VOL. 17, NO. 24, DECEMBER 2022 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

DEVELOPMENT OF A 1KVA FUELLESS GENERATOR USING A BRUSHED DIRECT CURRENT MOTOR

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ABSTRACT

In this paper, the fuel less generator just as the name implies is a power generating system that doesn't require any kind of fossil fuel for its operation. It is safe to say the fuel less generator is a zero-carbon energy system with two major categories; Dynamic Fuel less Generators and Static Fuel Less Generators. The constructed 1kVA Fuel less Generator comprised of a 240W Brushed Direct Current Motor, a 1kVA Alternator, Couplings, Flywheel, 12V 100AH Deep Cycle Battery, 12V 4A Charging Panel or Rectifying circuit (AC-to-DC), Automatic Voltage Regulator, Frame, and other accessories. The Brushed Direct Current Motor was directly coupled to the alternator with the flywheel in-between, also a digital thermometer was connected to the Brushed Direct Current Motor and alternator to monitor their temperature. A digital Direct Current Ammeter and Voltmeter were connected in series with the 12V 100AH Battery and across the Brushed Direct Current Motor terminals respectively to observe and obtain readings of the fuel-fewer generators. A digital energy meter with a current transformer was also connected between the power output of the alternator and the 5A single pole circuit breaker to obtain output parameters such as Voltage, Current, Frequency, Power Factor, and energy consumed. A handheld Digital Tachometer was used to obtain the speed of the fuel less generator during testing. Various tests such as the No-Load and Load Test, Temperature Test, and Speed Test were carried out during the performance evaluation using varying loads from the range of 0W to 800W. During the test, it was observed that the temperature of the Brushed Direct Current Motor increased drastically when a load of 300W was introduced into the system and the generator had its maximum efficiency of 88.71% at the same 300W load. The fuel less generator was operated with and without the flywheel which gave an output frequency of 40Hz and 25Hz respectively. The construction of fuel less generator with the ability to be in perpetual motion and continually generate electric energy is achievable provided the motor speed, torque, and cooling system are properly calculated. This research can be used to replace the conventional gasoline generators used in residential buildings and by Small and Medium Entrepreneurs (SMEs). The inclusion of a direct-coupled flywheel, power torque formula, and temperature monitor and control play an important role in the development of an efficient fuel less generator.

Keywords: fuel-less generator, zero-carbon emission, greenhouse gases, bushed direct current motor.

1. INTRODUCTION

A Fuel Less Generator (FLG) can be defined as a power-generating equipment or system that doesn't require any combustible fuel or fossil fuel for it to operate. That is, there is no carbon emission, and can therefore be regarded as a Green Energy Source. Man's daily activities have now been tied to the availability of electricity, and the increase in population and the rising electricity demand have brought about the development of energy systems that can provide power that meets man's needs. Man's reliance on conventional energy sources has contributed immensely to the emission of greenhouse gases (GHGs) like Carbon dioxide (CO_2) and Carbon Monoxide (CO). The accumulated concentration of these gases has led to the depletion of the earth's ozone[1]. FLGs are renewable and, may be categorized into two types, namely; Static or Non-Rotating Fuel less Generators (SFLGs), and Dynamic or Rotating Fuel less Generators (DFLGs) [2]. SFLGs are energy systems that do not have or require any continuously moving or rotating component to generate power. A good example of SFLG is the Solar Photovoltaic system, which consists of Photovoltaic Panels, Charge Controllers, Batteries, and Power Inverters. While DFLGs are energy systems that rotate or require a continuous motion for generating power. Examples include but are not limited to Dynamos, Self-Induced Fuel less Generators, etc. Today, one of the major challenges affecting the development and productivity of the Nigerian economy is access to clean; reliable, and affordable energy. This also applies to developing nations as well. Small and Medium Enterprises and start-up businesses struggle to grow due to limited access to clean, reliable, and affordable energy. Most individuals rely on conventional energy sources like; Firewood, Crude Oil, and fossil fuel power generators owned by them for their daily activities. And it is for this reason that the United Nations has made it one of its seventeen Sustainable Development Goals (SDG). Also, the recent events of extreme weather and global warming call for concern. According to data from the United Nations SDG 7 which is affordable and Clean Energy; in the year 2018, just before the Corona Virus Pandemic (Covid-19), 789 million people lacked electricity [3]. Also, the issues of noise and Carbon Dioxide Emissions which in the year 2018 rose globally by 1.7% to a historic 33.1GTCO$_2$. While CO2 emissions from the Power sector increased and accounted for almost two-thirds of the emissions growth [4]. In Nigeria, the average indoor power line is 240V at

50Hz [5], hence, fossil fuel sources of energy accounted for 87% of the total electrical power supply in the year 2018[1]. And with the increase in population, comes the rise in demand. Finally, from previously designed and constructed Fuel less Generators (FLGs), the issues of Speed and Voltage Drop (power quality) have been a challenge [6]. Moreover, this research aims to design and construct a 1kVA Fuel less Generator using a Brushed Direct Current Motor (BDC) coupled with an alternator. The specific objectives of this research are to design and construct a fuel less generator using a BDC motor as the prime mover, and to evaluate the performance of the FLG. This technology is very attractive [7]. The justification of this study is very significant. This research is significant to achieving the United Nations Sustainable Development Goal (UN SDGs) 13(Climate Action to Tackle Climate Change) and this is due to the rise in the amount of Green House Gases (GHGs) emissions and depletion of the earth's ozone layer which has led to Global Warming and Climate Change. It is the UN's goal to half the current value of emissions by the year 2050. Furthermore, the development of FLGs can contribute immensely to achieving UN SDG 7 (Access to Affordable and Clean Energy) especially, in the residential and small commercial sectors. Finally, the absence of any known or published research on FLGs where temperature sensors and flywheels are directly coupled with a BDCM and alternator is another rationale behind this study. The significance of this research is worthy of attention because it promotes the development and use of free clean energy. In the process of achieving United Nation SDGs 7 and 13, the issues of a decent workplace free of pollution, making our communities more habitable, and ensuring the sustainability of resources for future generations. Furthermore, this research identified various parameters like torque and temperature which were not initially considered in previous related works and these parameters are vital for future designs of FLGs. Finally, it addresses the issues of Climate Action which is required to curtail the effects of Global Warming and climate change. And this is goal 13 of the United Nations SDG.

