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The Effect of Load on Stability and Performance of a Developed Fuel -Less Generator

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Abstract **Original Research Article**

This study presents the design and performance evaluation of a fuel-less generator as well as the effect of load on the stability of the generator aimed at providing sustainable and cost-effective electricity in Nigeria. The generator utilizes a flywheel energy storage system, driven by an electric motor, to rotate an alternator and produce electrical power without fossil fuels. Performance tests were conducted over three consecutive days under varying load condition such as 1.05kw and 1.52kw on the 3.5KWA fuel less generator, with voltage readings recorded at 30minute interval for 6hrs in 3days. Results revealed that the generator maintained stable voltage output under zero load conditions, while higher loads induced progressive voltage decline, highlighting the influence of load magnitude on the system stability. Simulation modeling was conducted using GNU Octave to analyze system dynamics, including motor speed, alternator RPM, and voltage regulation under varying loads. Results indicate stable voltage output across multiple load conditions, with minimal deviation, demonstrating the viability of fuel-less generation for domestic and small-scale industrial applications. The study contributes to the growing body of renewable energy solutions tailored towards solving power outage problems in developing countries.

Keywords: Fuel-less generator, flywheel energy storage, voltage regulation, renewable energy, kinetic energy, simulation modeling.

1. INTRODUCTION

Nigeria faces persistent challenges in electricity generation and distribution, with over 40% of the population lacking reliable access to due to frequent power outages power Chibuzor, E. et al (2012).. Conventional generators, heavily reliant on fossil fuels, contribute to environmental degradation and impose high operational costs. In response, this study explores the development of a fuel-less generator that leverages kinetic energy storage to produce electricity without combustion.

The concept of fuel-less generation is not entirely new, but its application in low-cost, locally adaptable systems remains underexplored. This research aims to design and evaluate a generator that is capable of delivering consistent power output by using a flywheel-driven alternator system. The goal is to provide an alternative energy source that is clean, efficient, and scalable for not only Nigerian households but also in other parts of the world still grappling with steady power supply.

The following are the precise goals of this project work:

i. To perform a fuel-less generators design calculations.

ii. To use locally accessible materials to build a fuel-less generator

iii. To assess the fuel-less generator's performance in terms of load influence and stability

2. LITERATURE REVIEW

Fuel-less generators typically rely on mechanical energy storage systems such as flywheels, compressed air, or magnetic levitation. Flywheel systems are particularly attractive due to their simplicity, durability, and ability to store rotational energy with minimal losses.

Previous studies have examined the use of flywheels in hybrid vehicles, uninterruptible power supplies (UPS), and grid stabilization. However, few have addressed their integration into stand-alone generators for domestic use. Research by Adeoye et al. (2020) demonstrated the feasibility of flywheel-based systems in rural electrification, while Okonkwo and Eze (2019) highlighted the limitations of battery-only solutions in terms of lifespan and cost.

This study builds on existing work by incorporating a simulation-driven design process and evaluating real-world performance under varying load conditions.

3. METHODOLOGY

3.1 Design Calculations and Drawings

The generator consists of three main components:

(i) **Electric Motor**: Initiates rotation of the flywheel using stored battery energy.

(ii) **Flywheel**: Stores kinetic energy and maintains rotational inertia.

(iii) **Alternator**: Converts mechanical rotation into electrical output.

A V-belt-pulley connects the motor to the flywheel and the flywheel to the alternator. The flywheel is constructed from high-density steel to maximize energy retention.

