Reactive power compensation in squirrel cage rotor type of three-phase induction motors

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Abstract. The purpose of this study is to produce: (1) The average real power in squirrel-cage rotor type of three-phase induction motor load. (2) The average reactive power in squirrel-cage rotor type of three-phase induction motor load. (3) The best capacitor value for saving reactive power in squirrel-cage rotor type of three-phase induction motor load. The research method used is a quantitative description approach by applying measurement methods in the Laboratory of Department of Electrical Engineering Education, Nusa Cendana University, Kupang. The study population was the entire squirrel-cage rotor type of three-phase induction motor controller using the star to delta method. The sample is a number of measurements of voltage, current, and power ion n a three-phase induction motor using the star to delta method. The conclusions of the research are: (1) The average real-power for delta-connection load without capacitor obtained a value of 24.4 [Watt]. The average reactive power for delta-connection load without capacitor obtained a value of 205 [VAR]. (2) The average-real power for delta-connection load with the capacitor of 11.57 [µF] obtained a value of 9.9 [Watt]. The average reactive power for delta-connection load with the capacitor of 11.57 [µF] obtained a value of 9.4 [VAR]. (3) Capacitor value 11.57 [µF] is the best value for reactive power savings in squirrel-cage rotor type of three-phase induction motor.

1. Introduction

Induction motors are widely used in daily life both in industry and in household activities. In the industrial sector, mostly use a three-phase induction motor while for household purposes, generally applying a single-phase induction motor. Because of the large number of industries that apply three-phase induction motors, a study of the use of electrical power is needed so that there is no waste in the cost of electricity used [1-4].

Electrical equipment has a value in the form of resistive and reactance loads, it is said to be a resistive load if the equipment is pure resistance, whereas if the electrical equipment is said to be a reactance load if there is an inductive or capacitive value. Inductive reactance load is an electrical equipment in which consist of a coil.

Induction motors consisting of coils could be classified as inductive loads. This inductive load results in the real power indicated on the nameplate of an Induction motor with watt units, not in accordance with the real power used in units of volts-amperes, this power difference is usually called the power-factor. Ideally, the power-factor is worth as one, whereas the power-factor at an inductive load is smaller than one, or can be said to be a power loss [5].

A way to save electricity usage especially for inductive loads is by avoiding transient currents in the form of compensation. Inductive load, the compensation is done by adding a capacitor to the load.
Reactive power compensation can be applied to many things, both in the distribution of electricity and the use of electricity such as in a power transformer at the substation and distribution substations, but in addition it can also be applied to AC electric motors in either single-phase or three-phase. This research will only discuss compensation for three-phase AC electric motors [5].

An induction motor is an inductive load and requires compensation so that the power-factor can be approached ideally, that is why a study of reactive power compensation on a three-phase induction motor is needed [5]. This article examines inductive load reactive power compensation by applying variations in AC capacitors that correspond to the large capacity of the squirrel-cage rotor type of three-phase induction motor load.

2. Method

2.1. 3 phase AC motor control

AC induction motor that have a large power capacity usually have a fairly complicated problem in determining the appropriate starting method for the motor. The choice of motor starting for these motors is usually greatly influenced by factors such as power capacity, type of motor such as a squirrel-cage rotor motor or a winding rotor motor, type of motor design (basic motor, high torque, low torque) then the types of loads being moved [6].

There are two starting methods used to run an AC induction motor, namely: (1) Starting using the full voltage from the network. Starting with this method uses the full mesh voltage, which is connected directly to the motor terminal. This starting method is often called as “Direct on Line Starting (DOL Starting). (2) Starting with a drop voltage [7-9]. This study uses a voltage reduction method.

Running an induction motor requires a large amount of power provided by the source voltage. The amount of power needed is quite large compared to the motor after fully operated (running). The amount of power required by this motor to start is equal to the amount of current taken by the motor itself. This current ranges from 4 to 8 times the full load current of the motor. Although the amount of current that flows is done in a short time, for a large motor capacity it will take large power, and able to disrupt the existing network system as well as damaging the motor system itself. Therefore, to overcome the danger that might arise due to the large current flowing at start time, several starting methods are used by reducing the voltage, i.e.: (1) Starting by using the Star/Delta connection system. (2) Starting by using Primary Resistance Starting. (3) Starting by using the Starting Autotransformer [9].

