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Modeling and Economic Assessment of a Hybrid Renewable Energy System for Grid-Connected Applications

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Abstract- The increasing demand for reliable, affordable, and environmentally sustainable electricity has intensified the need for alternative energy solutions that can complement or replace conventional fossil fuel=based power generation. Hybrid renewable energy systems (HRES) have emerged as a viable solution by integrating multiple energy sources to improve system reliability. This study presents the modeling and economic assessment of a grid-connected hybrid renewable energy system comprising photovoltaic (PV) panels, battery energy storage, generator, power converters and the utility grid. The objective is to determine the optimal system configuration capable of meeting the electrical load demand with minimum life-cycle cost while maximizing renewable energy utilization and ensuring high system reliability. The proposed hybrid system is modeled using HOMER pro and MATLAB/Simulink. The system performance is evaluated using key techno-economic indicators, including Net Present Cost (NPC), Levelized Cost of Energy (LCOE), operating cost, renewable energy fraction. The results demonstrate that the optimized hybrid configuration significantly reduces dependence on grid electricity, lowers annual operating costs, increases renewable energy penetration and minimizes greenhouse gas emissions compared with a conventional grid-only supply system. The system gave a least Net Present Cost of ₦8,435,340,000.00, Least Operating cost of ₦13,445,300.00 and Levelized Cost of Energy of ₦10,674.56/KWh the CO2 gas emission was also reduced from 58,040.77Kg/yr to 33,561.00Kg/yr of CO2 emitted representing a 42.18% reduction. The findings highlight the technical feasibility and economic viability of grid-connected hybrid renewable energy systems as a sustainable solution for modern electricity supply. The proposed modeling framework provides valuable guidance for engineers, researchers, policymakers, and energy planners involved in the design, optimization and deployment of renewable energy systems for residential, commercial, industrial, and institutional applications.

I. INTRODUCTION

An essential area of study in renewable energy is the modeling of hybrid energy system. The global demand for electrical energy has continued to increase rapidly due to population growth, industrialization, urbanization, and technological advancements. Reliable electricity has become indispensable for economic development, healthcare education, communication, and industrial productivity. However, many countries, particularly developing nations, continue to experience inadequate electricity supply resulting from aging power infrastructure, increasing fuel costs, transmission losses, and the growing dependence on fossil fuel-based power generation. These challenges have prompted governments, researchers, and energy planners to explore sustainable and environmentally friendly alternatives capable of ensuring long term energy security. Renewable energy technologies have emerged as promising alternatives to conventional fossil fuel energy sources because of their environmental benefits and sustainability. Among the available renewable energy resources, solar photovoltaic (PV) systems have received considerable attention due to their widespread availability and declining installation costs. Nevertheless, these renewable sources are inherently intermittent and highly dependent on weather conditions, making them incapable of providing continuous and reliable power when used individually. To address these limitations, hybrid renewable energy systems (HRES) have been developed by integrating two or more complementary energy sources with energy storage systems and where available, the utility grid. A typical grid connected hybrid renewable energy system combines

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solar PV, wind turbines, battery energy storage, power electronic converters, and the utility grid to achieve improved reliability, enhanced energy efficiency, and reduced operating cost. The integration of battery storage enables excess renewable energy generated during periods of high production to be stored and utilized during periods of low renewable generation or peak electricity demand. Furthermore, the presence of the utility grid provides additional operational flexibility by allowing energy import during shortages and energy export when excess renewable power is available. Beyond improving energy reliability, hybrid renewable energy systems contribute significantly to environmental sustainability by reducing greenhouse gas emissions and dependence on fossil fuels. They also provide economic benefits through reduced fuel consumption, lower operating cost, and improved utilization of renewable resources. Consequently, hybrid renewable energy systems have found extensive applications in residential buildings, hospitals, educational institutions, telecommunication base stations, industrial facilities, agricultural farms, and community microgrids. Although numerous studies have investigated hybrid renewable energy systems, many have focused primarily on isolated off-grid applications or emphasized technical performance without adequately considering comprehensive economic assessment and sensitivity analysis for grid-connected configurations. Moreover, the increasing variability of electricity tariffs, renewable resource availability, and component costs necessitates further investigation into economically optimal grid-connected hybrid systems capable of adapting to changing operating conditions. This study therefore aims to model and economically assess a grid-connected hybrid renewable energy system incorporating photovoltaic panels, battery energy storage, power converters, and the utility grid. The system is modeled in HOMER Pro and MATLAB/Simulink. The economic viability of the proposed system is evaluated using Net Present Cost, Levelized Cost of Energy, operating cost, renewable energy fraction, and carbon dioxide emission. The outcome of this study is expected to provide a practical framework for designing reliable, cost effective and environmentally sustainable hybrid renewable energy systems for grid connected applications.