2. REVIEW OF RELATED WORKS

In [8], the author compared two fuel less generator prototypes that were already developed to ascertain which of them was more efficient. The difference between the two prototypes was their coupling methods. One used the Direct Coupling Method, while, the other used a V-Belt and Pulley Drive method. The two prototypes were operated and run on different loads ranging from 0W to 500W for the load and no-load test. And, this test was carried out for 300 seconds (5 minutes) for each load. From the results, it was observed that the Direct Coupled prototype was more efficient with an efficiency range of 0 - 89.9%. While the V-Belt Coupled prototype had an efficiency range of 0 - 73.23%. In other words, the direct coupling is best suited for the Fuel less Power Generating Set to mitigate transmission losses. However, the Flywheel Energy Storage System (FESS) wasn't considered for the directly coupled prototype.

Author [8] also developed a 2.5kVA Self-Induced Power Generating Set which was an improved version of his previous work in 2014. This research focused on providing an alternative power-generating set that required low maintenance and is reliable, affordable, and clean. The major components in this design were the Direct Current (DC) Motor, Alternators, 12V 100AH Deep Cycle Lead Acid Battery, and a Transformer. However, unlike his previous design, [8] introduced an Automatic Voltage Regulator (AVR) to compensate for the voltage drops that were experienced in his previous work on Fuel less Power Generating Set. More so, the direct coupling method was used to mechanically connect the alternator to the DC Motor which acted as the prime mover and to avoid losses due to wind age and transmission losses. The Self-Induced Power Generating Set was initialized and operated using the 12V 100AH Deep Cycle Lead Acid Battery. The DC Motor was energized by the Battery and there was a rotatory motion. This also rotated the alternator and electrical power was generated. Short-circuit and no-load tests were carried out with various ranges of loads from 0 - 2000W for 60 seconds (1 minute). It was observed from the results that the Self-Induced Power Generating Set had a maximum efficiency of 100% at a 1200W electrical load. The author recommended that a battery of higher capacity, a new DC Motor, and a new Alternator be used to ensure the output voltage is kept between a range of 200 - 240V and a longer running time. In [9], the author reviewed various applications of the Flywheel Energy Storage System (FESS) which included applications in Electric Machines, Power Electronics, Bearings, Housing, Voltage Sag Control, Uninterrupted Power Supply (UPS), and Transportation. However, the one crucial application of the Fuel less Power Generator system was the Voltage Sag Control Application, which could be referred to as Voltage Drop. They noted that including a FESS in Fuel less Power Generating System will greatly improve the quality of power and frequency regulation which affects sensitive loads but how well does this improve the system? Similarly, [10] used basic calculations to design and determine the energy stored in a Flywheel. He also went further to construct a Free Energy Generating System with a Motor-Generator and Flywheel Energy System (FES). He defined a Flywheel as a simplified mechanical energy storage device that stores energy by rotating a disc to spin about its axis. He also stated that the energy in a flywheel is proportional to its mass (kg), and the square of its rotational speed (m/s). The major components of this design were the; Pulley, Belt Drive, AC Motor, Generator/ Alternator, and Flywheel. The author further mentioned that the major disadvantage of a flywheel is its Explosive Shattering when it is overloaded. Although this disadvantage can be avoided by not exceeding the limit of the flywheel's tensile strength and the material used in manufacturing the flywheel plays a major role in its tensile strength value. Two major materials used are Steel and Carbon Fibre composite. From the work, he observed that the flywheel doubled the alternator output power as a result of its proper sizing. Also, [11] developed a Self-Induced Fuel-Less generator Set to solve the problems of

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ARPN Journal of Engineering and Applied Sciences

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incessant Power outages in Nigeria and mitigate carbon emissions into the atmosphere. Its features included a 1hp 12V DC Motor, 800VA Alternator, 12V 100AH Lead Acid Deep Cycle Battery, Connecting Shaft, Charging Panel (Transformer, Capacitor & Diode), and a Frame. For its initialization and operation, the DC Motor was powered by a single unit of 12V 100AH Lead Acid Deep Cycle Battery which caused the motor to rotate since it was mechanically coupled to the alternator using an elastomeric flexible material. The elastomeric flexible material used by the author reduced the vibration and shock effects between the two machines. However, the author recommended that for further research, a 12V 200AH Deep Cycle Lead Acid Battery be used and it should be ensured that the rate of charge is greater than the rate of discharge for the batteries because the one used in the research didn't charge the battery well. Authors [12] designed and constructed a self-sustaining 1kVA Fuel-Less generator using a 950VA Alternator, directly coupled to a Brushed DC Motor. The authors' design did not take into account the use of a flywheel. However, the fuel-less generator was initialized and run using a 12V 62AH Battery. The other components include a 950VA alternator, a 4A 12V full-wave rectifying or charging circuit, a permanent magnet direct current motor, DC and AC Voltmeter. During the Open Circuit Test (No Load Test) conducted, the output power quality was good but, when varying electrical loads ranging from 100 – 800W were introduced, the quality dropped and the maximum efficiency of 84.94% was reached at 10.5% rated capacity loading. He observed that there was a decrease in the power output of the generator as the loads gradually increased. However, he suggested that for future designs, the number of batteries used should be increased and must be Lead Acid Deep Cycle Batteries. Opeyemi, (2020)also suggested a charge controller be included for regulating the charging current of the battery bank as they are been discharged during the operational time of the generator, instead of the transformer and rectifying diode circuit used. In [14], designed and constructed a 1kW Power Generator that also used the direct coupling method. A Speed Control Panel was introduced into this design to regulate the speed of the DC Motor (Prime Mover) used. He also introduced a charger to charge the battery as the generator ran but it was discovered that when a load of 800W and 100W were connected to the Alternating Current (AC) output of the generator, the speed of the generator became low and high respectively and since the efficiency of the machine was affected by its output, the higher the load, the less efficient the generator became and vice versa. Maintaining constant speed was a major challenge.