2.2. Power triangle

Measurement of electrical power requires a measuring instrument called watt-meter, in which what is measured on the watt-meter is called measuring the actual power, that is, real-power-P, whereas in reality there are known three units of electrical power. Electrical equipment has a value of resistance R and reactance L as in AC induction motors, which are supplied by real-power S and also consist of a real-power component P and a reactive-power component Q. S is the amount of vector of components P and Q. The π angle is the angle between the real-power and the real-power vector, which is the phase angle shift. The comparison of real-power and reactive-power is called the power-factor or cos π [2,10,11].

![Figure 1. Power triangle [10].](image)
The addition of capacitors to the induction motor, the reactive power component \( Q \) is expected to be reduced or often called reactive-power compensation. Based on Figure-5, it can be seen that with the reduction of power-factor from value 1 to value 0.6, the result is real-power decreases, while reactive-power increases or vice versa by increasing the power-factor from value 0.6 to value 1, obtained greater real-power. Thus, because the wattmeter only measures the real-power of \( P \) in watts, while the power available at the load of an induction motor is real-power in volt-amperes, we expect the magnitude of the real-power \( P \) to be close to the real-power or \( S \) value, so we need a treatment to improve the power-factor from a low value to a higher value, for example from a value of 0.6 to a value of 1.

Improvements to power-factors can occur, a compensation for AC operation is needed by connecting an inductive load, in this case an AC induction motor with a capacitor connected in parallel [12]. The magnitude of the capacitance of capacitors for reactive-power compensation can be found by the equation:

\[
C = \frac{3185 \cdot P \left( \tan \pi_1 - \tan \pi_2 \right)}{U^2}
\]

Where:
- \( C \) = Capacitance [Microfarad]
- \( P \) = Total Power [Watt]
- \( 3158 = \frac{10^6}{2 \pi f} \)
- \( F = 50 \) [Hertz]
- \( \cos \pi_1 \) = power-factor before the capacitor is installed.
- \( \cos \pi_2 \) = power-factor after the capacitor is installed

3. Method
The research method used is a quantitative description approach by applying measurement methods in the Laboratory of Department of Electrical Engineering Education, Nusa Cendana University. The research is conducted at Laboratory of Department of Electrical Engineering Education, Nusa Cendana University, Kupang. The study population was the entire squirrel-cage rotor type of three-phase induction motor controller using the star to delta method. The sample is a number of measurements of voltage, current, and power ion a three-phase induction motor using the star to delta method. The research instrument used the 3 phase induction motor power measurement figure
and the main circuit of 3 phase induction motor control figure as the guidance. Data collection techniques used in this study are measurement techniques through observation at Laboratory of Department of Electrical Engineering Education, Nusa Cendana University. While the tools used are: 3 phase induction motor, magnetic contactor, 3 phase wattmeter, ampere-meter, voltmeter and capacitor.

![Figure 4](image4.png)

**Figure 4.** Measurement of three-phase power and power-factor [14].

![Figure 5](image5.png)

**Figure 5.** Measurement of voltage and current on an induction motor [14].

4. Results and discussion

4.1. Result of research

Figure 6, shows the variation of phase currents at I_R loads, with variations: I_R star connection without C (capacitor), I_R delta-connection without C, I_R delta-connection with C 0.72 [µF], I_R delta-connection with C 1.45 [µF], I_R delta-connection with C 2.89 [µF], I_R delta-connection with C 5.06 [µF], I_R delta-connection with C 10.12 [µF], I_R delta-connection with C 11.57 [µF].

![Figure 6](image6.png)

**Figure 6.** I_R phase current.
Figure 7 shows the variation of phase currents at $I_S$ loads, with variations: $I_S$ star connection without C, $I_S$ delta-connection without C, $I_S$ delta-connection with C 0.72 [$\mu$F], $I_S$ delta-connection with C 1.45 [$\mu$F], $I_S$ delta-connection with C 2.89 [$\mu$F], $I_S$ delta-connection with C 5.06 [$\mu$F], $I_S$ delta-connection with C 10.12 [$\mu$F], $I_S$ delta-connection with C 11.57 [$\mu$F].

Figure 8 shows the variation of phase currents at $I_T$ loads, with variations: $I_T$ star connection without C, $I_T$ delta-connection without C, $I_T$ delta-connection with C 0.72 [$\mu$F], $I_T$ delta-connection with C 1.45 [$\mu$F], $I_T$ delta-connection with C 2.89 [$\mu$F], $I_T$ delta-connection with C 5.06 [$\mu$F], $I_T$ delta-connection with C 10.12 [$\mu$F], $I_T$ delta-connection with C 11.57 [$\mu$F].

