DEVELOPMENT AND PERFORMANCE EVALUATION OF A 2kVA FUELLESS GENERATOR

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ABSTRACT

Electricity supply has been unreliable for a long period in Nigeria. The energy generating capacity has the potential to generate 12,522 MW of electric power from existing plant, however, approximately 4650 MW is daily generated. Consequently, most homes and industries use internal combustion engine generating sets as an alternative to power grid failure. This does not only contribute to the amount of CO_2 that people inhale in the atmosphere but also contributes to ozone layer depletion and climate change. The need for new energy generating sources with no negative impact on our environment had led to several alternatives cleaner source of power that is environmentally friendly and affordable for the masses. In response to this, a fuelless generator was developed using local materials to serve as a standby generator against the incessant power outage. The generator was developed by using a D.C battery, D.C motor, alternator, connecting shaft, charging panel (transformer, diode and capacitor), and a frame. A 12V, 100Ah battery was used to drive a 12V DC motor which in turn spun the alternator to optimal speed to generate electrical power. The output voltage was used to power varying loads of 0W to 2KW, with efficiency reducing with load increase. This paper presents the design and construction procedures, as well as the performance evaluation of the generated result.

KEYWORDS: Electricity, Direct Current, Fuelless generator

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INTRODUCTION

Lack of routine maintenance in the generation, transmission and distribution of electrical networks and systems had caused significant deterioration in plant output, thus contributing to the lingering electric power crisis in Nigeria (Ajav and Adewumi 2014). Consequently, industrial and residential consumers of energy resulted in using standby generating plants thus making the country the largest buyer of internal combustion engines globally (Okediyi, 2010). In finding alternative means of producing energy, the transition to non-conventional and renewable energy sources is on the increase daily. One of these alternatives is the fuelless generator which generates electricity without the use of fossil fuel such as petrol, diesel, oil, or coal (AIP, 2013).

Fuelless generator has the potential of generating energy at optimal capacity consistently without interruption. It operates on the principle of an external rechargeable battery used to drive/power a DC motor to produce mechanical rotation which spins the alternator to generate electricity and in turn charges the battery using a rectifying diode. To regulate the variation of the load demand, a simple controller is used. Meanwhile, a fuelless generator can be constructed based on the capacity of the load demand. The economic impacts of a fuelless engine are a non-air pollutant, self-dependence, noiseless and it contributes to the ongoing SDGs target of having a low carbon economy.

In this paper, we examined the mechanism of operation of a generator and then the details of the design and construction of a fuelless generator. The rest of the paper is organized as follows: Section II focuses on the literature review of previous works while section III explains the materials and methodology used in executing this project. The results and discussions are presented in section IV while section V contains the conclusions and recommendations.

LITERATURE REVIEW

Electricity consists of small negative charge electrons which when at standstill are said to be static electricity and dynamic electricity when they are forced to move (Halliday and Resnick 1974). Electricity generation has been a major contributing factor to the growth and development of developing countries since all sectors (such as banking, manufacturing, media, aviation, healthcare, and a lot more) depend on it to operate maximally (Esom and Aneke 2020). However, uninterrupted and reliable power supply in Nigeria remains a delusion. Contributing factors include lack of infrastructure, outdated generation plants and equipment as well as poorly maintained transmission and distribution networks.

A generator is a machine that operates using the principle of Faraday's law of electromagnetic induction to convert mechanical energy into electrical energy (Shouters, 2019). There are two major types of generators.

AC Generators

AC generators are referred to as alternators. It is the most efficient means of producing electricity since most electrical appliances use AC as their primary source of power while some that use DC have an inbuilt AC to DC converter. AC generators can either be induction or synchronous. An induction generator operates when the conductor coils turn in a magnetic field at a constant speed actuating a current and a voltage. It requires no separate regulator controls, DC excitation, governor, or frequency. However, the synchronous generator is mainly used in large power plants. Similarly, the synchronous generator can be a rotating field or rotating armature type. The rotating field has high power generating capacity without slip rings or brushes. It is the most used armature type in a generator. The generator is combined with a turbine which makes it function as a motor-generator set and finds application in areas such as naval, oil and gas extraction, mining machinery, wind power plants, etc.