Nigeria has been faced with electricity shortage. According to Ogujor and Orobor (2018), the utility grid is unreliable with a variation of the range of 39 to 66% in the reliability of the power supply. Whenever the grid is available the supply voltage fluctuates. This consequently gives rise to load shedding, which affects the domestic, commercial and industrial activities which has led to the use of non-renewable energy sources. However, both the economy and the ecology suffer when fossil fuel generators are used. The environment could suffer greatly as a result of the greenhouse effect's propensity to initiate hazardous changes in the climatic condition of the atmosphere change. The use of fossil fuel generators in producing electricity is more expensive than the use of utility grid. According to Adegoke and Babalola (2019), Approximately 78% of the total operating costs of the terrestrial cellular sites are attributable to the costly maintenance and operation of diesel generators. To lessen their dependence on fossil powered sources, nations are incorporating clean energy into their energy strategies. The depletion of fossil fuel supplies, the world's population growth, and the numerous signs of global warming have all increased interest in the use of clean energy sources. Therefore, the cost of running terrestrial cellular sites tends to increase when fossil fuel generators are used.

Achieving quality, scalability, dependability, sustainability, cost-effectiveness, and stability in power supply, whether in off-grid or grid-connected systems, would be greatly aided by the combination of renewable and non-renewable energy sources to create hybrid power systems. Kosai (2019) asserts that the simplest way to reduce the use of fossil fuels is through the adoption of renewable energy sources. In order to address the growing energy demand, environmental challenges, and energy scarcity, power generation-based renewable energy sources can address these issues.

Utilizing hybrid power systems is an alternative and cost-effective way to provide rural communities with improved educational opportunities, standardized mechanized agriculture, sustainable health care systems, and efficient communication channels. The advancement and incorporation of renewable energy sources and clean power systems can help meet future demands for population growth, a decrease of the environmental effects of burning fossil fuels, and a decrease in reliance on fossil fuels for transportation, industry, and commercial and residential buildings.

According to Gbenai, Bettayeb, Brdjanin and Hamid (2019), one significant step toward reducing climate change and ensuring energy security is the use of renewable energy sources.

According to Zhai Wang and Chuang (2019), the use of Diesel Generators (DG) in powering base transceiver stations has proven to be less viable for network companies for the following reasons.

- High fuel and operating and maintenance costs of diesel generators.
- Environmental impact of harmful emissions of gases like carbon dioxide, sulfur dioxide, and nitrogen oxides from diesel fuel, which causes ozone layer depletion, acid rain, genetic mutation, and global warming;
- Global warming is caused by emissions of carbon dioxide (CO_2) gas, a byproduct of fossil fuels.

Infrared radiation (IR) can be trapped in the atmosphere by CO_2. By absorbing the reflected light from the earth's surface, CO_2 creates vibrations. Due to these disadvantages, network operators are now looking for methods to lower operating and capital costs while fostering an eco-friendly system. The BTS system's fundamental power requirements cost-effectiveness, efficiency, dependability, and sustainability can be successfully satisfied by optimizing operating costs and leveraging the numerous technological advancements in renewable energy systems.

Therefore, by lowering harmful gas emissions through cost optimization and the use of clean energy sources, network operators can effect a reduction of their operating costs which will subsequently reduce the impact on the environment. To optimize the benefits of hybrid systems, the BTS stations should use a complex design, control, planning and cost optimization method to save energy and deliver the best services.

Fan, Li, Dong, and Jermsittiparsert (2021), presented a system integrating wind, hydropower, and photovoltaic systems. Maximizing power generation and minimizing energy fluctuations in electricity generation were the goals of their study. In order to tackle the optimization challenge, they used three applications in their investigation.

