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Development and Testing of an Improvised Fuel-less Motor-Generator System as Energy Optimizer

Chapi Jonah[1], Nasiru Aliyu[2], O. L. Daniyan[3], Ezeugwu C. Benneth[4], Egbujor C. Onyema[5], Okala A. Paul[6], Omeje N. Felix[7], Enete O. Christian[8], Obi N. JohnPaul[9], Obetta T. Nnamdi[10], Ezenwa N. Loveth[11], Eze E. Emmanuel[12], Okafor S. Chukwuma[13], Eze. Ndubuisi[14], Ademu U. Seidu[15]
Instrumentation Division, Centre for Basic Space Science Nsukka, Enugu State, Nigeria
Correspondence e-mail: chapi4real@gmail.com

Abstract—*Since future energy-saving technologies necessitate low-cost supply and high-efficiency energy conversion, there is a growing global demand for energy-saving devices. This research proposes a feasible design, fabrication, and testing of a motor-generator system as an energy optimizer using materials sourced locally. This system consumes the least amount of energy, saves money, and emits no carbon dioxide. A cutting machine and a drilling machine are used as primary loads to compare and assess energy consumption and energy costs. The result of this case study using an energy optimizer between the source and load show that $0.087/kWh cost of energy was consumed compared to $0.342/kWh incurred from direct grid connection, implying that using energy optimizer would save you approximately 75% fund when appropriately installed. Furthermore, because it is noiseless and fuel-less, it emits no harmful gases such as carbon and nitrogen oxides.*

Keywords—*Alternator, Emission, Energy Consumption, Energy optimizer, Fuel-less generator, Power Saver.*

I. Introduction

Electrical energy is critical to a country's socioeconomic development. The power system in Nigeria has been characterized by a series of constant power failures and outages, the majority of which are either technical or non-technical in nature. Six national grid failures have occurred in the year 2022 alone [1]. These issues range from line tripping due to faulty equipment to a constant increase in load that exceeds the available power supply. Others may be natural or weather-related issues such as wind, flood, and so on. Rapid population growth, combined with an increase in smart electronic devices, has increased per-capita power consumption; as a result, a reliable power source and proper energy consumption management must be expanded at the same rate to balance the excessive power demand. Powerful generators transmit electricity across the national grid for distribution throughout cities. Smaller electrical generators, in the same way that these generators harness their power, distribute power to houses for household appliances because power from the national grid is unreliable.

This work aims to create a Motor-Generator (M-G) system out of a salvaged electric motor and alternator in order to generate enough energy to supplement or even completely cover domestic needs while consuming very little energy from the grid for motor starting. It is divided into four sections: the AC Motor section, the Flywheel section, the Alternator section, and the Load section.

According to [2,] a fuel-less engine typically runs very smoothly and quietly, and the best part about the design is that it produces no harmful gases such as carbon monoxide (CO), carbon dioxide (CO2), and so on. The speed can be adjusted or built to run at a single speed with an engine that does not use gasoline, oil, or any other combustible fuel. The free electrical energy generated by the fuel-less generators is recycled and reused by the motor. A power generator, on the other hand, is a device that converts mechanical energy into electrical energy for use in an external circuit.

It has been observed that noise is a hazard that humans are exposed to on a daily basis without thinking about it. It can result in both physical problems, such as permanent hearing loss, and psychological traumas, such as stress [3].

II. Literature Review

The construction of a fuel-less generator was investigated by J. O Otulana and et al [4], and they created a fuel-less generator using locally sourced materials. The research employs a 1hp direct current electric motor powered by a 12 Volt battery, which spines the 0.95kW alternator to generate electricity with an output power of 1kVA while also providing feedback for battery charging via a diode.

Similarly, [5] presented the Development of a Self-Induced Fuel-Less Generating Set for viable Power Supply in Nigeria Using Local Resources. It is made up of a DC battery, a DC motor, an alternator, a connecting shaft, a charging panel (transformer, diode, and capacitor), and a frame. The rotating DC motor (prime mover) turns the alternator to full speed, releasing electrical energy. To keep the battery charge optimal, a portion of the output power was recycled (feedback) to a battery charger. As a result, the output power was as good as that of a conventional fuel generator, but it is better because it is less expensive to run and maintain than conventional types that use petrol or diesel and lubricants.

