

Design, Fabrication, And Performance Evaluation of a Flywheel– Alternator-Based Power Generation System

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ABSTRACT: The system was designed to optimize power output, efficiency, and stability under different load conditions. After testing, the generator achieved a peak output of 240V at a flywheel speed of 2000 RPM which is the energy conversion reached high efficiency ratings, demonstrating the system's viability for efficient power generation. This project work however, presents an overview of the applications of flywheel energy storage system (FESS) in power system and also analyses the design parameters in order to improve the energy density of the fuel-less generator. By converting mechanical energy stored in a flywheel into electrical power, the system eliminates the need for traditional fossil fuels, providing a sustainable alternative for power generation. The system was designed to optimize power output, efficiency, and stability under different load conditions. At the end of the project work, it was discovered that the flywheel energy storage system (the fuel-less generator), possessed a great power density (983.4kw/kg), capable of producing 3.5kw of electricity supply, although its energy density intensity (3.71kwh/kg) remains minimal, it however cripples its sustainability. The machine was also found out to be 75.9% efficient. From the research and results, certain parameters such as increasing the flywheel's energy density have been discovered to enhance the machine's sustainability. Despite these challenges, the 5 kVA fuel-less generator offers a promising solution for reliable, off-grid power generation, particularly in settings with limited access to fuel or a need for environmentally sustainable alternatives

KEYWORDS: flywheel energy storage system, fuel-less generator, off-grid power generation, Alternator Efficiency, Kinetic Energy of Flywheel.

1. INTRODUCTION

The rising global energy demand and concerns over climate change have necessitated the development of alternative power generation methods that do not rely on fossil fuels. The environmental and economic drawbacks of conventional generators, which primarily rely on petrol or diesel, are well-documented. These systems are not only costly to operate due to fluctuating fuel prices, but they also contribute significantly to greenhouse gas emissions and environmental degradation (Amiryar et al., 2017). As a result, researchers and engineers are exploring sustainable energy solutions that can provide reliable power without the need for fuel, one of which is the fuel-less generator. Fuel-less generators, specifically those that utilize mechanical energy storage in flywheels, have emerged as a promising technology due to their ability to provide continuous power without the use of traditional fuel sources (Arani et al., 2017). This technology is particularly relevant for areas where fuel access is limited or where the environmental impacts of fossil fuels are a concern (Mousavi et al., 2017). In contrast to solar and wind energy systems, which are intermittent and weather-dependent, fuel-less generators offer consistent energy output, making them suitable for critical applications such as powering university campuses, hospitals, and industrial

facilities (Li & Palazzolo, 2022). Flywheels have been used for centuries in energy storage applications, but recent advancements in materials science and engineering have dramatically improved their performance. Modern flywheels, constructed from advanced materials like carbon fiber composites, can store significantly more kinetic energy while reducing energy losses due to friction (Dongxu et al., 2023). When coupled with a high efficiency alternator, the stored kinetic energy in the flywheel can be converted into electrical energy, providing a fuel-less and sustainable power generation system (Barelli, et al., 2019). Since power has been defined by Choudhury (2021) as the rate of doing work; this simply means that the productivity of a country will largely depend on the availability of power from different source. The majority of problems of Nigeria are traceable to the erratic power supply nature of the country, where many activities has been paralyzed due to the power outage (Conteh & Nsofor 2016). Analysis has clearly shown that Nigeria lose up to about ₦220 billion annually, due to unstable nature of the country power supply which has posed a threat, hence reducing the capacity of industries to increase productivity (Shen et al., 2019; Ayodele et al., 2020). Fuel-less generator are used to operate electrical equipment from the power produced by a car or boat battery or renewable

energy sources, like solar panels or wind turbines. DC power is what batteries store, while AC power is what most electrical appliances need to run, so generator is necessary to convert the power into a usable form. Therefore, the goal of this study is to design and develop a flywheel fuel-less generator that operates using a flywheel and alternator system based on the dynamo principle.