In order to sustainably operate a remote cold storage facility for underdeveloped nations, Kanti and Ganguly (2021) investigated a hybrid power system based on solar and hydrogen. The proposed system includes a stack of proton exchange membrane fuel cells, an array of solar photovoltaic modules, an electrolyzer bank, compressed hydrogen storage, and an array of parabolic trough collectors with short-term thermal storage to meet the thermal and electrical needs of a standalone multi-commodity cold storage.

De Campose et al. (2021) evaluated the impact of installing floating PV electricity in the massive Sobrinho hydrogen plant reservoir in Brazil, which is situated in the Sao Francisco River, between 2009 and 2018. From 50 to 1000MW, the installed PV power capacity was modified in the simulated scenarios. A number of these investigations were carried out with software for hybrid system design, sizing, optimization, and functional control.

The ozone layer is being destroyed as a result of excessive fossil fuel use, which has caused environmental crises. Adoption of hybrid energy sources that are renewable is therefore crucial. But because of their sporadic nature, these energy sources struggle to supply the system's long-term energy requirements. They recommended using a hybrid energy system in their conclusion. To lower the energy consumption of the terrestrial cellular hybrid energy system, several authors have used a variety of techniques.

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Rinaldi, Moghaddampor, Najafi, and Marchesi (2020) used HOMMER to model the system using Systems with single, independent, and hybrid components to determine the ideal system size by taking into account the setup with the lowest operating costs, least Cost of Energy (COE), and least amount of CO2. Their results indicate that the best configuration was the Solar-Wind-Diesel system. Economic index is typically taken into consideration when choosing the objective function for certain configuration studies.

The input data set was obtained from a hybrid renewable energy system powering a Terrestrial Cellular Base Transceiver Station in Aba with the station name AB 8946. The data set were collected for a period of one year

Table 1 depicts the yearly energy data set while Table 2 depicts the yearly load profile. Table 3 depicts the summary of all the modeling result of the techno-economic analysis of the test hybrid energy system over the system lifetime of 25 years.

The hybrid system components comprise of the PV panels, The Diesel Generators, Converters, Charge Controllers and Batteries. The PV panels, Batteries and DG were combined to provide the output system. The Panel capacity is 6KW and the site has16 panels. The Battery capacity is 200AH, 24V. The load requirement of the BTS is 165.59KWh/day, giving a total of 60,440.35KWh/yr. The total number of batteries in the site is 16 while the Generator is a 25KVA Mikano sound proof Generator. The Converter is a 40KW, 480V DC, 50Hz bi-directional converter.

Table 1 Yearly Energy Data Set from Aba Hybrid Station

QUANTITY	VALUE
Total Grid Run Hour	48.73h/yr
Total Grid KWh/yr	268.23KWh/yr
Total Generator Run Hour	4,043.77h/yr
Total Generator KWh/yr	21,606.96KWh/yr
Total Generator Working Hour	4,054.01 h/yr
Total Battery Run Hour	2,726.1h/yr
Total Battery Charge KWh	10,025.49KWh/yr
Total Battery Discharge KWh	8,268.8KWh/yr
Total Solar Run Hour	69.86 h/yr
Total Energy Surplus KWh	1,064.31 KWh/yr
Total Fuel Consumption	11,609.59 L/yr
Total Fuel Consumption Rate	798.76 L/h/yr
Total AC Supply KWh	22,356.69 KWh/yr
Total DC Supply KWh	KWh/yr
Total Power Usage Effectiveness	1,227.63
Total Electric Production	30,820.11KWh/yr
Total Solar KWh/yr	652.08KWh/yr
Total Fuel Cost	#94,066,245
Total CO_2 Gas Emissions	57,352.03Kg

Table 2 Yearly Load Profile from Aba Hybrid Station

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Table 3. Cost Values of the Modeled Hybrid Energy System

COMPONENT	CAPITAL COST OF COMPONENT (₦)	COMPONENT LIFETIME (YRS)
PV SYSTEM	5,472,000	25
BATTERY	2,400,000	10
CONVERTER	1,450,000	10
GENERATOR	2,500,000	
CAPITAL COST	8,271,909,947.5825	

Economic and Environmental Impact Assessment

2.1.1 Carbon Emissions

The ecological footprint of the hybrid energy system is evaluated by calculating the carbon emissions associated with each energy source.

$$CO_2\ Emissions = Egen(t) \times CO_2\ Emissions\ Factor \quad (1)$$

Where:

- Emission Factor = emission rate per unit of energy generated by the fossil fuel generator.