As a result, [6] designed and tested a system that included a direct current motor powered by a high current rechargeable battery and used as a prime mover to exert rotational force on the alternator. The system included a control circuit that automatically turned on and off the generator and monitored the voltage output from both the grid and the generator system

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to select the best source as the load's output. It was also stated that when a fault is detected, the working condition generates an alarm. Important protective devices were also included to protect and isolate the system or load from short circuits, overloads, switching, magnetizing surges and other faults.

Another study that was reviewed [7] included a Solar Panel in the system. To charge the battery, a solar panel with a maximum current of 1A was used. The energy system is intended to supply 220V alternating current from a 12V DC source provided by the battery. As an auxiliary backup, a maximum-power rechargeable battery is used, allowing the system to supply power to the load when necessary. The goal was to produce conventional fuel from unusual sources.

For this purpose, an IC 3524-based (pulse width modulator) circuit was designed, which can run on a 12V sealed maintenance-free battery and thus provide an uninterruptible power supply.

TABLE I. Short Literature Review comparison

System Configuration	Motor Type	Output Power	Remarks
Motor Powered by 12V Battery [4]	DC Motor	1kVA	No flywheel
Motor Powered by 12V Battery [5]	DC Motor	5kVA	No flywheel
Motor Powered by 12V Battery [6]	DC Motor	2kVA	No flywheel
Motor Powered by 12V Battery [7]	DC Motor	1kVA	No flywheel

III. MATERIAL AND METHODS

3.1. Material

This system was designed with essential components such as AC Motor, Alternator with Automatic Voltage Regulator (AVR) and Digital Voltage Display Unit, Flywheel, Metal Supporting Base, Connecting Cables, Conveyor Belts and other basic accessories and ancillaries.

3.2. Methodology

The electromechanical device (alternating current motor) used to replace the internal combustion engine of the conventional generator is designed in such a way that it uses less power than the alternator power output, so that one can still have an adequate Power left to power home appliances and other industrial tools. This is the main ideology behind the development of fuel less generator. The generator was built by assembling a centralized flywheel in between a 5KVA alternator and 2hp AC motor that act as a prime mover to the synchronous machine. The motor was powered by a single phase 220V power source. The alternator works on the principle of Faraday's Laws of electromagnetic induction to generate an induced electromotive force (EMF) whenever the magnetic flux linked with a circuit changes at time interval (t) according to [8]. The alternator rotor was the conductor placed in the magnetic field of the stator which was linked together by magnetic flux, and the rotational force was applied to the rotor by the prime mover.

3.3. System Design:

The design parameters of the motor, alternator and flywheel are shown in i, ii, and iii respectively. Moreover, the overall system capacity is 5kVA.

i. *Motor*
- Input voltage – 220V
- Input current – 5.22A
- Frequency – 50Hz
- Output power – 2hp or 1.492kW
- Speed – 1,800rpm
- Torque – 15.824Nm

ii. *Alternator*
- Apparent power – 5kVA
- Real power – 4.25kW
- Power factor (p.f) – 0.85
- Output voltage of alternator – 220V

iii. *Flywheel*
- Weight of Flywheel – 60kg
- Density of Flywheel Material (Steel) – 7,800kg/m^3
- Volume of (Steel) in Flywheel – 0.0077m^3
- Random Thickness of the Flywheel – 0.1m
- Round area of the side of the flywheel – 0.077m^2
- Radius of Flywheel – 0.157m
- Diameter of Flywheel – 0.314m
- Moment of inertia for a cylinder Flywheel – 0.739kgm^2
- Angular Acceleration – 3.407$^{rev}/_{s^2}$
- Time taken to accelerate Flywheel to Motor Rated Speed – 8.81s
- Kinetic Energy of the Flywheel at Full Speed – 36.3kJ

The output power of the proposed system is given by the following expression;

5kVA x Power factor = output real power, thus,
= 4,250W or 4.25kW.