3.1.1 Design specification

The design specifications of the fuel less generator are:

i. Voltage = 220V

ii. Power factor = 0.85

iii. Apparent power of generator = 1 KVA

iv. Number of poles = 4

v. Magnetic flux = 0.02 Weber

vi. Speed of rotation, N = 2000rpm

vii. Frequency = 60 Hz

3.1.2 Determination of Design Parameters

The following design parameters were determined;

i) Determination of Current Produced in the Armature Coil

The current produced in the armature coil of the developed generator was determined by Equation (3.1).

$$I_a = \frac{P_a}{V} \qquad (3.1)$$

Where V = Voltage of the battery (220 Volts)

I_a = Armature coil current

P_a = Apparent power in KVA

ii) Determination of the Power Input to the Coil

The power input to the coil was determined by applying Equation (3.2).

$$Pi = IVCos\theta \qquad (3.2)$$

Where P_i = power input to the coil

Cos θ = Power factor taken to be 0.85

The power input into the armature coil was calculated to be 850.85 Watt

iii) Determination of the Back Electromotive Force (E. M. F.)

The back e.m.f which opposes the induced voltage in the coil was determined using Equation (3.3)

$$Eb = \phi \times n \times Z \times N60 \qquad (3.3)$$

Where

Eb = Back E. M. F.

Z = Number of armature conductors

N = Speed of shaft in rpm

Φ = Magnetic flux in Weber

n = number of pole pairs i.e. 2. The back e.m.f was determined to be 666.67 V

iv) Determination of Angular Speed of Shaft

The angular speed of shaft was determined by applying Equation (3.4)

$$\omega s = 2 \times \pi \times N60 \qquad (3.4)$$

Where

ωs = Angular speed in rad/s. The angular speed was determined to be 209.5 rad/s

v) Determination of the Electro-Mechanical Power from the Direct Current Coil

The Electro-Mechanical power developed by the direct current coil was determined by Equation (3.5)

$$P_m = Eb \times Ia \qquad (3.5)$$

Where

P_m = Electro-mechanical power from the direct current coil

vi) Calculation of Torque

The torque developed was calculated by applying Equation (3.6)

$$T = Pm\omega s \qquad (6)$$

Where

T = Torque developed in the coil

vii) Determination of the Electrical Power

The electrical power is the product of armature voltage and the current [18]. This is as given in Equation (3.7)

$$P_E = (Va) \times R + Eb \times Ia \qquad (3.7)$$

Where

P_E = Electrical power developed

viii) Determination of the Battery Power

The power capacity of the generator battery was determined using Equation (3.8)

$P_B = Va \times I \times Cos\phi$ (3.8)

Where

P_B = Power capacity of the battery

3.1.3 Design Drawing

Figure 3.1 shows the assembly drawing of the fuel-less generator. The detail drawings and technical specification are shown in appendix 1.