DC Generators

DC generator is mostly used in off-grid power generators. These generators power the storage devices directly and the DC power grid without special equipment. A DC-AC converter is used to power AC appliances. Three types of DC generators based on the development of a magnetic field in the stator are Permanent-magnet DC generators; Separately-excite DC generators and Self-excited DC generators.

Fuelled Generator

The combination of an internal combustion engine with an electrical generator makes up a fuelled generator. It makes use of various fossil fuels such as diesel, gasoline, propane (in liquefied or gaseous form), or natural gas. As air is compressed in the cylinder at high pressure, fuel is injected into the compressed air chamber causing combustion and subsequently rotation of the prime mover. The mechanical rotation from the prime mover spins the alternator which in turn generates electricity. However, the alternator can be set in motion by other means to generate electricity.

Review of previous works

Otulana et al., 2015 used a locally sourced material to develop a 1 kVA fuelless generator with a driving mechanism of 1hp DC motor to spines a 0.95 kW alternator. The DC motor was powered by a 12 V rechargeable battery which recharges through a rectifying diode. Dipali et al. (2017) worked on a simple and efficient means of generating electricity with readily and easily available materials. The authors revealed that the system can be built to any capacity depending on the load requirement, and the system does not require frequent mechanical maintenance.

A 2.5 kVA self-induced fuelless generator was constructed by Adewumi (2016) using a self-induced engine as an alternative to isolated power generation from renewable energy sources because of its low cost of purchase and maintenance, as well as the reliability. The component used for the construction includes DC motor, 12V 100Ah battery, AVR panel, and charging panel. The performance evaluation was performed using loads ranging between 0 W and 2 kW for 300 seconds. The outcome of the research shows that the self-induced power generating set must make use of a new direct current motor and alternator for future study for reliability and better performance of the system.

MATERIALS AND METHODOLOGY

This project was executed using a 12V/100Ah battery to drive a 1hp DC motor which served as the prime mover for the 2 kVA alternator. The operation mechanism functions without the need for an internal combustion engine which usually requires fuel (Adewumi and Adelekan 2016). The system produces electricity perpetually without fuel with the driving mechanism being a DC motor driven by a battery (Abatan et al., 2013). For the design, the DC motor and the alternator were joined using a flexible coupling while a metallic framed basement was constructed to accommodate the set-up of the generator for easy movement. The performance of the generating set was studied after a critical analysis of the selected component.

Materials: The essential components used in the design and construction of the fuelless generator are the alternator, battery, coupler, connecting cables, DC motor, and other basic electronic components of the control units.

Alternator: A 2 kVA capacity alternator was used with an output voltage of 220V, 5A current. The proposed output rating of the alternator when fully spun with a DC motor is 2 kVA and the power factor is 0.85.

DC Motor: The rating of the alternator was slightly below that of the motor to cater for friction and windage losses in the motor-alternator coupling. This is done to have a high-efficiency power transfer from the battery to the alternator. The DC motor was selected based on the frequency of the motor at no load to full load. The oscillatory frequency equation is given by Eqn(1).

$$f = \frac{p \times n}{120} \quad (1)$$

where p denotes the number of poles (always a multiple of 2) presents in the motor winding, n is the speed of the magnetic field inside the motor stator in revolution per minute (rpm), f is the applied frequency in Hz. Input voltage – 12VDC, Input current – **62.17A,** Output power – **1hp or 746 watts,** and Shunt motor rating – 1KW

Battery: The load rating and minimum load duration were the selection criteria for the battery. For this work, a wet-cell lead-acid battery of output voltage 12V/100AH was used. The load rating was varied from 0 to 2KW.

Coupling: Torgue transmission between the alternator and the motor shafts was achieved with the use of an elastomeric flexible or adjustable coupling. This was done to eliminate vibration between the alternator and DC motor when in operation, as well as reduction of routine maintenance to the barest minimum.

Charging Unit: A charging unit was integrated into the system to aid the charging of the battery during operation using a rectifying diode system. To regulate the charge going into the battery, a charge regulator was used to monitor and regulate the voltage due to the load variations from consumers.