The mass of CO_2 emission is calculate using CO_2 emission rate of 2.68 Kg/KWh of Electrical power generated by the Generator and 0.5Kg/KWh of Energy generated by the utility grid. (Oti and Lewachi, 2017)

Where the mass of CO_2 emitted is given by

Mass of CO_2 emitted = 2.68 x KWh of E_{gen} + 0.5 x KWh of E_{grid} (2)

The diesel cost is calculated based on the unit cost of a liter of diesel as #1,300.

Where the cost of diesel consumed is given by

Cost of diesel Consumption = Liters of diesel Consumed x ₦1,300 (3)

The mass of CO_2 gas emitted is modeled in figure 1.1

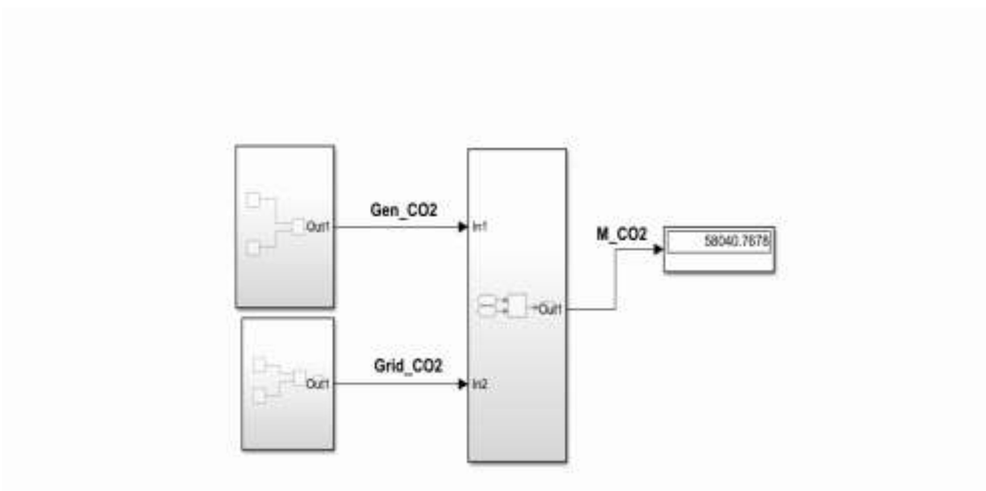

Figure 1 Modeling of the mass of CO2 liberated in the Hybrid Energy System

The model consists of the grid and the generator. In the model, the amount of CO2 emitted from the generator and the Grid are calculated and sum together by applying the formula stated in equation (2) . The sum block is used to add the two values together to generate the total amount of CO2 emitted.

From the modeled system, the mass of CO2 emitted from both the gennerator and grid was 58,040.7678kg/yr.

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2.2 Net Present Cost (NPC)

The net present cost (NPC) which is referred to as the life-cycle cost. It is computed by deducting the present value of all installation and operating costs from the present value of all revenues the component is expected to generate over its lifetime. It is expressed as

$$NPC = C_{investment} + OM_{npv} + R_{npv} - S_{npv} \quad (4)$$

Where

$C_{investment}$ = the capital cost of investment

OM_{npv} = the operation and maintenance cost

R_{npv} = the replacement cost

S_{npv} = the salvage value

The OM_{npv} is modeled using the formula

$$OM_{npv} = F_I \times OC \times \left[\left(\frac{1+F_e}{d-F_e}\right) \times \left(1 - \left(\frac{1+F_e}{1+d}\right)^N\right)\right]$$

(5)

F_I = percentage of Initial Cost (5%)

F_e = rate of cost increase assumed to be 5%

D = Discount rate, assumed to be 7.88%

N = Number of years (25 years)

OC = Capital Cost of Investment

The replacement cost is given by

$$R_{npv} = P \times (1 + i)^N \quad (6)$$

Where

P = Initial Capital Cost for replaced Component

i = Rate of interest assumed as 7.88%

N = System life period =25 Years. The salvage value is given by

$$S_{npv} = R_{npv} \times \frac{R_{rem}}{N} \quad (7)$$

Where

Rnpv = Replacement cost

R_rem = Remaining life of the component at the end of the system's lifetime.