2. MATERIAL AND METHODS



1: The Fuel-less generator using flywheel

- a) **Flywheel:** the flywheel was the component with the most weight available on the generator. At 37kg, it is constructed from cast steel chosen for its strength-to-weight ratio, which enhances the flywheel's energy storage capacity. The flywheel is designed with a high moment of inertia to store substantial amounts of kinetic energy.
- b) **Alternator:** The alternator used in this system is a custom-built three-phase alternator, optimized for low-speed energy conversion. The alternator is equipped with strong neodymium magnets to enhance the magnetic flux and improve energy conversion efficiency. At 2800RPM it can yield 230-240V. However, it can generate power at 1500RPM from the flywheel but due to energy lost in the system it won't be optimum for operation.
- c) **Bearings and Shaft:** Low-friction bearings are selected to minimize energy losses due to mechanical friction. The flywheel is mounted on a stainless-steel shaft to ensure durability and minimal wear over time.
- d) **Battery System:** A 75Ah 12V Bosch battery is integrated into the system to store electrical energy

2.1 Materials Selections

Selecting the right components is crucial for optimizing the performance of the fuel-less generator. Each component is chosen based on its compatibility with the overall system design, its ability to operate under specific conditions, and its contribution to system efficiency.

Thereafter, the system using flywheel consist majorly of five units; the power supply unit, the generating unit, the power supply unit, and the frame/ transmission unit as shown in

generated by the alternator. This ensures that the system can provide consistent power, even when the flywheel's rotational speed fluctuates. The battery is also utilized to kick start the flywheel during inactivity, it is trickle charged by a motor that is connected to the flywheel through a A38 belt which leads to a cyclor operation.

- e) **DC/AC Motors:** There will be an implementation of two motors in the system, one AC and DC motor. The function of these motors is to work hand in hand to drive the flywheel. As the flywheel is driven by the DC motor it powers the AC motor which assists it to drive the flywheel, improving it efficiency

The AC generator

The choice of selection of an alternator depends on the capacity required by the intended user. According to Wang et al. (2017), an alternator required for used in a fuel-less generator should be 20% higher than the intended load capacity. The generator was also selected based on availability. Therefore, the generator for the project was obtained from a 3.5Kw petrol generating set that was abandoned due to bad combustion unit as shown in Figure 2



Figure 2: An AC generator (Tsao et al., 2003)

1.1.1 The AC motor

The main criterion for the selection of the AC motor is the efficiency of energy transfer from the power supply unit to the alternator. It is known that AC motors are designed to give maximum efficiency at, or near the rated load (Eltaweel & Herfatmanesh 2024). Another consideration was the speed of the AC motor. It is well known that the frequency of the generated voltage in an alternator is given by:

$$f = \frac{p}{2} \times \frac{n}{60} \quad (1)$$

Where P is the number of poles of the generator, and n is the rotor speed in rpm. For the same reason, a constant speed motor was desired so that from no load to full load, the same frequency of generated voltage would be obtained. Thus, for a 50Hz generated voltage using a two pole generator, the specification of the motor selected for this study is a 3HP electric motor with a maximum operational speed of 2060 rpm, as shown in Figure 3



Figure 3: An AC motor (Tsao et al., 2003)

The flywheel

It is known that kinetic energy of a moving particle is affected by its mass, as shown in the equation below;

$$E = \frac{1}{2}mv^2 \quad (2)$$

However, the kinetic energy developed by a flywheel is given by:

$$K.E = \frac{1}{2} \times I \times \omega \quad (3)$$

Where; I = moment of inertia

ω = angular velocity of the flywheel

Hence, if a flywheel of a greater mass that the frame can withstand is used, the kinetic energy it produces increases which in turn rotates the generator to produce a great electrical output. Also, a flywheel with mass concentrated at the rim enhances the system's efficiency. Hence, a flywheel of mass 60kg concentrated at the rim was used for the project. However, the 60kg flywheel is shown in Figure 4



Figure 4: The 60kg flywheel

The cable, bearing and Allen key

Various lengths of insulated wires for carrying current to power household electrical appliances were used for the design, and ball bearings were utilized to reduce rubbing or sliding friction. An element having rotational symmetry is interposed between the two moving surfaces that roll over each other for easy movement. The selected bearing made of mild steel is chosen so as to resist wear due to abrasion.

