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A Prototype of Low Power Permanent Magnet Generator for Renewable Energy Applications

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Abstract. One type of generator used in renewable power generation systems is a permanent magnet generator. This generator provides a constant excitation produced by a permanent magnet, but does not provide a mechanism to regulate the excitation current. It can also directly generate a voltage when the rotor has been rotated, but it is quite difficult to control the output voltage when the load is changed. The present study attempts to design a low power 2-pole permanent magnet generator by modifying a single-phase induction motor. It begins by designing the stator and rotor. The stator consists of 24 slots. The stator coil is designed to have 325 turns for each pole. The rotor is a squirrel cage rotor that is modified by implanting 10 pieces of neodymium type permanent magnet with a dimension of 20 x 15 mm. The results of the tests showed that in no-load conditions, a permanent magnet generator was able to generate a voltage of 69.5 - 223.7 V and a frequency of 33.5 - 50.9 Hz when rotated at speeds of 2000 - 3000 rpm. The generator voltage dropped from 202.5 to 47.7 V when loaded with 10 - 80 W incandescent lamps and rotated at 3000 rpm.

INTRODUCTION

It has been known that the natural resources found in remote areas can be used to generate electricity. To develop a power generation system in such area, the main criteria are how to make it simple, easy to maintain and easy to operate by the community.

A synchronous generator is an electrical machine used to convert the mechanical energy into the electrical energy through an electromagnetic induction process. The speed of the rotor and the stator magnetic field is equal. Permanent magnet generators have a stator and a rotor like synchronous generators. The difference between the two generators lies in how to generate the magnetic field. The magnetic field in the permanent magnet generator is generated by the permanent magnet, while the magnetic field in the synchronous generator is generated by a DC voltage connected to the field winding.

Permanent magnet generators offer a constant excitation produced by permanent magnets. It is very useful in the process of generating electricity. When the rotor is being rotated, the voltage will be generated directly in the stator winding. Another advantage of this machine is that it has high efficiency, high torque density, smaller size and low maintenance [1]. Nevertheless, it also has disadvantage, including the difficulty in adjusting the output voltage because it does not give an alternative way to regulate the excitation current, the high price of a permanent magnet, and the potential demagnetization [2].

When designing an electric machine, one of the main concerns is the cost of production. In this case, the use of materials already available on the market is better than ordering special materials [3]. The most expensive part of permanent magnet generator is a permanent magnet that can increase the engine price by 25%. By using the same materials, the cost of a permanent magnet depends on the shape, dimensions and direction of magnetization [4]. The design of a permanent magnet generator must be optimized to reduce the size of the permanent magnet so that it will reduce the size and weight of the generator. The design must also guarantee that the permanent magnet is well protected from the effects of field current demagnetization [3].

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The design of the stator winding is influenced by the number of slots in the stator, the width of the slots, the selection of the type and cross-sectional area of the enamelled wire, the type of coil arrangement, and the number of poles [5]. The last design of the stator winding becomes the basis of rotor manufacturing. The fabrication process includes the manufacture of the rotor core and the rotor shaft. The existence of a radial flux in the rotor core depends on the dimensions and the density of the magnetic flux available on the market, the number of magnets, and the installation of magnets in the rotor core [6].

Several designs of permanent magnet generators have been proposed. The design of a permanent magnet generator with an exchangeable rotor makes it possible to choose rotors with different materials depending on the price of the permanent magnet. Ferrite rotors are much heavier than neodymium rotors, but they will be more profitable for the application of a vertical axis wind turbine where the generator is placed at the ground [7]. Radial flux permanent magnet generator, where magnetic flux crosses the air gap in the radial direction, is widely used in commercial wind turbines. This configuration can be classified as a concentrated flux permanent magnet generator. Most generators are inner rotor type, but there is an outer rotor type in which the rotor will rotate outside the stator [8]. The axial flux permanent magnet generator has a higher torque volume density and a shorter axial length than radial flux [9]. Multiple poles, low-speed, and slotless permanent magnet generators are applied to produce minimal torque. The stator winding is concentrated and placed in the resin [10, 11].

The armature voltage (E_a) is generated at the armature winding. It is also different from the terminal voltage. It is equal to the terminal voltage when there is no current on the machine. The relationship between the armature voltage and the terminal voltage is shown in Eq. 1 as follows:

$$E_a = V + IR_a + jIX_a \quad (1)$$

With E_a is the armature voltage, V is the terminal voltage, R_a is armature resistance, and X_a is armature reactance.