N = System life period =25 Years. (Adeyeye et al 2018)

The remaining life of the component is given by

$$R_{rem} = L_C - (N mod L_C) \quad (8)$$

Where

R_{rem} = Remaining life of the component at project end

L_C = Lifetime of the component (years)

N = project/system lifetime

Therefore, for the converter with a lifetime of 10 years, Rrem = 10 -(25mod10) (9)

$R_{rem}$for converter = 10 -5 = 5

Similarly for the battery storage, with a lifetime of 10years

R_{rem} for battery = 10 -(25mod10) = 5 (10)

For the PV system with a lifetime of 25 years,

R_{rem} for PV system = 25 -(25mod25) = 0 (11)

The remaining life of the PV system is zero because the lifetime of the PV system is the same as the project lifetime which is 25years. Hence the PV system has no replacement cost. These values are modeled in the formulae to obtain the salvage value which is subsequently used to model the Net present cost of the hybrid system station. The cost parameters obtained from the modeled system test station is given in table 3

In modeling the Net Present Cost of the system, we first model the replacement cost of the various system components like the battery, converter, the total operation and maintenance cost as well as the total replacement cost of all the system components and finally the salvage value of the hybrid system. Figure 2 depicts the MATLAB/Simulink model of the hybrid energy system for the total replacement cost, total operation and maintenance cost, salvage value and replacement cost for some key system components.

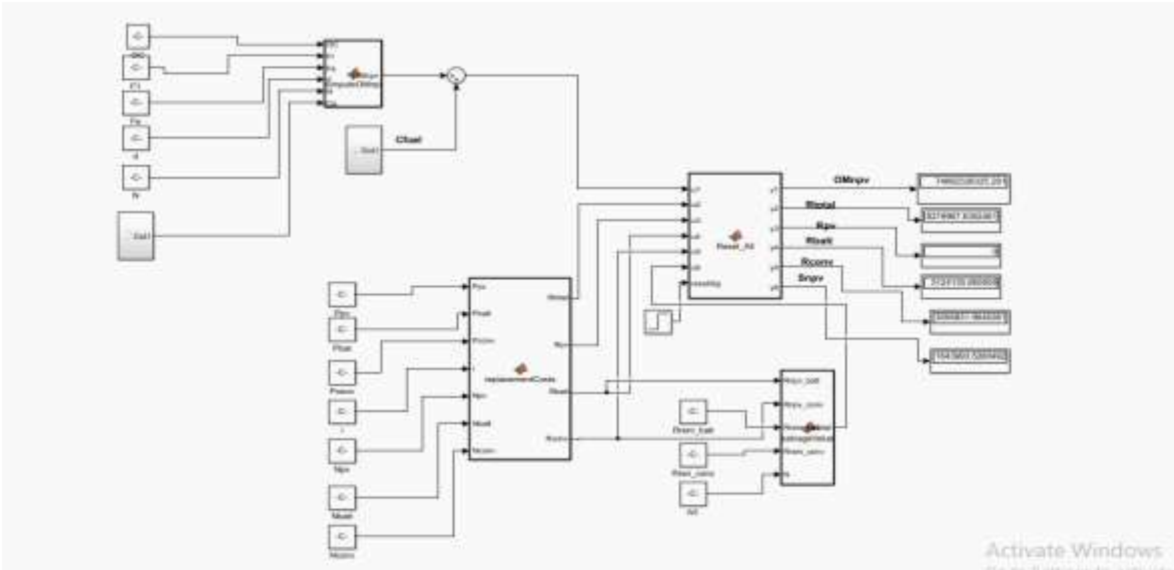

Figure 2 Hybrid Energy System Model for Calculating Replacement Cost and Total Operation and Maintenance Cost