The following Mathematical equations were derived with respect to this study for Motor and Alternator:

3.4. Electric Motor

i. *Motor Speed:*

Synchronous motors are designed to be operated at a synchronous speed, which is deduced as in eqn. (1).

$$S = \frac{120f}{N_p} \qquad (1)$$

Where,

S Represents the synchronous speed in revolution per minute (rpm)

f is the voltage Frequency

N_p is the motor's number of Poles

ii. *Motor Voltage:*

$$V = E_b + I_a(R_a + JX_s) \qquad (2)$$

Where,

Chapi Jonah, Nasiru Aliyu, O. L. Daniyan, Ezeugwu C. Benneth, Egbujor C. Onyema, Okala A. Paul, Omeje N. Felix, Enete O. Christian, Obi N. JohnPaul, Obetta T. Nnamdi, Ezenwa N. Loveth, Eze E. Emmanuel, Okafor S. Chukwuma, Eze. Ndubuisi, and Ademu U. Seidu, "Development and Testing of an Improvised Fuel-less Motor-Generator system as Energy Optimizer," *International Research Journal of Advanced Engineering and Science*, Volume 8, Issue 2, pp. 106-111, 2023.

International Research Journal of Advanced Engineering and Science
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V is the Applied Voltage, E_b is the Back emf, I_a is the armature current, while R_a and X_s are Armature resistance and synchronous reactance respectively.

iii. Motor Resultant Voltage:

This can be defined as the magnitude of voltage difference between applied voltage V and the back EMF E_b.

$$E_R = V - E_b \quad (3)$$

Substituting for V in eqn (3) from eqn (2)

$$E_R = I_a(R_a + JX_s) \quad (4)$$

iv. Internal Angle:

This is the angle by which armature resultant voltage E_R leads the armature current I_a or armature current I_a lags the armature resultant voltage E_R . Internal angle is represented by the tangent of the angle θ.

$$Tan\theta = \frac{X_s}{R_a} \quad (5)$$

v. Back Electromotive Force (EMF) Generated:

$$E_b = K_a \varphi_a S \quad (6)$$

Where,

K_a Stands for constant of the armature winding, φ_a stands for magnetic flux per pole of the motor rotor, while S is the synchronous speed.

Substituting for S in eqn. (6) from eqn. (1), back EMF can also be derived as in eqn. (7),

$$E_b = \frac{120 K_a \varphi_a f}{N_p} \quad (7)$$

***vi.** Motor Input Power:*

The electrical input power of a single phase synchronous motor is given by;

$$P_{in} = VI_a Cos\theta \quad (8)$$

Where,

θ is the angle between applied voltage and armature current

vii. Mechanical Power in Motor Rotor:

$$P_{mech} = E_b I_a Cos(\alpha - \theta) \quad (9)$$

$$P_{mech} = P_{in} - I_a{}^2 R_a \quad (10)$$

$$P_{mech} = T_g S \quad (11)$$

Where,

α is the output load angle between V and E_b, θ is the angle between V and I_b, T_g is the gross Torque produced by the motor, while S is the motor rpm.

viii. Motor Torque:

The gross Torque (T_g) produced by the motor can be gotten by dividing the total mechanical power with synchronous speed. Thus;

$$Torque(T_g) = \frac{P_{mech}}{S} \quad (12)$$

$$T_g = \frac{E_b I_a N_p}{120 f} \quad (13)$$

Torque can also be gotten from eqn. (6) by substituting E_b in eqn. (13)

$$T_g = K_a \varphi_a I_a \quad (14)$$

3.5. Alternator:

i. Output Electrical Frequency and Speed:

Alternator electrical Frequency and speed can be deduced as in eqn. (15).

$$F_E = \frac{N_r P}{120} \quad (15)$$

Where,

F_E represents the electrical frequency (Hz)

P is the number of poles

N_r is the alternator's rotor speed

ii. Alternator Voltage:

$$E_a = K_c \varphi_r N_r \quad (16)$$

Where,

K_c is the constant representing the construction of generator, φ_r stands for magnetic flux per pole of the rotor, while N_r is the rotor's synchronous speed.

$$V_\varphi = E_a - R_a I_a - jX_s I_a \quad (17)$$

Where,

V_Φ is the Applied Voltage, E_a is the Back EMF, I_a is the armature current, while R_a and X_s are Armature resistance and synchronous reactance respectively.

iii. EMF Equation of Alternator:

The EMF value for a single phase alternator is deduced from eqn. (18 and 19)

$$V_{RMS} = 4.44 f\phi T \quad (18)$$

Actual generated single phase voltage

$$V = 4.44 K_c K_d f\phi T \quad (19)$$

Where,

V is the generator Voltage for a Single Phase Alternator K_c is for pitch factor, K_d stands for distribution factor, f is the frequency and T is the number of turns.

