Analyzing Characteristics of the Sheda's Method for Operating the 3-phase induction Motor on Single Phase Supply (Case studies: output power and efficiency of the motor)

Zuriman Anthony

Department of Electrical Engineering, Institut Teknologi Padang (Padang Institute of Technology)
JL. Gajah Mada Kandis Nanggalo Padang, West Sumatra, Indonesia

Abstract – *Scheda was a person who published a method for operating the 3-phase induction motor on singlephase supply in 1985. The method installs a capacitor circuit on the terminal of the motor. So the motor operated like a single phase induction motor. This method only creates some formulas for calculating the capacitor that suitable for operating the 3-phase induction motor on single phase supply. The formulas could not be used for predicting characteristics of the motor in variation speed conditions. Therefore, this research is proposed to create a steady-state equivalent circuit includes its formulas for analyzing the motor on varying speed conditions, especially for power output and efficiency of the motor. The 3-phase induction motor used in this research was the motor of 1.5 HP, 380/220V, Y/Δ, 2.75/4.7A, 4 poles, 50Hz, 1400 RPM. For validating the formulas, the motor also tested in a laboratory. The results showed that the formulas and equivalent circuit was given had good accuracy when they compared with the results of experiments in the laboratory.*

Keywords: *equivalent circuit, capacitor circuit, single-phase supply*

I. Introduction

The 3-phase induction motor is an electric motor operating under normal condition by using the 3-phase power supply. The motor is widely used today because this motor has a robust construction and simple control operation system. In particular condition, this motor can operate on single phase power by using capacitor circuits that installed on the terminal of the motor. This method had provided several advantages such as a large starting torque, fast response and improving power factor of the motor [2,3,7,9].

There are several methods had been creating until today. One of the methods will be discussed in this paper is the method that published by Scheda[7]. The formulas were given only for calculating the capacitor used for operating the 3-pase induction motor on single phase supply. There were no any formulas for predicting characteristics of the motor on varying speed condition. In this research, the Scheda's method will be analyzed by using a new equivalent circuit includes its formulas that used for predicting characteristics of the motor, especially for power output and efficiency of the motor.

The method of operating the 3-phase induction motor on single phase supply that created by Scheda is shown in Fig. 1[7].

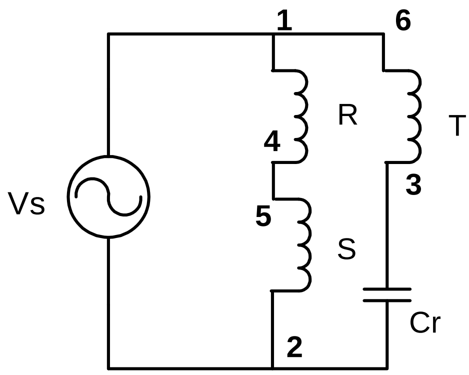

Fig. 1 Capacitor circuit that created by Scheda

Fig. 1 only displays the capacitor run circuit on the terminal of the motor. The formulas are given by Scheda completely on 7th reference.

II. Equivalent Circuit

The 3-phase induction motor usually operates under normal condition by using the 3-phase supply system. The windings of the 3-phase induction motors are designed specific. The motors have three identical coils 1200 distributed electricity[8]. The motor will run well when the motor operated in normal operation on 3-phase supply system. If the motor is operated on single phase supply system, then the coil must be created like a single phase induction motor. The motor can work with a large torque if the capacitor circuit is installed on the winding of the motor. Therefore, when the 3-phase induction motor is operated on single phase supply, the equivalent circuit of the 3-phase induction motor must be similar to the 1-phase capacitor motor.

The equivalent circuit of the 3-phase induction motor when operated on single phase system then can be made as shown in Fig. 2 [1].

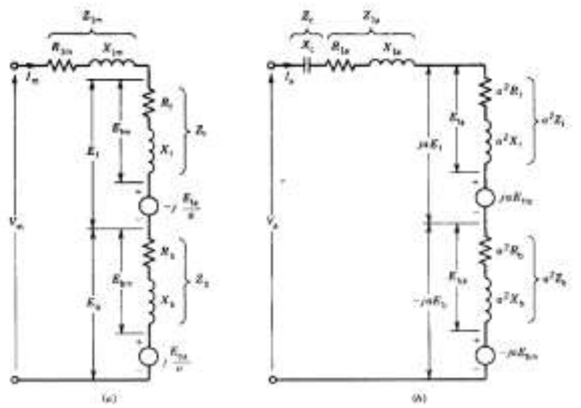

Fig. 2. Equivalent circuit of the capacitor-run motor; a) equivalent circuit of the main winding, b) equivalent circuit of the auxiliary winding