The total operational and maintenance cost accounts for the periodic expenses incurred in ensuring system reliability and performance. The simulation yielded a total operational and maintenance cost of ₦74,862,326,325.29 over the 25 years project lifetime. The total replacement cost quantifies the cumulative expenditure associated with the component replacement from the simulation; the total replacement cost was estimated at ₦8,219,967.63. The battery subsystem also experiences performance degradation due to frequent charging and discharging cycles and temperature fluctuations. The battery has a lifetime of 10 years. The simulation results indicate a battery replacement cost of ₦5,124,135.67. The salvage value from the result of the simulation stood at ₦1,643,993.53. Similarly, the power electronic converter plays a crucial role in bidirectional power flow control between the DC bus, the battery and the load with. The converter replacement cost was obtained as ₦3,095,831.96

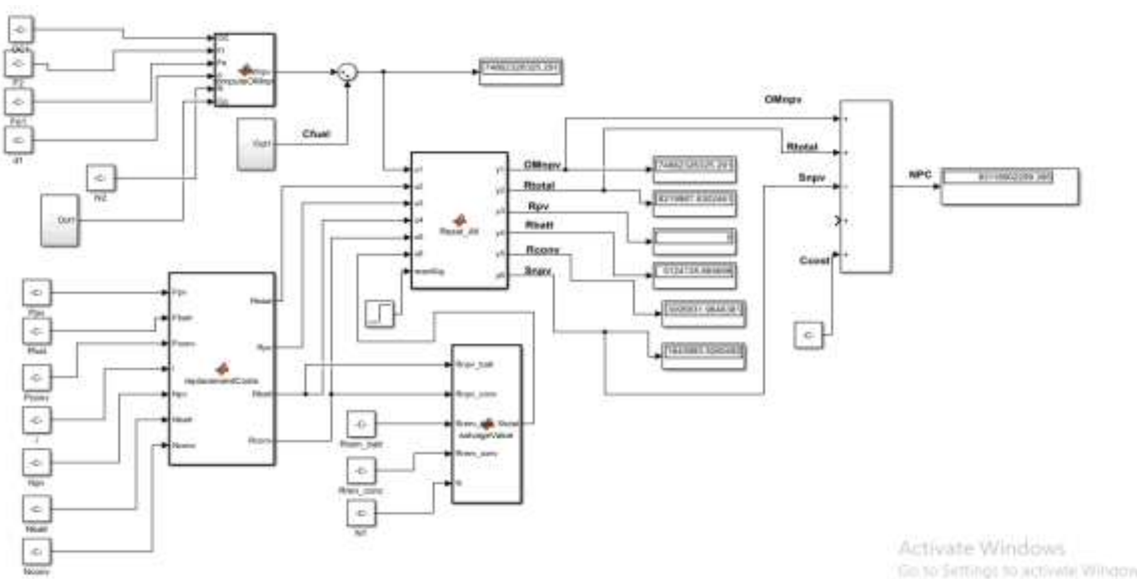

Figure 3 Hybrid Energy System Model for Calculating the Net Present Cost (NPC)

Figure 3 depicts the hybrid energy model for calculating the Net Present Cost. The Net Present Cost represents the total cost incurred throughout the lifetime of the hybrid energy system, expressed in present value. It is a key economic indicator used to assess the long-term financial feasibility and cost-effectiveness of the system configuration. The NPC accounts for all capital, replacement, operation and maintenance and fuel costs minus the discounted salvage value. The MATLAB/Simulink simulation yielded a Net Present Cost of ₦83,118,902,299.40. This high cost in NPC was as a result of the high cost of fuel used in running the hybrid energy station.

2.3 Levelized Cost of Energy (LCOE)

Several cost objective functions, including Levelized Cost of Energy (LCOE), Lifecycle or Net Present Cost, and the Annualized Cost, have been established in the past to be minimized. The Levelized Cost of Energy is the price of solar-generated electricity over the lifespan of the PV system; it is the present value of the entire cost of building and operating a power plant over an estimated lifetime; it allows for the comparison of various technologies (such as wind, solar, and natural gas) with varying lifespan and project sizes. The goal of optimizing hybrid energy systems is to minimize costs while taking into account a number of constraints in order to meet energy demand.

