Novel Design Method for a PMSM Based on Loading Separation

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Abstract – This paper presents a new optimal design method for a PM motor based on loading separation. Using the relationship between the loadings of the power equation and the motor's geometries, it is revealed that the arbitrary selection of four variables p, D_g, L_{stk} and g_m provides a unique motor with the required output power. Consequently, the optimal design is determined through characteristic evaluation and comparison of the motors designed with a myriad combination of four independent variables. To verify the validity of the proposed method, an optimal design is performed for a 5 kW SPMSM and the performances are analyzed.

1 Introduction

The loading separation method, which has long been used to design PM synchronous motors (PMSM), uses statistical averages obtained from existing machines in determination of electric and magnetic loadings, so the design procedure is quite simple, but the results are frequently inaccurate [1]. This study shows that it is possible to separate the loadings that satisfy the required output power from the arbitrary selection of p, D_g, L_{stk} and g_m, and presents the procedure for optimal design of the motor using the separation. In the design procedure, the anti-demagnetization conditions and the maximum speed operation conditions are considered. Finally, the usefulness of the proposed method is confirmed by analyzing the performance of the optimally designed 5kW SPMSM.

2 Proposed Method for Optimal Design

Equation (1) shows the power of the non-salient PMSM with the rated voltage V_{ph} and the number of pole-pairs p operating at the base speed ω_m where $N_{ph.e}I_{ph}$ is the electric loading and $p\hat{\Phi}_{PM}$ is the magnetic loading from PM. For the convenience of the study, the design of a SPMSM of Fig. 1 is dealt with. If the four variables p, D_g, L_{stk} and g_m are determined, the air gap flux density B_{PM} by the magnet can be calculated, and the PM magnetic loading $p\hat{\Phi}_{PM}$ is calculated using (2). Thus, the electric loading $N_{ph.e}I_{ph}$ is determined by (1). In the same way, the air gap flux density $B_{W.g}$ by the loading $N_{ph.e}I_{ph}$ can be calculated, and $\hat{\Phi}_{W.g}$ is obtained from (3). Under the MTPA condition, $\hat{\Phi}_{PM}$ and $\hat{\Phi}_{W.g}$ are orthogonal to each other, so the air-gap net flux $\hat{\Phi}_{g.net}$ of (4) is achieved [2]. The obtained $\hat{\Phi}_{g.net}$ and the set values of the current density of a conductor and the flux densities of the teeth and yoke can be used to determine the complete geometries of the stator and rotor cores. The voltage equation of (5) is used to separate the number of windings $N_{ph.e}$ and the rated current I_{ph} from the electric loading $N_{ph.e}I_{ph}$. It will be explained detailed separation

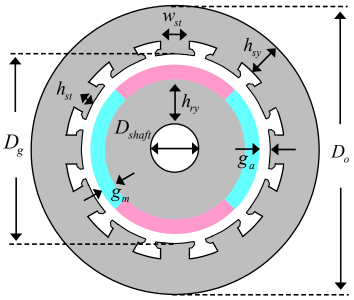


Figure 1: Basic Structure of SPMSM

$$P_{out} = 3E_{PM}I_{ph} = \frac{3}{\sqrt{2}}\omega_m p N_{ph.e} I_{ph} \hat{\Phi}_{PM} \tag{1}$$

$$\hat{\Phi}_{PM} = L_{stk} r_g \int_0^{\pi/p} B_{PM}(\theta)\, d\theta \tag{2}$$

$$\hat{\Phi}_{W.g} = L_{stk} r_g \int_0^{\pi/p} B_{w.g}(\theta)\, d\theta \tag{3}$$

$$\hat{\Phi}_{g.net} = \sqrt{\Phi_{W.g}^2 + \Phi_{PM}^2} \tag{4}$$

$$V_{ph} = \sqrt{\left(R_{ph}I_{ph} + E_{ph}\right)^2 + \left(E_{W.g} + E_{W.leak}\right)^2} \tag{5}$$

