Magnetic Equivalent Circuit for Saturation Modeling of a deep-bar induction motor

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Abstract — A closed-slot deep-bar induction motor is modeled by a magnetic equivalent circuit (MEC). A simple magnetic equivalent circuit can model a linear open slot motor. Additional subdivision is required for modeling of a closed-slot deep-bar rotor to take saturation into account. The results of MEC modeling are compared to those of finite element analysis (FEA) to verify the feasibility of the method for machine design stage.

I. INTRODUCTION

The magnetic equivalent circuits are well known as a tool to design static electrical machines, for instance, transformers, etc. They may offer less accurate results than FEA, but very much more accurate than analytical models. They have received much attention in motor modeling in recent years due to less consuming time [1-2]. The effort to improve the accuracy of MEC for saturated motor is the main objective of this study.

The previous researches have studied induction motors with a simple rotor-bar structure. The saturation is modeled by building up a function of Bμ-curve [2-3]. However, several parameters for this function need to be defined beforehand by using some procedures. The saturation effect has been modeled by changing the reluctance value as a function of average flux density over a long rectangular reluctance. The universal reluctance network has been built up [4], but it is very heavy and challenging for modeling. If MEC model is too complicated, the merit of MEC is not valid any more.

The geometry of deep-bar rotor is more complicated than normal. Therefore, the proper subdivision of rotor bar will improve the accuracy for MEC modeling of a deep-bar induction motor, and still secure the time consuming advantage of MEC.

II. METHOD

The typical stator and rotor slots of a deep bar IM are shown in Fig. 1. The slots are subdivided into several regions to calculate accurately the reluctances. Unlike FEA, the MEC defines the direction of flux before modeling. The radial and circumferential reluctances of every object are calculated as described in [4], for instance, the equivalent reluctances of a trapezoidal object r4 of rotor are as follows

$$R_r = \frac{h}{\mu l(w_2 - w_1)} \ln \frac{w_2}{w_1} \quad (1)$$

$$R_\varphi = \frac{(w_2 - w_1)}{\mu l h} \frac{1}{\ln \frac{w_2}{w_1}} \quad (2)$$

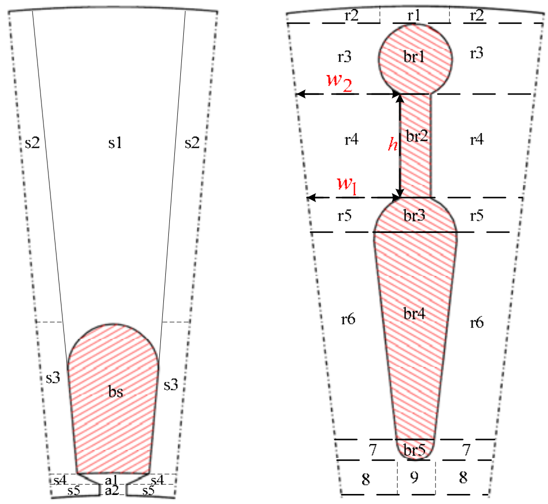

Fig. 1. The subdivided stator and rotor slot

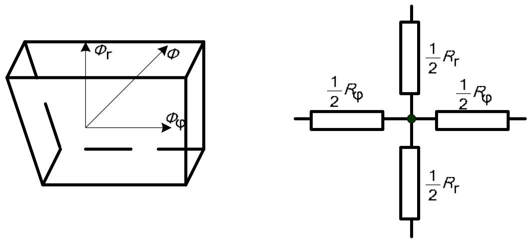

Fig. 2. Flux-path and equivalent reluctances

The saturation modeling is very challenging for analytical approach, but MEC model can take the saturation into account. The BH curve is converted to the Bμ curve. Normally, we have several data point or BH curve from manufacturer as shown in Fig. 3. The Newton's method is used to solve a nonlinear system of equation (3) [4].

$$\left[\mathrm{R}^k\right]\left[\Phi^k\right] = [\mathrm{F}] \quad (3)$$

[R], [Φ] and [F] - flux, reluctance and MMF matrix.

The reluctance element of step k is defined as

$$R_\mathrm{i}^{\mathrm{k-1}} = \frac{l_\mathrm{i}}{\mu_0 \mu_\mathrm{i}^{\mathrm{k-1}} A_\mathrm{i}} \quad (4)$$

$$R_\mathrm{i}^{\mathrm{k}} = R_\mathrm{i}^{\mathrm{k-1}} - \frac{\partial \mu_\mathrm{i}^{\mathrm{k}}}{\partial B_\mathrm{i}^{\mathrm{k}}} \frac{l_\mathrm{i}}{(\mu_\mathrm{i}^{\mathrm{k}})^2 \mu_0 A_\mathrm{i}} \quad (5)$$

The interpolation is required to update the μ and derivative of μ for saturation modeling. To simplify the saturation modeling, the simple procedure to obtain the permeability and its derivative in Matlab are shown in Fig. 4. It is recommended that the degree of the polynomial n is 3 to get reasonable results and maintain the small time consuming.