The relationship between frequency and the rotational speed of the generator is shown in Eq. 2 as follows:

$$f = \frac{n.p}{120} \quad (2)$$

With f is the frequency, n is the rotational speed, and p is the number of poles.

MATERIALS AND METHODS

The present research was initiated by designing the stator winding. The used stator has 24 slots as shown in Fig. 1. The generator is designed to work at a nominal rotational speed of 3000 rpm so that it will have two poles. The stator winding is designed so that there are 325 turns on each pole. The material used to make the stator winding is enamelled wire of the German type with a size of 0.4 mm. The coil span is five slots. Slot number 1, 2, 3 and 4 will be filled with 60 turns, while slot number 5 will be filled with 85 turns so that there are 325 turns/poles. The selected stator winding is a concentrated type as shown in Fig. 2.

The used rotor is a squirrel cage type rotor modified by implanting a cylindrical permanent magnet. For this purpose, 10 holes in the rotor are prepared using an electric drill. Neodymium permanent magnet with dimensions of 20 x 15 mm is implanted around the rotor. The shape and method of fitting the magnet into the rotor are shown in Fig. 3, while the shape and dimensions of the permanent magnet are shown in Fig. 4.

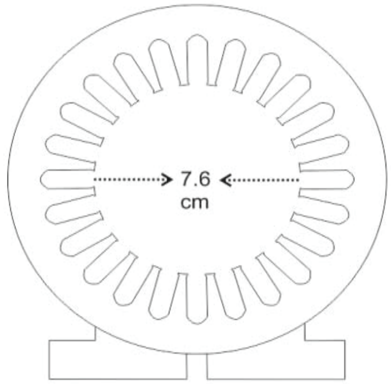

FIGURE 1. The shape of the stator.

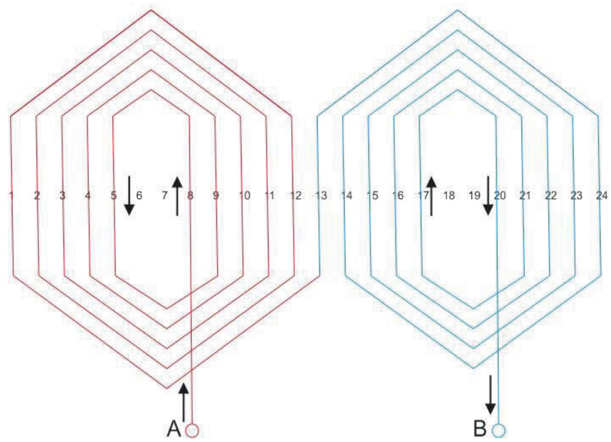

FIGURE 2. The design of stator winding.

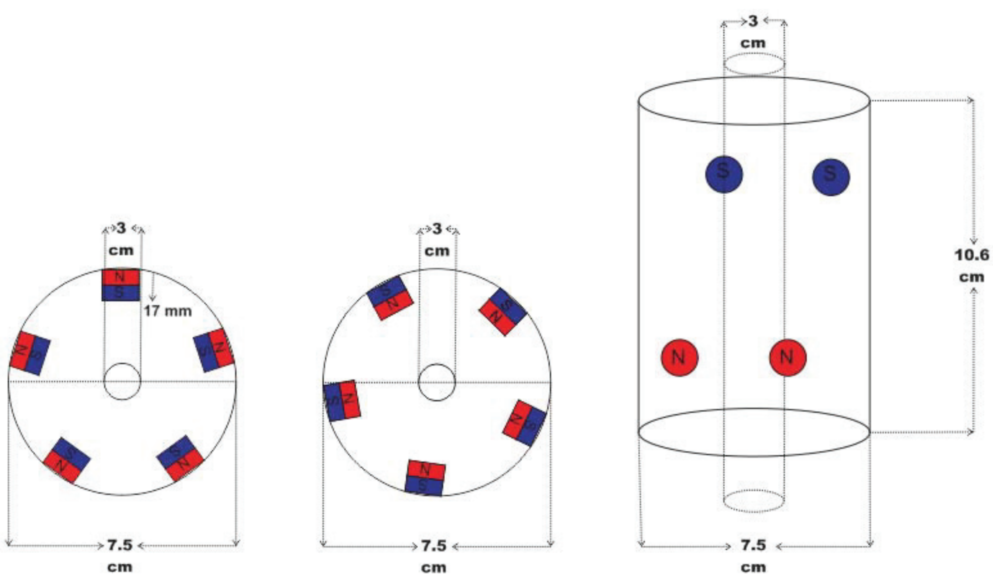

FIGURE 3. The shape and method of fitting the magnet into the rotor: (a) Front view, (b) Rear view, (c) Side view.

