Design of a single-phase flux radial generator with opposite poles (U-S) using permanent Neodymium magnet (NdFeB)

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Abstract. Nowadays, the energy crisis is one of the main problems in Indonesia. The depletion of fossil fuels is the most dominant factor. Therefore, new energy solutions are needed. Generators are an essential factor in renewable energy in generating electricity. Further research is required to create a generator that may work at low rotational speeds. Electricity supply service from year to year continues to increase in any hemisphere due to the needs of the community that separated from the demand for electrical energy, especially in Indonesia. There are still many regions of Indonesia that have not to be electrified, especially remote areas, borders, and outer islands. Thus, alternative energy sources are needed, such as new and renewable energy, as electricity producers. One effort to overcome the scarcity of electrical power is the use of water and wind energy in electricity generation both on a large scale and on a small scale. Indonesia has considerable wind potential related to the energy sector, but this system also requires batteries or energy storage media. Innovations on energy conversion technology, especially in permanent magnet NdFeB permanent radial and axial flux generators have been developed. An electric generator is a device that can convert mechanical energy (motion) into electrical energy. In designing radial flux generators with opposite poles, they have 24 coils on the stator and 12 magnets on each rotor, where each coil has 450 windings connected in series with 24 Neodymium Iron Boron (NdFeB) magnets on the rotor. The diameter of the email wire used in this generator is 0.3 mm. Tests carried out using a resistive load of 3000 Ω, which is paralleled as much as 1, 2, and 3 as a load. Tests carried out on the voltage, current, and rotational speed of the rotor to determine the power and efficiency of the generator. The test results show that this magnetic flux change produces a voltage of 101 volts without load.

Keywords: generator, radial flux, neodymium, double stator, phase

1. Introduction
Nowadays, the energy crisis is one of the main problems in Indonesia. The depletion of fossil fuels is the most dominant factor. Due to this, new energy solutions are needed. Generators are an essential factor in renewable energy in generating electricity. Therefore further research is...
required to create a generator that can work at low rotational speeds. Direct-drive radial flux synchronous generators are considered a modern wind turbine drive train [1]. Wave energy is a form of renewable energy that is untapped mainly with some promising attributes, including higher energy density, more consistency, and greater predictability than wind energy and solar energy [2]. The electromagnetic and mechanical design aspects of the double radial rotor magnet are permanently designed wind permanent magnet generators with aerated (no iron) stator winding [3]. Two main reasons for advocating a cost-effective micro wind turbine power system: the need to provide viable alternative solutions for classical energy production and pollutants and the need to make it affordable for middle-class citizens, especially in Eastern Europe where GDP per capita is lower than in Western Europe [4]. The main reason for this popularity is higher energy density, lower cogging torque, lower cost, and high mechanical torque for PM generator applications [5].

Various permanent magnet generators (PMGs) have been proposed and developed for small renewable energy systems. This generator is used to extract maximum strength from wind speed [6-8]. Radial permanent flux has a magnitude generator output voltage and torque ability higher than permanent flux axial generator generators [9]. It is also used in the design and analysis of conventional electric engine performance [10]. To design a hybrid flux PM machine for high power density, which combines the radial and axial flux engine with integrated winding [11]. Besides, phase waveforms can be obtained sinusoidally from the output [12-15]. It is an essential factor to consider for determining the minimum wind intensity needed to produce power in an engine-generator [16]. In searching for better wind generator systems, direct-drive (gearless) permanent magnet generators (PMG) full-scale grid-connected electric power converters are currently receiving a lot of attention in research and from the industry [17-20]. The advantages of using a turbine with two counter-rotation stages for the energy conversion of ocean currents include almost zero reaction force in the supporting structure, near-zero built rotations, and relatively high rotational speeds. For a complete energy conversion system using such turbines, the generator with two rotating rotors counterclockwise and one single winding stator is an exciting machine. However, it is still a somewhat unexplored concept [21].

The use of permanent magnet machined core rotor winding rotor (PM) has many advantages such as no loss, zero cogging torque, no tensile force between the rotor and the rotor, and the possibility of in-situ replacement of the faulty generator. The use of non-overlapping concentrated stator windings has proven to be very beneficial in terms of ease of manufacturing and assembly, copper savings, and machine performance [22-24]. However, the drawbacks of this engine are the significant attraction between PM motors and the relatively large amount of PM material used due to the large air gap, which seems extraordinary. The latter may be the reason for the relatively little work that has been published on this machine and the low number of applications in higher power levels [25-30].

2. Materials and methods
In designing the tool, the two rotor flux radial generator has three parts, namely the outer, middle, and inner parts. The outer part is the outer rotor (Outer rotor), the central section is the stator, and the inner part is the inner rotor. The placement of the stator is between two rotors, which aims to determine the performance of the radial flux generator when using a double rotor. Some of the components used in this radial flux generator include stator, rotor, permanent neodymium magnet, iron core, and windings (coils). The stator has a diameter of 15.7 cm, which contains a coil with a total of 450 turns. It has 12 loops on the outside and inside, which are placed on the stator. The plate associated with using an iron core is in the first and third layers. The rotors
contain permanent neodymium magnets with a magnetic diameter of 15.4 mm for the outer rotor and 12x2 for the inner rotor with a magnetic field strength of 0.89 mT for the distance between magnets of each magnet 2.8 cm for the rotor outside and 1.1 cm for the rotor inside. Laying magnets placed in a circle by following the shape of the rotor (Figure 1).

