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Discussion of Test Results and Possible Domestic uses of Commercially Available Micro- Permanent Magnet 3-Phase Generator

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Abstract

3-phase alternator that is commercially available. These tiny rotating machines can deliver a few Watts of electric power and can be used to power small electronic appliances and devices in the home. These alternators or generators can be utilized particularly in rural areas where homesteads are typically off-grid or in urban areas where customers may suffer from lack of available power during load-shedding. The aim of this paper is to highlight the importance of permanent magnet AC generators. To this end a small commercially available machine was inspected and tested with the intention of reviewing the internal components and estimating some parameters like the Winding Factor and Air-gap Flux resulting in the appropriate generated voltage. The paper also investigates the generated voltage at different shaft speeds and loads. The open-circuit and full-load tests are also performed. The paper also looks at ways in which losses can be reduced and the output power can be optimized. It is noted that such generators are suited to relatively slow shaft speeds that could be provided by steady streams of water, wind-power and other direct-drive mechanisms like motors found around the home. These machines have simple construction consisting of rotating and fixed components made from relatively inexpensive metals and could be candidates for manufacture on the African continent using indigenous materials. Finally, a brief discussion is introduced related to the manufacture and production of such a machine and the possible demand constraints in the current economic climate.

Key words: ***Permanent magnet AC generator, winding factor, distribution factor, cost***

Introduction

The Permanent Magnet 3-Phase AC Generator discussed in this paper is a Micro-Electrical Machine able to generate less than 5 Watts of power. Permanent Magnet Synchronous Generators (PMSGs) are driven directly by rotating their shafts and are capable of generating electricity without the need for field excitation. The permanent magnets provide a constant field that generates current in the coils that cut the field due to rotation, based on Faraday's Law of Electromagnetic Induction (Chapman, 2012).

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Figure 1, shows the components of this simple machine, which is manufactured from relatively easily obtainable materials. Table 1, shows the materials used in the production of the machine as well as the relevant manufacturing processes.

