Effect of Air Gap on Armature Voltage on Axial Flux Permanent-Magnet Generator ac by Using NdFeB 52

by Nurul Hiron

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Abstract

There is an increase in the development of Axial Flux Permanent Magnet Generator (AFPMG) which is proven by numerous types of machine variations which are developed and studied. AFPMG has advantages in terms of lossless and thinner construction and its use in various fields of micro electromechanical system and domestic utilities. In the implementation of this design, we used ANSYS software to design the construction, flux distribution, and the expected voltage. In the design of this AFPMG, we made dual-rotor permanent magnet constructions clamping the stator containing an armature winding with a three-phase AC output voltage with a star winding configuration. The design process also included a simulation of the effect of gap distance differences on the electromotive force generated by the armature winding. The design results were implemented then tested with varying rotation and significant changes in air gap from 2 mm until 6 mm to produce the performance of the machine. Based on the test results, the maximum voltage in the zero-load condition, in which the air gap was at 2 mm, was 10.7. In the loaded test with rpm variation, the voltage regulation was with a range of 32.96% and 43.75% for a 2 mm air gap.

Keywords: Axial Flux Permanent-Magnet Generator, Various Speed, air gap, NdFeB 52

1. Introduction

The development of electricity generation by converting mechanical power continues to grow on a small scale known as the micro-electromechanical system (MEM). MEM with the use of magnetic material as a conversion medium one of which by using axial flux permanent magnet generator (Holmes et al. 2005)

The use of AFPMG is applied to the needs of wind farms(Ashraf & Malik 2017)with 1,200 watts or low power by either using single(Nur et al. 2013) or double savinous turbines (Alqodri et al. 2015). The other uses of AFMG are related to the need for small mechanical motions such as electromagnetic launchers(Sezenoglu & Balikci 2015) also used in vehicles and trains (Gör & Kurt 2015).

The output voltage of the AFPMG is an alternating voltage normally get into the grid but some researches suggest that adding a rectifier generated the DC output used to fill the accumulator(Wijaya et al. 2016). Similarly, continuous developmental construction starts with single-rotor single-stator (Alqodri et al. 2015) single-stator double-rotor (Gör & Kurt 2015) or with TOROS-S Structure (Taran & Ardebili 2014). Various studies suggest that the speed will affect the output voltage as well as the frequency generated which are in accordance with the law of EMF. Therefore, in order to generate AC voltage that can get into the grid, the generator frequency must equal to the frequency of the system.

In line with the high demand of permanent magnets, nowadays, the growth of the permanent magnet industry is becoming a promising industry, especially the NdFeB permanent magnet. Fig 1 shows the growth of permanent magnet production from several country producers. The demand of NdFeB-type magnets is projected to be significantly increased, especially between 2015 and 2020 reaching more than 120 (kt). Currently, China is the largest producer of permanent magnets compared to Japan, Europe and other countries including USA (Fig.1.a). While the world's need for permanent magnets is dominated by the Nd-type permanent magnet (Fig. 1.b).

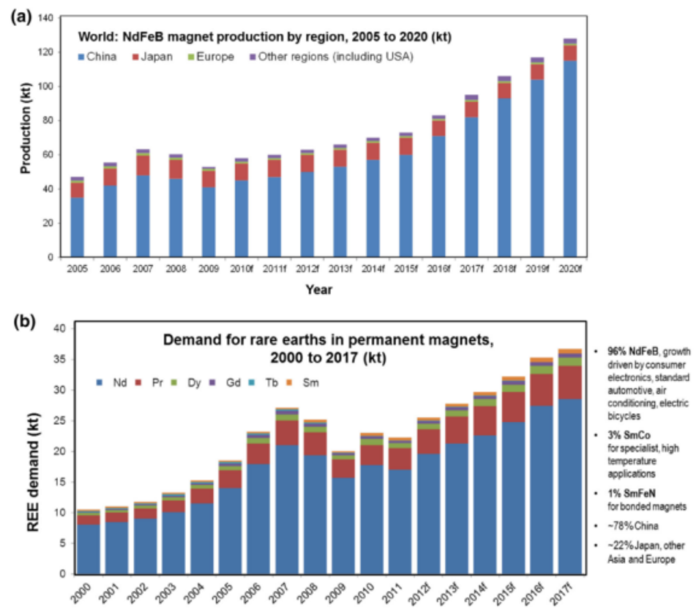


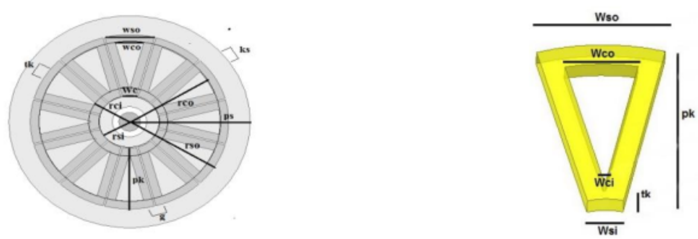
Fig.1: Global production of NdFeB permanent magnets and the demand for the REEs (Shaw S 2012)**,** (Yang et al. 2016)**. (a) Total global NdFeB magnet production and prediction: 2005–2020, (b) Total global REE demands for permanent magnets** (Yang et al. 2016)