![Image](image_url)

**Figure 1.** The axial-flux generator with double neodymium permanent magnets: (A) Shafts used for pulley placement; (B) Coils; (C) Magnets; (D) Inner Rotors; (E) Stator (F) Outer Rotor

### 2.1 Performance measurement method

#### 2.1.1 Generator test

This generator test aims to obtain the generator output current (I1) and the generator output voltage (V1). Tests carried out using a resistive load of 300 Ω in parallel of 1, 2, and 3. The speed of the generator is measured using a tachometer. Measurements are made on the rotating shaft following the rotor rotation on the generator. A dish to measure the rotational speed of a generator mounted on the generator rotor. Furthermore, the frequency produced by the generator is measured using an oscilloscope attached to the output line to line on the generator.

The test is carried out using four different voltages, namely 10 V, 20 V, 30.5 V, and 50.5 V. In the no-load test data obtained from the voltage test results of 28 V with 669.8 RPM with a frequency of 133.96 Hz. The following data received a voltage of 61.98 V with an RPM of 1663 and 332.6 Hz. The highest test data without load is obtained at 101.2 V and an RPM of 2668 and a frequency of 533.6 Hz. Measurement of the 10 V generator voltage uses a 3000 Ω load. In parallel 1, parallel 2 and parallel 3 obtained 271.8, 284.5, 343.4 RPM is 0.00296 A, 0.00685 A, 0.01028 A, respectively. At a voltage of 20 V with a load of 3000 Ω in parallel 1, parallel 2 and parallel 3 an RPM of 504.8, 528.4, 568.2 and a current of 0.00682 A, 0.01372 A, 0.02065 A. At a voltage of 30.5 V with a load of 3000 Ω parallel 1, parallel 2 and parallel 3 obtained an RPM of 862.1, 874.9, 1010 with a current of 0.01039A, 0.02075 A, 0.03098 A. At a voltage of 50.5 V with a load of 3000 Ω parallel 1, parallel 2 and parallel 3 obtained RPM 1605, 1881, 2547 with currents of 0.01728 A, 0.03513 A, 0.05221 A. After measurement, power and efficiency calculations are performed. The power generated at each load obtained power at a voltage of 10 V with a sequence load of
0.0296 W, 0.0685 W, 0.1028 W. At a voltage of 20 V the power obtained is 0.1364 W, 0.2744 W, 0.413 for a voltage of 30.5 V obtained a power of 0.3169 W, 0.63288 W, 0.93869 W. Finally, at a voltage of 50.5 V the power obtained is 0.87264 W, 1.77407 W, 2.63661 W. Significant difference in current due to differences in generator rotational speed will affect the amount of power produced as shown in tables 1, 2 and 3.

3. Results and discussion

3.1. Effect of generator rotation speed on load

The size of the rotational speed of the rotor during a particular time will affect the output voltage generated by the radial flux generator. If the generator is given a large load with a constant output voltage, the rotational speed of the rotor will be even higher. Faraday’s Law, where the size of the energy is influenced by the number of turns and rotational speed of the rotor that affects the change of magnetic flux per unit time. It can be seen in Figure 1 that the immense rpm value is when the 10 V voltage is 343.4, at the 20 V voltage is 568.2, at the 30.5 energy is 1010 and when the 50.5 voltage is 2547.

![Figure 2. Effect of generator rotational speed on load](image)

In Figure 1, the decrease in the rotational speed of the rotor is related to the generator output voltage. The smaller the rotational speed of the rotor, the energy will be lower along with the reduced load. Because the output voltage is made constant, the rotational speed of the rotor will be smaller as the load decreases. In this case, the charge will be even higher if the resistance value is lower. It is because resistive loads are installed in parallel so that the amount of the resistance will be smaller, but the power at the resistive load will be higher.

3.2 Effect of speed with current and voltage for a long time battery charge

The smaller the load is installed, the increase in current occurs, as shown in figure 2. Where the value of the resistive load that is getting smaller is caused by packs that are connected in parallel so that the load resistance will be lower if the charges used are installed in parallel more and more. If the smaller the resistance value used, the higher the current generated. Where the amount of current is inversely proportional to the amount of resistance. But for voltage, the voltage is directly proportional to the amount of current. So that the correlation is obtained that the greater the current, the higher the energy will be.
Figure 3. Effect of current relations against load

It is under Ohm’s Law, where the amount of current flowing in a closed circuit is closed by the magnitude of the applied voltage and also the size of the resistance. If the voltage is increased, the electrical current will increase. However, if the resistance is also increased, the current will decrease. This is proven when the output voltage of 10 V with a load of 3000 Ω in parallel is 1, the smallest current is 0.00296 A and the highest current is obtained in a load of 3000 Ω in parallel 3, a current of 0.01028 A is obtained, when the output voltage is 20 V with a load of 3000 Ω in parallel is as much as 1, the smallest current is 0.00682 A and the biggest current is obtained in a load of 3000 Ω parallel as much as 3, current is 0.02065 A, when the output voltage is 30.5 V with a load of 3000 Ω in parallel is 1 obtained the smallest current that is equal to 0.01039 A and the largest current obtained at a load of 3000 Ω in parallel as many as 3 obtained a current of 0.03098 A.