According to Fig. 2 then can be made as follows[1,8]:

$$V_m = I_m(Z_{lm} + Z_f + Z_b) - j\frac{E_{fa}}{a} + j\frac{E_{ba}}{a} \quad (1)$$

$$V_a = I_a(Z_c + Z_{la} + a^2 Z_f + a^2 Z_b) + jaE_{fm} - jaE_{bm} \quad (2)$$

$$V_a = V_m = V_s = V_{LN} \quad (3)$$

$I_s = I_m + I_a$, is the input current (A) (4)

Where:

I_a = current flowing in the auxiliary winding (A)

I_m = current flowing in the main winding (A)

V_s = V_{LN} = voltage source (line to neutral) of the single phase supply (V)

V_a = voltage source of the auxiliarly windings (V)

V_s = voltage source of the main windings (V)

Z_{la} = R_{la}+ jX_{la}, is the leakage impedance of the auxiliary windings

Z_{lm} = R_{lm}+ jX_{lm}, is the leakage impedance of the main winding

Z_c = - jX_c, is the capacitor impedance conneted in series with the auxiliary winding

Z_f = forward leakage impedance

Z_b = backward leakage impedance

a = turns ratio of the winding/phase

and:

$E_{fa} = I_a a^2 Z_f$ (5)

$E_{ba} = I_a a^2 Z_f$ (6)

$E_{fm} = I_m Z_f$ (7)

$E_{bm} = I_m Z_b$ (8)

As we know, the 3-phase induction motors have three windings that have the same turn ratio ‘a’ on each coil. If the motors are operated on single phase supply, then ‘a’ must be 1[1]. If we see from fig.1, ‘windings R’ is installed series to the ‘windings S’. So, the total impedance of the windings 'Zlm' from fig.2 is becomes:

$Z_{lm} = Z_R + Z_S$ (9)

Where:

Z_R = is the leakage impedance of the windings ‘R’ from fig.1 (ohm)

Z_S = is the leakage impedance of the windings ‘S’ from fig.1 (ohm)

If we see again according to fig. 1, the capacitor ‘Cr’ is installed series to the winding ‘T’. This winding is called auxiliary winding. The total impedance of this windings can be made as follows:

$Z_{lm} = Z_T - jX_{C1}$ (10)

Where:

X_{C1} = is the capacitor impedance connected in series to the windings ‘T’ (ohm)

Z_T = is the leakage impedance of the windings ‘T’ from fig. 1 (ohm)

As a matter of fact, the windings of the 3-phase induction motor is designed to have three identical windings 120^0 distributed electricity[8]. But, the windings of 1-phase induction motor divided into two parts, namely main and auxiliary windings that are installed within 180^0 of electricity. When the 3-phase induction motor is operated on single phase supply by using the method on fig.1, there is an effect of 120^0 (3-phase windings) to 180^0 (1-phase windings) of the motor impedance. So, there is a factor of 180/120 or 3/2 that influence the impedance of the winding of the motor. So, according to fig.2 and equations (1) to (8), then can be made some new equations as follows:

$$V_m = \frac{3(Z_{lm} + Z_f + Z_b)}{2} I_m - \frac{3j(Z_f - Z_b)}{2} I_a \quad (11)$$

$$V_a = \frac{3j(Z_f - Z_b)}{2} I_m + \frac{3(Z_c + Z_{la} + Z_f + Z_b)}{2} I_a \quad (12)$$

Furthermore, currents I_a, I_m, and I_s can be solved from equations (11), (12) and (4). Power factor of the motor (PF) can also be calculated as follows.

$$PF = \cos\phi \quad (13)$$

where:

ϕ = the phase angle difference between V_s with I_s

According to fig.2, the power is developed in the windings of the motor can be made as follows:

$$P_{gf} = \mathrm{Re}(E_f I_m^* + jaE_f I_a^*) \quad (14)$$

$$P_{gb} = \mathrm{Re}(E_b I_m^* - jaE_b I_a^*) \quad (15)$$

where:

P_{gf} = forward air gap power

P_{gb} = backward air gap power

The torque developed by the motor will become[8]:

$$T_f = \frac{P_{gf}}{\omega_s} \qquad (16)$$

$$T_b = \frac{P_{gb}}{\omega_s} \qquad (17)$$

$$T = T_f - T_b = \frac{P_{gf} - P_{gb}}{\omega_s} \qquad (18)$$

where:
T_f = forward torque
T_b = backward torque
T = total torque of the motor

Because of a factor of 3/2 influence, the windings of the motor during operation on single phase supply, the mechanical power of the motor becomes:

$$P_m = \frac{3}{2}(P_{gf} - P_{gb}).(1-s) \qquad (19)$$

So, the other powers and efficiency of the motor can be given as follows.