3. METHODOLOGY

3.1 Description of Relevant Components

The DC motor will be energized by the Battery through the DC circuit breaker which causes the DC motor to rotate. As the motor gains speed, the alternator turns alongside it, due to the mechanical coupling. During rotation, the alternator magnetic field rotates with respect to the coil and the rotor produces rotating magnetic flux which rotates alongside and induces an AC emf across the armature winding. The rotor coil generates between 0-60V DC which will be sensed by the AVR. The alternator is excited by a DC power source which is provided by an AVR However, the generated AC power passes through a current transformer to collect readings such as terminal voltage, load current, frequency, power factor, power, and energy consumed. As soon as the voltage output stabilizes close to the nominal voltage of 220V, the loads are connected to the AC output socket. More so, the flywheel at the end of the coupling rod will compensate for energy losses and also help improve the frequency and rotational speed in turn. Figure-3.1 shows a block diagram of the FLG starting with a 12V 100AH Battery as the input which is controlled by a 100A Circuit Breaker (CB). The power output required from the alternator was 1kVA as long as the Brushed direct current (BDC) motor is been energized through the 12V/100AH Deep Cycle Battery. More so, standard engineering formulas were used to determine the sizes of some of the major components while other components were chosen from their specification sheets. The type of BDC motor used is a Permanent Magnet (PM) type. This is the most common type of BDC motor. It is used in fractional horsepower applications, for example in Toys, Slot cars Appliances, etc. It is made up of two permanent magnets which produce the magnetic field in the stator, i.e., it has good speed control. However, its only drawback is that these permanent magnets lose their magnetic properties over time. The torque equation of a DC motor is (τ), given by,

$$\tau(\mathrm{Nm}) = \mathrm{Force}(F) \times \mathrm{radius}(r) \tag{3.1}$$

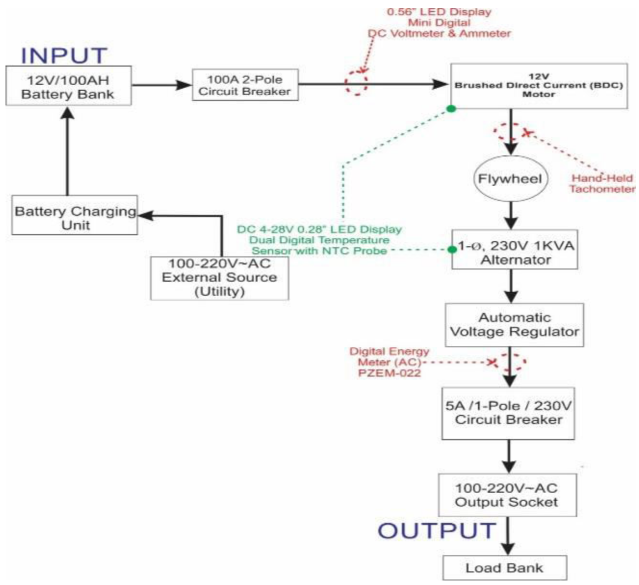

Figure-3.1. Block diagram of developed 1KVA FLG.

Where, τ = Torque (N-m), F = Force (N), R = radius (m). Recall that, Torque is defined as the tendency of a force to move an object about an axis or its axis.

Let Armature Speed be equal to;

$$N(rpm) = \frac{N}{60}(rps) \quad (3.2)$$

Recall, 1 revolution = 2π and 1 minute = 60 seconds. Armature speed during one revolution then gives you your Angular Speed (ω) is given by,

$$\frac{N}{60}(rps) = \frac{N}{60}\left(\frac{2\pi\ radian}{second}\right) = \frac{2\pi r N}{60}\left(\frac{radian}{second}\right) \quad (3.3)$$

Work done in 1 revolution (w.d) is given by multiplying force (F) by distance traveled in 1 revolution (2πr) as shown in Equation 3.4

$$w.d = F \times (2\pi r) \quad (3.4)$$

Recall that Power developed (P) in watts is shown in Equation 3.5 by diving work done (w.d) by time (t).$t = {}^{60}/_{N}$.

$$P = \frac{F \times 2\pi r}{t} \quad (3.5)$$

Using Equation 3.5, the Power Developed (P) in watts during 1 revolution is given by Equation 3.6.

$$P = \frac{F \times 2\pi r}{\frac{60}{N}} = \frac{F 2\pi r N}{60} \quad (3.6)$$

$$P = F \times r \times \frac{2\pi N}{60} = \frac{T_g 2\pi N}{60}(watts) \quad (3.6)$$

Where T_g = Gross Torque developed in the armature. While Angular Velocity (ω)= $\frac{2\pi N}{60}$.

Therefore, Power Developed (P) in watts can also be given as shown in Equation 3.7.

$$P = \tau \times \omega \quad (3.7)$$

The expression of DC Motor Voltage is given by Equation 3.8.

$$V = E_a + I_a R_a \quad (3.8)$$

Where, V = Voltage Supplied to DC motor (V), E_a = Emf induced in the armature (V), I_a = Armature Current (A), R_a = Armature Resistance (Ω). Multiply Equation 3.8 through by I_a to get Equation 3.9.

$$VI_a = E_a I_a + {I_a}^2 R_a \quad (3.9)$$

Where, Electrical Input = VI_a, Electrical Power Equivalent of Mechanical Power = $E_a I_a$, Armature Copper Loss = ${I_a}^2 R_a$. Recall;
Mechanical Power Developed (watts) =

$$E_a I_a \quad (3.10)$$

Equate Equation 3.6 to Equation 3.10 as shown in Equation 3.11,

$$\frac{T_g 2\pi N}{60} = E_a I_a \quad (3.11)$$

Recall, $E_a = \left(\frac{\emptyset ZN}{60} \times \frac{P}{A}\right)$ (3.12)

Where, Ø = Flux (Wb), Z = No of Conductors (turns and always fixed), N = Armature Speed (rps), P = No of Motor Poles also fixed, A = Area, Substitute E_a in Equation 3.12 into Equation 3.11 as shown in Equation 3.13

$$\frac{T_g 2\pi N}{60} = \frac{\emptyset ZNP}{60A} \times I_a \quad (3.13)$$

$$T_g = \frac{1}{2\pi}\emptyset ZNI_a \times \frac{P}{A} = 0.159\emptyset ZNI_a \times \frac{P}{A}(Nm) \quad (3.14)$$

The torque of a DC motor is directly proportional to the flux/pole and armature current. Relating Loss Torque (T_{loss}), Armature Torque (T_a) and Shaft Torque (T_{sh}) = T. Recall Equation 3.14.

$$T_g = \frac{1}{2\pi}\emptyset ZNI_a \times \frac{P}{A} = \frac{E_a I_a}{2\pi\frac{N}{60}}(Nm) \quad (3.15)$$

Therefore, Motor Power Output in watts is given by Equation 3.16.

$$\text{Motor Power Output} = \frac{2\pi N}{60} \times T_{sh} \quad (3.16)$$

$$T_{sh} \text{ or } T = \frac{\text{Motor Output Power}}{2\pi\frac{N}{60}}\ (Nm)$$

Simplify Equation 3.16, Torque (T or T_{sh}) when power is in watts is given by Equation 3.17.

$$= \frac{9.55 \times Motor\ Power\ Output(watts)}{N(rpm)}(Nm) \quad (3.17)$$

Where Constant $9.55 = \frac{60}{2\pi}$ after simplification of Equation 3.16, Torque (T) when power is in kilowatts is given by Equation 3.18

$$= \frac{9550 \times \text{Motor Power Output(kilowatts)}}{N(rpm)}\ (Nm) \quad (3.18)$$

Where Constant $9550 = \frac{60 \times 100}{2\pi}$ after simplification of Equation 3.16.

