Equivalent Circuits for the M31D-ZA Motor's Method (Case Studies: Currents and Power Factor of the motor)

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Abstract *- The M31D-ZA motor's method was a method used for operating the 3-phase induction motor (for delta connection standard) on single phase supply that presented by Anthony [1]. This method was very simple and has good characteristics during operation. This research was purposed to make the equivalent circuit model for the M31D-ZA motor's method, including its formula model. Case studies were focused to calculate the current and power factor of the motor when operating on single phase supply. The research was conducted at the Laboratory of the Electrical Engineering of Institut Teknologi Padang. The object used in this research was the 3-phase induction motor of 1.5 HP, 220V, Δ, 2.75A, 4 poles, 50 Hz, 1400 RPM. The results showed that the equivalent circuit and the formulas given have good accuracy, that is greater than 91% of the current and close to 100% for power factor of the motor if it is compared with the results of experiments in the laboratory.*

Keywords: *equivalent circuit, input current, power factor, single phase induction motor*

I. INTRODUCTION

The 3-phase induction motor is an electric motor which is widely used today, mostly in the industrial sector because this motor has a robust construction and produced in great power. In special application this motor has been widely applied to operate on 1-phase power by installing capacitor circuit to the windings of the motor. This method provides several advantages such as a large starting torque, fast response of the rotor and improving power factor of the motor [1,2,7]. The methods applied are very diverse and usually many emulate the principles of the 'capacitor-start capacitor-run motor'. Capacitors are used can be put on the windings with smaller impedance or on the windings with the larger impedance of the motor [1,4,7].

Several formulas have been developed to calculate the current and power factor of the 3-phase induction motors when operated on single phase supply, but only at certain load conditions, not for variable load conditions[1,4,7]. Therefore, we need a new equivalent circuit with an adequate formula for the motor if we want to analyze the motor with variable load conditions during operation on single phase supply.

This research is purposed to present an equivalent circuit model for the 3-phase induction motor while operating on single phase supply, especially that presented by Anthony [1] and called M31D-ZA method. The method is shown in Fig. 1.

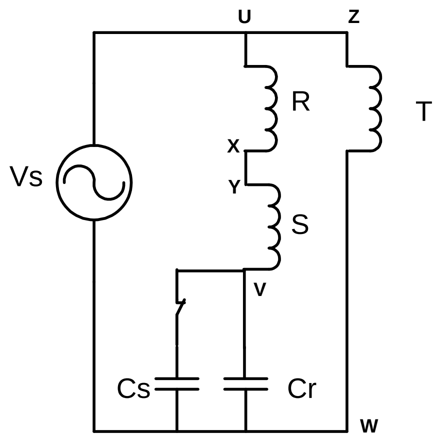

Fig. 1 The M31D-ZA method for operating the 3-phase induction motor on single phase supply

Refer to Fig. 1 can be explained the amplitude of the total capacitance of the start capacitor (Cs_Δ) and the total capacitance of the run capacitor (Cr_Δ) as follows [1].

$$Cs_\Delta = \frac{(0{,}11033).(I_L)}{(f).(V_{LN})} \quad \text{(Farad)} \tag{1}$$

$$Cr_\Delta = 0{,}0693x\frac{(I_{ph})}{(f)(V_{LN})} \quad \text{(Farad)} \tag{2}$$

Where:

$Cs = Cs_\Delta - Cr_\Delta$ (3)

Cr_Δ = Cr from Fig. 1

II. EQUIVALENT CIRCUIT

When the 3-phase induction motor operates on single phase power supply by using the circuit as present in Fig. 1, the motor will run as well as the 'capacitor-run 1-phase induction motor'. The equivalent circuit of the motor then can be made as shown in Fig. 2 [6].

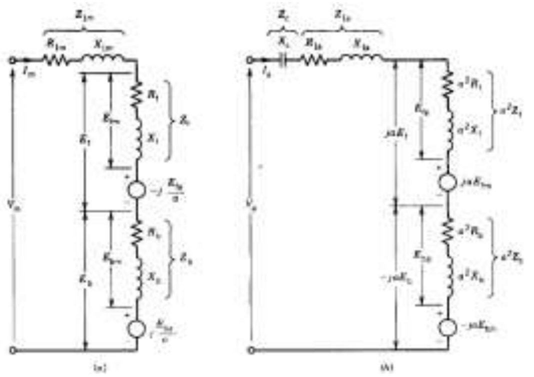

Fig. 2. Equivalent circuit of the capacitor-run motor; a) equivalent circuit of the main winding, b) equivalent circuit of the auxiliary winding

According to Fig. 2 can be made;

$$V_m = I_m(Z_{lm} + Z_f + Z_b) - j\frac{E_{fa}}{a} + j\frac{E_{ba}}{a} \quad (4)$$

$$V_a = I_a(Z_c + Z_{la} + a^2 Z_f + a^2 Z_b) + jaE_{fm} - jaE_{bm} \quad (5)$$

$$V_a = V_m = V_s = V_{LN} \quad (6)$$

$I_s = I_m + I_a$, is the input current (A) (7)

Where:

I_a = current flowing in the auxiliary winding (A)
I_m = current flowing in the main winding (A)
V_{LN} = voltage source of the single phase supply (V)
Z_{la} = R_{la}+ jX_{la}, is the leakage impedance of the auxialiary winding
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} = $I_a a^2 Z_f$ (8)
E_{ba} = $I_a a^2 Z_f$ (9)
E_{fm} = $I_m Z_f$ (10)
E_{bm} = $I_m Z_b$ (11)

