Characteristic Analysis & Optimum Design Standard Evaluation of Permanent Magnet Assisted Synchronous Reluctance Motor for Power Improvement

Young Hyun Kim, Jung Woo Kim and Jung Ho Lee
Department of Electrical Engineering, Hanbat National University
Dukmyung-Dong Yuseong-gu Daejeon, 305-719, KOREA
Sayzz1507@naver.com

***Abstract*— This paper deals with the characteristic analysis & optimum design criteria of Permanent Magnet Assisted Synchronous Reluctance Motor (PMASynRM) for power improvement. The focus of this paper is found firstly a design solution through the comparison of torque density and d, q-axis inductance according to the rotor magnet & flux barrier shape, dimensions variations in various rated wattage (1 HP – 7HP) and, Secondly, a mixed resolution with central composite design (CCD) is introduced and analysis of variance (ANOVA) is conducted to determine the significance of the fitted regression model. The proposed procedure allows the definition of the rotor magnet & flux barrier shape, dimensions starting from an existing motor or a preliminary design according to the rated wattage.**

***Index Terms*— PMASynRM, Response Surface Methodology (RSM), Finite Element Method (FEM)**

I. Introduction

The performance of a synchronous reluctance motor (SynRM) in terms of torque and power factor depends on the two-axis inductance L_d and L_q of the machine. The large difference of L_d - L_q is good for the machine's properties.

Therefore, Considerable attention has been paid in the past to improve rotor design of SynRM [1]–[2]. By adding a proper quantity of permanent magnets the torque density and power factor of SynRM can be greatly increased. It is called Permanent Magnet Assisted Synchronous Reluctance Motor (PMASynRM). And it is important to select an appropriate combination of design parameters to enhance more torque density than an existing PMASynRM.

In this paper, finite element analysis for a PMASynRM is presented and the d, q-axis inductance, torque characteristics analysis is performed. Comparisons are given with inductance and torque characteristics of normal Synchronous reluctance motor (SynRM) and those according to quantity of residual flux density (0T, 0.4T) in PMASynRM, respectively.

And then, it is confirmed that the PMASynRM result in high output power performance through numerical analysis data.

Also, this paper deals with the optimum design criteria of Permanent Magnet Assisted Synchronous Reluctance Motor (PMASynRM) for power improvement enhancement.

The focus of this paper is found design solutions through the comparison of torque density and d, q-axis inductance, especially torque ripple of PMASynRM according to the rotor magnet & flux barrier shape, dimensions variations under each rated wattage condition (1HP–7 HP) corresponding to the rotor diameters (66.82, 71.4, 84.95, 92.1, 101, 109.1 mm preliminary design).

Coupled finite elements analysis (FEA) & Response surface Methodology (RSM) have been used to evaluate design solutions [3]-[4].

II. Modeling And Principle Of PMASynRM

A. *Principles of PMASynRM for High Power Application*

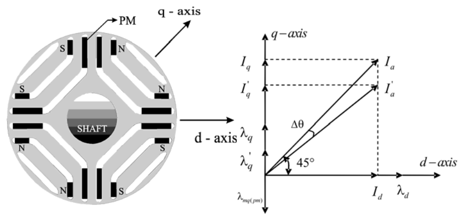

Fig. 1. Rotor cross-section and phasor diagram of PMASynRM

A cross-sectional view of a PMASynRM is shown in Fig. 1. A normal synchronous reluctance motor runs at a somewhat poorer power factor than the induction motor.

This problem can be alleviated by inserting permanent magnets between rotor segments. The principle can be illustrated by the following theorem.

When permanent magnets are included in the q-axis flux path the flux linkage expressions become

$$\lambda_d = L_d i_d \quad (1)$$

$$\lambda_q = L_q i_q + \lambda_{mq(pm)} \quad (2)$$

Where L_d and L_q are the d- and q-axis inductances and, $L_d \neq L_q$. Torque expression can also be written as

$$T_{pmr} = \frac{3}{2}\frac{p}{2}\left[\left(L_d - L_q\right) i_q i_d + \lambda_{mq(pm)} i_d\right] \quad (3)$$

It can be considered that a theoretical maximum torque for a PMASynRM is reached if L_q is zero. This possibility can be reached by use of the second term of (3). It can be assumed that the polarity of the magnets are reversed relative to the positive direction defined by direction of the stator q-axis MMF. Then, torque expression can be rewritten,

$$T_{pmr} = \frac{3}{2}\frac{p}{2}[L_d i_q i_d - (L_q i_q - \lambda_{mq(pm)}) i_d] \qquad (4)$$

The q-axis inductance can be made to approach zero theoretically. The compensating flux can normally be obtained by ferrite magnets since L_q is sufficiently low.