$$P_{out} = P_m - P_{rot} \qquad (20)$$

$$P_{in} = V_s.I_s.\cos\phi \qquad (21)$$

$$\eta = \frac{P_{OUT}}{P_{IN}}.x.100\% \qquad (22)$$

where:
P_m = mechanical power developed in rotor of the motor (W)
P_{out} = power output to the shaft rotor (W)
P_{rot} = rotational losses of the motor (W)
P_{in} = power input of the motor (W)
η = efficiency of the motor (%)

III. TEST RESULT

The motor used in this research was the 3-phase induction motor of 1.5HP, 380/220V, Y/Δ, 2.75/4.74 A, 4 poles, 50 Hz, 1400 RPM. Parameters of the motor were R1 = 11.4 Ω, R2 '= 5.7913 Ω, X1 = X2' = 10,9635 Ω, Xm = 111,4465. The capacitor used was a Cr = 30 µF. The capacitors used in this research had been given less from the calculation proposed by Scheda's method to limit the current through the windings of the motor. So that the current through the windings does not exceed the limit standard when the motor operated on single phase supply. The result of this research is shown in Table 1. Photograph of equipment and circuit control devices used to conduct experiments in the laboratory are shown in Fig. 3 and Fig. 4 respectively.

Table 1. Calculation results at 219.1V when compared to the experimental results at the rotor speed 1366 RPM

Parameters	Experimental results	Calculation results	Error (%)
Power output	260.52	284.9418	9.37
Efficiency	52.49	51.7391	1.431

From the Table 1 can be seen that the calculation results almost the same as the experimental results. The error (%) in table 1 shows the percentage error of the calculation results when compared to the laboratory results. There is only a little difference between the calculation results and the laboratory results. From table 1 can be seen that the efficiency and the output power only have error 1.431% and 9.37% respectively. So, the formulas given had the accuracy above 90% and 98% of efficiency and output power respectively. So the formulas are given applicable for predicting the output and efficiency of the motor when the motor operated on varying speed condition.

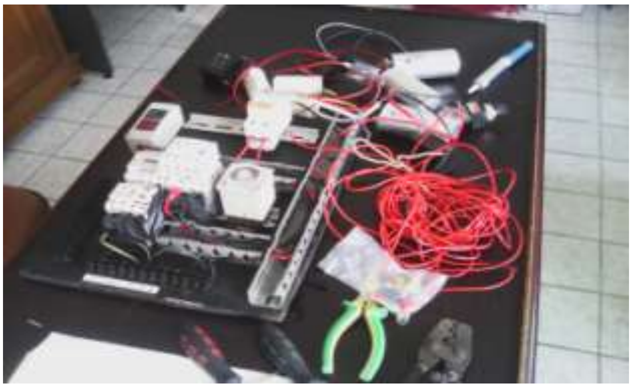

Fig. 3 Circuit control devices that are under construction in the laboratory

Fig. 4 Electrical measuring instruments used in the laboratory

By using equations (1) to the equation (22) can be calculated and simulated the forms of the performance of the 3-phase induction motor during operation on single phase supply (in particular the method of scheda). Furthermore, using Matlab program will be shown Characteristic of the power developed (especially Pm, Pout and Pin) and the efficiency of the motor as shown in Figure 5 and 6 respectively.