Methodology

The generator was constructed using a direct coupling method with a 2 kVA alternator and a 1hp DC motor which serves as the prime mover. An external rechargeable DC battery is used to power the DC motor for a separate excitation of both the field coil and the rotor winding of the motor. The DC motor acts as the prime mover to set the alternator in rotation and operate using Faraday's law to generate an induced electromotive force whenever the magnetic flux linked with a circuit changes (Oyekola et al., 2018, Singh et al., 2006).

Mathematically,

$$Induced\ emf = \frac{N\Phi_2 - N\Phi_1}{t} \quad (2)$$

where $N\Phi_1$ is the initial flux linkages, $N\Phi_2$ is the final flux linkages, N is the number of coil turns and t is the time. The design of the DC motor was done using the electromagnetic induction principle to generate an induced emf to drive the coil.

$$e_b = \frac{\Phi ZNP}{60C} \quad (3)$$

where C is the number of parallel paths of the conductor in the armature. Z is the number of conductors in the armature. N is the speed of shaft rotation in rpm. Φ is the flux density. P is the number of poles.

In a lap wound DC motor C=P. Hence

$$e_b = \frac{\Phi ZN}{60} \quad (4)$$

$$e_b \propto w, \quad therefore\ e_b = k_c w$$

$$w = \frac{2\pi \times N}{60} \quad (5)$$

where w is the angular speed and k_c is the constant voltage. Armature voltage V consists of two parts; back emf (e_b), and the voltage drop across armature resistance ($i_a R$).

$$V = i_a R + e_b \quad (6)$$

Multiplying V by i_a

$$V i_a = i_a^2 R + e_b i_a \quad (7)$$

where $V i_a$ is the armature power

$i_a^2 R$ is the power loss due to the armature resistance, $e_b i_a$ is the mechanical power (P) developed by the DC motor.

$$Torque(T) = \frac{Mechanical\ Power}{Angular\ Speed} = \frac{p}{w} \quad (8)$$

$$Since, P = e_b i_a$$

Substituting w from equation 5

$$T = \frac{60 e_b i_a}{2\pi N} \quad (9)$$

Substitute e_b from equation 3 to equation 9

$$T = \frac{\Phi ZNP i_a}{2\pi NC} \quad (10)$$

$$At\ constant\ speed, T \propto I_a$$

$$So, T = K_T I_a$$

where K_T= Torque Constant

The effective torque which overcomes the first rotational torque at current i_a is

$$T = K_T i_a - T_f$$

$$Hence, i_a = \frac{T+T_f}{K_T} \quad (11)$$

Substitute equation 11 into equation 6

$$V = \frac{T+T_f}{K_T} R + K_c w \quad (12)$$

$$k_c w = V - \frac{T+T_f}{K_T} R$$

$$w = \frac{V}{kc} - \frac{T+T_f}{K_T \times K_c} R$$

$$w = \frac{(K_T \times V) - (T \times R) - (R \times T_f)}{KT \times Kc}$$

$$w = \frac{(K_T \times V) - (R \times T_f)}{KT \times Kc} - \frac{T \times R}{KT \times Kc}$$

Practically, $T_f \approx 0$

$$w = \frac{((KT \times V) - (T \times R))}{KT \times Kc} \quad (13)$$

Equation 13 is the angular speed of the DC motor while the electrical power is supplied to the armature, the mechanical power developed and the power loss into the armature resistance is evaluated from equation 7. Recall that the battery used by the DC motor will be recharged automatically. Hence, the design specification of the battery was determined using:

$$P = IV \quad (14)$$

The 12V, 1hp DC motor was used to calculate the current rating of the battery.

$$1hp = 0.7457kW = \approx 74.6\ kW$$

Since $P = IV, I = \frac{P}{V}$ (15)

$$W = VA \times \cos \emptyset$$

$$therefore,\ VA = \frac{W}{cos\emptyset}$$

Power factor cos∅ =0.85, therefore,

$$VA = \frac{W}{cos\emptyset} = \frac{746}{0.8} = 932.5VA = 0.9325KVA$$

Substituting the power in VA to 15

$$I = \frac{P}{V} = \frac{932.5}{12} = 77.71A$$

Therefore the battery ratings are 12V, 78A, 1hp power.

Efficiency

This is calculated by finding the ratio of output power to the input power expressed in percentage.