method in the full paper. Consequently, it is possible to design a motor meeting the output power requirement for each selection of 4 variables. The whole flow-chart for the proposed optimal design is shown in Fig. 2. It checks out the conditions for anti-demagnetization of PM and the maximum speed operation capability through the characteristic analysis using the circuit parameters of the designed motors. A single motor having the optimal performance is selected by comparing characteristics such as efficiency, power factor, volume, and price etc. for every motor satisfying the conditions. As a case study, a 5kW PMSM with the specifications of table I is designed in this study. For instance, the variables of 3 types of models are given in table II, and the motors are designed with the proposed procedure. The geometries of designed motors are depicted in Fig. 3, and their N_{ph} and I_{ph} are given in table III. The analysis results of the designed motor are presented in table IV. It shows that the models have different electrical parameters and volumes from each other, but they all satisfy the required output power 5kW. Thus the proposed method enables the design of numerous motors meeting the P_{out} condition. It will be demonstrated that the way to select the best model considering the objective function in the full paper.

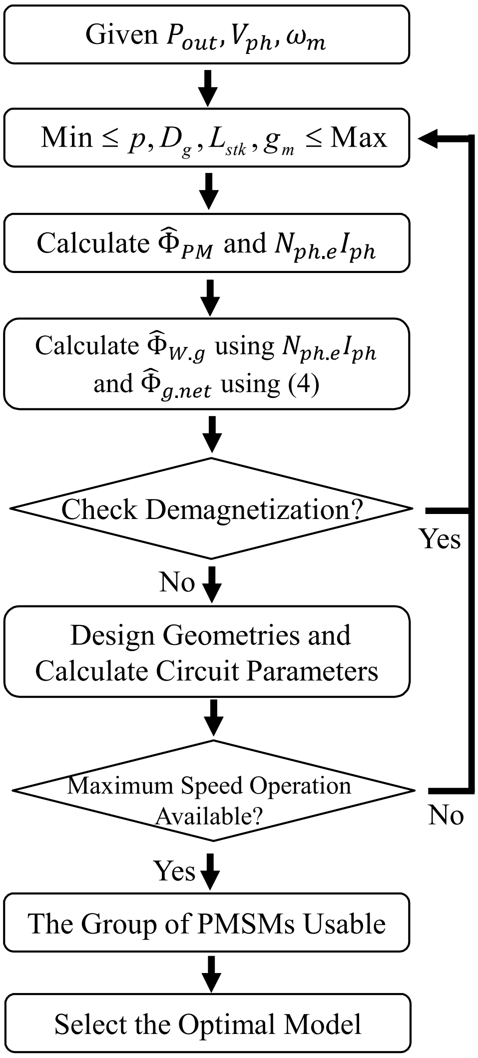


Figure 2: Flow SPM Design Procedure

Table I - Given Specifications

	P_{out}	V_{ph}	ω_m
Value	5kW	380V	1800rpm

Table II - Selected Variable

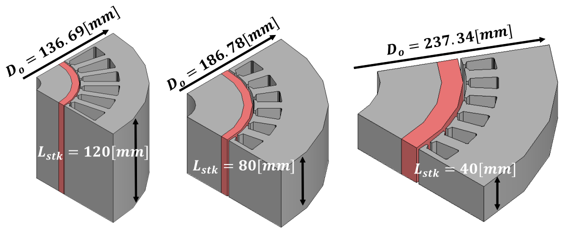
	Model 1	Model 2	Model 3
p	2	2	3
D_g	60mm	100mm	150mm
L_{stk}	120mm	80mm	40mm
g_m	4mm	5mm	10mm

Table III - N_{ph} and I_{ph}

	Model 1	Model 2	Model 3
N_{ph}	338	322	415
I_{ph}	5.19A	4.96A	4.91A

Table IV – Obtained Result

	Model 1	Model 2	Model 3
P_{out}	5kW		
E_{ph}	325.53V	355.47V	359.73V
R_{ph}	5.16Ω	4.82Ω	4.73Ω
X_{syn}	28.58Ω	18.19Ω	10.81Ω
η	92.45%	93.67%	94.12%



(a) Model 1 **(b) Model 2** **(c) Model 3**

Figure 3: Designed SPMSM Shape

References

[1] Hamdi, E. S. Design of small electrical machines. England: Wiley, 1994.
[2] Miller, T. J. E. Brushless permanent-magnet and reluctance motor drives. England: Clarendon Press, 1989.