Fig.1 shows a phasor diagram including the effects of a permanent magnet in which the q-axis flux is assumed to be completely canceled.

Fig. 2 shows the torque characteristics of SynRM and PMASynRM at the same input current conditions, respectively.

And one should notice that the PMASynRM can be obtains a lower current amplitude and angle value than those that predicted by a normal SynRM for the same torque density. The proposed form of rotor magnets is a guarantee that the counteract effects of q-axis current can spatially increase the output power as shown in Fig. 3.

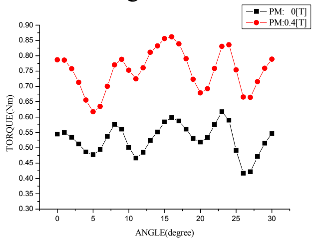

Fig. 2. Torque characteristics of SynRM & PMASynRM (1HP)

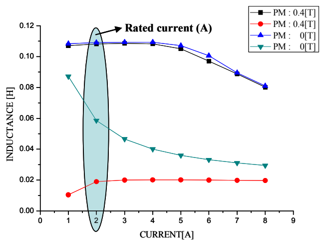

Fig. 3. d, q-axis inductance characteristics of SynRM & PMASynRM(1HP)

III. Optimization Process

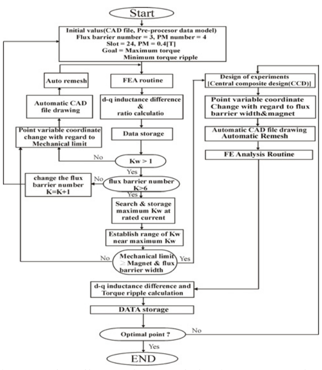

Fig. 4 The flow chart of design procedure

Fig. 4 shows the flow chart of total design strategy.

The shape coordinates of the rotor have been drawn as a condition until the mechanical constraint moment of machine is reached. The ribs have a fixed value due to inherent manufacturing limitations. And the new CAD file is automatically redrawn with regard to the change of K_w of Eq. (5) and the number of flux barriers as shown in Fig. 4.

$$K_w = \sum(W_{air}) / \sum(W_{iron}) \qquad (5)$$

where, $\sum(W_{air})$: Total flux barrier width

$\sum(W_{iron})$: Total rotor iron sheet width

Design solution will be derived from a central composite design (CCD). Finally, the optimization process is performed for maximizing torque density and minimizing of torque ripple.

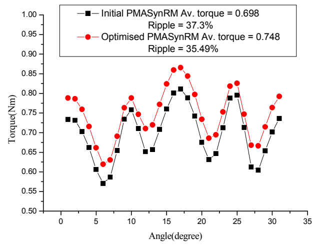

Fig. 5. Torque characteristics of initial and optimized PMASynRM (1HP)

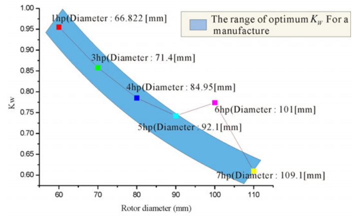

Fig. 6. K_w function according to rotor diameter increasing

Fig. 5 shows the torque characteristics of initial and optimized PMASynRM (1HP) in same input current conditions, respectively.

It can be found that optimized PMASynRM is more counteracted q-axis flux than initial model and in addition, d-axis inductances are enhanced.

As a result, the torque density of optimized PMASynRM is higher than initial model and the torque ripple of optimized PMASynRM is less than initial model, as shown in Fig. 5.

Fig. 6 shows results of K_w of each optimized model accord ing to increasing rotor diameter (1HP-7HP) and each rated cur rent, it is observed that the maximum torque density and mini mum torque ripple are nearly closed to $K_w = 1$ by decreasing r otor diameter. On the other hand, these are shifted to $K_w = 0.5$ and flux barrier number increased according to enla rging rotor diameter or rated wattage.

More detailed results and discussion will be given in final paper. And the mathematical expressions for response surface methodology will be also given in extended version.

References

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