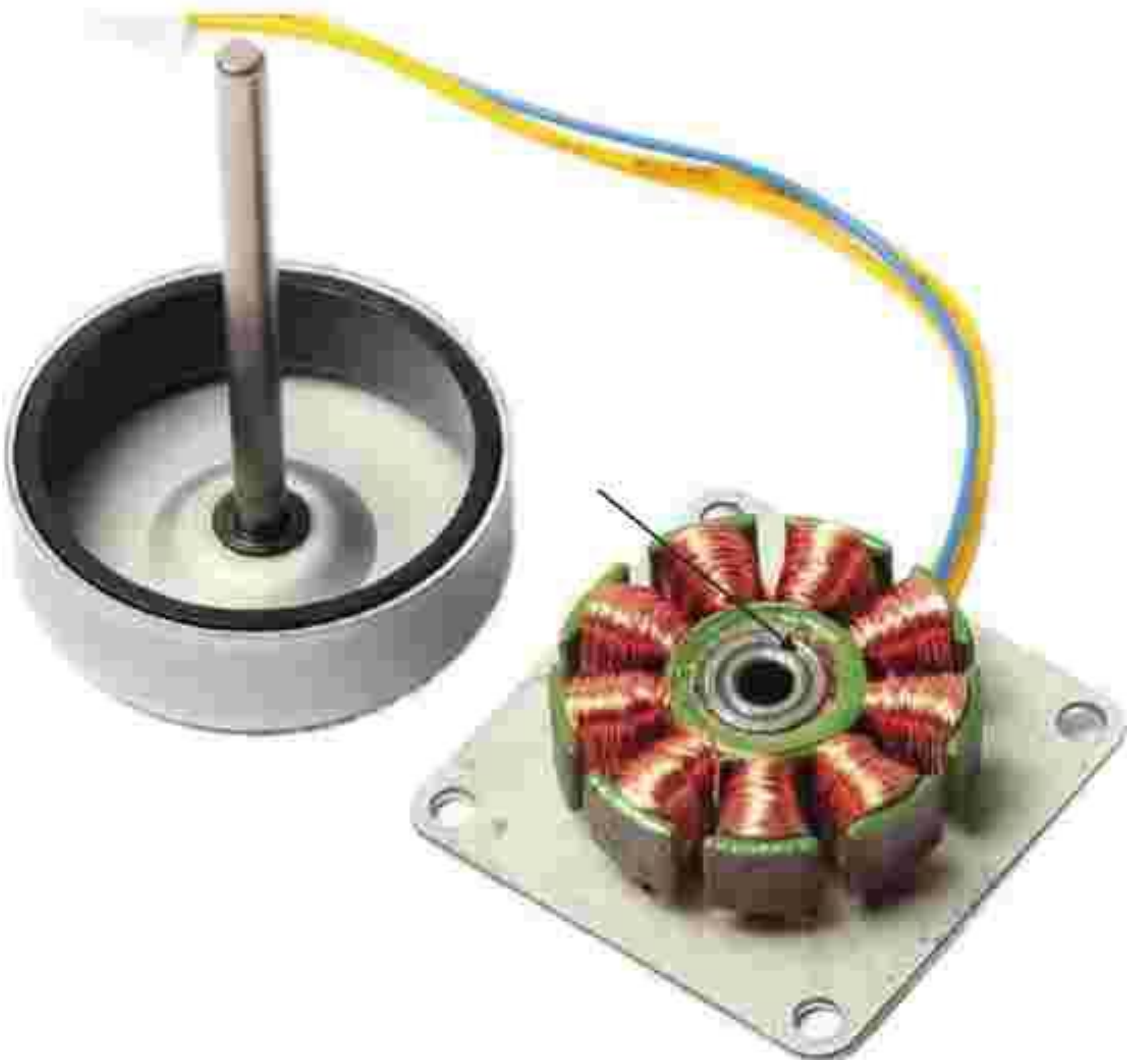

Figure 1: 3-Phase Permanent Magnet AC Generator Components

Table 1

3-Phase Permanent Magnet AC Generator Components, Materials & Manufacturing Process

Description	Material	Manufacturing Process
Shaft	Mild Steel	Drawn. Turned. Polished.
Rotor Hub	Galvanized Steel	Drawn. Punched.
Magnetic Strip (12 poles, 6 North, South)	Ferrite Magnetic Strip	Cut. Glued.
Connecting Wires	Copper Strip	Soldered. Cut.
Stator Plate	Galvanized Steel	Stamped. Cut.
Laminations (0.5mm x 12 pieces)	Silicon Steel	Stamped. Cold Rolled. Laser
Stator Coils (9 coils, 80 Turns, 0.25 diameter)	Copper	Wound. Soldered.
Friction Bearing	Mild Steel	Cut. Polished.

Discussion on the Winding Factor & Generated Voltage

The Per-Phase Generated Voltage (E) given in Volts is equal to the factor 4.44 ($\sqrt{2}*\pi$) times the Winding Factor which is comprised of the k_p (Pitch Factor) times the k_d (Distribution Factor), times the frequency (f) in Hertz (Hz), times the Number of Turns (N) which is dimensionless, times the Magnetic Flux (Tesla) (Chapman, 2012).

For this particular Micro-Machine, k_p = 0.866 (Parsons, 2019). Note that there are 9 stator poles and 12 rotor poles (See Equation 2). Because the windings in this machine are concentrated on each stator pole k_d = 1. Equation 1, shows the Shaft Speed (N_m) (Revolutions per Minute) versus Frequency (f_e) (Hz). It can be seen from Equation 1, that the electrical frequency depends on the shaft speed and number of rotor poles. Equation 3, represents the Pitch Factor where θ_m is the stator pole angle and ρ_p is the rotor pole angle. The parameters of Equation 4 are given only for information purposes. In this case the winding factor $k_w= k_p* k_d$ (See Equation 1) (Chapman, 2012).

$$E=4.44* k_w* f_e*N* \varphi_m \quad \text{(Equation 1)}$$

$$N_m= (120 * f_e)/p_{Rotor} = (120* f_e)/12 \quad \text{(Equation 2)}$$

$$k_p= \sin((v* \rho)/2)= \sin((1*\theta_m/(\rho_p*180°))/2)= \sin((360°/9)/(360°/12)(180°)/2)=0.866 \quad \text{(Equation 3)}$$

$$k_d= \sin(q\, \alpha/2)/(q* \sin(\alpha/2))=1 \quad \text{(Equation 4)}$$

Test Methodology

The Open Circuit Test (Chapman, 2012) was performed by driving the shaft with the DC Motor (shaft) and measuring the output voltage (with no load connected) between two lines of the 3-Phase output. The assumption used was that the phase voltages are balanced. The Generated Voltage given by Equation 1, is the phase voltage for this machine. Thus, to calculate the Phase Voltage given the measured terminal voltage between lines E needs to be divided by $\sqrt{3}$.

