Characteristics Analysis of Single Phase Induction Motor by Equivalent Circuit Method Considering Saturation Factor

SuYeon Cho, SangHwan Ham, IkSang Jang, GwangHyeon Ryu, MiJung Kim, and Ju Lee
Electrical Engineering, Hanyang University
HaengDang-Dong, SeongDong-Gu, Seoul, 133-791, South Korea
chosynet@gmail.com

Abstract — This paper presents the analysis method for motor characteristics by equivalent circuit. For design high efficiency single-phase induction motor, the motor characteristics analysis by equivalent circuit is very important. The accuracy of the motor characteristics depends on the accuracy of the parameters, especially saturation factor. The saturation factor made the cyclical relationship on the process. Therefore, using the proposed method, the saturation factor was calculated by iteration routine and numerical techniques. And this method was verified by comparing with FEM result and the dynamo test results of manufactured prototype model.

I. INTRODUCTION

For design high efficiency single-phase induction motor, characteristics analysis of the motor by equivalent circuit is very important to exclude heuristic knowledge like output coefficient. The accuracy of the characteristics by equivalent circuit depends on the accuracy of the parameter value in the equivalent circuit. In particular, to calculate magnetization reactance, saturation factor is required. If the saturation factor is assumed the conventional heuristic value, many errors occur on the analysis results of characteristics. It reduces designed motor efficiency.

In this paper, the analysis method for motor characteristics by equivalent circuit was presented. Key point of this method is calculating more accurate saturation factor.

II. EQUIVALENT CIRCUIT OF SINGLE PHASE INDUCTION MOTOR

In the case of single phase induction motor, main winding and auxiliary winding are not same. So it has the structure of two-phase motor unbalanced. In order to analyze characteristics of motor under the unbalanced condition, symmetrical two-phase equivalent circuit was made up [1]. Fig. 1 shows the equivalent circuit has the parameters compensated to the main winding part [2].

Parameters in the equivalent circuit could be calculated by the motor dimension, material information and electrical specifications. But magnetization reactance is affected by saturation factor.

$$X_{mm} = 2\pi f_1 \frac{4\mu_0 {W_m}^2 {K_{wm}}^2}{\pi^2} \frac{L_{stk} K_{Fe} \tau_p}{p_1 g K_c K_s} . \qquad (1)$$

K_s : *saturation factor*

So the accuracy of the motor characteristics depends on the accuracy of the saturation factor. The saturation factor is very important to know exactly.

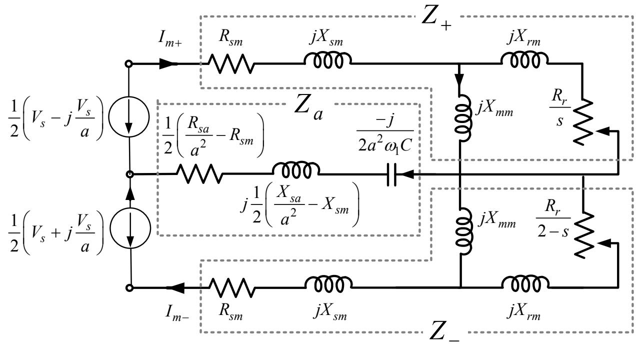


Fig. 1. Equivalent circuit for single-phase induction motor

III. SATURATION FACTOR

The saturation factor was defined as follows:

$$K_s = 1 + \frac{2(F_{teeth,s} + F_{teeth,r}) + (F_{core,s} + F_{core,r})}{2F_g} \qquad (2)$$

To calculate the saturation factor, it needs to know the magnetomotive forces in each parts of the motor. So the magnetic circuit method was used. Total magnetomotive force could be expressed as following equation.

$$F_{1m} = \frac{m_1}{2} \frac{2W_1 I_0 \sqrt{2} K_{w1}}{\pi p_1} \qquad (3)$$

I_0 : maximum current value at no load

To calculate the magnetomotive forces in each parts of the motor, airgap magnetic flux density should be used. Unlike three-phase induction motor, in the case of single-phase induction motor, phase difference between the main winding current and auxiliary winding current should be considered for the airgap magnetic flux density [4]. The airgap magnetic flux density equations are as follows:

$$B_{g\_1ph} = \frac{\mu_0}{gK_cK_s} F_{m1} \cos\omega_1 t \cos\theta_{es} + \frac{\mu_0}{gK_cK_s} F_{a1} \cos(\omega_1 t + \gamma)\cos(\theta_{es} + \pi/2) \qquad (4)$$

The phase difference could be calculated using the equivalent circuit [3], but the saturation factor was required again. So, the saturation factor made the cyclical relationship on the process. From this cyclical relationship, iteration routine and numerical techniques were applied.