However, the power of the motor was determined by using a DC Voltmeter and Ammeter to measure the voltage across the motor terminals and the current being drawn by the motor during an open circuit test. The values of this measure were observed and recorded. The recorded values are 12V, 20A, and 2890rpm for Voltage, Current, and Speed respectively. This was used because the nameplate of the DC Motor was missing. Using Equation 3.18 and measure and obtained, the Torque was determined.

$$\therefore \text{ DC Motor } Torque(Nm) = \frac{9550 \times 0.240}{2890} = 0.79Nm$$

The alternator used was recovered from a 1kVA Gasoline Generator purchased from a second-hand dealer, with its Stator and Rotor windings intact and in good condition. The carbon Brushes were also in good condition with the attached Automatic Voltage Regulator Unit. The Rotor or Armature Assembly and Stator assembly are the major components of the alternator that converts the mechanical energy of the DC motor to electrical energy. Alternators are the workhorse of the power generation industry. It generates power at a specified frequency and can also be referred to as Synchronous Machine (generator). It produces AC power through Electromagnetic Induction. The alternator turns alongside the BDCM due to the mechanical coupling. During rotation, the alternator magnetic field rotates with respect to the coil and the rotor produces rotating magnetic flux which rotates alongside and induces an AC emf across the armature winding. The rotor coil is excited by a DC power source which is provided by an AVR. It is important to note that the required speed (synchronous) and rated current of the alternator were derived using given parameters and some standard engineering formulas shown in Equations2.1 and 3.20 Recall Equation 2.1, the Synchronous Speed (N_S) is given by:

$$N_s = \frac{120f}{P}$$

Given; Frequency(f) = 50Hz, No of Poles = 2 poles, Therefore, $N_s = \frac{120\ (50)}{2} = \frac{6000}{2} = 3000rpm$.

Note that rpm means Revolutions per Minute, which is the S.I Unit for Synchronous Speed of a Machine. Secondly, the currents were determined for two different power factors. Recall the Single Phase Power formula as shown in Equation 3.19

Power = Voltage × Current × Power Factor

$$P = VI \cos\theta \tag{3.19}$$

Making the Current in Equation 3.19 as shown in Equation 3.20.

$$\therefore I = \frac{P}{V \cos\theta} \tag{3.20}$$

Where P = Power in Watts (W), V = Supply Voltage (V), I = Current in Amperes (A), Cos θ = Power Factor. Given the following Alternator Parameters; P = 1000W, V = 230V.

At 0.8pf, input values in equation 4.

$$\therefore\ I = \frac{1000}{230 \times 0.8} = \frac{1000}{184} = 5.4A$$

At 1pf, input values in equation 4 again.

$$\therefore\ I = \frac{1000}{230 \times 1} = \frac{1000}{230} = 4.4A$$

The alternator recovered from the salvaged generator had an AVR in its housing unit with a carbon brush compartment. The AVR is required for voltage or power stability during generation. It controls and maintains the output terminal voltage of a generator or alternator within a set value. Whenever the load connected to the alternator or generator increases, the speed of the alternator also decreases. The speed of an alternator is directly proportional to the frequency which will cause a decrease in output terminal voltage. More so, as soon as the output terminal voltage decreases below the set value, the AVR will increase the rotor field current (I_f) to adjust the output terminal voltage back to its set value. The output terminal voltage of the alternator is high above the set value, the AVR reduces the rotor field current (I_f) to reduce the output terminal voltage back to its set value. In summary, the AVR senses the output voltage, compares it with the set value, and adjusts the output voltage to keep it within a set value. A flywheel is a mechanical energy storage device that stores energy as it rotates at a specified speed due to its structural design and construction material. A flywheel could be made from two common materials; Cast Iron and Fibre. However, it is always advisable and safe not to overload a flywheel to avoid an explosion of the flywheel. A flywheel is necessary for this design because it helps with Voltage Sag Control which is a decrease in the output terminal voltage of an alternator or generator under load. The Voltage Sag problem is caused by voltage drop. Using the flywheel parameters, the energy capacity of the flywheel was mathematically determined using the Kinetic Energy formula in Equation 3.21.

$$E = \frac{mv^2}{2} \tag{3.21}$$

Where; E = Energy Stored in flywheel (J), m = Mass of Flywheel (kg), v = Linear Velocity of Flywheel (m/s). However, the linear velocity (v) measured in meters per second is given by Equation 3.22.

$$v = \frac{\pi DN}{60} = r\omega \tag{3.22}$$

Where; D = Diameter of Flywheel (m), N = Flywheel Speed (rpm), π = 3.142, r = Radius of Flywheel (m), ω = Angular Velocity of Flywheel (rad/s), v = Linear Velocity (m/s). The Angular Velocity is given by equation 3.23;

$$\omega = \frac{2\pi N}{60} = \left(\frac{rad}{s}\right) \tag{3.23}$$

From Table 3.4, D = 0.15m, N = 3000RPM, m = 1.508Kg and π = 3.142. To determine the Energy stored by the flywheel with parameters in Table 3.4, we must first determine Linear Velocity (v). Therefore, recall equation 3.22;

$$v = \frac{\pi DN}{60} = \frac{\pi \times 0.15 \times 3000}{60} = \frac{\pi 450}{60} = 23.56\, m/s$$

Recall Equation 3.21 since linear velocity (v) has been determined. Therefore, Energy Stored in Flywheel is given as;

$$E = \frac{mv^2}{2} = \frac{1.508 \times 23.56^2}{2} = \frac{837.05}{2} = 418.53\, J$$

3.2 Constructional Procedure

The FLG power rating played a vital role in sizing and selecting the components. More so, due to economic reasons as regards the DC motor, a Permanent Magnet BDC Motor was used. The FLG components are wired as shown in Figure 3.20 with all its measurements and controls. The battery charger was connected to an external AC source to ascertain its maximum charging or rectifying capacity.

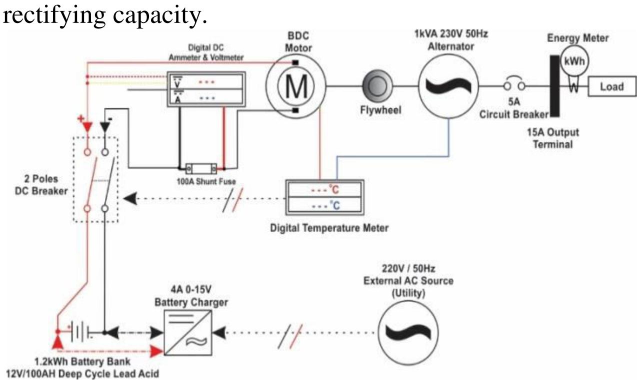

Figure-3.2. Wiring diagram of the FLG with associated components.