Figure 2, shows the measured terminal voltages at various speeds. The rated speed of 3000 RPM (10 V) (Mantech, 2021) was not easily achieved because of safety constraints while testing (rotating coupling speed limitations and temperature rise.

This test was performed to portray the voltages that could be obtained on open-circuit. It should be noted that the machine presented in Figure 1 is a radial flux machine as compared to axial flux machines studied by Carrillo-Rosero, Carillo, Claudio-Medina & Mayorga-Pardo (2018).

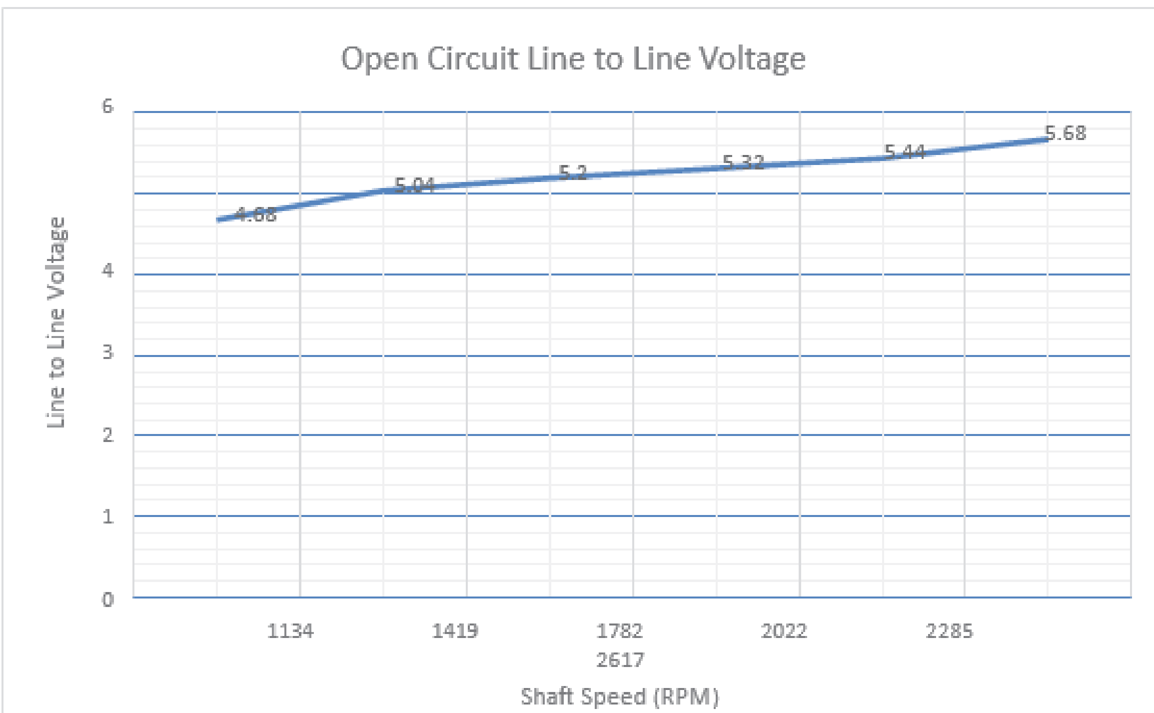

Figure 2: Open Circuit Terminal Voltage at Different Shaft Speeds

Load Tests (Chapman, 2012) were performed with various resistive loads as depicted in Figure 3. Using resistive loads of 2.2 Ω, 5.6 Ω and 8.2 Ω per phase (star-connected), load testing was performed at various speeds. The resistors were rated at ½ Watts. Line voltages were measured as shown in Figure 3.