Belt selection

There are lots of factors to be considered when selecting the type of belt to be used;

- The speed of the driving or driven pulley
- The power to be transmitted
- The center distance between pulleys
- Speed ratio
- Service condition

Considering the above factors, V-belt was considered for the design as shown in Figure 5

According to Wang, et al. (2017), in analyzing, the following design equations are used to generate the parameters needed for the belt design;

Length of the belts:

$$L = \frac{\pi}{2} (D + d) + 2C + \frac{(D-d)^2}{4C} \quad (4)$$

Belt Center Distance:

The belt center distance is however given by;

$$C = 2 \times \sqrt{(D + d) \times d} \quad (5)$$

Where L = length of the belt

D= diameter of big pulley

d = diameter of small pulley

C = center to center distance

Angle of lap (arc of contact);

Belt speed:

The belt speed is however given by;

$$V = \frac{\pi DN}{60} \quad (6)$$

Belt tension:

When a belt is fitted around pulleys, it is given an initial tension which only exists while the system is at rest. Since the belt continuously runs over the pulleys, some centrifugal force is caused whose effect is to increase the tension on both the tight as well as the slack sides. The belt tension can be obtained from the following relationship;

$$P = (T_1 - T_2)v \quad (7)$$

Where: P = power of motor

T₁ = Tension on the tight side (resisting side)

T₂ = Tension on the slack side (pulling side)

v = Velocity of the belt

Bearing selection

Though, the required bearing for greater efficiency for the fuel-less generator is magnetic bearing, but because of its high cost and less availability, mechanical bearing was selected for the project. However, Bearing dimensions have been standardized on an international basis. The dimensions are a function of the bearing bore and the series of bearing: Extra light (100); Light (200); Medium (300); Heavy (400). In order to select the correct bearing for the design, the basic dynamic radial load was calculated, multiply by the service factor. The bearing is then selected from the basic static and dynamic capacity table (Wang et al., 2017). The mathematical relationship for the bearing selection is presented below:

$$\text{Service life; } L_H = \text{years} \times 1\text{day} \times \text{hrs/day} \quad (3.10)$$

The roller bearing was chosen and is shown in Figure 3.8.



Figure 5: The roller bearing

Frame design

Choosing frame material: One of the key elements of the design process of objects under cyclical changing loading is the knowledge of service load history. It is especially important in the case of the fuel-less generator in which components are under threat of fatigue damage formation because of the diversified influence of many factors of deterministic and random nature. Therefore, *steel* was used

for the frame because they can be inexpensively repaired and have the ability to reveal frame stress injuries before they become failures.

Frame dimensions: Figure 6 shows the dimensions of the various sections that make up the frame. The frame is used to support the various loads that are mounted on it. All the dimensions are however given in millimeter (mm).