The levelized Cost of Energy is essentially the Cost of Energy and is expressed as

$$LCOE = \frac{Total\ annualize\ cost}{Total\ Energy\ served} = \frac{Totalnetpresentcost}{\sum_{t=1}^{T} P_{Load\,(t)}} \text{ X CRF} \quad (12)$$

Where

Annualize cost = Total cost x CRF

CRF = the total recovery factor which is given by

$$CRF = \frac{i(1+i)^N}{i(1+i)^N - 1} \quad (13)$$

Where

i = the interest rate (Discount rate = 7.88%)

N = System life period =25 Years. (Oti and Lewachi, 2017)

The levelised cost of energy for the hybrid energy system was modeled in Matlab/Simulink and shown in figure 4.

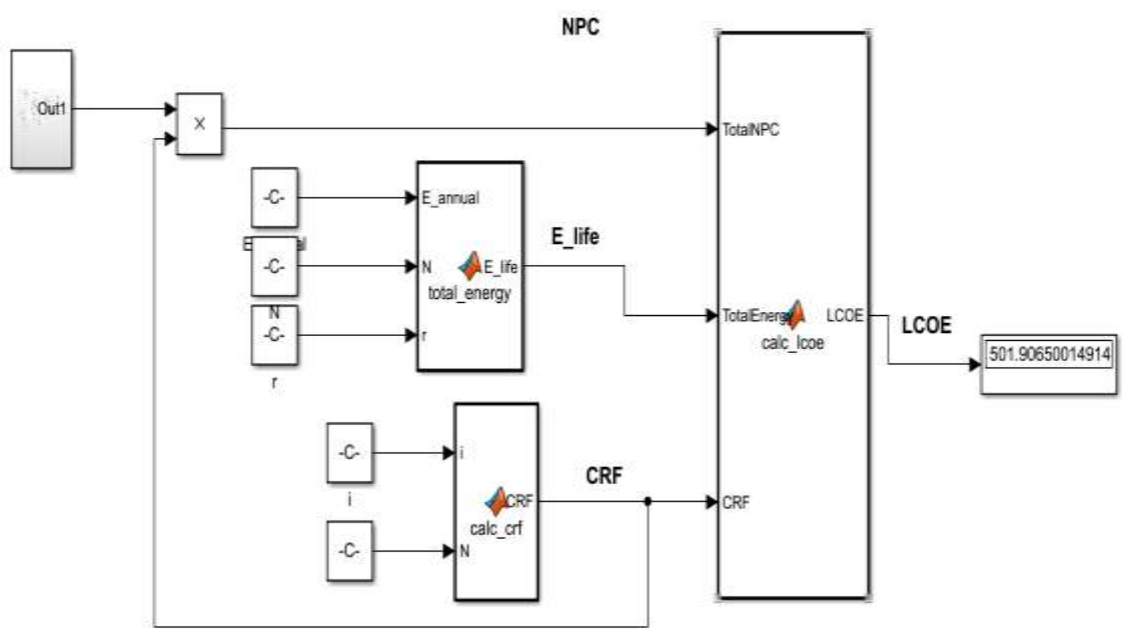

Figure 4 Hybrid Energy System Model for calculating the Levelized cost of Energy

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Figure 4 depicts the Simulink model for calculating the Levelized cost of energy. The LCOE represents the average cost of generating one kilowatt hour (KWh) of electricity over the entire lifetime of the hybrid energy system. The result of the simulation gave an LCOE of ₦501.91/KWh. The result indicates that integrating solar PV with battery storage and grid support significantly reduces long-term energy costs while ensuring reliability and sustainability. The relatively moderate LCOE is attributed to

i. High solar contribution reducing fuel dependency
ii. Optimized battery operation minimizing generator runtime
iii. Stable operation and maintenance costs over the project lifetime.

