Energy harvesting applications using 3D-printed coreless generator

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Abstract. 3D-printed coreless generator has been presented for energy harvesting applications using permanent magnet as source of external magnetic field in the rotor. The phototype of proposed coreless generator is built using 3D-printer with Black Polylactic Acid (PLA) as a filament for stator housing, rotor and other parts. The major parts of the proposed coreless generator are the stator, which has four coils of winding copper wire and the rotor with eight permanent magnets which are arranging N and S magnet poles alternately. This research is conducted to determine how much power can be generated from the proposed 3D-printed permanent magnet generator. The prototype permanent magnet generator is tested with rotational speed and load condition. The experimental results have been shown that the coreless generator can generate the electrical energy up to 5 W at 6000 rpm.

1. Introduction

Permanent magnets generators (PMGs) exhibit a prospect to build energy efficient machine [1]. The stator and rotor are the major parts of PMGs. The main function of the stator is to generate alternating current from conductor windings while the rotor consists of permanent magnets as external magnetic field to generate the magnetic interaction with the stator. Nowadays PMGs are rapidly used in numerous applications in term of powering small or large-scale electronic systems, such as wind turbine application [2], hydroelectric generation [3] and others. Even though PMGs are able to achieve high efficiency compared with other generator types, however PMGs still more costly compared to other generators [4]. Therefore, many research works focus on the design of PMGs with basic requirements such as high output power, lightweight, simple construction, and low cost [1]. Unfortunately, the design consideration of those basic requirements should be carefully conducted based on the generator configuration and materials [4].

3D printing technology has become significant importance as rapid process to develop prototypes for various type of applications such as RF/microwave components [5], aerial vehicle wing structures [6], electromagnetic shielding [7] and biomedical applications [8]. Since the 3D printing technology has capabilities to develop complex geometries from the digital drawing, this technology becomes the major advantage in the manufacturing systems. The other advantage is that the 3D printing technology can be used to develop functionalities with other manufacturing methods [9]. Additionally, 3D printing technology can improve the design and lower the weight of the structure, resulting to a very cost-effective solution and reduction of lead times [10]. Based on these results, it is a worthy probability to use 3D printing technology for developing a generator. The development of generator using 3D-printing technology have been proposed by many research works such as 3D-printed electrostatic generator [11], 3D-printed triboelectric generator [12], and 3D-printed materials low speed PM generator [13].

In this work, the possibilities of implementing 3D printed coreless generator for energy harvesting applications is reported. Following sections will explain the design of the 3D-printed coreless generator, fabrication of the generator, and the test results of the proposed 3D-printed coreless generator.
2. Materials and methods

2.1. Design of 3D printed coreless generator

The generator is meant to convert mechanical energy into electrical energy. However, the coreless generator is a generator that uses the core for coil of winding copper wire by non-ferrous materials. Most of these type of generators use Permanent Magnet (PM) in the rotor. PM in generator supplied the magnetic excitation as conversion device producing all electromagnetic energy. The advantage of coreless generator is that it can eliminate the strong interaction in magnetic field between PM and ferrous core resulting to a high resistant on rotating rotor. Therefore, the coreless generators are suitable for harnessing renewable energy such as wind, rain water, river water, and tidal energy, which produce relatively small energy. Hence, the coreless generator can capture a small amount of energy by smooth rotation without any resistant of magnetic field.

The main parts of the generator are stator and rotor. There are two types of generator; the first type has stator which is fixed at the middle and a rotor that is located at the outer stator housing, and the other type has rotor at the middle and the stator is fixed at the outer housing. The stator functioned as conductor winding to generate alternative current. While, the rotor, where the PM took place, is operating as external magnetic field to generate the magnetic interaction with the stator, thus can produce the alternative current.

All parts of the coreless generator are designed using Autodesk Inventor. The design of stator and rotor are as shown in figure 1 and figure 2, respectively. In the stator design, there are four stacks for winding coil of copper wire that are placed perpendicular to the next coil. The rotor as shown in figure 2 is designed for 8 permanent magnets in the slot for easier placement. The stator is the stationary part in the outer housing whereas rotor is the inner part which rotates. The specification of designed coreless generator are summarised in table 1.