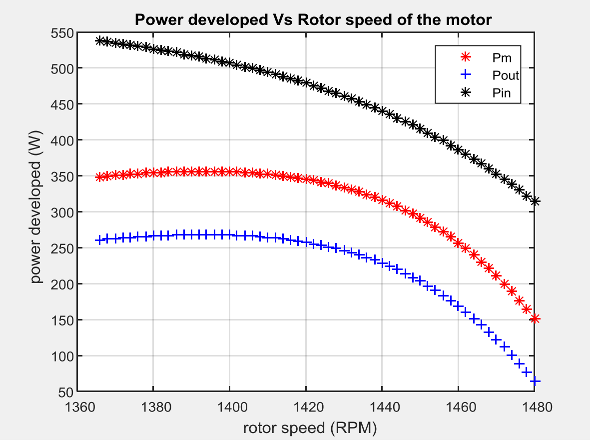

Fig. 5 Characteristic of the power developed Vs rotor speed of the motor

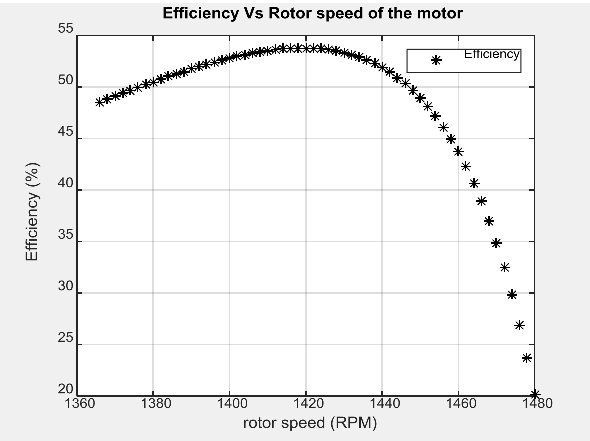

Fig. 6 Characteristic of the efficiency Vs rotor speed of the motor

From fig.5 can be seen that when the load of the motor is increased (shown by decreasing of rotor speed), power developed of the motor will increase. So, characteristic of the power developed is increased during the load is increased. But, the power output of the motor is shown decreased after the rotor speed decrease below 1400 RPM. This occurs because the motor has been given a load beyond its ability so that the motor speed drops below its standard speed. Because the motor has been given a load beyond its ability, then the losses power in the motor will increase that make the efficiency of the motor will go down as shown in Fig.6.

As the end of the result of this research can be concluded that fig.2 can use for predicting the shape of the characteristics of the 3-phase induction motors when operated on single phase supply in varying speed conditions. The adequate formulas for Scheda's method have created for fig.2 as given from equations (1) to the equation (22). Especially for predicting the output power and efficiency of the motor, equations (20) and (22) can be used respectively.

IV. Conclusions

From the research that has been done can be summarized as follows.

1. The formulas and equivalent circuit for analyzing the characteristic of Scheda's method have been create successfully.
2. There is only a little difference between the calculation results and the laboratory results. Especially for analyzing power output and efficiency of the motor, they have only error level of 9.37% and 1.431% for power output and efficiency respectively.

Acknowledgment

I extend special thanks to the assistant and team at the laboratory of electrical engineering of the 'Institut Teknologi Padang' who have helped this research run better.

References

[1] Anthony Zuriman, "Equivalent Circuit for The M31D-ZA Motor's Method (case studies:currents and power factor of the motor)", International Journal of Engineering Trends and Technology (IJETT), ISSN. 2231-5381, Seventh Sence Research Group, India, Vol. 25, No. 1, pp. 49-52, July 2015,

[2] Anthony Zuriman, "Simple Method For Operating The Three-Phase Induction Motor On Single Phase Supply (for Wye Connection Standard)", International Journal of Engineering Trends and Technology (IJETT), ISSN. 2231-5381, Seventh Sence Research Group, India, ISSN. 2231-5381, Vol. 5, No. 1, pp. 49-52, Nov. 2013.

[3] Badr M.A, Alolah A.I and Halim Abdul M.A, "A capacitor start three phase induction motor", IEEE transaction on energy conversion, Vol. 10, No. 4, pp. 675-680, December 1995.

[4] Bellure Anand, Aspalli, Dr. M.S, "Dynamic d-q Model of Induction Motor Using Simulink", International Journal of Engineering Trends and Technology (IJETT), ISSN. 2231-5381, Seventh Sence Research Group, India, Vol. 24, No. 5, pp. 252-257, June 2015.

[5] Huang H, Fuchs EF and White J.C, "Optimal placement of the run capacitor in single phase induction motor designs", IEEE transactions on energy conversion, Vol. 3, No. 3, pp. 647-652, Septermber 1988.

[6] Krause, P.C., " *Analysis of Electric Machinery* ", Mc. Graw-Hill Book Company, USA, 1986.

[7] Scheda, F. A.," Operating 3-phase Motors on 1-phase Power ", *EC&M*, January, pp. 40-41, 1985.

[8] Sen, P.C., *"Principles of Electric Machines and Power Electronics"*, John Wiley & Son, New York, pp. 397-410, 1989.

[9] Smith, Otto J., "Large Low-Cost Single-phase Semihex™ Motor ", IEEE Trans. on Energy Conversion, 14 (4) , pp. 1353-1358, 1999.

Zuriman Anthony is a lecturer in the 'Institut Teknolgi Padang' (Padang Institute of Technology) on Department of Electrical Engineering. His research's interest in Electrical Machines and Control. He received an M. Eng. (M.T.) from Gadjah Mada University, Yogyakarta, Indonesia in 2002. He always active in many researches about the 3-phase induction motors.