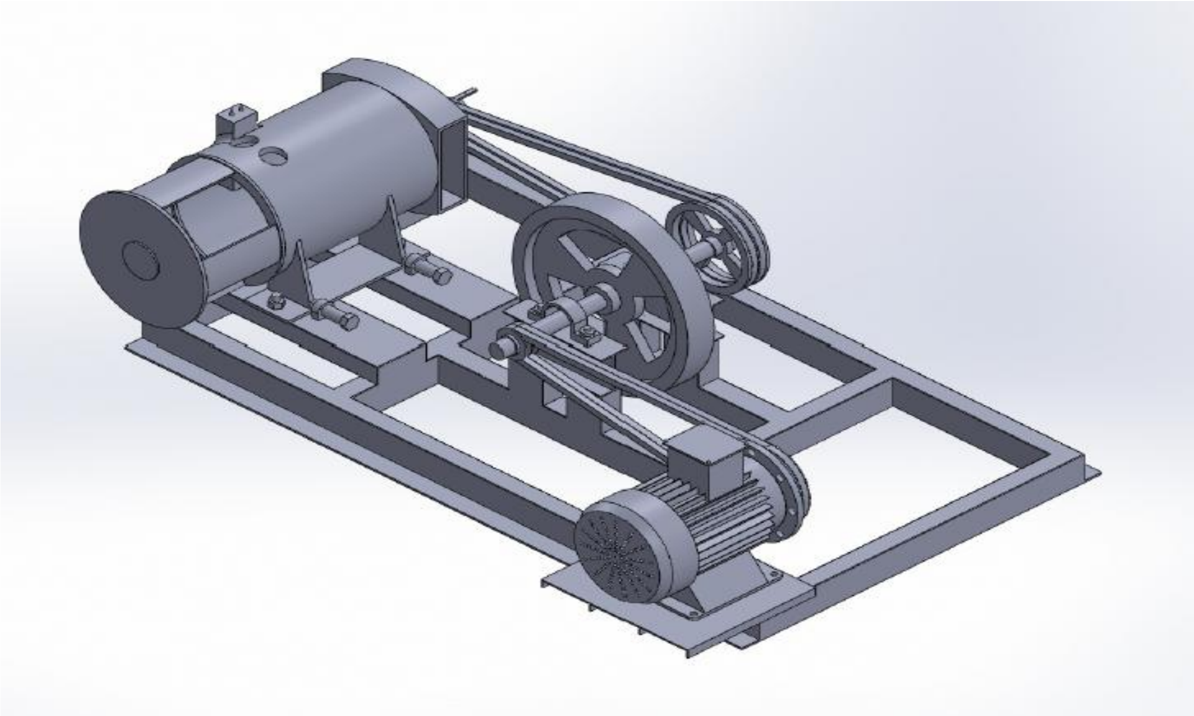

Figure 3.1: Assembly Drawing of the Fuel-Less Generator

3.2 Construction and Performance Evaluation

3.2.1 Construction Materials

i. Direct Current Motor: DC motor with one horsepower

ii. Battery: a 12-volt battery that provides the motor with direct current.

iii. Alternator: it uses a capacitor to produce an alternating voltage and current.

iv. Diode: The diode is responsible for the battery's continuous recharge.

v. Capacitor: it facilitates the transformation of alternator energy into alternating voltage.

vi. Ignition key: This is used to turn the generator system on and off.

vii. Shaft: The alternator receives torque from the DC motor via the shaft.

viii. Cables: Current is transferred from a source to a load via cables.

3.2.2 Construction of a Fuel-less Generator

Plate 3.1 shows the picture of the constructed fuel-less generator. A 12 V battery is connected to a 1 horsepower DC motor. The battery's red and black cables were attached to the DC motor's positive and negative components, respectively. The motor is then linked via a shaft to a 1kVA alternator. Through the circuit switch, the load plug was indirectly connected to the alternator's power outlet. The key starter is positioned next to the monitoring board, and the capacitor was also linked to the capacitor lines exiting the alternator. For a test run, the load outlet was then linked to a cable that was attached to a lightbulb. By using a diode to link the alternator to the battery, the cycle is finished.

Plate 3.1; the Constructed Fuel-less Generator

3.2 Simulation Modeling

GNU Octave was used to simulate system behavior. Key parameters include:

I Motor speed (RPM) ii Flywheel inertia iii Alternator voltage output iv Load resistance

Equations governing rotational dynamics and energy transfer were implemented to predict system performance.

3.3 Performance Testing

To assess the fuel-less generator design, tests and user trials were carried out. Using a variety of loads, including a pressing iron, microwave, and refrigerator on day two, and a washing machine, welding machine, and air conditioner on day three, the generator's design was tested for three days in order to evaluate its performance. Measurements were taken every 30 minutes during the first test of the 3.5 KVA fuel-less generator, which was run without any load for six (6) hours. According to the findings of the performance test, there was no change in output. The recorded values are shown in table3.1

Table 3.1 Performance Test for Time Vs Voltage for Day 1, Day 2, Day 3

TIME	DAY 1 (NO LOAD)	DAY 2 (1.05 KW)	DAY 3 (1.52KW)
10:00	242	242	240
10:30	242	242	240
11:00	240	240	239
11:30	240	241	238
12:00	240	240	238
12:30	239	238	238
13:00	241	236	236
13:30	240	236	235
14:00	241	235	233
14:30	240	234	230
15:00	239	232	230
15:30	240	232	225
16:00	240	230	220