An Open Circuit Test (No-Load Test) was conducted to determine the speed and torque of the BDCM since it didn't have a nameplate to display torque specifications from the manufacturer. The Chassis for the FLG was fabricated with 19 – 20 mm diameter steel pipes and Angle Irons. The FLG chassis comprises two parts chassis; the modified 1kVA gasoline generator chassis which is the first part and, it houses the Alternator, Crankshaft Housing, Flywheel, Control Board, and Crankshaft. While the second chassis houses the BDC Motor and Coupling Shaft. The chassis was measured using a Vernier caliper, and a measuring tape and drawn using the CAD software SOLIDWORKS 2019. The chassis was fabricated using a round 19mm diameter pipe, with less than 2mm^2 Thickness Density. Figure-3.24 shows the picture of the recovered chassis. This frame served as the sitting base for the 1kW Alternator, Crankshaft, and flywheel. An isometric projection and real-time picture of the chassis are shown in Figure-3.21. Figure-b shows a detailed dimension used in the fabrication of Figure 3.21.

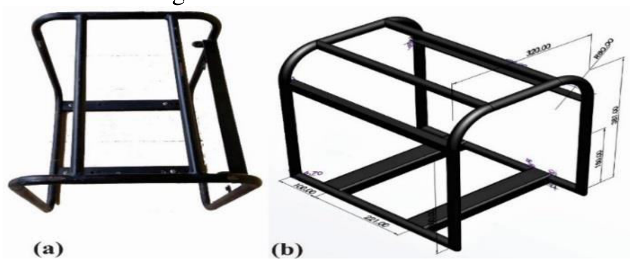

Figure-3.21. Recovered 1KVA gasoline generator chassis real frame.

From designs done using SolidWorks, the finished FLG Chassis looked like the image in Figure-3.23. The same SolidWorks 2019 was also used to design the structure for the BLDCM Chassis before construction. Figure-3.22 shows an isometric projection of the design and the finished chassis after construction.

Figure-3.22. BLDC motor chassis.

Its main surrounding frame was constructed using circular 19mm Iron Pipes while the reinforcing and BLDC Motor sitting base was constructed using Angle Iron to form weldments on the surrounding frame of the chassis.

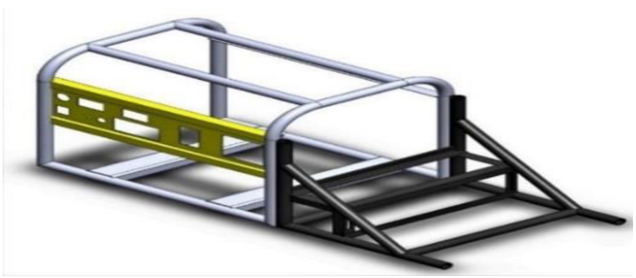

Figure-3.23. Complete designed FLG chassis using solid work software.

3.3 Design and Construction of FLG Control Panel

The FLG control panel or dashboard consists of a piece of iron sheet folded to fit in the FLG chassis. This Iron sheet as seen in Figure-3.24 houses all the control, and Instrumentation components which includes the Digital Voltmeter, Digital Ammeter, Energy Meter, Digital temperature meter, Ignition Key, Indicator lamp, Circuit Breaker, and AC socket Outlet. Meanwhile, the following steps were taken to construct the control panel; firstly, the dimensions of each display and control device like the switches, circuit breakers, and speed regulator

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were measured and marked on the sheet. After carefully executing the first step, a drilling machine, angle cutting machine, a file, chisel, Hammer, and jigsaw were used to make cut-outs on the sheet to fit the displays and control devices as shown in Figure-3.25 with cut-out positions.

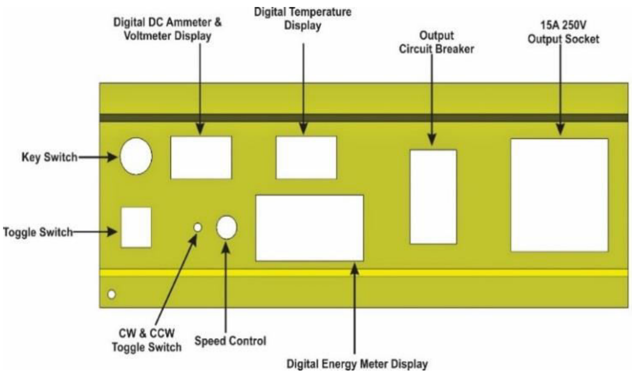

Figure-3.24. Cut-out locations of instrumentation and control components for the FLG control panel.

Figure-3.25. FLG control panel showing mark outs and cut-outs.

The finished control panel is shown in Figure-3.26, with all displays and control devices fixed.

Figure-3.26. Completed FLG control panel.

3.4 Assembling the FLG

In assembling the FLG, the alternator and Crankshaft housing needed to be coupled first. Figure-3.27 shows the parts of the FLG which were assembled.

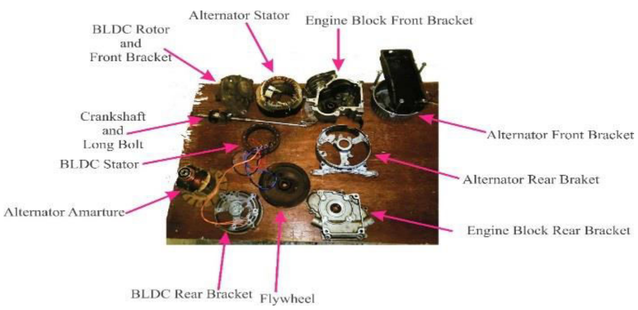

Figure-3.27. Part of the FLG displayed in the table.

The engine block which houses the crankshaft was put together. It is comprised of two bearings (one on the crankshaft and the other on the front bracket of the engine block) as shown in Figure-3.28.

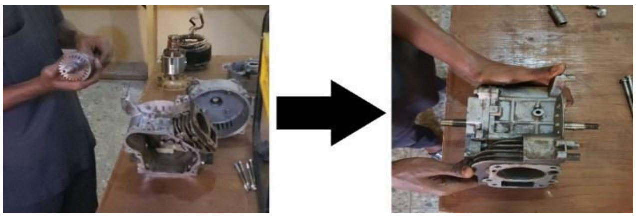

Figure-3.28. Assembling the crankshaft housing /engine block.