This study focuses on preparing simulations for analyzing Air Gap Effect on Armature Voltage on Axial Flux Permanent Magnet AC generator by using NdFeB 52. NdFeB 52 magnets are used because NdFeB 52 magnets have a unique character that is the Maximum Energy Product (Bhmax) is 50 -52 MGOe (398-422 MGO (KJ / m3) (Shaw S 2012)(Yang et al. 2016).

2. Method

The design of Axial Permanent Magnetic Flux Generator was done by using ANSYS in order to find out the finite element distribution and also the magnetic field (Holmes et al. 2005). The use of ANSYS was also carried out to find out the design parameters (Sadeghierad et al. 2008) so that the rotor dimension, big stator winding, and other things are known.

In this design, the dimension of the stator winding that would use was a type of stator that has no iron core on the coil. This is because the type of stator with no iron core was more suitable to the low axial generator. We used 12 coils of armature winding to produce three-phase AC voltage, in other words, in every phase there were 4 coils.



a. The shape of stator disk with 12 coils **b. The shape of stator disk with 1 coil**

Fig. 2: The stator disk with a winding shape

The shape of the armature winding itself is a type of trapezoidal winding with the number of coil windings per phase was 150 winding or 38 winding per coil with non-overlapping windings form. The designed coil was a non-overlapping type aimed at maximizing the induction of the magnetic field on the coil and avoiding the addition of thickness to the stator. We used copper wire with a diameter of 1 mm. As for the dimensions of the stator itself, it can be seen in table 1.

Table 1: The Size of the Stator

No	Description	Size (mm)
1	Stator Diameter	280
2	Stator Length (ps)	140
3	Stator Thickness (ks)	25
4	Distance Between Stator (g)	2
5	Outer Width (wso)	57.5
6	Inner Width (wsi)	16
7	Width of Stator Foot (wc)	2
8	Coil Length (pk)	80
9	Coil Thickness(tk)	10

The type of permanent magnet to be used in the design of the rotor was a Neodynium-Iron-Boron Permanent Magnet (NdFeB). This type of permanent magnet has larger magnetic field value and magnetic flux density than other permanent magnets that is 1.43 tesla. The use of permanent neodynium-iron-boron (NdFeB) permanent magnet (specifically the type of magnet used was N52) aimed at obtaining the maximum magnetic flux value so as to obtain maximum induction voltage.

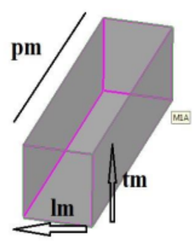


Fig. 3: Dimmension of permanent magnet

The design of the rotor consisted of 8 magnetic poles on each inner side of the rotor. The design of the maximum number of coils and permanent magnets would increase the value of the induced frequency and induced voltage. Installation combinations of magnetic poles were performed in accordance with the N-S type which aimed to increase the magnetic flux density value between the two rotors.

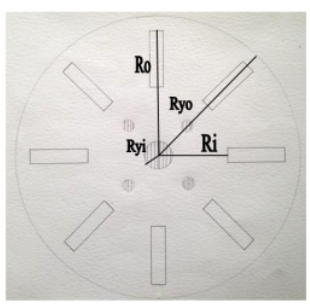


Fig. 4: The distribution of 8 pairs of N-S magnetic poles

As for the stator dimension, it can be seen in the table below:

Table 2: The Size of the Rotor

No	Description	Size (mm)
1	Rotor Diameter (dr)	210 mm
2	Rotor Thickness (kr)	5 mm
3	The outer radius of the rotor (ryo)	110 mm
4	The inner radius of the rotor (ryi)	9.5 mm
5	The outer radius of the magnet (ro)	105 mm
6	The inner radius of the magnet (ri)	65 mm

Then, when the rotor configuration and the three-phase axial stator flux permanent magnet generator with double rotor were set, they were as shown below

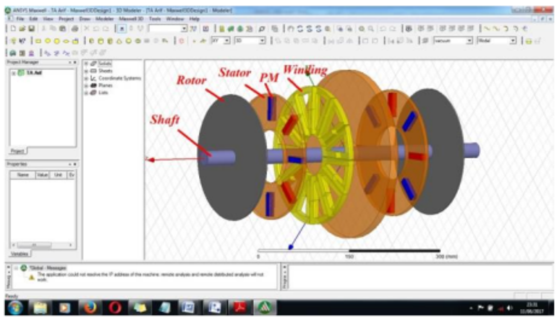


Fig. 5. Double rotor configuration and stator in AFPMG

The flux distribution test was carried out by doing a simulation on ANSYS to understand the spread and magnetization of the armature winding. The spread of this magnetization can be seen in the figure below