iv. Alternator Input Power:

The alternator input power is given by;

$$P_{in} = T_{app} \omega_r \quad (20)$$

Where,

T_{app} is the torque applied and ω_r is the mechanical speed of the rotor

v. Converted Power:

$$P_{con} = T_{ind} \omega_r = 3E_a I_a Cos\gamma \quad (21)$$

vi. Output Power:

$$P_{out} = 3V\varphi I_a Cos\theta \quad (22)$$

Where,

Chapi Jonah, Nasiru Aliyu, O. L. Daniyan, Ezeugwu C. Benneth, Egbujor C. Onyema, Okala A. Paul, Omeje N. Felix, Enete O. Christian, Obi N. JohnPaul, Obetta T. Nnamdi, Ezenwa N. Loveth, Eze E. Emmanuel, Okafor S. Chukwuma, Eze. Ndubuisi, and Ademu U. Seidu, "Development and Testing of an Improvised Fuel-less Motor-Generator system as Energy Optimizer," *International Research Journal of Advanced Engineering and Science*, Volume 8, Issue 2, pp. 106-111, 2023.

International Research Journal of Advanced Engineering and Science
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T_{ind} is the Torque induced in rotor

vii. Voltage Regulation:

$$VoltageRegulation = \left(\frac{V_{nl} - V_{fl}}{V_{fl}}\right) \times 100\% \qquad (23)$$

Where
V_{nl} stands for Voltage at no load, while V_{fl} is the voltage at full load

viii. *Efficiency:*

$$\eta = \left(\frac{P_{out}}{P_{in}}\right) \times 100\% \qquad (24)$$

$$P_{in} = P_{out} + P_{cu} + P_{iron} + P_{mech} + P_{stray} \qquad (25)$$

Where
η is the generator efficiency, P_{in} is the input Power, P_{out} is the Output Power ,P_{cu} is the copper loss, P_{iron} is the iron loss, P_{mech} is the mechanical Power while P_{stray} is the stray loss.

The flowchart for the modeling and implementation of this system is shown in Fig. 1 below;

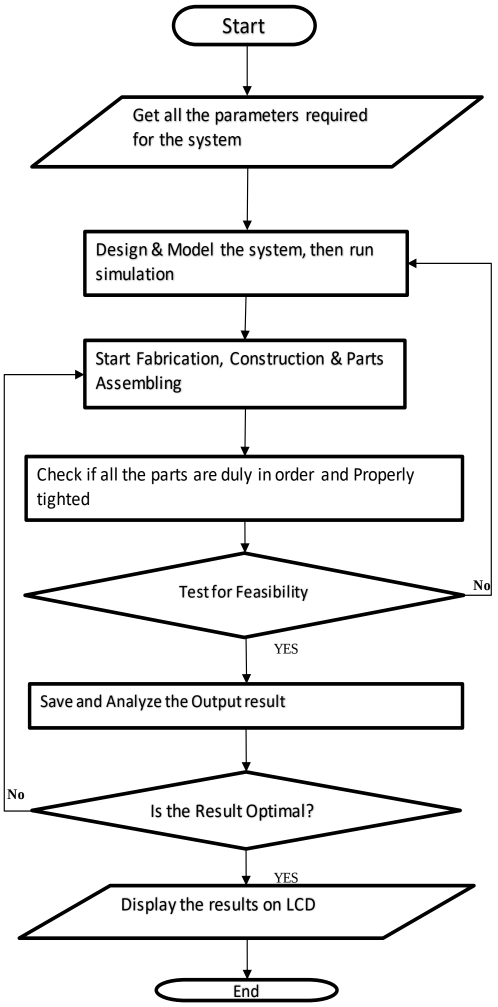

Figure 1. Flowchart for System Design

3.6. Study on Model Development and System Characteristics

This paper was modeled using two different case studies: (1) direct connection to the grid without a fuel-less energy optimizer, and (2) connection with an energy optimizer. The primary goal of these two cases is to compare energy consumption and the economic impact of the Fuel-less Energy optimizer system.