After executing the above step, the alternator front bracket was coupled to the crankshaft housing using four provided bolts to hold them together as shown in Figure-3.28. Then, the Armature of the alternator was positioned and centralized at the rear end of the crankshaft using the provided long bolt in Figure-3.27. The positioning of the armature is shown in Figure 3.29.

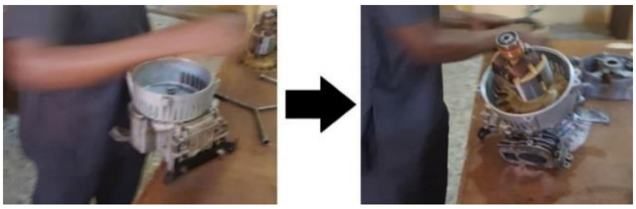

Figure-3.29. Positioning of the front bracket and armature.

Figure-3.30 shows how the alternator stator was placed; resting on the inner circumference of the alternator front bracket, ensuring an equal air gap between the armature and stator.

Figure-3.30. Placing the alternator stator on the front bracket.

The AVR and carbon brush were fixed and connected to the stator terminals with the power output terminals projected out of the alternator rear frame as shown in Figure 3.31.

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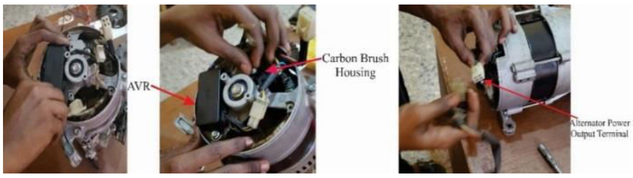

Figure-3.31. Mounting of the AVR and brush assembly.

The alternator and crankshaft assembly were then lifted by hand and positioned on the dampers provided with the FLG frame/chassis as shown in Figure-3.32.

Figure-3.32. Positioning the alternator and crankshaft housing onto the FLG chassis.

After successfully mounting the alternator and crankshaft housing, the BDC motor was the next to be mounted as it is the prime mover of the FLG and will require some technicalities as regards balance and alignment. The BDC motor was then placed with its rotor shaft carefully inserted into the groove of the coupling shaft as shown in Figure 3.33. After which, proper alignment was ensured.

Figure-3.33. The BDC motor was then placed with its rotor shaft.

The BDC motor was then held in place by hand. Meanwhile, the BDC motor was adjusted and positioned properly before securing to its chassis with two bolts, two nuts, and four washers as shown in Figure-3.33.

Finally, Figure-3.34 shows the control panel mounted. Also, the control and instrumentation devices were connected as shown in Figure-3.2.

Figure-3.34. Control panel mounted on the FLG chassis.

Figure-3.35 shows the final look of the generator after it was completely assembled.

Figure-3.35. Final look of the FLG.

3.5 FLG Test

There were various tests carried out to evaluate the performance of the constructed 1kVA FLG. The preceding subsection lists the types of tests carried out on the FLG and its components. The following tests were carried out on the FLG in the laboratory, and they include; instrumentation test, No-Load or open circuit test, short circuit test, temperature test, and speed test. The instrumentation and measurement test were conducted to ensure the measuring instruments like the energy meter, DC Voltmeter, Dc Ammeter, Digital Thermometer, and sensor were working before assembling or connecting to the FLG. Similarly, the No-Load or Open circuit test was carried out by running the FLG without loading with any external load to determine its standby load this test can also be used to determine the iron losses in the system for further studies. Short Circuit Test involved running the FLG on varying loads ranging from 100W to 1000W. This was important as it helped in determining the FLG system efficiency and also determines at what load rating the FLG performs best. Results are shown in Table-4.2. A temperature test was carried out using a Digital thermometer with NTC Sensors. It was paramount to monitor the temperature change in the FLG main Components. Results are shown in Table-4.3. In addition, a speed test was carried out. This test is required to relate speed and frequency to the generator output. The standard speed for generating power at 50Hz is 3000rpm. Results are shown in Table-4.4. Finally, the battery charger was tested with an external AC source to determine its charging current and voltage. Results are displayed in Table-4.5.

4. RESULT AND DISCUSSIONS

This section report and discusses the results obtained from the various test conducted after the development of the FLG. Different loads were used to assess the performance of the FLG taking into account the effects of load on its speed and temperature. The whole test lasted a total of 30 minutes excluding the time taken for the BDCM to cool. Tables 4.1, 4.2, 4.3, 4.4, and 4.5 shows the result obtained from the various tests. The whole tests were conducted at once but for clarity purposes, were separated into the various listed tests.

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4.1 No-Load Test and Load Test

A No-Load test was conducted on the BDC motor and its results are shown in Table 4.1. The FLG after assembling was tested and Table 4.2 gives the result in detail. The no-load test carried out on the FLG lasted for 3 minutes: 30 seconds. However, the Load Test for the FLG was conducted alongside the No-Load test with a total of nine trials, all lasting not more than 3 minutes 30 seconds and the results are can be seen in Table 4.2. These readings were obtained from the DC Ammeter, DC Voltmeter, and AC Energy Meter.

Table-4.1. BDC motor no-load test result.

Voltage across terminals	**12Vdc**
Refresh rate	20A
Tachometer speed reading	2890RPM

Table-4.2. FLG No-load and load test result.

Trial	**Load (W)**	**Input (Dc)**			**Output (Ac)**			**Efficiency** $(\frac{Output}{Input} \times 100\%)$
		Voltage (V)	Current (A)	Power (W)	Voltage (V)	Current (A)	Power (W)	
0	0	11.40	30.40	346.56	233	0.00	0.00	0.00
1	100	11.30	65.10	735.63	154	0.32	197.74	26.88
2	200	11.00	62.10	683.10	150	0.64	385.20	56.39
3	300	10.90	60.20	656.18	146	1.28	582.10	88.71
4	400	10.50	63.10	662.55	136	2.57	562.50	84.90
5	500	10.10	69.50	701.95	127	3.99	506.35	72.13
6	600	9.90	70.20	694.98	120	4.14	496.32	71.42
7	700	9.50	72.20	685.90	109	4.80	523.31	76.30
8	800	9.20	74.50	685.40	102	5.27	537.74	78.46

Table-4.3. BDC motor and 1KVA alternator temperature result.