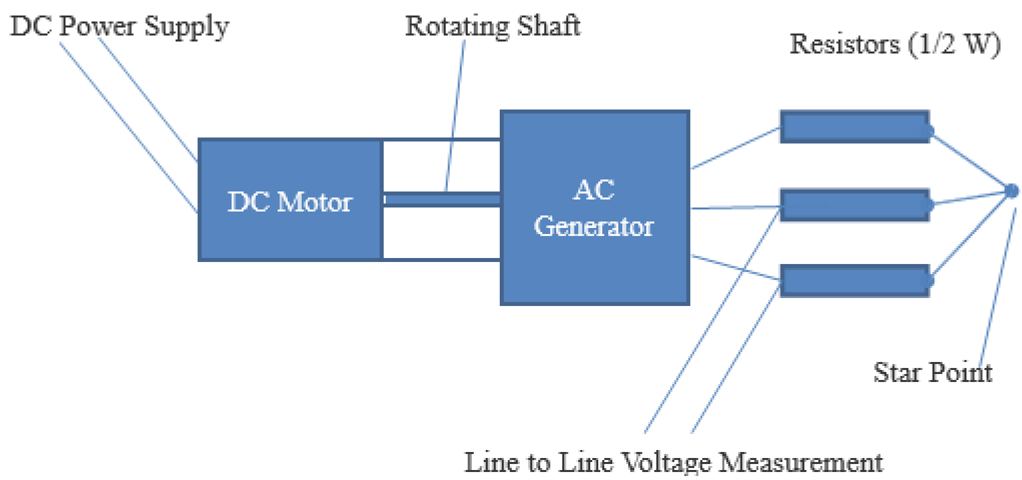

Figure 3:Load Voltages Measured at Different Speeds

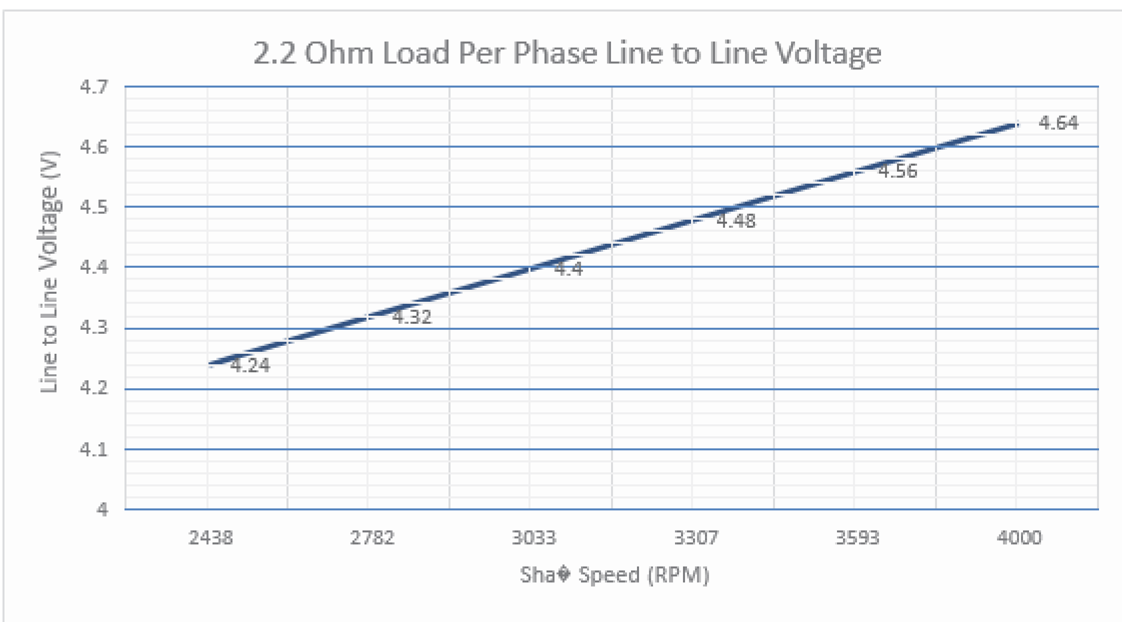

Figure 4: Terminal Voltage with 2.2 Ohm Star-Connected Load

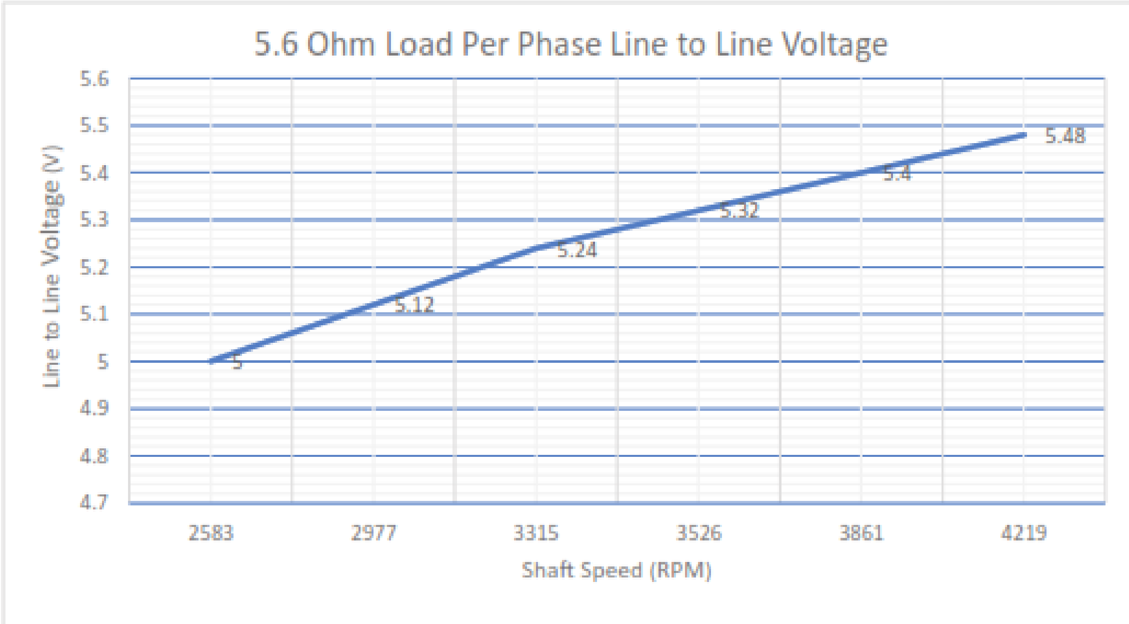

Figure 5: Terminal Voltage with 5.6 Ohm Star Connected Load

The results shown in Figure 4, Figure 5 and Figure 6 depict the voltages between lines as shown in Figure 3. It can be noted that as the load resistance increases more input power is needed to maintain the relative terminal voltages. Thus, designers are urged to be careful when matching the machine output to input speed required and the load parameters.

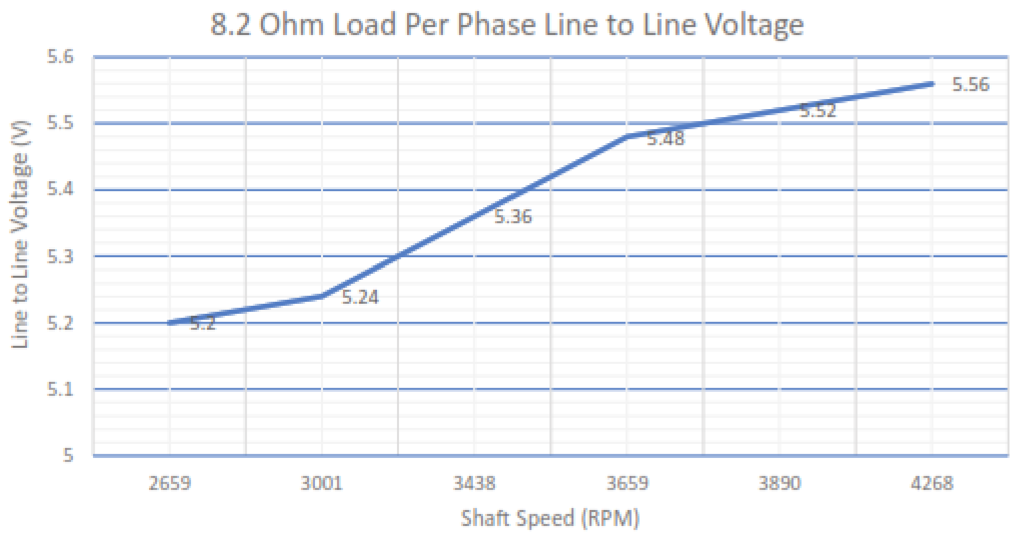

Figure 6: Terminal Voltage with 8.2 Ohm Star-Connected Load

Manufacturing Process

As shown in Figure 7, the component parts of small motors are relatively simple, but require precision engineering. The components shown in Figure 7 are for a Brushless Coreless DC motor (Assun, 2021), which has some similarity to the Permanent Magnet AC Generator shown in Figure 1. The PM AC Generator is much simpler in that windings are placed on the stator only while the rotor contains a permanent magnet strip consisting of 12 magnets with alternating poles. The paper written by Nordelof & Tillman (2017), clearly explains the manufacturing process for a Permanent Magnet Synchronous Motor (PMSM) which can be adapted and applied to the manufacture of the Permanent Magnet Synchronous Generator described in this work.

Review of Figure 1 and Table 1 clearly indicates that components can be easily manufactured and bought-in from local suppliers. Precision Engineering skills and processes would be required to improve quality in mass-producing these micro-machines.