IV. Construction, Testing and Results

The fuel-less generating Energy optimizer was built by connecting the system's various components. First, a flywheel was machined and built to connect the electric motor to the alternator. Then, various holes were bored for coupling the electric motor, alternator, flywheel pulley bolts, and nuts. Following that, the various components were assembled in the prefabricated main frame. Appropriate cabling and terminations were used, and the electric motor was connected to the power source's equivalent terminals. The output terminal was connected to the alternator's output. The construction stage is depicted in pictorial form in Figure 2.

Figure 2. construction stages with materials used

The results were obtained by using a digital multimeter to measure the output voltage and current of various loads while using a fuel-less Energy Optimizer versus a direct supply from the grid, which formed a Power data table over a period of 20 minutes. Table II shows the ratings of the various pieces of equipment used as loads in this study.

TABLE II. Rating of different Loads used in testing this study

S/N	Items	Load (Watt)	Load (VA)	Curr (A)	Volt (V)	PF
1	Drilling Machine	900	924	4.2	220	0.97
2	Cutting Machine	2,100	2,134	9.7	220	0.98

Chapi Jonah, Nasiru Aliyu, O. L. Daniyan, Ezeugwu C. Benneth, Egbujor C. Onyema, Okala A. Paul, Omeje N. Felix, Enete O. Christian, Obi N. JohnPaul, Obetta T. Nnamdi, Ezenwa N. Loveth, Eze E. Emmanuel, Okafor S. Chukwuma, Eze. Ndubuisi, and Ademu U. Seidu, "Development and Testing of an Improvised Fuel-less Motor-Generator system as Energy Optimizer," *International Research Journal of Advanced Engineering and Science*, Volume 8, Issue 2, pp. 106-111, 2023.

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V. Analysis And Conclusion

5.0 Analysis of the Case Study:

In this case study, a drilling machine and a cutting machine with power ratings of 900W and 2,100W respectively, were connected directly to the utility grid without the energy optimizer system, and their power consumption readings were taken over a twenty-minute period. The system was then disconnected and reconnected with the energy optimizer set between the grid and the load. It was discovered that during trial period, the first case consumed an energy unit of 3,000Wh or 3kWh, while the second case consumed 1,492Wh or 1.492kWh. This result was obtained while running the equipment at full capacity. The power input and output of the two scenarios were also measured using a digital instrument. The power consumption of each load in the two case-studies was measured every four minutes for a total of twenty minutes. The results obtained are shown in Table III below, while Fig. 3 depicts the case comparison.

TABLE III. Results of energy consumption between two case studies

S/N	Time Interval	Energy Consumption with Fuelless Generating System (Wh)	Energy Consumption without Fuelless Generating System (Wh)
1	4 minutes	99.46	200
2	8 minutes	198.93	400
3	12 minutes	298.40	600
4	16 minutes	397.86	800
5	20 minutes	497.30	1000
	Total Power	**1,492 (Wh)**	**3,000 (Wh)**

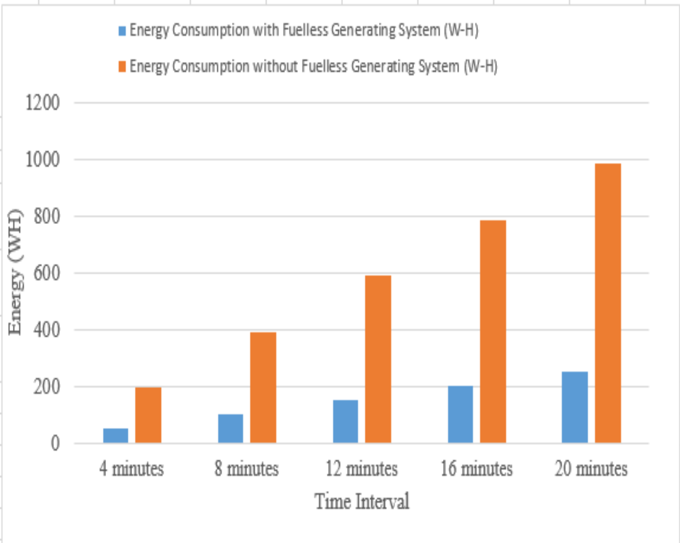

Figure 3. Energy Consumption Comparison between Case 1 and Case 2

Similarly, from an economic standpoint, the amount of money spent via direct grid connection without a fuelless energy optimizer system is three times more than the amount spent while connected to a fuelless energy optimizer system. According to local utility rates, the current cost of energy (COE) for this study is $0.116/kWh. As shown in table IV, fig. 4, and fig. 5, the total cost of the system with direct grid connection is 75% higher than that of system with energy optimizer . This means that the motor-generator fuelless energy optimizer is very economical and saves electricity consumers a lot of money.