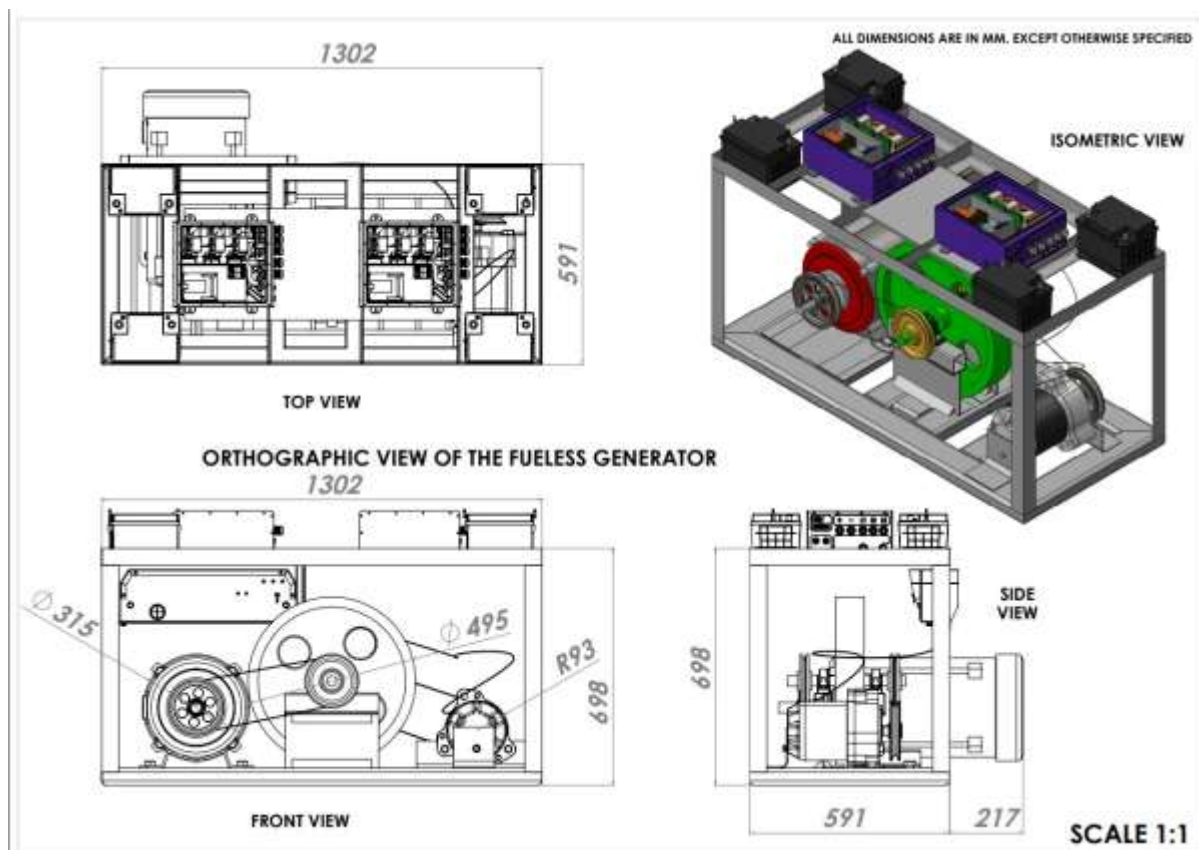


Figure 6: Dimensions of the frame

3.2 Assembly of the Components

After finalizing the design and selecting the appropriate components, the next step was to develop a working prototype of the fuel-less generator. The development process involved assembling the components according to the system design, ensuring that each part was correctly aligned to

maximize efficiency.

- a) **Flywheel Installation:** The flywheel was mounted on the stainless-steel shaft, which was supported by low-friction bearings to ensure smooth rotation. The flywheel's position was adjusted to minimize energy losses due to misalignment.



Figure 7: Fabrication of the 5 KVA Fuel

- b) **Alternator Integration:** The alternator was coupled with the flywheel via a belt and pulley system. This setup allowed the rotational energy from the flywheel to drive the alternator's rotor, generating electrical power.
- c) **Control System Configuration:** Sensors were installed to monitor the rotational speed of the flywheel and the power output from the alternator. These sensors were connected to the control system, which managed the generator's operation to ensure consistent performance.
- d) **Integration of battery and Motors:** The battery was mounted on the chassis of the generator where it was

integrated with the motors and the rest of the generator. We had to make sure the battery and motor were compatible for the system so not to experience return in electricity back to the generator.

3.0 RESULTS AND DISCUSSION

3.1 Input Parameters

The input parameters as shown in Table 1, represent the known values from which the general design was based upon. It includes the operational speed of the flywheel and generator to produce the required voltage which were obtained from the specification of the DC motor purchased.

Table 1: input parameters for the analysis

S/N	PARAMETER	VALUE	SYMBOL	UNIT
1.	Generator power rating	3.5	P_A	KW
2.	Motor power rating	3	P_B	HP
3.	Rotational speed of generator	1500	ω_A	r/min
4.	Rotational speed of motor	2060	ω_B	r/min
5.	Diameter of small pulley of first belt drive	200	D_1	mm

6.	Diameter of large pulley of first belt drive	300	D_2	mm
7.	Diameter of small pulley of second belt drive	200	D_3	mm
8.	Diameter of large pulley of second belt drive	300	D_4	mm
9.	Distance between centres of each pulleys	650	x	mm
10.	Mass of flywheel	50	m	kg

3.2 Output Parameters

Table 2 shows the results obtained from the evaluation of the models in chapter three. It shows the summary of the output

data of the analysis of the system which include the selection of the flywheel and belt drive of the system, sizing of the pulleys etc.