4. RESULTS AND DISCUSSIONS

4.1 Results

The results obtained from the performance test in table 3.1 is analyzed in terms of number of days, mean voltage, standard and minimum and maximum voltage as well as voltage regulation and presented in table 4.4

Table 4.4: Voltage Characteristics under Varying Load Conditions

Day	Mean Voltage (V)	Standard Deviation (V)	Maximum Voltage (V)	Minimum Voltage (V)	Voltage Regulation (V)
Day1 (NO Load)	240.23	0.83	243	239	1.66
Day2 (1,05KW)	236.77	4,07	242	230	5.07
Day3 (1.52KW)	234.00	4.21	240	228	5.11

Moreover, the performance behavior and comparison for day 1 (zero load test), day 1 versus day 2, and day 1 versus day 2 and day 3 under various loads are presented graphically in the figures below:

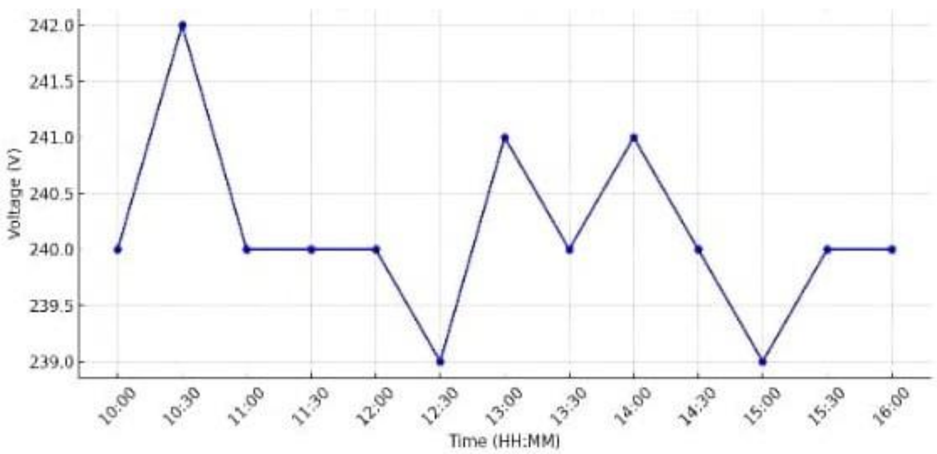

Figure: 4.1. Zero Load Voltage Text for fuel less 3.5KVA Generator.

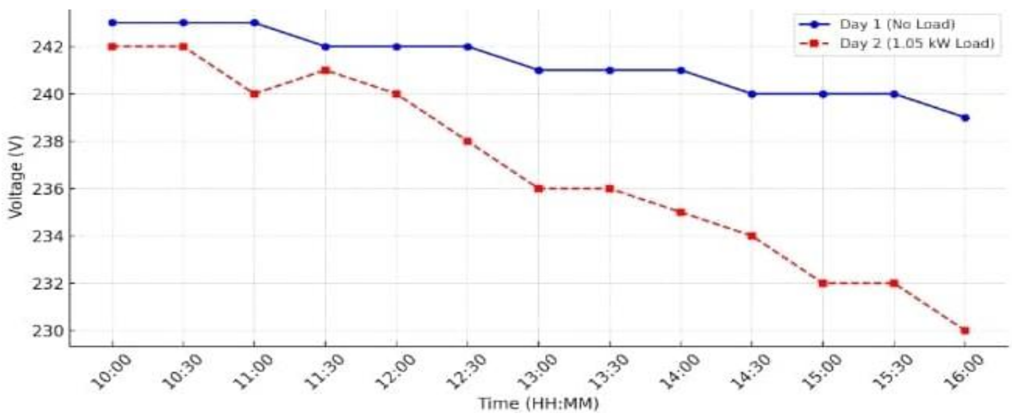

Figure 4.2 Voltage Test for Fuel-less 3.5 KVA Generator with Zero Load vs 1.05kw load (Day 2).