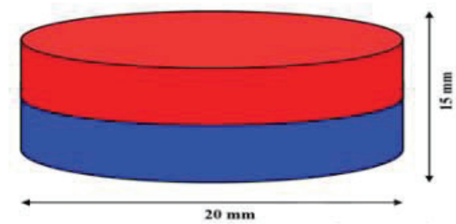

FIGURE 4. The shape and dimensions of the permanent magnet.

The prototype of a permanent magnet generator was tested in the laboratory. The test was carried out in no-load and loaded condition. In the no-load test, the generator speed varied from 2000 to 3000 rpm. In the loaded test, the generator speed was kept constant at 3000 rpm and the generator load varied from 10 to 80 W. In each test, the rotational speed, voltage, frequency and current were measured.

RESULTS AND DISCUSSION

No-Load Test of Permanent Magnet Generator

The generator is rotated by using a prime mover, i.e. an induction motor equipped with a speed controller. The rotational speed of the generator is varied from 2000 to 3000 rpm. The measurement results of the voltage and frequency of the permanent magnet generator in no-load conditions are shown in Table 1.

TABLE 1. The result of no-load test

No	Rotational speed (rpm)	Voltage (V)	Frequency (Hz)
1	2000	69.5	33.5
2	2100	76.1	35.1
3	2200	81.7	36.0
4	2300	87.7	37.8
5	2400	114.6	40.7
6	2500	127.7	42.2
7	2600	143.9	44.2
8	2700	164.3	46.3
9	2800	178.5	47.5
10	2900	195.0	48.8
11	3000	223.7	50.9

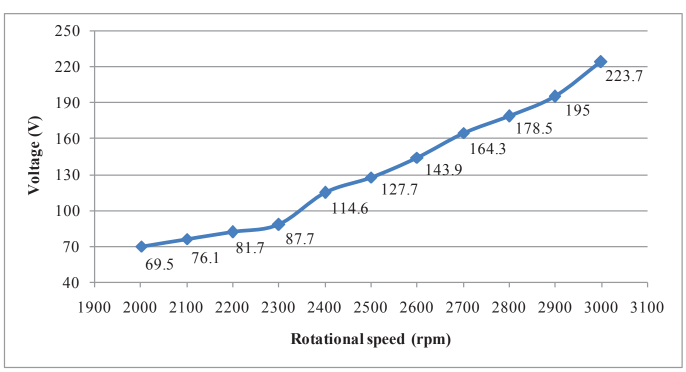

FIGURE 5. The relationship between rotational speed and generator voltage.

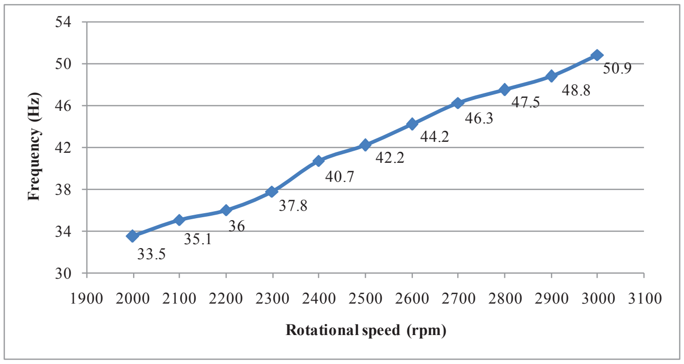

FIGURE 6. The relationship between rotational speed and generator frequency.