TRIAL	**LOAD (W)**	**BDC MOTOR TEMPERATURE**		**ALTERNATOR TEMPERATURE**	
		Initial (^{0}C)	**Final (^{0}C)**	**Initial (^{0}C)**	**Final (^{0}C)**
0	0	28.30	36.20	28.30	28.80
1	100	32.00	40.30	28.80	30.60
2	200	40.30	44.30	30.60	32.60
3	300	44.10	49.50	31.50	34.00
4	400	49.00	53.10	32.60	35.80
5	500	52.50	57.80	34.00	37.20
6	600	55.80	59.20	35.40	39.00
7	700	58.70	63.80	35.10	45.30
8	800	60.00	67.60	40.80	49.20

4.2 Temperature Test

The Digital Temperature meter and NTC Sensor were used to get the readings on the temperature of the BDC motor and 1kVA Alternator. The temperature period was also 3 minutes; 30 seconds for each trial. The temperature rises are seen in Table-4.3.

4.3 Speed Test

The speed of the BDC motor (FLG) was noted throughout the test. Table 4.4 shows the results as observed on the Tachometer and the Output frequency was observed on the Energy Meter.

Table-4.4. Speed test result.

TRIAL	LOAD (W)	SPEED (RPM)	FREQUENCY (Hz)
0	0	2211	40
1	100	1760	37
2	200	1485	29
3	300	1516	30
4	400	1317	34
5	500	1216	28
6	600	1026	26
7	700	1011	24
8	800	1001	21

4.4 Battery Charge Test Result

The battery charger was tested and a Digital Multimeter was used to obtain the value of the charging current and voltage when it was powered by an external AC power source. A 12V battery that was drained to 9V was used to test the charging rate and the results are shown in Table-4.5.

Table-4.5. Battery charging result.

Battery Used	Brand Name	CHITEX
	Model Number	6-FM-18
	Battery Technology	Valve Regulated Lead-Acid (VRLA)
	Rated Output	12V 18AH
	Standby Use	13.5 – 13.8V
	Cycle Use	14.7 – 15.0V
	Initial Current	Less than 2.1A
	Constant Voltage Charge @ 25^{o}C	
Battery Voltage Before Charging	9Vdc	
Charger Input Voltage	220V~	
Charging Voltage	15V	
Max Charging Current Observed	3.02	
Duration of Charging	12minutes;18seconds	
Battery Voltage After Charging	13.15Vdc	

4.5 Graph and Analysis

Various parameters and values were obtained from the results in Table-4.1 and a graph was plotted using these parameters. Figure-4.4 shows that on the FLG input side which is a DC input, there was a gradual drop in voltage as the current and load increased. This could be a result of the electrical loads introduced into the system.

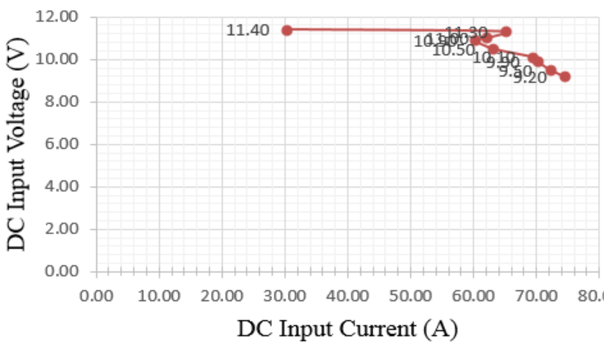

Figure-4.4. FLG input voltage against current.

Figures 4.5 and 4.6 show a gradual drop in FLG output voltage which is an alternating current. The current increases as the load demand increases; therefore, the

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voltage drop is a result of the increase in load demand. This trend is also seen in Figure-4.6.

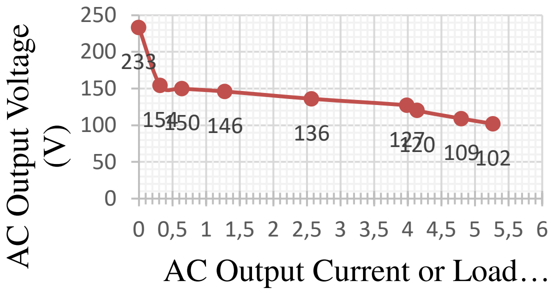

Figure-4.5. FLG output voltage against current.

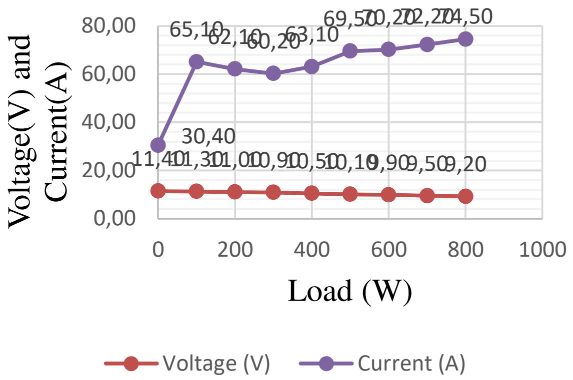

Figure-4.6. FLG input voltage and power against load.

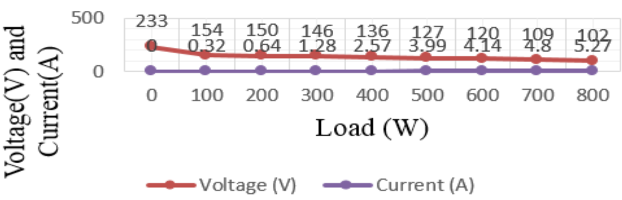

Figure-4.7. FLG AC output voltage and current against time.

Figure-4.8 shows the graph plotted between the FLG Efficiency and Load. It shows that there was maximum efficiency of 88.71% was reached when the FLG load was 300W and the FLG Input power of 656.18W.

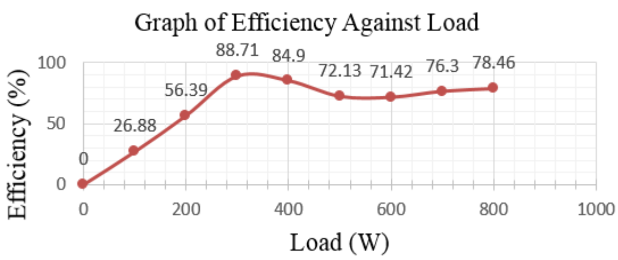

Figure-4.8. Graph of efficiency against load.

Figure-4.9 shows the gradual rise in temperature for the alternator and a steady and significant rise in BDC motor temperature. The rise in the BDC motor temperature is a result of the added electrical loads in combination with the mechanical loads which include the weights of the flywheel, crankshaft, and alternator armature in the FLG system. This means more work is been done by the BDCM.