Figure 9 shows variations in real-power at a load, with variations: power in a connection star-connection without C, power in delta-connection connection without C, power in delta-connection connection with C 0.72 [$\mu$F], power in delta-connection connection with C 1.45 [$\mu$F], power in delta-connection connection with C 2.89 [$\mu$F], power in delta-connection connection with C 5.06 [$\mu$F], power in delta-connection connection with C 10.12 [$\mu$F], power in delta-connection connection with C 11.57 [$\mu$F].

Figure 10 shows variations in reactive-power at a load, with variations: power in a connection star-connection without C, power in delta-connection connection without C, power in delta-connection connection with C 0.72 [$\mu$F], power in delta-connection connection with C 1.45 [$\mu$F], power in delta-connection connection with C 2.89 [$\mu$F], power in delta-connection connection with C 5.06 [$\mu$F], power in delta-connection connection with C 10.12 [$\mu$F], power in delta-connection connection with C 11.57 [$\mu$F].
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Figure 9. Real-power.

Figure 10. Reactive-power.

4.2. Discussion
The average voltage for the delta connection load with a 11.57 µF capacitors is 244.5 [V]. The average real power for the delta connection load with a 11.57 µF capacitors is 9.9 [Watt]. The average reactive power for the delta connection load with a 11.57 µF capacitors is 9.4 [VAR]. The average $I_R$ current for the load delta connection with 11.57 µF capacitors obtained a value of 0.0845 [A]. The average $I_S$ current for the load delta connection with 11.57 µF capacitors obtained a value of 0.1577 [A].
average $I_T$ current for the load delta connection with 11.57 µF capacitors obtained a value of 0.0763 [A].

Based on table-1, it shows that there is a relatively small reduction in real power and reactive power for the delta connection between C of 10.12 µF with those using C of 11.57 µF, where it appears that the load on the delta connection with a C value of 11.57 µF has a smaller real power and reactive power value. Therefore, it can be seen that the value of real power is almost the same as the value of the two power is getting smaller, especially the reactive value decreases relatively greater, so it is expected that the reactive value is close to zero. The analysis of $I_S$, $I_T$, $I_R$ load currents shows that there is a difference in value that may not be meaningful and can be interpreted as a load in a steady-state. The delta connection with a C value of 11.57 µF has a relatively smaller load current compared to the delta connection load current with C 10.12 µF.

Table 1. The data of delta connection load with C 11.57 µF.

| SCALE | 55 | 57 | 61 | 65 | 67 | 69 | 73 | 75 | 77 | 78 | AVG |
|---|---|---|---|---|---|---|---|---|---|---|---|
| V  | 200 | 210 | 220 | 230 | 240 | 250 | 260 | 270 | 280 | 285 | 244.5 |
| WATT | 7 | 8 | 9 | 10 | 10 | 10 | 11 | 12 | 13 | 12 | 9.9 |
| VAR | 0 | 0 | 1 | 2 | 5 | 9 | 11 | 16 | 22 | 28 | 9.4 |
| $I_R$ | 0.065 | 0.068 | 0.07 | 0.072 | 0.075 | 0.08 | 0.09 | 0.1 | 0.11 | 0.115 | 0.0845 |
| $I_S$ | 0.13 | 0.14 | 0.14 | 0.15 | 0.152 | 0.16 | 0.165 | 0.17 | 0.18 | 0.19 | 0.1577 |
| $I_T$ | 0.065 | 0.068 | 0.07 | 0.071 | 0.072 | 0.074 | 0.078 | 0.082 | 0.09 | 0.093 | 0.0763 |

5. Conclusion
The conclusions of the research are: (1) The average real power for delta-connection load without capacitor obtained a value of 24.4 [Watt]. The average reactive power for delta-connection load without capacitor obtained a value of 205 [VAR]. (2) The average real power for delta-connection load with the capacitor of 11.57 µF obtained a value of 9.9 [Watt]. The average reactive power for delta-connection load with the capacitor of 11.57 µF obtained a value of 9.4 [VAR]. (3) Capacitor value 11.57 µF is the best value for reactive power savings in squirrel-cage rotor type of three-phase induction motor.

The advantages of reactive power compensation by applying the voltage reduction method using the delta star connection are better than the primary resistance or with the autotransformer as follows: (1) Stability of the voltage stages when running. (2) Stability of the stages of current consumed. (3) Does not produce excessive heat in the control.

The implications of the research are: (1) Running a three-phase induction motor by applying a star to delta system can reduce large initial currents. (2) Reducing reactive power losses can be done by applying reactive power compensation by applying capacitors in parallel to the load of three-phase induction motors.

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