Table 1 and Fig. 5 show that when the generator is rotated at a speed of 2000 rpm, a voltage of 69.5 V is generated. When the rotational speed is increased to 3000 rpm, a voltage of 223.7 V is generated. By varying the rotational speed from 2000 to 3000 rpm, the voltage will be increased from 69.5 to 223.7 V. The results of this test indicate that the higher the rotating speed of the generator, the higher the voltage. The tested generator has two poles, thus theoretically, the nominal voltage will be achieved when the generator's rotational speed is 3000 rpm. It is consistent with the results of the test where a nominal voltage of about 220 V is generated by the generator with rotational speed of 3000 rpm.

Table 1 and Fig. 6 also show that when the generator is rotated at a rotational speed of 2000 rpm, a frequency of 33.5 Hz is generated. When the rotational speed is increased to 3000 rpm, a frequency of 50.9 Hz is produced. By varying the rotational speed from 2000 to 3000 rpm, the generator frequency will vary from 33.5 to 50.9 Hz. The results of this test indicate that the higher the rotating speed of the generator, the higher the frequency. The results of this test verify the theory, because a nominal frequency of about 50 Hz is generated by a 2-pole generator with rotational speed of 3000 rpm.

Loaded Test of Permanent Magnet Generator

The test of the generator in a loaded condition is done by rotating the generator at a constant rotational speed of 3000 rpm. The generator is connected with a resistive load consisting of 8 pieces 10 W incandescent lamps. The test results of a permanent magnet generator under loaded conditions are shown in Table 2.

TABLE 2. The result of loaded test

No	Power (W)	Voltage (V)	Current (A)
1	10	202.5	0.06
2	20	173.0	0.11
3	30	146.7	0.15
4	45	116.4	0.19
5	50	99.6	0.20
6	60	93.2	0.22
7	70	73.2	0.24
8	80	47.7	0.27

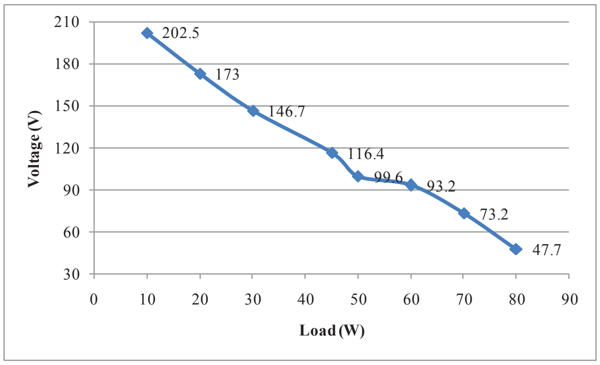

FIGURE 7. The relationship between load power and generator voltage.

Table 2 and Fig. 7 show that a voltage of 202.5 V is generated by the generator when loaded with 10 W incandescent lamps and rotated at 3000 rpm. A lower voltage of 173 V is generated by the generator when it is loaded with an incandescent lamp of 20 W. This voltage drop continues when the load is increased. By increasing the load from 10 to 80 W, the generator voltage will drop from 202.5 to 47.7 V. In general, it can be stated that the greater the load connected to a permanent magnet generator, the smaller the voltage. In this test, the rotational speed is kept constant, hence the load will the only parameter to the generator voltage fluctuations. The greater the load, the greater the current supplied by the generator as shown in Table 2. The impedance of stator winding is constant. When a current flows in a winding, a voltage drop will occur on the winding. In this test, the voltage drop is only affected by the magnitude of the current because the impedance of the winding is kept constant. The results of this test indicate that there is a significant voltage drop when the generator is loaded with a small load. It indicates that the impedance of stator winding is quite high. The size of the stator winding can be increased to achieve the higher capacity of generator.

CONCLUSION

The stator of a 2-pole permanent magnet generator has 325 turns/poles. Moreover, 10 pairs of neodymium permanent magnets with dimensions of 20 x 15 mm in a cylindrical shape are implanted around the squirrel cage type rotors.

In no-load conditions, a permanent magnet generator can generate voltages from 69.5 to 223.7 V and frequencies range from 33.5 to 50.9 V at rotational speeds of 2000 to 3000 rpm.

The voltage of permanent magnet generator will drop from 202.5 to 47.7 V when rotated at a constant speed of 3000 rpm and loaded from 10 to 80 W.

Further development of a permanent magnet generator can be done by increasing the size of the enamelled wire in the stator coil, the number of a permanent magnet in the rotor, or the size of the permanent magnet. With such methods, the capacity of the generator will increase and a larger load can be supplied.

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