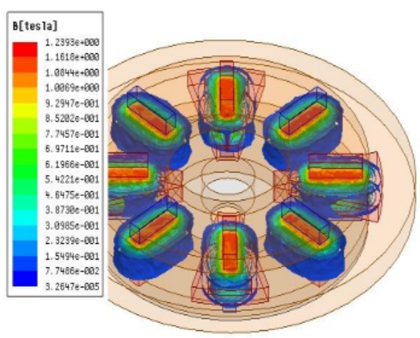


Fig. 6: The simulation of flux distribution by using ANSYS

It produced the flux quantities with the air gap variables with a range of 2 mm and 6 mm from each rotor to the stator as in the table below. There was a non-uniformity of the flux distribution in each winding phase due to the uneven distribution of flux to the position of each winding.

Table 3: The testing of the flux distribution

Phase	The Effect of Air Gap on Flux Distribution				
	2mm	**3mm**	**4mm**	**5mm**	**6mm**
Phase R	1.239 T	0.993 T	0.860 T	0.764 T	0.698 T
Phase S	1.189 T	0.988 T	0.866 T	0.765 T	0.663 T
Phase T	1.212 T	1.014 T	0.868 T	0.761 T	0.667 T

In the form of a flux distribution graph for the three-phase shown below, it can be seen that the larger the gap the smaller the flux distribution that occured due to the flux became the loss in the air gap, thus the optimum flux distribution was at 2mm. This distribution also did not occur uniformly on each phase windings R, S and T due to the uneven position of the magnetic field toward the winding.

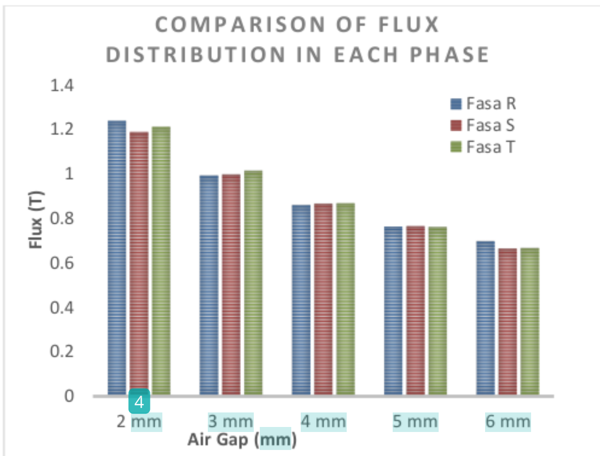


Fig. 7: Flux Distribution

3. Testing and results

The test was carried out by burdening the generator with varying resistance loads with changes in motor speed from 300 to 800 and with a variation of the air gap from 2 mm to 6 mm. This test showed the optimal gap of the generator to produce the greatest power.

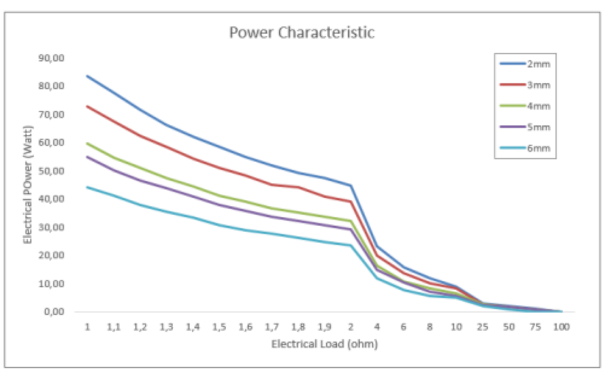


Fig. 7: The testing with variations of air gap with various load quantities

In this test, the rate of decline in electrical power decreases and inversely proportional to the load, as well as the air gap, it was known that the air gap that produced optimal power was at 2 mm. The larger air gap the smaller the power delivered.

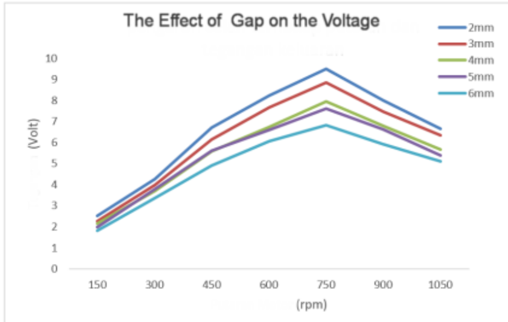


Fig. 8: The effect of air gap on rotation

4. Conclusions

Based on the experiments, it can be seen that optimal air gap was at 2 mm produces flux amounted to an average of 1.2 t. In the test with electrical load load produces the largest electrical power in the gap of 2mm, as well as on testing with variations of motor rotation gap 2 mm The greatest voltage because the air losses are less in comparison with other air gap.

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