary Winding

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**Abstract**—A single phase induction motor has two windings for operating. The winding design was more complicated than the poly-phase induction motor. As a fact that the current density flowing in each motor winding is not the same for fluctuating load conditions. Because of that, this study was aimed to show a new design that simply by using 4 windings in the stator and the controlled current in auxiliary winding. This design was focused for capacitor-start capacitor-run induction motor. The design has 4 windings, one winding act as the main winding and the other three windings act as the auxiliary windings. The windings current rating of the proposed motor was 2.74A and 3.15A for the main and auxiliary winding, respectively. The auxiliary winding current of the motor was controlled by the Arduino control system. The performances of the proposed method were compared to the performances of a conventional single-phase induction motor that had the same construction of the stator, rotor and current rating. The conventional single-phase induction motor used in this study was a single-phase induction motor of 220V, 8.3A, 4 poles, 1 HP, cage rotor, 1440 RPM, 50Hz. The proposed motor with 4 windings design in this study showed better performances than the conventional induction motor.

**Keywords**—4 winding design, single phase induction motor, current controller, auxiliary winding

## I. BACKGROUND

Induction motors are very widely used by society today in both the industrial and household sectors [1]. The motors that used in these sectors usually work at 50 Hz or 60 Hz frequency. Several attempts have been made to improve the performance of the motor, including by optimally designing of the rotor slot and stator windings [2] as well as the use of copper windings in rotor with a smooth rotor geometry [3], so that the rotor power losses are smaller. Another method has been developed by using amorphous laminate armor [4], soft magnetic composite material [5], and the selection of iron particle size on Fe / silicate magnetic material on soft magnetic material [6] on the stator to improve the performance of induction motors. But, all of these methods are only suitable for motors that work with high frequencies (400 Hz to 1000 Hz), but not at low frequencies.

Single-phase induction motor usually used in household application. This motor usually used a single phase power system and is produced in low power rating [1]. Motor application is widely used such as washing machine, fans, etc. Single-phase motor has two windings, the main and auxiliary winding, so it has lower efficiency than the poly-phase induction motor. By referring to some researches, the performances of a three-phase induction motor can be

improved by operating it on a single phase power system [7]–[12]. It can be seen that these methods generally applied the principle of a single-phase induction motor to three-phase induction motor by using bank capacitor mounted on the motor. The motor still used 3 windings when operated on a single phase power system, so that the motor would operate close to its power rating. Further research has also been developed by designing a single phase motor using 3 windings such as a three-phase motor design [13]. The research shows that the motor can operated with better performance than conventional single-phase induction motors that had the same stator and a rotor frame design. It had also been developed that single-phase induction motor with 4 identical windings design [14]. By using 4 identical windings, the motor operated with a slightly lower power capacity than the conventional motor and the motor had bad performance while operated on low load condition. Therefore, this study is focused on discussing about a 4 windings design of single-phase induction motor that auxiliary winding current is controlled by the Arduino control system. The object focused on about power factor, output power, and winding current of the motor.

## II. CONVENTIONAL SINGLE PHASE INDUCTION MOTOR

Single phase induction motors usually operate by using 2 windings at starting. When the motors use a capacitor bank, the motors will operate with better performance. This motors are called capacitor motor [1]. By using the capacitors, the torque generated by the motor is increased and the motor work like a two-phase induction motor while running. Fig. 1 show the winding connection and capacitor installed on the motor [13].

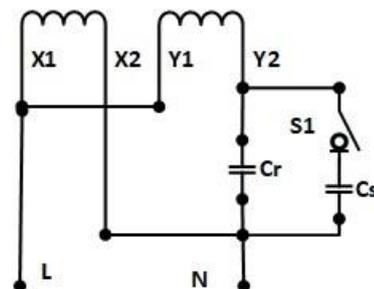


Fig. 1. Winding connection and capacitor installed on the motor.

By paying attention to Fig. 1, it can be explained that the motor has a winding 'X' which is marked with X1 and X2 is called the main winding, while the winding 'Y' which is marked with Y1 and Y2 is called the auxiliary winding. 'Cr'

in Fig. 1 is the run capacitor that used both at starting and running, while the 'Cs' in Fig. 1 is the start capacitor that used by the motor at starting only. The 'S1' in Fig. 1 is the switch that represents the centrifugal switch on the motor, and the 'N' and 'L' labels in Fig. 1 are the 'Neutral and Line' of the voltage source of a single phase power supply respectively.

### III. RESEARCH METHOD

This study is purposed to discuss about a single phase capacitor motor that has 4 windings design with current control on auxiliary windings. Three windings acts as a auxiliary winding and the other windings act as an main winding. The windings were not identical. The motor had the main and auxiliary windings with a cross-sectional area of 0.65 mm<sup>2</sup> and 0.75 mm<sup>2</sup> respectively. The main windings of the motor had a current rating of 2.74 A. In order to operate the motor with the same current density, the current rating on the auxiliary winding of the motor is set with a maximum current of 3.15 A. The motor has the start and run capacitors of 20 μF and 25 μF, respectively. But, when the load below 70%, the run capacitor was set 15 μF that is controlled by using 'Arduino Uno control system'. The winding connection with the capacitors installed on the motor is shown in Fig. 2. The run capacitor in Fig. 2 was varied by using the Arduino control system with relay and contactor programed to the motor.

