Study of 8/12 Flux Reversal Machine as an Alternator

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Abstract – Flux Reversal Machine (FRM), an emerging doubly salient PM motor is well known for retaining advantage of switched reluctance and PM machine. The paper presents study of a Flux Reversal PM machine as an alternator. Analysis, construction, and experimental results for a 8/12 prototype FRM as a single-phase flux reversal alternator are presented.

Keywords: Flux Reversal Alternator, FEM, ANSYS Multiphysics

I. Introduction

High speed alternators used in automobiles require high output power but with volume constraint due to limited size available. FRM can be considered as an alternative option for such applications with robust construction and high power output. FRM is a doubly salient permanent magnet (DSPM) machine with permanent magnets (PM) and concentrated windings on the stator. Due to presence of magnets on the stator, FRM possess advantages like simple construction, low inertia, high power density over conventional PMBL and are suitable for high or very low speed applications [1].

The simple structure of FRM makes it cost effective and suitable for mass production. It has a low self and mutual inductance, hence a low electrical time constant and high fault tolerance. The cogging torque can be drastically reduced, while maintaining a high peak-to-peak flux variation, by skewing the rotor to a certain degree [2]. The paper is organized as; Section II will present a review on the literature present for FRM, FEM analysis of an 8/12 FRM is elaborated in Section III, Section IV contains the results obtained from the experimental 8/12 FRM developed as an alternator and finally the conclusion of the present work is given in Section V.

II. Technical Background

Typical 2D and 3D view of an 8/12 FRM have been shown in Fig 1 and Fig 2. An 8/12 pole FRM is analyzed and its working as a single phase alternator studied is presented in this paper. Many methods have been reported in the literature for reduction of flux leakage and reduction of cogging torque in FRM. The simplest technique for reducing the cogging torque in PM machines is rotor skewing. Wang et. al. reported this method for controlling cogging torque in a three-phase flux reversal machine. The design of the machine has been optimized to ensure (i) high PM flux linkage in the winding, and (ii) low cogging torque and PM weight [3]. In [4], author suggested rotor teeth pairing method i.e., adjusting width of pair of rotor teeth for cogging torque reduction. A new method for minimizing leakage flux was achieved by providing a flux barrier on the edges of rotor poles [5]. Design techniques for reduction of cogging torque in FRM are bifurcated teeth, chamfered magnet poles, chamfered rotor tooth tips and rotor skewing [6].
### Table I

**Details of Experimental Machine**

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air gap, mm</td>
<td>0.5</td>
</tr>
<tr>
<td>Magnet thickness, mm</td>
<td>2</td>
</tr>
<tr>
<td>Rotor pole span angle,° mech.</td>
<td>12.5</td>
</tr>
<tr>
<td>Stator pole span angle,° mech.</td>
<td>35.8</td>
</tr>
<tr>
<td>Stator pole span, mm</td>
<td>15</td>
</tr>
<tr>
<td>Rotor pole span, mm</td>
<td>4.8</td>
</tr>
<tr>
<td>Stator pole height, mm.</td>
<td>13</td>
</tr>
<tr>
<td>Rotor pole height, mm.</td>
<td>9</td>
</tr>
<tr>
<td>Outer diameter of rotor, mm.</td>
<td>43</td>
</tr>
<tr>
<td>Number of turns/pole</td>
<td>90</td>
</tr>
<tr>
<td>Stack length of machine, mm.</td>
<td>19</td>
</tr>
<tr>
<td>Stator pole width, mm.</td>
<td>10</td>
</tr>
<tr>
<td>Stator core width, mm.</td>
<td>7</td>
</tr>
<tr>
<td>Shaft diameter, mm.</td>
<td>8</td>
</tr>
</tbody>
</table>

Considering the cogging torque, back-EMF and the average torque together, it is found that adequate degrees of skew is the most effective for cogging torque reduction [7]. Control scheme for FRM is simulated in [2], and it is concluded that under proper control FRM can operate as a high speed motor.

### III. FEM Analysis 8/12 Pole Flux Reversal Machine

The developed 8/12 pole FRM has been analyzed using FEM ANSYS Multi-physics software and flux density variation has been studied. The details of the developed FRM has been shown in Table 1. Fig. 3 shows angular variation of flux density ($B_\theta$) and Fig. 4 depicts the variation of effective flux density ($B$) in air gap along the periphery. The above figures show that the number of flux reversal is equal to the number of poles in the stator. It also shows the reversal of flux along the periphery due to magnets, and this reversing flux is being linked to the stator coils, and hence alternating EMF will be induced in the stator coils.

![Flux density in airgap along the periphery of 8/12 FRM](image)

A node is chosen in the air gap between stator and rotor as shown in Fig 5 and variation of flux densities have been observed with angular displacements of rotor. Fig. 6 shows variations of flux density ($B_\theta$) and Fig. 7 variation effective flux density ($B$) at the middle of a stator pole. All these plots shows that with the movement of rotor, flux reverses at each and every node in the air gap. Hence when these reversing flux links with the stator coil, an alternating EMF is induced in it. The flux density is not perfectly sinusoidal which may be due to the gap introduced between two PMs pasted on the stator pole.

### IV. 8/12 Pole Flux Reversal Machine As An Alternator

The FRM has 8 salient pole stator and 12 pole variable reluctance rotors. Each stator pole has concentrated windings placed on it. NdFeB magnets are pasted on the salient stator poles. PMs of alternate polarity are placed on stator pole shoe in a sequence of NS on one pole and SN on adjacent pole. Fig. 7 shows the experimental set up for testing of developed FRM as an alternator. The developed FRM was rotated using DC motor. Initially all the 8 concentrated coils were not connected with each other and no-load induced EMF of each coil is observed. It was observed that near sinusoidal EMF is induced in each of the coil. Fig 8 shows EMFs of coils, placed on geometrically opposite poles, which are perfectly same, as they are facing similar rotor movement at a particular time. Thus their flux variations and hence induced EMFs are exactly same.

![Node 1 at which parameters are measured with rotor in motion](image)
Fig. 6. Flux density components variation at a node at the middle of stator pole with rotor in motion

All these 8 coils have sinusoidal EMF with identical zero crossing, so all the coils were connected in the manner to form a single phase winding, and the total EMF of all coils is shown in Fig 9. The zero crossings of total EMF of series connected coils and that of a single coil EMF are identical. No-load induce EMF of a single coil is observed with respect to speed, and it is observed that induced EMF is directly proportional to the speed as shown in Fig 10.

V. Conclusions

An 8/6 pole FRM as an alternator has been developed and its FEM and experimental studies have been reported. Flux density variations at different nodes of FRM are plotted and perfectly sinusoidal flux is observed at the stator poles where PMs are present. A prototype of the same is being developed to ensure its feasibility in practical environment. The results obtained shows that the characteristics of flux reversal alternator are similar to those of DC shunt generator.

REFERENCES

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