Radially-Magnetized Transverse Flux Permanent Magnet Generator

Zhiyong Lan, Chen Xu and Li Li

ABSTRACT

The transverse flux permanent magnet motor attracts wide attention in the field of low-speed direct-drive wind power due to its high torque density, good low-speed performance and other advantages. Aiming at the problem of high leakage coefficient of permanent magnet in the attached transverse flux permanent magnet wind power generator, a radially-magnetized transverse flux permanent magnet generator (RM-TFPMG) is proposed in this paper. Details of the structure and principle of the proposed machine are introduced firstly, and then the main parameters of the RM-TFPMG are calculated by the magnetic circuit method. Finally, the three-dimensional finite element analysis of the radial load flux transverse flux permanent magnet generator is carried out by ANSYS Maxwell software, and the parameters of machine and Back Electromotive Force (EMF) are obtained under the condition of no-load, and the rationality of the designed motor is verified.

Keywords: radial magnetizing, transverse flux, no-load, 3-D finite element method.

INTRODUCTION

Wind turbines play an important role in the wind power system. It converts wind energy into mechanical energy and then into electrical energy. And it transforms primary energy into secondary energy, which is good for energy utilization and long-distance transportation.

At present, there are many kinds of permanent magnet motors that can be used for wind power generation, among which transverse flux motor is especially suitable for the field of low-speed wind power generation because of its unique advantages. The transverse flux means that the rotation direction of the motor is perpendicular to the plane of the magnetic line of force [1-2]. Because of the decoupling of the circuit and magnetic circuit of the transverse flux motor, it solves the low power density of the conventional permanent magnet...
generator. In addition, its structure is simpler than conventional permanent magnet motor, and the phases are independent of each other, so it is easier to realize multiphase structure.

Now many scholars have made a considerable research on the transverse flux machine, a lot of new structures about transverse flux permanent magnet machine have been put forward [3-5]. Scholars who are come from the KTH University in Sweden have a lot of researches on rotor ring hollow structure of the transverse flux permanent magnet machine. They draw the conclusion through the method of finite element, that is, the more numbers of pole-pairs means the higher utilization of materials [6]. The scholars from Shanghai University and Southeast University have studied in low speed of transverse flux machine applied in the field of wind power generation. The former put forward a new type of transverse flux machine which has an assembled magnetic structure. And they manufacture a 10.4MW machine with the group of stator cores which combined and fixed by an E shape sleeve. It greatly simplifies the machine structure and reduces the cost of production [7-8]. The latter propose a kind of transverse flux permanent magnet generator with a magnet flux switching structure. The permanent magnets are put in the stator core of the proposed structure [9].

In this paper, a radially-magnetized transverse flux permanent magnet generator (RM-TFPMG) is proposed to reduce the leakage coefficient. The corresponding operational principle is given, and then the main parameters of RM-TFPMG is calculated by magnetic circuit method. At last, three-dimensional finite element analysis of the radial load flux transverse flux permanent magnet generator is carried out by ANSYS Maxwell software, and the parameters of machine and Back Electromotive Force (EMF) are obtained under the condition of no-load.

THE BASIC STRUCTURE and OPERATING PRINCIPLE of RM-TFPMG

The basic structure of the RM-TFPMG

Figure 1 shows the structure of Radially-Magnetized Transverse Flux Permanent Magnet Generator, including stator steel and rotor steel. The whole stator contains one group of stator core and armature winding, the group of stator core is composed of numbers of stator core which is distributed in the outer rotor teeth, each of the stator core adopts modular structure, the two teeth of adjacent stator core arranged symmetrically on the circumferential direction. The armature winding is placed in the stator slot in the core group. The whole rotor core is composed of numbers of rotor teeth, each two pieces of magnetization are embedded in the opposite direction on every rotor teeth. The permanent magnets are magnetized in radial direction, and adjacent permanent magnets in circumferential direction are magnetized in the opposite direction.
The Operating Principle of the RM-TFPMG

The operating principle of radially-magnetized transverse flux permanent magnet machine is shown in Figure 2. The group of stator core is represented by A winding of the stator core. In Figure 2(a), the teeth of A winding of the stator core align with the rotor teeth at the left side and the rotor teeth at the right side in the radial direction. And the two pieces of permanent magnet magnetized in the opposite direction under the same rotor teeth. It can be seen from the Figure 2(a) that the magnetic flux in the group of A winding of the stator core are counterclockwise in this condition. When the machine rotor is located in the position shown in the Figure 2(b), the teeth of A winding of the stator core charge to align with the rotor teeth at the right side and the rotor teeth at the left side in the radial direction. It can be seen in this condition, the magnetic flux in the group of stator core is charge to clockwise. Therefore, when the machine rotates continuously, the magnetic flux direction is charged periodically in the group of stator core, the induced electromotive force is produced.
ONE POLE of MAGNETIC CIRCUIT IN RM-TFPMG

Figure 3 shows the one pole structure of RM-TFPMG, where $l_1$ and $l_{pm}$ represent radial length of the right rotor core and radial length of permanent magnet, respectively. $l_2$ is the radial length of the middle iron core, the corresponding parts of the rotor core and the stator core are designed in a coaxial way and the corresponding parts of the axial length are equal.