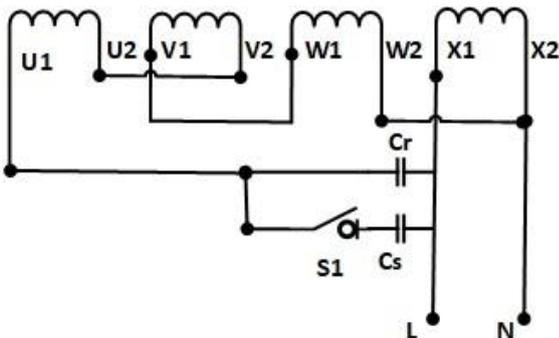


Fig. 2 Four winding constructions with capacitor installed on proposed method

In order to know the performance of the proposed motor, the motor was test in laboratory and was compared to conventional single-phase induction motor. Both motors had identical stator and rotor construction but different in winding design. The conventional single-phase induction motor used in this study had the main and auxiliary windings with a cross-sectional area of 0.65 mm<sup>2</sup> and 0.9 mm<sup>2</sup> respectively. The main windings of the motor had a current rating of 2.74 A. The conventional single-phase induction motor had another data: 1 HP, 220V, 4 poles, 1440 RPM, 8.3 A, 50 Hz, Cs = 200μF and Cr = 30μF.

The capacitor connection system in Fig. 2 can be changed by moving the capacitor connection from terminals U1 and X1 to terminals W2 and X2. The winding 'X' marked from X1 to X2 in Fig. 4 is the main winding, while the 'U' winding marked from U1 to U2, the 'V' winding marked from V1 to V2, and the 'W' winding marked from W1 to W2', are the auxiliary windings. So, the auxiliary

winding designed in this method has 3 windings connected in series. The auxiliary windings are deliberately made 15% larger than the main winding so that the auxiliary windings can be flowed with a higher current and produce higher torque. The capacitors are deliberately installed on the auxiliary windings consisting of 3 windings connected in series, so that the motor can use a smaller capacitor capacitance when compared to using the capacitors installed on the main winding that only has 1 winding.

The capacitive reactance of the capacitors used in this study is calculated by using (1), (2), (3) and (4) as follows.

$$Cst = \frac{(0.18)I_N}{(f)(V_{LN})} (Farad) \quad (1)$$

$$Cr = 0.1991(Z) \frac{I_N}{(A_Z)(f)(V_{LN})} (Farad) \quad (2)$$

Where [14]:

$$A_Z = \frac{N_U + N_V + N_W}{N_X} \quad (3)$$

- $I_N$  = main winding current rating (A)
- $V_{LN}$  = single phase voltage (V)
- $f$  = frequency (Hz)
- $A_Z$  = constants of Zuriman Anthony
- $N_U$  = the number of slots on 'U' windings
- $N_V$  = the number of slots on 'V' windings
- $N_W$  = the number of slots on 'W' windings
- $N_X$  = the number of slots on 'X' windings
- $Z$  = 0.6, for load below 70%
- = 1, for load above 70%

The 'start capacitor' capacitive reactance (Cs) in Fig. 2 must be calculated using (3) as follows [13].

$$Cs = Cst - Cr (Farad) \quad (4)$$

The voltage of the capacitor 'Vc' and the reactive power of the 'run capacitor' (VARc) then can be determined respectively by using (5) and (6) as follows [13].

$$Vc = A_Z \cdot V_{LN} \quad (5)$$

$$VARc = (\omega Cr)(A_Z \cdot V_{LN})^2 \quad (6)$$

Apparent power (S) of the proposed motor then can be determined by using (7) as follows[13].

$$S = VARc \quad (7)$$

Then, the motor line current ( $I_L$ ) must be calculated by using (8) as follows[13].

$$I_L = \frac{S}{V_{LN}} \quad (8)$$

The proposed motor will has power factor close to 0.97 when while operate at its standard speed rotation. So, the power factor of the motor (*PF*) can be determined by using (9). And then, the input power (*Pin*) of the motor can be determined by using (10) as follows.

$$PF = \text{Cos}(\varphi) = 0,97 \quad (9)$$

$$Pin = S \cdot \text{Cos}(\varphi) \quad (10)$$

#### IV. RESULT AND DISCUSSION

The conventional motor could not operated properly according to its nameplate data, where the motor did not operate with its standard current at a standard speed of 1440 RPM. Therefore, the motor was operated with a speed close to 1400 RPM. Under these conditions, the proposed motor design was also operated at speeds close to 1400 RPM. Both characteristics of the motors will be discussed as follows.

##### A. Output Power of the Motor

Fig. 3 shows characteristic of the output power as a result from the laboratory.