Table 2: output parameters for the analysis

S/N	PARAMETER	VALUE	SYMBOL	UNIT
1.	Input force of the flywheel	1.17	F_F	KN
2.	Input torque of the flywheel	0.29	T_F	KN.m
3.	Flywheel input rotational speed	960	N_{Fi}	r/min
4.	Flywheel output rotational speed	1650	N_{Fo}	r/min
5.	Speed of small pulley of the first open belt drive	1440	N_1	r/min
6.	Speed of the large pulley of the first open belt drive	960	N_2	r/min
7.	drive	960	N_3	r/min
8.	Speed of the small pulley of the second open belt drive	1650	N_4	r/min
9.	belt drive	0.67	V_{R1}	-
10.	Speed of the large pulley of the second open belt drive	1.72	V_{R2}	-
11.	belt drive	1.39	V_R	-
12.	First stage velocity ratio	1990	L	mm
13.	Second stage velocity ratio	3.5	P_M	KW
14.	Overall velocity ratio	2.16	P_G	KW
15.	Length of open belt drive	75.9	D	%
16.	Input power (power delivered by the electric motor)	0.2	T_1	KN
17.	motor)	0.14	T_2	KN
18.	Power output (power delivered by the generator)	2.85	P_B	KW
19.	generator)	19	α	Degree
20.	Overall efficiency	142	Θ	Degree
21.	Tight tension	222.4	E_{max}	Kwh
22.	Slack tension	3.71	E.D	Kwh/kg
	Power transmitted by the belt			
	Angle of lap			
	Angle of contact			
	Maximum flywheel energy storage			
	Energy density of flywheel			

3.3 Results from Fabricated System

Table 3 shows the results from the fabrication. It shows the dimensions obtained as measured from the fabricated machine.

Table 3: Results from fabricated system

S/N	PARAMETER	VALUE	SYMBOL	UNIT
1.	System total length	1600	L	Mm
2.	Belt centre distance	2000	κ	mm
3.	Current	14	I	A
4.	Voltage	200	V	V
5.	Speed of the generator	1400	ω_g	r/min
6.	Power output	4.16	P	KW
7.	Overall efficiency	85.9	η	%

3.4 Discussion

After a successful completion of the fabrication, the following data in Table 4.4 were measured using suitable equipment for the purpose of analysing the characteristic of the fuel-less generator.

Table 4. Measured Values from Fabricated Project

S/N	GRAPH Voltage &Speed		Load & Speed		Power & Speed		Power & Efficiency	
	Voltage (v)	Speed (rpm)	Speed (rpm)	Load (kw)	Power (w)	Speed (rpm)	Power (w)	Efficiency (%)
1.	0.00	0.00	1100.00	0.50	0.00	0.00	0.00	0.00
2.	40.31	250.31	1150.78	0.40	500.00	15.00	500.00	15.71
3.	80.45	500.46	1200.57	0.30	1000.21	30.21	1000.00	30.22
4.	120.44	750.67	1350.78	0.20	1500.32	45.00	1500.00	45.66
5.	160.35	1000.75	1400.57	0.10	2000.00	60.21	2000.00	60.00
6.	180.50	1250.78	-	-	2500.02	75.00	2500.00	65.21
7.	-	-	-	-	-	-	3000.00	60.00
8.	-	-	-	-	-	-	3500.00	55.21

Relationship between the speed of the motor, generator speed and voltage produced

The computation and analysis carried out, it was observed that the speed of the flywheel and generator pulley have a linear relationship. Varying the size of either of the motor

wheel or the flywheel that is connected to the generator will have an effect on the amount of voltage produced and also the amount of work done on the system. Thus increasing either of them will result to an increase in the speed of the generator and thus increase in the voltage produced in Figure 8.