![Figure 3. One Pole Structure of RM-TFPMG.](image)

The conventional design method of permanent magnet machine is adopt in this paper, the calculated main parameters of RM-TFPMG are shown in Table 1. On the basis of the structure of the radially-magnetized transverse flux permanent magnet generator (RM-TFPMG), the main parameters are calculated.

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coercive force of permanent magnet/(A*m-1)</td>
<td>890000</td>
<td>Pole-arc coefficient</td>
<td>0.75</td>
</tr>
<tr>
<td>Air gap axial length/mm</td>
<td>0.3</td>
<td>Part of rotor core radial length/mm</td>
<td>10</td>
</tr>
<tr>
<td>Pole-pairs</td>
<td>6</td>
<td>Rotor core inner diameter/mm</td>
<td>100</td>
</tr>
<tr>
<td>speed/(r*min-1)</td>
<td>500</td>
<td>Permanent magnet radial length/mm</td>
<td>8</td>
</tr>
<tr>
<td>Number of winding</td>
<td>400</td>
<td>Permanent magnet axial length/mm</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 1. Main Parameters of RM-TFPMG.

To simplify magnetic circuit problem, the edges effect and leakage flux in the graph are ignored. The magnetic force of permanent magnet is obtained as:

$$F_c = H_c l_{pm} \quad (1)$$

Where $H_c$ is the coercive force of permanent magnet, $l_{pm}$ is the radial length of the permanent magnet.

![Figure 4. The Equivalent Magnetic Circuit Diagram of RM-TFPMG.](image)
The equivalent magnetic circuit of machine is given in Figure 4. Here, $R_0$ represents permanent magnet reluctance among the magnetic circuit. $R_{g1}$ and $R_{g2}$ represent the air gap magnetic resistance in the main magnetic flux, respectively. $R_{fe1}$ is the middle part of the rotor core magnetic resistance in the magnetic flux, $R_{fe2}$ denotes the stator core magnetic resistance in the main magnetic flux, $R_{fe3}$ represents the right rotor core magnetic resistance in the main magnetic flux. And they can be expressed as:

$$R_0 = \frac{l_{pm}}{\mu_{pm} S_{pm}} \quad (2)$$

$$R_{g1} = R_{g2} = \frac{g}{\mu_{g} S_g} \quad (3)$$

$$R_{fe1} = \frac{1}{\mu_r W h} \quad (4)$$

$$R_{fe2} = \frac{2h_d + l_p + l_r}{\mu_{fe} W_i (h_i - h_d)} \quad (5)$$

$$R_{fe3} = \frac{l_i}{\mu_{fe} W_r h_r} \quad (6)$$

Where $\mu_0$ and $\mu_{fe}$ represent permeability of the vacuum and the silicon steel respectively, and $\mu_{pm}$ denotes the permanent magnet. The equivalent area of the permanent magnet and the air in the main magnetic flux are represented by $S_{pm}$ and $S_g$ respectively.

**THE FINITE ELEMENT ANALYSIS OF THE MACHINE**

The machine model should be modeled in Solidworks because the proposed structure is a nonstandard structure. And then three-dimensional transient field analysis is given by ANSYS Maxwell. The grid subdivision of one pole DW-TFPMG model is pictured in Figure 5.

It can be seen from Figure 6 that the magnetic flux density in the stator core and the rotor core is about 1.5T at the position of the maximum magnetic flux. And it is still in the unsaturation state.
(a) The Location of the Maximum Magnetic Flux Density (b) The Location of the Minimum Magnetic Flux Density

Figure 6. Magnetic Distribution in Maximum and Minimum Flux Linkage.

(A) The Back-EMF Waveforms of the Surface Attached Transverse Flux Permanent Magnetic Generator

(B) The Back-EMF Waveforms of the Radial Magnetized Transverse Flux Permanent Magnet Generator

Figure 7. The Back-EMF Waveforms under No-Load Condition.

The model of the surface attached transverse flux permanent magnetic generator and the radial magnetized transverse flux permanent magnetic generator is established by using the
same size, proportion and material. The back-EMF waveforms of them are pictured in Figure 7(a) and Figure 7(b) respectively under no-load condition. It is can be seen from the comparison of the two waveforms that the back-EMF waveforms of the surface attached transverse flux permanent magnetic generator is more sinusoidal than that of radial magnetized transverse flux permanent magnet generator. However, the latter has a peak of about 3 times the former in the condition that the total magnetic flux of both is about 0.00022Wb. This is because that the radial magnetizing transverse flux permanent magnet generator has magnet congregate effect, and it also indicates that the latter structure shows a smaller leakage flux coefficient than the former.

CONCLUSION

This paper proposes a Radially-Magnetized Transverse Flux Permanent Magnet Generator, the structure of the RM-TFPMG is constructed and operation principle of that is given in the first. Then, the main parameters of RM-TFPMG are calculated by the magnetic circuit method. Finally, the electromagnetic characteristics are calculated in three-dimensional transient magnetic field using the method of finite element by ANSYS Maxwell software. The proposed structure is simpler than traditional machine. In addition, Radially-Magnetized Transverse Flux Permanent Magnet Generator decouples circuit and magnetic circuit on the space, thus it has high utilization of permanent magnet and machine power density.

REFERENCES