The 3-phase induction motor has three windings that have the same turn ratio on each coil, so that while the 3-phase induction motors operating on single phase power system, then a = 1. Then, according to fig. 1, the obtained results Z_{la} = 2 x Z_{lm}, because the auxiliary winding contain coil 'R and S' in series with the capacitor, while the main winding only coil 'T'. From Eqs. (4) to (11) then can be made as follows.

$$V_s = V_m = (Z_{lm} + Z_f + Z_b)I_m - j(Z_f - Z_b)I_a \quad (12)$$

$$V_s = V_a = j(Z_f - Z_b)I_m + (Z_c + Z_{la} + Z_f + Z_b)I_a \quad (13)$$

The 3-phase induction motor has three identical coils 120^0 distributed electricity. To analyze on single phase system, it is necessary to transform the analysis by using the 'abc method (stationery)' to 'qd0 method (arbitrary reference frame)' that can be made as follows.

$$F_{qd0s} = K_s . F_{abcs} \quad (14)$$

Where:

$$K_s = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (15)$$

According to equation (15), there is a multiplier factor 2/3 to analyze the motor in 'qdO method'. Therefore, the multiplier factor 2/3 needs to be put on the impedance in equation (12) and equation (13). Furthermore, inserting '2/3' into the equations (12) and (13) will get the new equations as follows.

$$V_s = \left\langle \frac{2}{3}(Z_{lm} + Z_f + Z_b) \right\rangle I_m - j\left\langle \frac{2}{3}(Z_f - Z_b) \right\rangle I_a \quad (16)$$

$$V_s = j\left\langle \frac{2}{3}(Z_f - Z_b) \right\rangle I_m + \left\langle \frac{2}{3}(Z_c + Z_{la} + Z_f + Z_b) \right\rangle I_a \quad (17)$$

Furthermore, Equitions (16), (17) and (7) can be solved to obtain the winding currents I_a, I_m and I_s. Then, The amplitude of power factor (PF) of the motor can be calculated as follows.

$$PF = \cos\phi \quad (18)$$

Where:

ϕ = the phase angle difference between Vs with Is

III. Test Result

The motor used in this research is the 3-phase induction motor of 1.5 HP, 220V, Δ, 4.74 A, 4 poles, 50 Hz, 1400 RPM. Parameters of the motor are R_1 = 11.4 Ω, R_2 '= 4.8589 Ω, X1 = X_2' = 9.6213 Ω, Xm = 99.774 Ω.

Photograph of equipments and accessories used to conduct experiments in the laboratory is shown in Fig. 3 and control circuit used for operating the motor is shown in Fig. 4[1].

Fig. 3 Equipments and accessories used in the laboratory

The research is focused to calculate the current and power factor of the motor by using equivalent circuit of the motor by using Equations (16) and (17). For validating the results of this research, the results using Equations (16) and (17) will be compared against the results of the experiment in the laboratory.

The test result of this research is shown in Table 1. Table 1 displays the Comparative results of the calculation against the experiments in the laboratory with the rotor speed 1404 RPM. From the Table 1 can be seen that when the calculation results compared with the experimental results, it turns out the formula given had a level of accuracy of above 91% for the current (due to a calculation error of less than 9%), and close to 100% for the power factor of the motor. From the results of Table 1 can be seen that the formulas given to analyze the performance of the motor can be done well because the accuracy of the formulas given highly qualified.

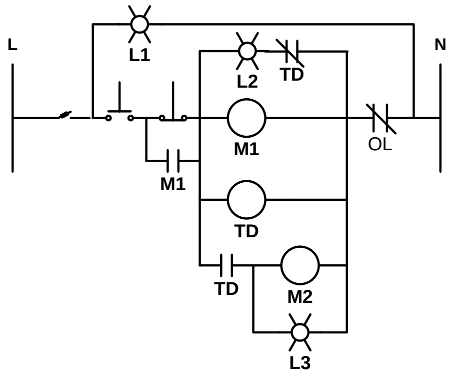

Fig. 4 Control circuit used in Fig. 1

Table 1. Calculation results when compared to the experimental results at the rotor speed 1404 RPM

Parameters	Experimental results	Calculation results	% error
I_s (A)	4,7500	4,3600	8,2105
I_m (A)	2,5000	2,7140	-8,5600
I_a (A)	2,4000	2,5850	-7,7083
Power Factor	1,0000	0,9998	0,0175

From table 1 can be explained that:

% error = percentage error of the calculation results when compared to the experimental results

IV. Conclusions

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

1. The equivalent circuit of the M31D-ZA motor’s method is like the capacitor-run induction motor’s, but by input 'a = 1', ‘Z_{la} = 2 x Z_{lm}’, and providing a multiplying factor 2/3 on the impedance matrix of the motor.
2. The equivalent circuit with the formulas that given in this research could use to analyze the performance of the 3-phase induction motor when operating on single phase supply.
3. The formulas that are given in this research have high accuracy in calculating the currents and power factor of the 3-phase induction motor when operate on single phase supply. The formulas given highly qualified.

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References

[1] Anthony Zuriman, “A simple method for operating the delta connection standard of the 3-phase induction motor on single phase supply”, International Journal of Engineering Trends and Technology (IJETT), Vol. 15, No. 9, September 2014, ISSN. 2231-5381, Seventh Sence Research Group, India, pp. 13-16.

[2] 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, December 1995, pp. 675-680.

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

[4] 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, Septermber 1988, pp. 647-652.

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

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

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

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