TABLE IV. Results showing cost spent on energy between the case studies over 20 mins

N/S	Time Interval	Energy Cost ($) with Fuelless Generating System	Energy Cost($) without Fuelless Generating System
1	4 minutes	0.0058	0.0228
2	8 minutes	0.0116	0.0456
3	12 minutes	0.0174	0.0684
4	16 minutes	0.0232	0.0913
5	20 minutes	0.0290	0.1141
Total Cost Spent		**0.087**	**0.3422**

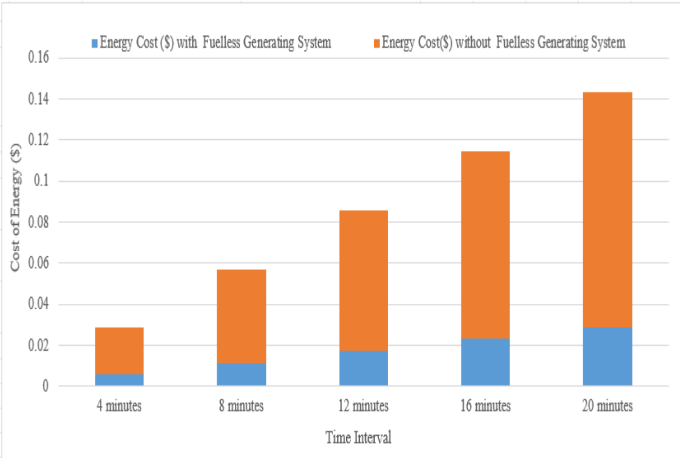

Figure 4. Comparison of energy cost between the cases

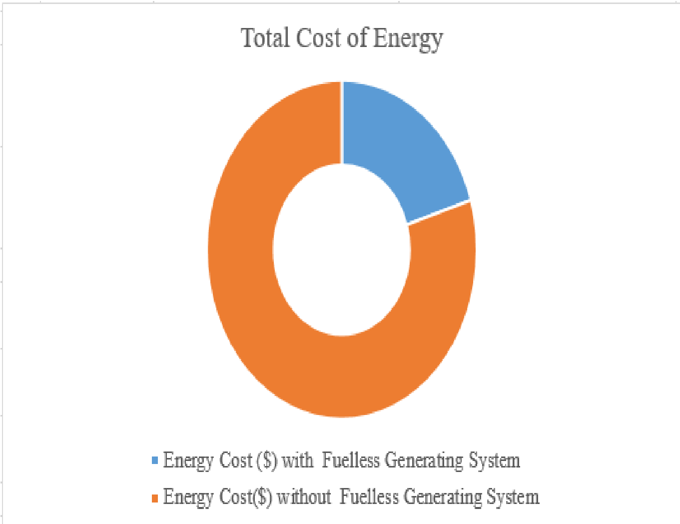

Figure 5. Comparison of total cost incurred during the testing period

VI. Conclusion

In wrapping up this study, it is inferred that steady power supply together with minimum energy consumption and power management could be the only solution to solving Nigerian poor economic problem. Also, it is on the known that a good number of health issues and challenges associated with air pollution in Nigeria are quite colossal and ample attention should be in place to curtail this menace. Air pollution resulting from vehicles and other mechanical emissions like generating sets, climate change and environmental degradations, gas flaring and burning of fossil fuel put together are the root cause of various human ailments. Therefore, carbon free generating set and allied systems such like this Energy optimizer are good steps in the right direction to fight this ugly trend. Again, this research found out that Energy or Power optimizers are highly cost-effective considering the cost of energy recorded against the normal conventional or grid dependent systems. In addition, this system is quite profitable due to the fact that it has zero fuel cost.

Furthermore, it was concluded that this system configuration can be used for domestic and commercial purposes to get optimal energy conservation. The proposed lifetime of this optimizer system is 20years or longer depending on the usage.

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