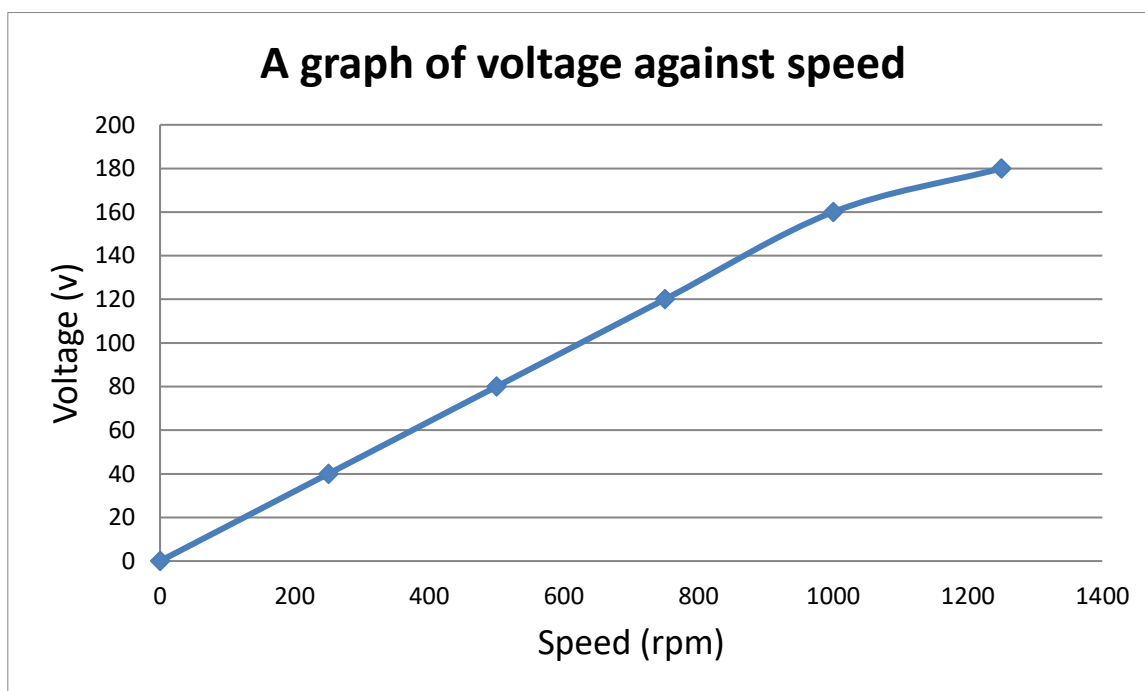


Figure 8: A graph of generated voltage and speed

Relationship between generator speed and power produced

From figure 9, it was observed that the power produced by the electric generator increased as the rotational speed of the generator increased. Hence, to harness a great power output from the generator, the speed of the generator is needed to be

kept at its maximum intensity. It was also observed that to keep the generator running at high speed, the flywheel is needed to rotate at a very high speed. Therefore, friction losses due to air drag between the flywheel surface and air should always be eliminated and magnetic bearings used to pulverize frictional effects on the flywheel, thus increasing its

rotational speed and subsequently increasing the speed of the generator which analogously increases electrical output and hence the efficiency of the generator.