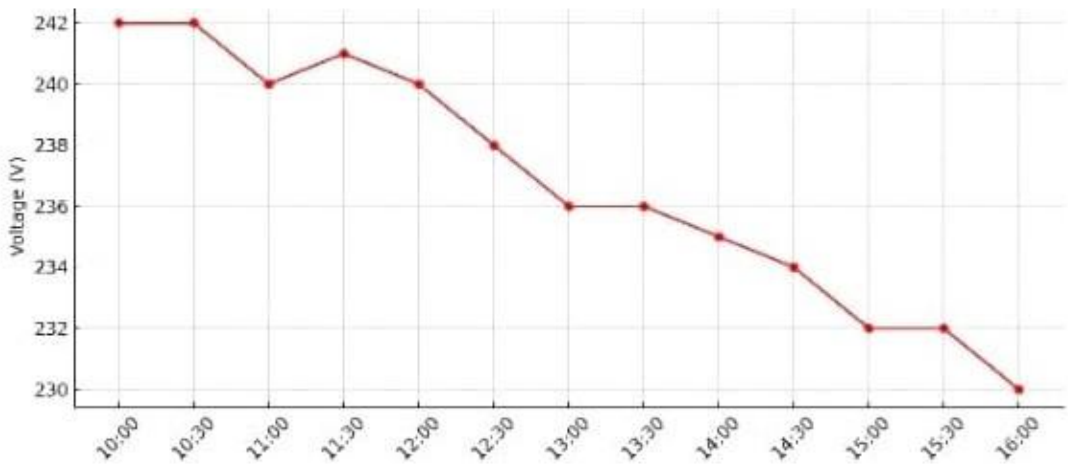

Figure 4.3: (Day two) 1.05KW Load Test

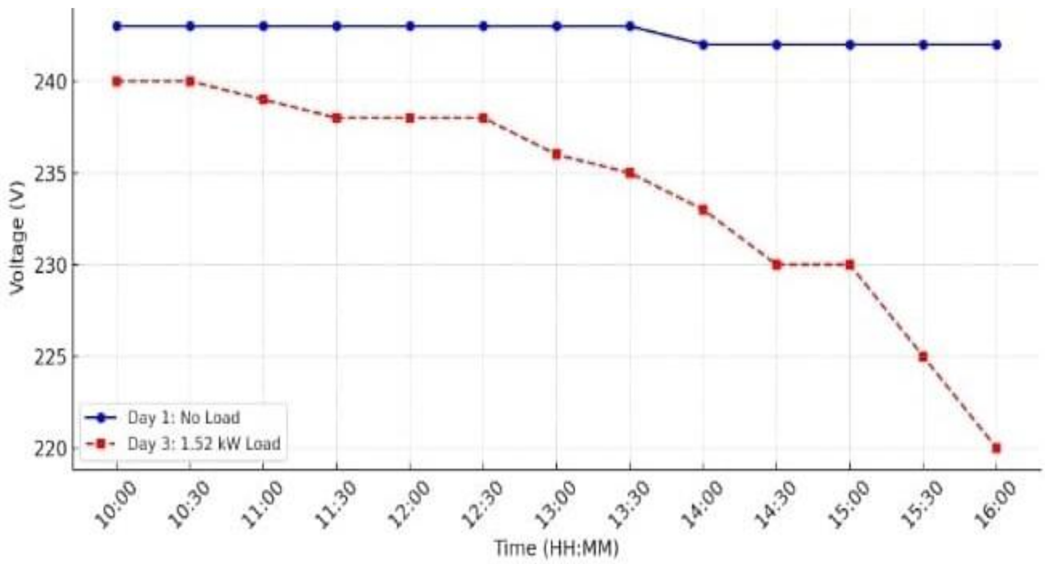

Figure 4.4: Voltage performance of 3.5 KVA Fuel less Generator for (Zero Load vs and 1.52KW Load

4.2 Discussions

A thorough examination of the recorded data is provided: The average voltage across all readings is 240.23 V, which is quite close to the standard 240 V needed for this type of generator. The following are the main conclusions drawn from the graph:

(a). Stability: The average voltage swings just ±1V, at 240.23V. Small differences in the generator's internal regulation or measurement limits could be the cause of the typical minor fluctuations (±1V).