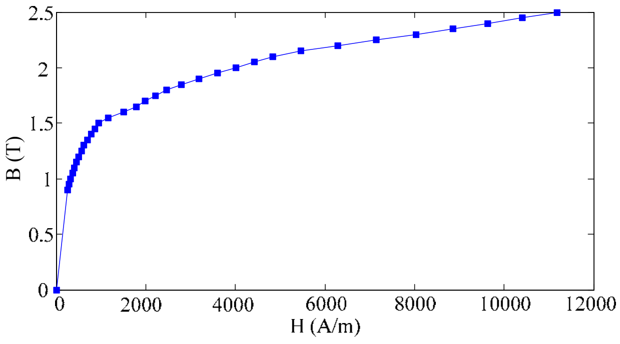

Fig. 3. BH curve of motor iron.

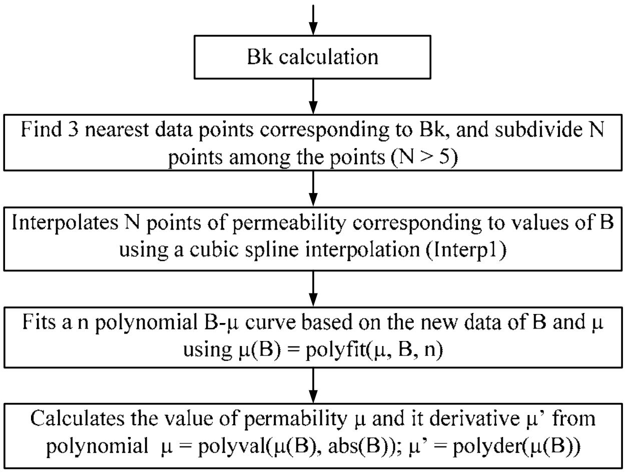

Fig. 4. Flow chart for updating the permeability and its derivative

III. RESULTS

A 30 kW deep-bar induction motor is used to verify the proposed method. For simplification, the modeling is performed at static condition to see how well the method can model a saturated machine.

1. Linear modeling

A deep-bar semi-open slot induction motor can be linearly modeled with a simple MEC as shown in Fig. 5. The constant reluctances in several regions are summed up and represented by the only reluctance in MEC model, for instance, the radial stator reluctance R_{sr} is defined

$$R_{sr} = R_{sr2} + R_{sr3} + R_{sr4} + R_{sr5} + R_{ag} \quad (6)$$

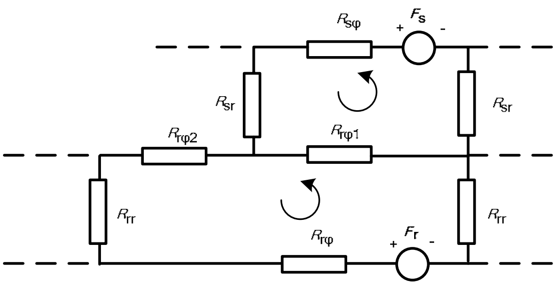

Fig. 5. simple MEC model.

Fig. 6 shows the flux density in the air gap calculated by analytical approach, simple MEC, and FEA at rated current 50 A. The simple MEC model has a better agreement with FEA as compared with analytical approach.

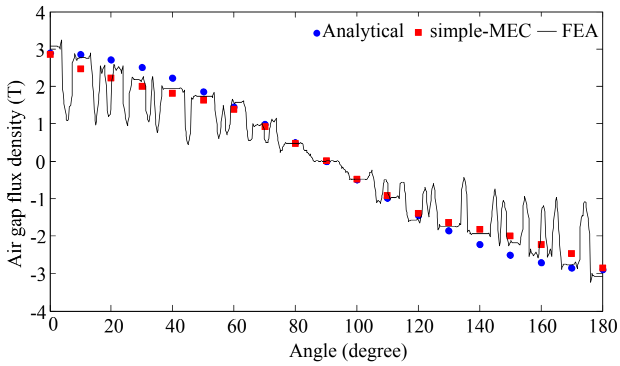

Fig. 6. Air gap flux density of linear IM.

2. Saturation modeling

The deep-bar closed-slot induction motor is modeled by using equivalent reluctances as shown in Fig. 2 for each element in Fig. 1 to take the saturation into account. The BH curve of motor iron is described in Fig. 3. The permeability and its derivative are obtained by using the proposed method. Fig. 7 shows the flux density in the air gap at different approaches at rated current 50 A. The simple MEC is not suitable for saturation modeling. Additional subdivision is required to have a better agreement with FEA.

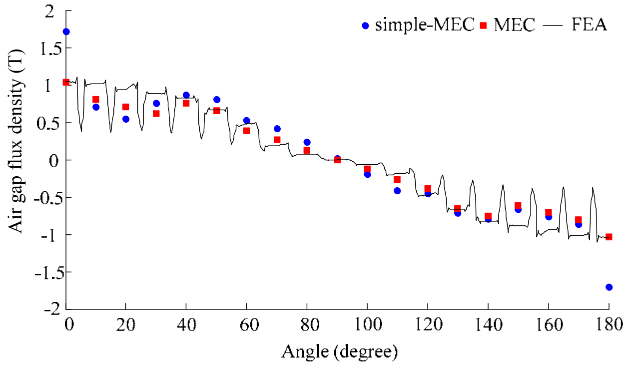

Fig. 7. Air gap flux density for saturation modelling.

IV. CONCLUSIONS

A method for saturation modeling of MEC for a deep bar IM is proposed and successfully performed. The simple MEC model is only suitable for linear case. The additional subdivision would help improve the accuracy of modeling the saturation of a closed-slot deep-bar IM. The extended - paper will describe more details of MEC.

V. REFERENCES

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