![Stator design in Inventor Autodesk](image1)

![Rotor design in Inventor Autodesk](image2)

**Table 1.** 3D printed coreless generator specification

| Parameters                  | Value           |
|-----------------------------|-----------------|
| Pole numbers                | 8 poles         |
| Stator Slot for winding     | 4 slots         |
| Rotor diameter              | 45 mm           |
| Length of stator stack      | 39 mm           |
| Stator inner diameter       | 50 mm           |
| Stator outer diameter       | 97 mm           |
| Air gab length              | 2.5 mm          |
| Magnet dimension            | 60 x 10 x 5 mm³|
2.2. 3D printed coreless generator fabrication

Anet A8 3D printer is used for the coreless generator fabrication with 1.75 mm of diameter of Black Polylactic Acid (PLA) as a 3D printing filament. Before running the 3D printer, the design of stator and rotor should converted to stl file, then the file is opened in Cura software for printer setting as shown in figure 3. The setting are; the heating bed temperature and nozzle temperature set to 60°C and 210°C, respectively. The printing speed is 60 mm/s with the density of 60%. The support placement was chosen as “Everywhere” type to support hanging profile and can be removed easily without effecting the whole product. Figure 4 shows the construction of stator during operation of 3D printer.

A 0.60 mm copper conductor wire is used for winding coil for four slots of the stator with 500 turns in each slot as presented in figure 5. It is essential to count the turns for winding correctly and carefully. One turn of copper wire is set next to the other with enough tense and less gaps in between the turns of copper wire [4]. This is done to produce successful coils. At the rotor, 8 poles neodymium magnets are chosen due to stronger magnets with less volume to produce the external magnetic fields as shown in figure 6. The arrangement of the N and S magnet poles are set alternately.

Figure 4. Coreless generator fabrication using Anet A8 3D printer

Figure 3. Configuration setting on Cura Software for 3D printing
2.3. Experimental setup

In conducting this prototype, the coreless generator was tested using load of 12 V bulb. The prototype of coreless generator can be seen in figure 6(a), while the diagram of experimental setup can be seen in figure 6(b). The connection wire between the coils and connection to a bridge rectifier to convert AC to DC current, load, voltmeter, and amp meter are clearly shown in figure 6(b). The prototype of the coreless generator was tested with rotational speed ranging from 0 rpm up to 6000 rpm.

The experiments were conducted with three different conditions. First, the coreless generator was running without any load to observe an amount of voltage that could be produced. Second, the coreless generator was running with 1 load of 12 V 5 W bulb. Lastly, the coreless generator was running with 2 loads of 12 V 5 W connected parallelly. For second and third experiments, the current produced from the coreless can be observed by Amp meter and Voltmeter for monitoring voltage. The coreless generator was connected to 100 W AC motor to drive the rotor during the experiments that can be controlled by speed controller from 0 rpm up to 6000 rpm.

3. Results and Discussion

Figure 7 summarized the voltage produced from the coreless generator. It can be observed that the increasing voltage is depending on the increasing of speed linearly. From the experimental work, the proposed generator can generate voltage of up to almost 25 volt at 6000 rpm. Therefore, it can be concluded that this coreless generator needs higher speed to get higher voltage. Therefore, for efficient
energy conversion related to the use of renewable sources, identification of the gear ratio between generator and turbine is crucial to obtain higher voltage.

![Figure 7. 3D printed coreless generator voltage with increasing speed](image)

By applying loads at proposed generator during the experimental work, the production of voltage reduces. If higher load is implemented, at lower voltage will be generated as shown in figure 8. However, the increasing load can increase the output current. At 6000 rpm, the voltage without load can generate almost 25 volt, then by giving 1 load and 2 load, the voltage reduce to 17 volt and 10 volt, respectively. While the output current by giving 1 load and 2 loads, can increase from 350 mA to 500 mA at 6000 rpm.

![Figure 8. 3D printed coreless generator voltage and current with increasing speed at 1 and 2 Loads](image)

Figure 9 shows the output power produced from the coreless generator with 1 load and 2 loads. It is clearly shown that both of loads can produce similar results, eventhought, the voltage and current produced from 1 load and 2 loads are different. This coreless generator can produce up to 5 W at 6000
rpm. Therefore, it can be concluded that regardless of loading applied on this coreless generator, the generator will produce similar output power especially under the two loads conditions as tested in this study.

Figure 9. 3D printed coreless generator power with increasing speed at 1 and 2 Loads

4. Conclusions
In this work, the experiments with prototype of coreless generator created using 3D-printed are presented. The coreless generator is aimed to be applied in energy harvesting system. It was found that 3D-printed coreless generator can generate electric energy up to 5 W at 6000 rpm that can be used in low-power system. Therefore, the development of coreless generator using 3D-printed exhibits promising potential to be used for this generator. Nevertheless, further studies are required to study the process developments in variety of filaments and setting on 3D printer.

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