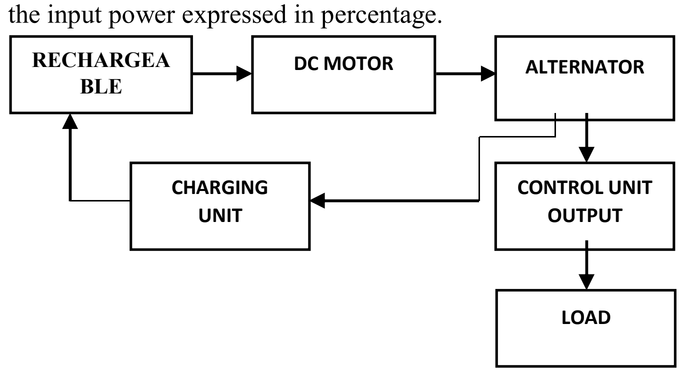

Figure 1: AC Power Generator System Block Diagram

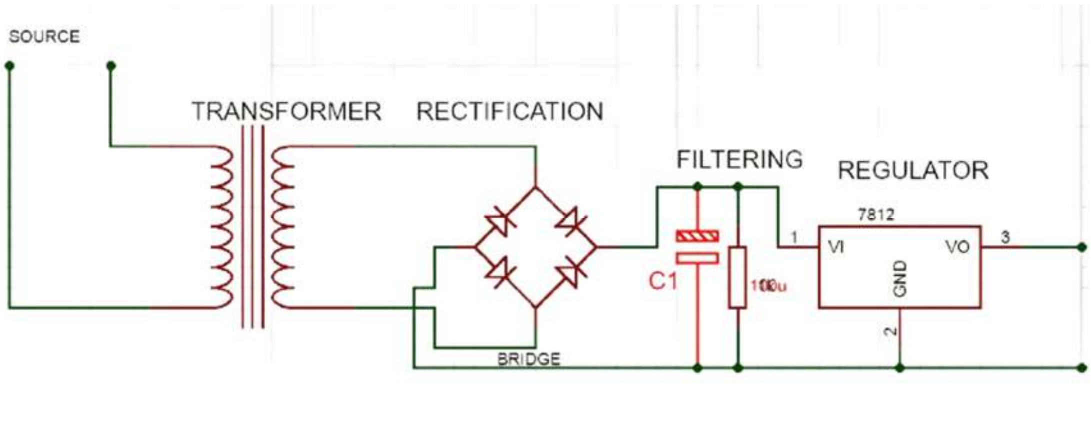

Figure 2: Charging Unit Circuit Diagram

Figure 3: Generator Coupling

Figure 4: Generator Mounting (Adegoke, 2020)

RESULTS AND DISCUSSION

Performance evaluation of the designed generator was carried out to determine if the system satisfied the designed specification. Figure 5 showed the system in operation with several loads connected to it. The output efficiency of the system was computed using the output data obtained during the testing process with varied load capacities as presented in Table 1. The load capacity used for testing ranges from 0 W to 1800 W. The experiment shows that as the load capacity increases, the efficiency of the system decreases with the lowest efficiency recorded when the load capacity was at 1800W. Although, it was observed that when the load was increased from 0 to 100 W, the efficiency increased but started to decrease thereafter. A graphical plot showing the relationship between the variation in loads and the efficiency of the system is presented in Figure 6. The treadline illustrate trends in data series.