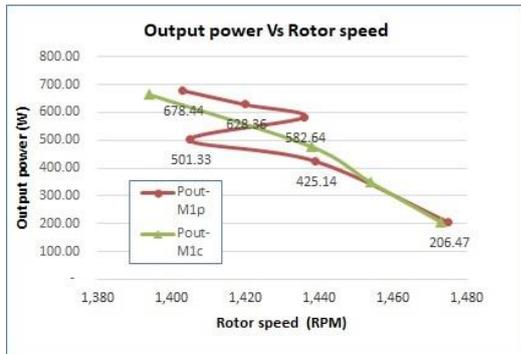


Fig. 3 Characteristic of the output power of the motors

From Fig. 3 can be seen that the output power performance of the single phase proposed motor (*Pout-M1p*) is better than the conventional motor (*Pout-M1c*). The proposed motor always had an output power higher than the conventional motor. The highest output power of the proposed motor and the conventional motor were 678.44 W and 664.36 W respectively. So, it can be concluded that the proposed motor is more powerful than the conventional motor. This occurs because the mechanical torque generated by the proposed motor is greater than the conventional motor, so that the mechanical output power generated by the proposed motor also becomes larger.

##### B. Power Factor of the Motor

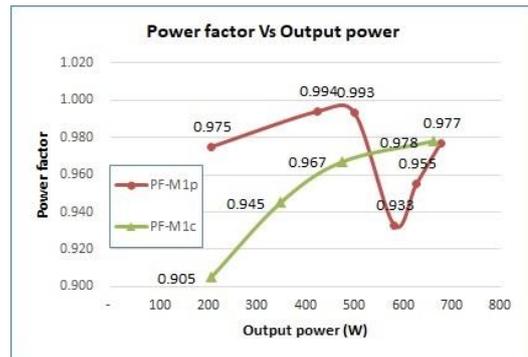


Fig. 4 Characteristic of the power factor of the motors

Fig. 4 show the characteristic of power factor as a result from the laboratory. From Fig. 4 can be seen that characteristic of the power factor of the proposed motor (*PF-M1p*) almost the same with the conventional single phase induction motors (*PF-M1c*) for high load condition. But at low load condition, the proposed motor has better performance than the conventional single phase motor.

##### C. Winding Current of the Motor

Fig. 5 and Fig. 6 show winding current characteristic as a result from the laboratory.

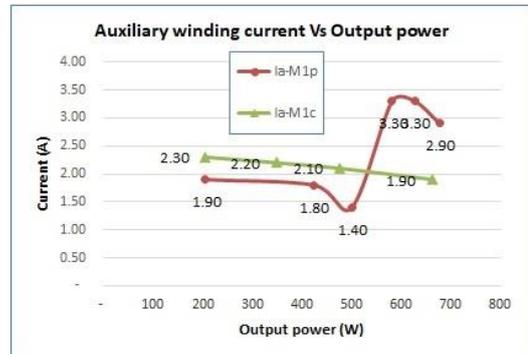


Fig. 5 Auxiliary winding current characteristic of the motors

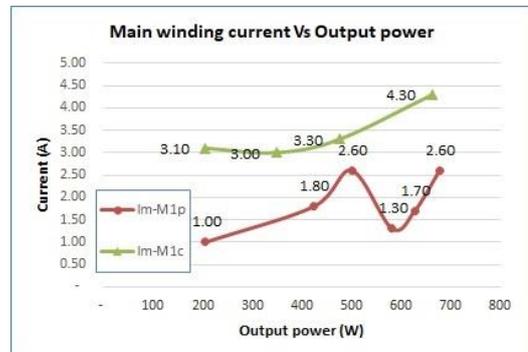


Fig. 6 Characteristic of the main winding current of the motors

Fig. 5 show both the auxiliary winding current for the motors. The proposed motor has low winding current (*Ia-M1p*) when operating at low loads condition and then rises at

high loads up to 2.9 A, but still below the nominal current 3.15 A. And when we see from Fig. 6, the main winding current of the proposed motor (Im-M1p) is always smaller than the single phase induction motor's (Im-M1c), so that the power losses on the proposed motor are smaller than conventional motor's. So that, this condition will make the proposed motor more powerful and efficient.

The results of the conclusion of the characteristics of both motors are shown in table 1.

TABLE I. CHARACTERISTIC CONCLUSION OF THE MOTORS

No.	Maximum Characteristic		
	Object	Single phase proposed motor	Conventional single phase induction motor
1.	Output Power (W)	678.44	664.36
2.	Power Factor	0.977	0.978
3.	Auxiliary Winding Current (A)	2.9	1.9
4.	Main Winding Current (A)	2.6	4.3

## V. CONCLUSION

This study was a 4 windings design of a single phase induction motor with current control in the auxiliary winding. The proposed motor had 4 windings, three auxiliary windings and one main winding. The proposed motor can use lower capacitor capacitance to operate the motor, so the cost of the proposed motor is cheaper than conventional motors. When the auxiliary winding is controlled by a smart control system, the motor can be operated with better performance. Almost all proposed motor characteristics were better and more powerful than conventional single-phase comparator motor's.

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