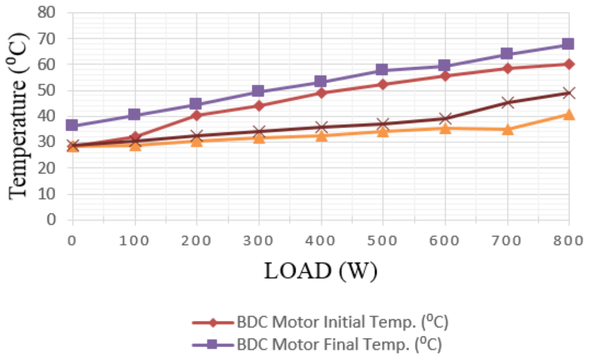

Figure-4.9. Graph of FLG temperature against load.

Figures 4.10 and 4.11 show the relationship between the frequency, Speed, and Load. That is the frequency is directly proportional to speed. And the speed is inversely proportional to the load. But for a normal 50Hz generator, the speed is to be kept constant at 3000rpm for optimal power output. Furthermore, recall that the mechanical loads: Crankshaft, Flywheel, and Armature or Rotor Assembly; weigh a total of 5.64kg. And this will have effects on the Torque and Speed of the BDC Motor.

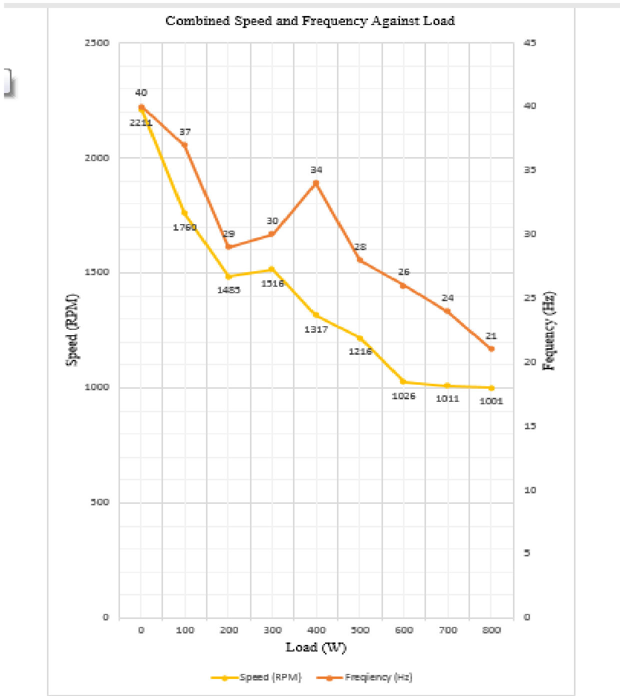

Figure-4.11. Graph of frequency against speed.

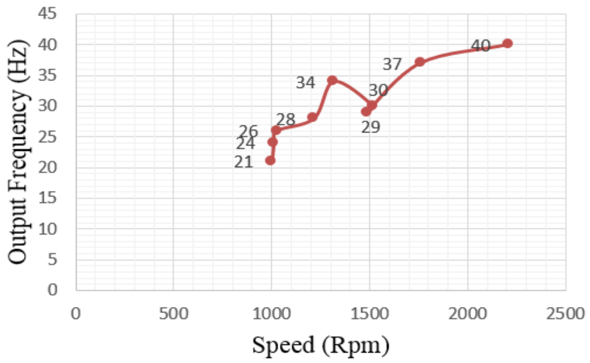

Figure-4.10. Combine speed and frequency against load.

5. CONCLUSIONS

This research features an FLG that is driven by a 100AH 12V Deep Cycle Battery through a BDCM. At the end of the design, construction, and performance evaluation of the 1kVA FLG. It can be deduced that the generator had the highest efficiency of 88.71% at a 300W load and the lowest at a 100W load with 26.88% as shown in Figure 4.8. It was also observed that when the FLG was run on no-load with the flywheel in place, its frequency was between 31-37Hz but, when the flywheel was removed, its maximum frequency reached was 25Hz. This means the flywheel improved the speed of the FLG. After proper observation and repeated tests, it was discovered that the torque of the BDC motor and constant speed played a vital role in the power generation of the 1kVA FLG. It is less noisy when compared to the conventional generator and has zero carbon emissions. This supports the United Nations Sustainable Development Goal 13 which is taking urgent actions to combat climate change and its impacts. Its ability to power small loads makes it a good contribution to achieving the United Nations Sustainable Development Goal 7 which is to ensure access to affordable, reliable, sustainable, and clean energy for all. It can be deduced that having a recline cycle of power generation and use all at once is feasible if various parameters and conditions are taken into consideration. For example, Temperature Requirement, Speed Requirement, Torque Requirement Input, and Output Power.

6. LIMITATION

During the performance evaluation, the planned duration for each trial was 5 minutes 30 seconds, but when a sharp increase in temperature was noticed, it was reduced to 3 minutes 30 seconds. A 1-minute to 5 minutes cooling time was observed between tests. The DC motor was discovered to consume more energy as its temperature rose and the electrical load increased. This means some of the input energy was lost in form of heat. Furthermore, there was a limitation with speed control as the BDC motor didn't have any form or speed control that would have allowed adjusting speed as the electrical load increased. More so, when the battery charger was connected to an external power source and then the battery it was observed as the motor ran; that, the rectifying or charging circuit current jumped to its maximum. This means the BDC motor was also drawing power from the terminals of the battery charger.

7. CONTRIBUTION TO KNOWLEDGE

This research focused on providing a carbon-zero energy source technology that will serve as a prototype for the design and construction of an efficient and cost-effective FLG by introducing flywheels into directly coupled FLG units. The effects of the flywheel in DFLGs were validated and confirms a flywheel as an ESS. Furthermore, the importance and determination of required torque play a major role in selecting a DC motor and this was discovered and addressed in this research. This research also provided a guide to designing new FLGs or retrofitting existing conventional gasoline generators and converting them to FLGs. Finally, the need for cooling technologies especially for the DC motor was discovered in the course of this research. The rise in temperature as the electrical load increased has proven that the operational time of the FLG can be extended by addressing issues of temperature change.

8. RECOMMENDATION AND FUTURE WORK

This research involved a typical unit 1kVA FLG Unit powered by a 100AH 12V Deep Cycle Battery which was connected to an externally powered 15V 4A Battery Charger. However, the following are recommendations for further work: The use of Brushed or Brushless Direct Current motors with constant speed and high torque will improve FLG output and efficiency. The use of DC Motors with good energy-saving features will also be good to produce more output from less input. Efficient Cooling technologies will have to be considered for the FLG system, especially for DC Motors. Finally, the construction of a Super Battery Charger and Rectifying circuit. This should allow a range of 0-100Vdc and 100A of current.

ACKNOWLEDGEMENT

The authors acknowledged Afe Babalola University for the financial support offered for the publication of this research.

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