Figure 5: Picture showing the efficiency of the Generator

Table 1: Performance Evaluation of the Efficiency of Fuelless Generator

Test	Load (W)	Input Voltage (D.C)	Output Voltage (A.C)	Input Current (A)	Output Current (A)	Input Power (W)	Output Power (W)	Efficiency (%)
1	0	23.32	220.3	0	0	0	0	0
2	100	23.25	219.4	4.15	0.43	96.46	94.34	97.802
3	200	23.15	117.65	8.45	0.89	195.34	104.71	53.60
4	300	23.04	115.87	13.23	1.40	304.76	162.22	53.23
5	400	22.97	93.65	17.32	1.85	397.87	173.25	43.54
6	500	22.91	90.78	16.84	1.84	386.82	167.04	43.18
7	600	22.86	98.76	17.25	1.66	394.34	163.94	41.57
8	700	22.80	96.43	22.85	2.15	520.98	207.32	39.80
9	800	22.73	106.34	25.40	1.89	577.34	200.98	34.81
10	900	22.67	101.95	21.03	1.62	476.75	165.16	34.64
11	1000	22.61	105.27	21.17	1.52	478.65	160.01	33.43
12	1100	22.56	99.14	23.36	1.63	527.00	161.60	30.62
13	1200	22.49	90.03	19.78	1.50	444.85	135.05	30.36
14	1300	22.43	99.45	23.96	1.47	537.42	146.19	27.20
15	1400	22.38	107.89	27.43	1.48	613.88	159.68	26.01
16	1500	22.32	85.65	21.61	1.42	482.34	121.62	25.22
17	1600	22.26	80.27	18.82	1.27	418.93	101.94	24.33
18	1700	22.20	82.63	20.34	1.19	451.55	98.33	21.77
19	1800	22.16	80.78	24.79	1.08	549.35	87.24	15.88

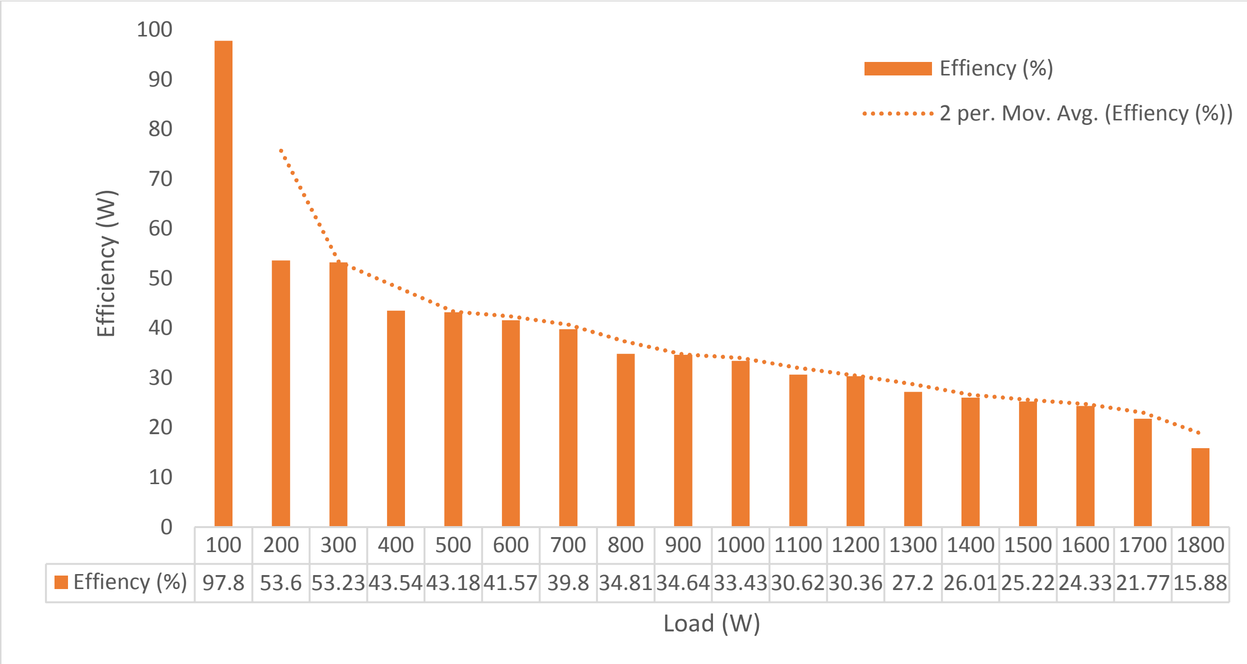

Figure 6: Load variations and efficiency

CONCLUSION

The performance evaluation of the fuelless generator above shows that the efficiency of the system decreases with the load capacity. Although the scope of our validation was within the range of 0W to 1800W. The analysis has clearly shown a decrease in the efficiency of the machine when there is a high increase in the load. Nonetheless, the constructed fuelless generating set has the highest efficiency of approximately 97% at a load of 100W. Implementation of fueslless generator on a large scale will add the overall energy on the power grid and also contribute to SGDs target for 2030 on a clean, affordable, reliable and sustainable source of energy.

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