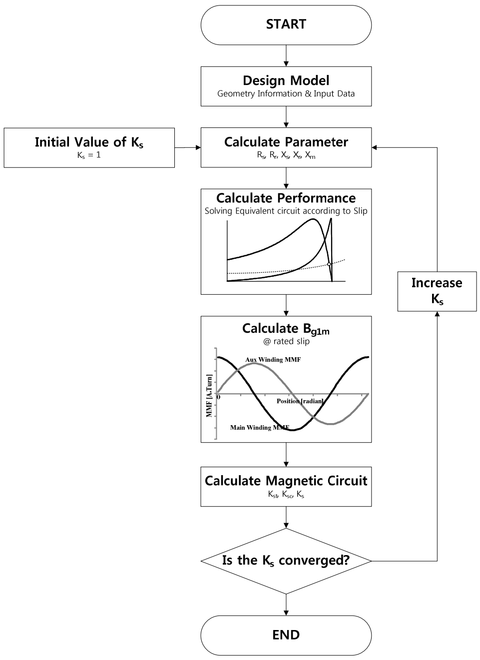


Fig. 2. Flow chart of Iteration routine for saturation factor

IV. ITERATION ROUTINE & NUMERICAL TECHNIQUES

Fig. 2 shows the iteration routine to calculate the more accurate saturation factor. For the basic design model, the iteration routine starts the calculation process with an initial value of the saturation factor. After analyzing the characteristics through the equivalent circuit, the airgap magnetic flux density is recalculated with the main and auxiliary winding current and phase difference between them. Using the recalculated airgap magnetic flux density, N+1 step value of the saturation factor is computed. The convergence condition of the iteration routine is that the error between the N+1 step value and N step value is lower than the criterion.

Also, in the process to obtain the magnetomotive forces from the magnetic flux densities in each part, numerical technique like the gaussian 4^{th} fitting function was used. This technique is very accurate to fit the B-H curve.

Finally, to reduce computation time of the iteration routine and to obtain faster convergence rate, another numerical technique like bracketing method was used

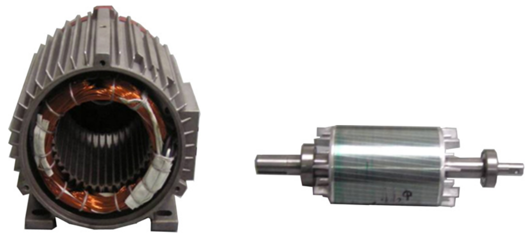
TABLE I
Analysis results using the proposed method and FEM

	Proposed Method	Finite Element Method	Unit
Torque	6.06	6.28	Nm
Speed	1766.0	1760	RPM
Power	1120.6	1128.2	W
Stator Copper Loss	64.23	69.53	W
Rotor Al Loss	23.0	47.3	W
Iron Loss	30.0	29.73	W
Efficiency	89.9	88.5	%
PF	96.8	96.5	%

V. COMPARISON BETWEEN CALCULATED AND FEM RESULTS

The analysis results by the proposed method in this paper considering the saturation factor were compared with the finite element analysis results. Table. I shows the results. Except for the loss of the rotor, the results were very close.

VI. MANUFACTURED AND TEST RESULTS



(a) Stator core and frame (b) Al die-casting Rotor

Fig. 3. Manufactured Prototype Model

The prototype model was manufactured for comparing with the results of proposed method. The rotor of this prototype model has the aluminum die-casting rotor bars. Fig. 3 shows the prototype model.

Because no standards have been established the loss separation test method for single-phase induction motor, input power, output power, and efficiency were measured by dynamo test set and power analyzer in the state of saturation temperature. Table. II shows the comparisons of them. It seemed little differences in measurements and the characteristics analysis results by the proposed method. It is thought that mechanical loss, stray loss and manufacturing error reduced efficiency by about 6%.

TABLE II
Comparison between the results by the proposed method and test results

	Equivalent Circuit Analysis	Prototype SPIM Model	Unit
Torque	6.06	6.05	Nm
Speed	1766	1735	RPM
Input Power	1246.5	1320	W
Output Power	1120.6	1110	W
Efficiency	89.9	84.14	%

VII. CONCLUSION

In this paper, characteristics analysis method by equivalent circuit considering the saturation factor was proposed. In order to more accurately calculate the saturation factor, iteration routine and numerical techniques was used. By comparing with FEM results and dynamo test results, it can be stated that the proposed method guarantees more accurate analysis results and design outputs.

VIII. REFERENCES

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