Companies that are typically involved in electric motor manufacturing or refurbishment and supply in South Africa appear to be involved in the production of 3-phase induction motors in the high kW ranges (>750 W to about 500 kW) (JEM SA, 2021) (WEG, 2021) or specialized motors (TEV, 2021) for industrial applications. Very few companies in South Africa manufacture small motor or generators (Bircraft, 2021). It would seem that many small electric motor and generators are manufactured in the East (especially China and India). Noting the simple components required as well as the “basic” processes, African manufacturers should consider growing this market especially in light of the growing demand for Renewable Energy devices (Valchev, Yankov & Marinov, 2009).

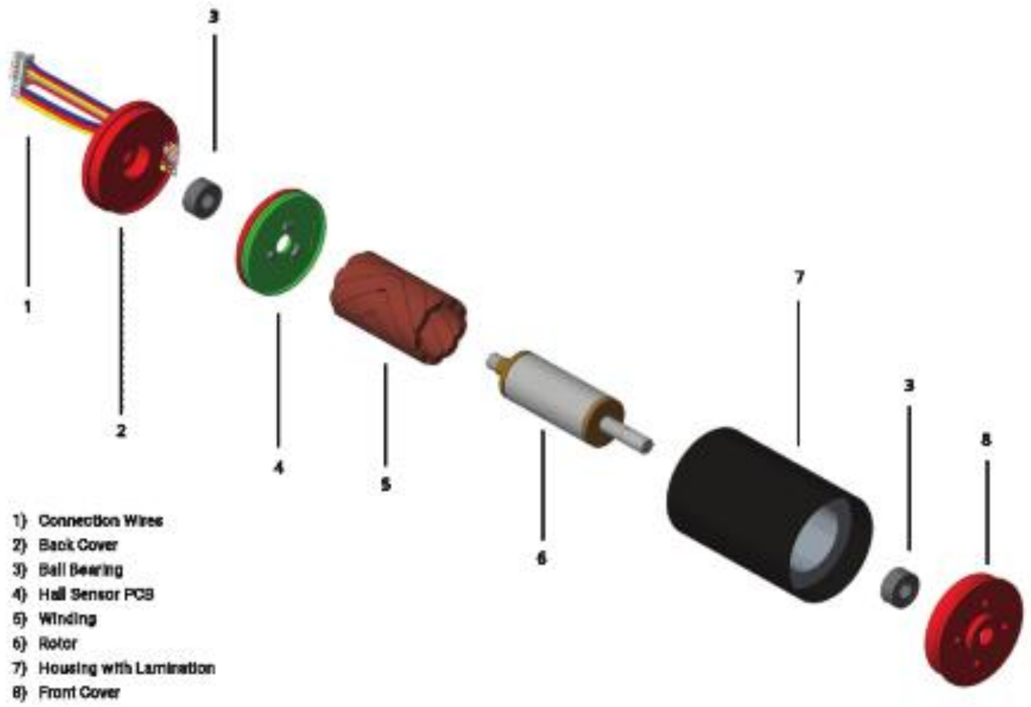

Figure 7: Manufactured Parts for Small Brushless Coreless Motor (Assun, 2021)

Possible Uses of the 3-Phase PM AC Generator

The use of PMSGs for generation of electrical power in Wind Turbines has drawn increased interest in the past years (Yang, Patterson & Hudgins, 2015). As discussed in this paper PMSGs that are driven directly by rotating shafts are capable of generating electricity without the need for Field Excitation (Chapman, 2012). The permanent magnets provide a constant field that generates current in the coils that cut the field due to rotation, based on Faraday's Law of Electromagnetic Induction (Chapman, 2012). Thus, the micro-machine discussed in this paper would be capable of generating sufficient power to charge small electronic devices like cellphones which require only 2 to 6 W (EUC, 2021) appliances and could be used to power sufficient power for small LED lighting needs. It should also be noted that these machines could be paralleled electrically to supply larger loads.

Conclusion

This paper has briefly discussed a Micro 3-Phase Permanent Magnet AC Generator or PMSG. These simple machines can be used to power small electronic devices like cellphone chargers and LED lighting for domestic use. The machine components and windings are briefly discussed as well as the generated voltage equation. The Open-Circuit Test and Load Tests are discussed and performed to show the output capability of these machines. The proposed manufacturing process of this type of PMSG is discussed showing the simple materials and precision engineering requirements needed to produce these machines in Africa. Finally, the possible uses of PMSGs for domestic use is highlighted. It is hoped that manufacturers and end users consider the making and use of such machines to supply electricity for their needs especially during load shedding and where grid-connectivity is reduced, such as in rural areas.

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