Figure 4. The effect of the voltage calculation of the generator on the load

The graph in Figure 3 shows that the calculated output voltage has increased and decreased. The impedance multiplication causes this with the generator output current at the generator output voltage, which results in a fluctuating value. So the percent error produced is not constant like the current and rotational speed of the radial flux generator. The motor, as the prime mover of the generator must be connected to the power supply so that the voltage entering the engine can regulate through the power supply.
Figure 5. Effect of output power relationship on load

Based on the graph in Figure 5, the relationship between output power and resistive load variation shows that the smaller the resistance value, the higher the output power will be with a constant output voltage. The output power is influenced by the size of the current as well as the power of each resistor. In this study, because the energy is constant, the amount of current that affects the magnitude of the output power. So it can be seen in Figure 4 that the power generated will be greater along with increasing voltage. The most excellent power occurs when a constant output voltage of 10 V with a load of 3000Ω parallel of 3 is known. The power of 0.1028 W and a voltage of 20 V with a load of 3000Ω in parallel 3 result in force of 0.413 W, a voltage of 30.5 V with a large load as much as 3000Ω parallel as much as 3. The biggest power is 0.938694 W, 50.5 V voltage with a load of 3000Ω parallel as much as 3 is obtained power of 2.636605 W. The magnitude of the power value is directly proportional to the value of current and voltage.

Figure 6. The relationship of efficiency to load

Based on the graph in Figure 6, it is known that efficiency is directly proportional to the load seen in the graph of the greatest efficiency value, namely when the load is 3000Ω parallel 3 (3kΩ / 3) at 7.96% at 10V voltage, 12.74% at 20V voltage, 15.70% at 30.5 V voltage and 15.77% at a voltage of 50.5 V. It is known that the efficiency resulted from a small radial flux generator. The power causes this on the motor as a prime mover that is too large. Neodymium Iron Boron magnets also generate immense motor power on rotors that have significant magnetic fields so that higher motor power is needed to rotate the rotors on radial flux generators. Also, this radial flux generator has an iron core, so that the iron core on the stator and Neodymium Iron Boron magnet on the rotor experiences a pulling force so that a vast motor power is needed as well.
**Table 1.** The radial flux generators test loaded with a voltage of 10 V

| Load (Ω) | Voltage (V) | RPM | Frequency (Hz) | Wave |
|----------|-------------|-----|----------------|------|
| 3k       | 10          | 271.8 | 54.36          |      |
| 3k/2     | 10          | 284.5 | 56.9           |      |
| 3k/3     | 10          | 343.4 | 68.68          |      |

**Table 2.** The radial flux generator test loaded with a voltage of 20 V

| Load (Ω) | Voltage (V) | RPM | Frequency (Hz) | Wave |
|----------|-------------|-----|----------------|------|
| 3k       | 20          | 504.8 | 100.96         |      |
| 3k/2     | 20          | 528.4 | 105.68         |      |
| 3k/3     | 20          | 568.2 | 113.64         |      |

**Table 3.** The radial flux generator test loaded with a voltage of 30.5 V

| Load (Ω) | Voltage (V) | RPM | Frequency (Hz) | Wave |
|----------|-------------|-----|----------------|------|
| 3k       | 30.5        | 862.1 | 172.42         |      |
| 3k/2     | 30.5        | 874.9 | 174.98         |      |
| 3k/3     | 30.5        | 1010  | 202            |      |

**Table 4.** The radial flux generator test loaded with a voltage of 50.5 V

| Load (Ω) | Voltage (V) | RPM | Frequency (Hz) | Wave |
|----------|-------------|-----|----------------|------|
| 3k       | 50.5        | 1605 | 321            |      |
| 3k/2     | 50.5        | 1881 | 376.2          |      |
| 3k/3     | 50.5        | 2547 | 509.4          |      |
4. Conclusions
Power and efficiency generated by single-phase radial flux generators using cylindrical Neodymium Iron Boron (NdFeB) cylinders with opposite poles (US) have many loads or smaller resistance values based on load variations. However, the power and efficiency produced will be even higher with a constant voltage output. It relates to the output current flowing at a higher load if the load increases or the resistance decreases. Besides this, the current correlation based on Ohm’s Law is inversely proportional to strength. The result showed when the constant voltage is 10 V with a resistance of 3000 Ω parallel one. The output current that flows is 0.00696 A with a power of 0.0296 W and an efficiency of 2.5784%.

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