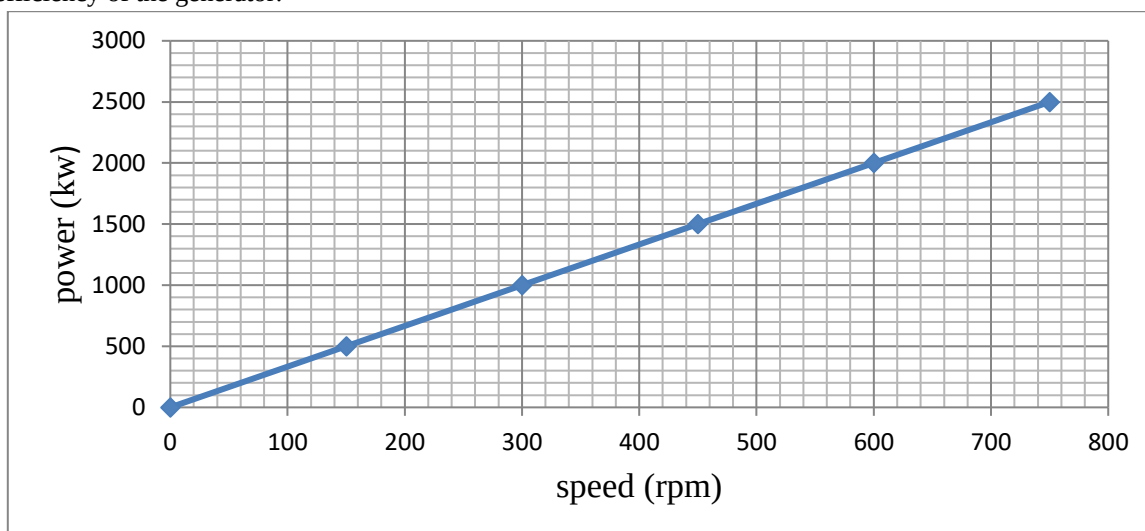


Figure 9: A graph of power against speed

Comparison of the flywheel fuel-less generator to other energy storage devices

To rate the preponderance of the flywheel fuel-less generator as to other fuel-less energy producing devices such as the Electric Double Layer Capacitors and Li-on battery system, a comparative analysis of the 3.5KW fuel-less generator with equivalent 3.5KW power rating of the aforementioned devices were carried out, as shown in Figure 8 and 9. It was

observed the flywheel fuel-less generator possesses a higher power density as compared to the other two devices, which makes it possible for the project to be used for other applications such as the photovoltaic cells and wind power generation as well as for un-interruptible power supply. However, the flywheel system does not poses a high energy density, which makes it limited for such application as constant power supply.