(b). Anomalies: At 12:30 and 15:00pm, there is a modest decrease to 239V, which is probably caused by a small load or sensor noise.
The initial warm-up may be indicated by the peak at 242V (10:30 AM).

(c). When there is no load, the generator generally shows outstanding voltage regulation on day one.

Additionally, on day 2, Voltage gradually drops over time, starting at 242V and decreasing to 230V by the end of the test from 10:00am to 16:00pm. The most significant drop occurs between 12: 30 and 16: 00pm (238V to 230V) a 4.96% drop from initial 242V. Statistical summary gives an Average Voltage of 236.77 V, Minimum Voltage: 230 V (16:00pm), Maximum Voltage: 242 V (10:00am & 10:30am), Voltage Fluctuation Range: 12 V (230 V – 242 V), Standard Deviation: 4.12 V (higher than no-load test, indicating instability under load). Time-Based Voltage Trend Three Distinct Phases namely:

Initial Stability for the first phase was seen between 10:00am and 12:00 noon, when the voltage was still about 240 V (±2 V). Recommends effective initial control under load. The voltage decreases from 238 V to 234 V during the second phase, known as the Moderate Decline (12:30–14:30pm).

Among the potential reasons are:

1. Windings become heated, increasing resistance.

2. As the load continues, the regulator finds it difficult to sustain voltage.

Between 15:00pm and 16:00pm, the third phase of the time base voltage rapid decline was seen, signifying a precipitous drop to 230V. This can be the consequence of inadequate power supply, component wear, or potential overloading. Figure 4.3 shows a single graph that combines the day one (no-load) and day two test graphs for the 1.05 kW load.

Furthermore, on day three (3), the load effect has a higher standard deviation, indicating less stability under load, which could be brought on by AVR saturation, increased winding resistance, or alternator heating.

According to the operational implications, many appliances can still withstand voltages of about 220V, but sensitive electronics may encounter undervoltage problems as the test progresses. A graph of day three is presented in figure 4.4 to provide a complete three-day performance comparison of the system, clearly illustrating the impact of rising load on voltage stability.

The fuel-less generator demonstrated reliable voltage output and adaptability to varying loads. The flywheel system effectively stored and transferred energy, minimizing reliance on continuous motor input. Compared to conventional generators, this system offers:

(i) Zero fuel consumption (ii) Lower maintenance (iii) Reduced environmental impact

Limitations include startup energy requirements and sensitivity to load spikes. Future iterations may incorporate magnetic bearings or regenerative braking to enhance efficiency.

5.2 Conclusions

1. The generator's output voltage remained almost constant when there was no load.

2. A detectable voltage drop occurred as the load increased; the 1.52 kW load test showed the steepest drop.

3. Although able to function with loads as high as 1.52 kW, extended use of such a high load diminishes voltage stability and could damage delicate technology.

4. In order to preserve performance and extend generator life, load regulation is necessary.

5. The electric generator's power production rose in tandem with its increased rotational speed.

Its design is cost-effective, environmentally friendly, and suitable for small-scale deployment. With further optimization, it holds promise for addressing Nigeria's energy deficit and reducing dependence on fossil fuels.

5.3 Recommendations

1. To reduce performance degradation, avoid operating at maximum rated load for extended periods of time.

2. To provide steady output under fluctuating loads, use a voltage control system.

3. To track voltage trends and spot early indicators of degradation, schedule routine performance tests.

4. To increase load tolerance, investigate design enhancements including superior magnetic materials and winding arrangements.

5. Integrate solar charging for the motor's battery system

6. Explore lightweight flywheel materials to reduce startup energy

7. Conduct long-term durability testing under field conditions

8. Advocate for policy support to promote fuel-less technologies.

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