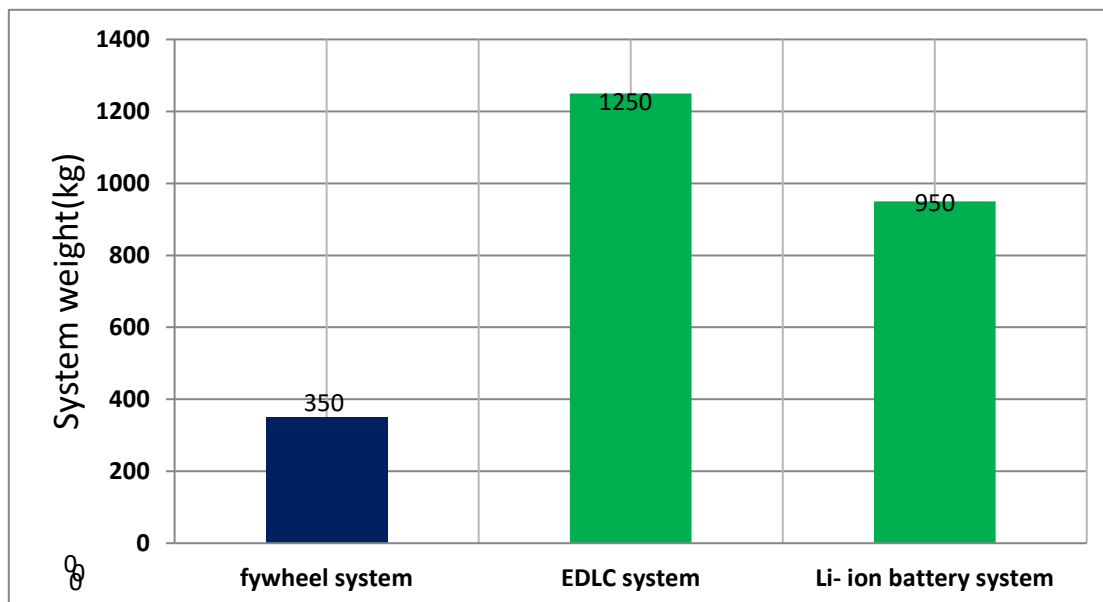


Figure 10: Comparison of the systems weight

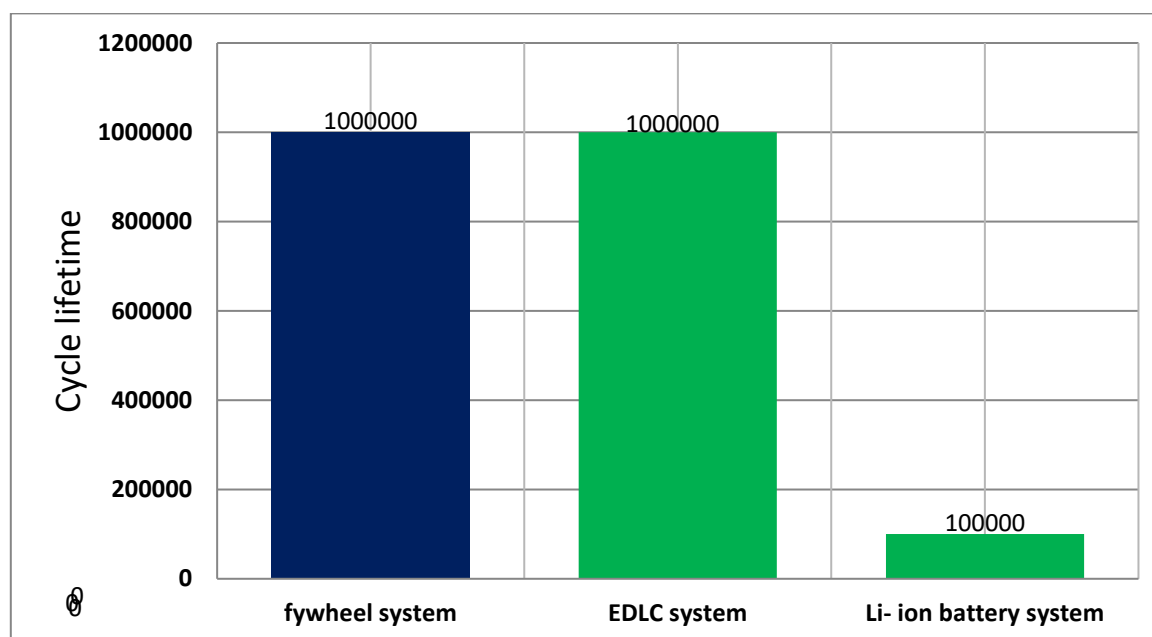


Figure 11: Comparison of the systems lifetime

3.5 Testing and efficiency

Upon completion of the fabricated system, it was tested using a multimeter and tachometer to measure the voltage produced and the speed at which the generator is producing that voltage respectively. It was found to produce a voltage of 180V and 12A at a speed of 1200 rpm. It was from this basis the output power was calculated and hence the overall efficiency of the system estimated 85.9%.

4. CONCLUSION

The cost of electricity in Nigeria has been a great nut to crack for so many individuals especially business owners, investors, companies and the population at large thereby prompting the need for alternative power generation. The need for new energy sources had led to a number of alternatives with their attendant teething high cost of fuel. However, in the future, if the technology is further developed and embraced, the costs for electrical supply will reduce, and electricity will be efficiently distributed. Flywheels are one of the most promising technologies for replacing conventional lead acid batteries as energy storage systems for a variety of applications, including automobiles, economical rural electrification systems, and stand-alone, remote power units commonly used in the telecommunications industry. A recent advance in the mechanical properties of composites has rekindled interest in using the inertia of a spinning wheel to store energy. The state of charge can easily be measured, since it is given by the rotational velocity. The first rotation of flywheel rotors is suitable for direct generation of high voltage. It has obtained (100%) extra electrical output which is free energy from the project. The AC generator has produced 3.5 kW of electricity by using flywheel rotated by an electric motor. The other main advantages of conventional free energy using flywheel is that it can generate without

extra equipment. Hence, it can be used in various applications like electric fuel cars and increase the efficiency of traditional electrical equipment. . The state of charge can easily be measured, since it is given by the rotational velocity. The first rotation of flywheel rotors is suitable for direct generation of high voltage

CONFLICT OF INTEREST

The authors declared that there is no conflict of interest

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