2.4 Cost of Operation

The total cost of operation is given by

$$\text{Total operation cost} = C_{fuel} + C_{O\&M} + C_{rep} + C_{penalty} - C_{rev} \quad (14)$$

Where

C_{fuel} = cost of fuel

$C_{O\&M}$ = cost of operation and maintenance

C_{rep} = cost of replacement

$C_{penalty}$ = penalty cost for unmet load

C_{rev} = revenue generated from sale of electricity

The cost of fuel is given by

$$C_{fuel} = \sum_{t=1}^{T_{project}} \frac{F_{rate} \times P_{fuel} \times H_{opt}}{(1+r)^t} \quad (15)$$

Where

F_{rate} = Fuel consumption rate (Litres/h) =798.76L/h/yr

P_{fuel} = Price of fuel (₦/litre) = ₦1000/litre

H_{opt}= Generator operating hours =4,043.77h/yr

r = Discount rate =7.88%

Thus applying the formula

$$C_{fuel} = \sum_{t=1}^{T_{project}} \frac{F_{rate} \times P_{fuel} \times H_{opt}}{(1+r)^t} = \sum_{t=1}^{T_{project}} \frac{798.76 \times 1000 \times 4043.77}{(1+r)^t} \quad (16)$$

$$C_{fuel} = \sum_{t=1}^{T_{project}} \frac{3230001725.2}{(1+r)^t} \quad (17)$$

$$C_{fuel} = \sum_{t=1}^{T_{project}} \frac{F_t}{(1+r)^t} \quad (18)$$

Where

F_t = Annual fuel cost = ₦3,230,001,725.2/h/yr

The cost of operation is modeled in Matlab/ Simulink and is shown in figure 5

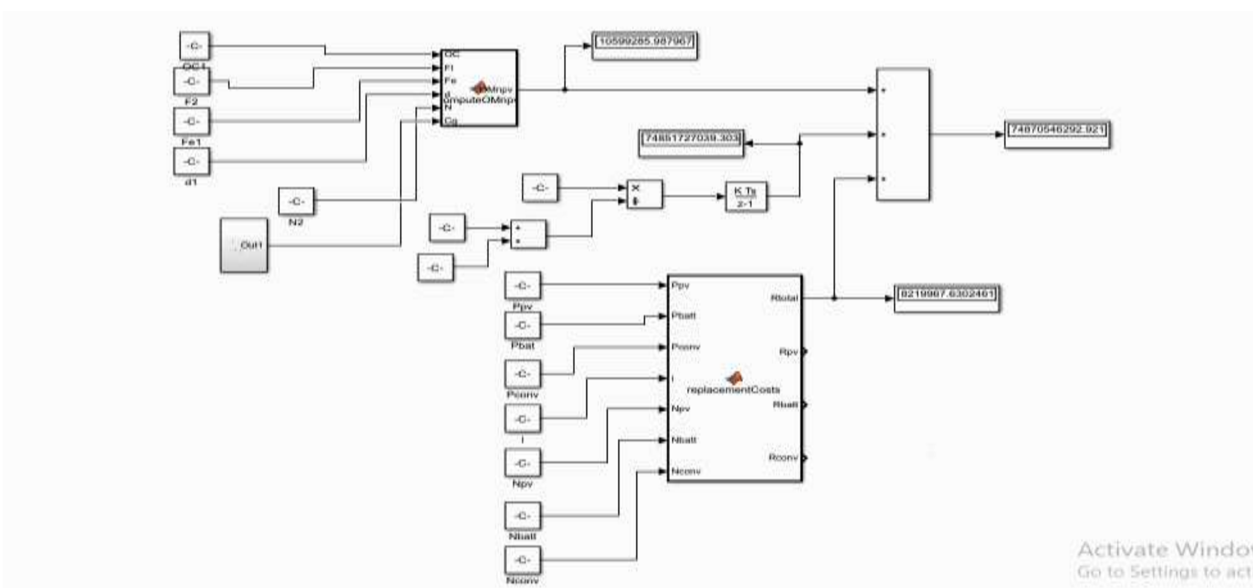

Figure 5 Modeling of the Cost of Operation of the Hybrid Energy System

The result of the simulation indicates that the annual fuel cost was ₦3,230,001,725.2/h/yr. Thus, simulating this fuel cost over the system lifetime of 25 years gave a fuel cost of ₦74,851,727,039.30, while the cost of operation stood at ₦74,870,546,292.92. Also, the total replacement cost of the components was ₦8,219,967.63.

3.1 Simulink Model of the Hybrid Energy System

The Simulink model of the hybrid energy system is shown in figure 6.

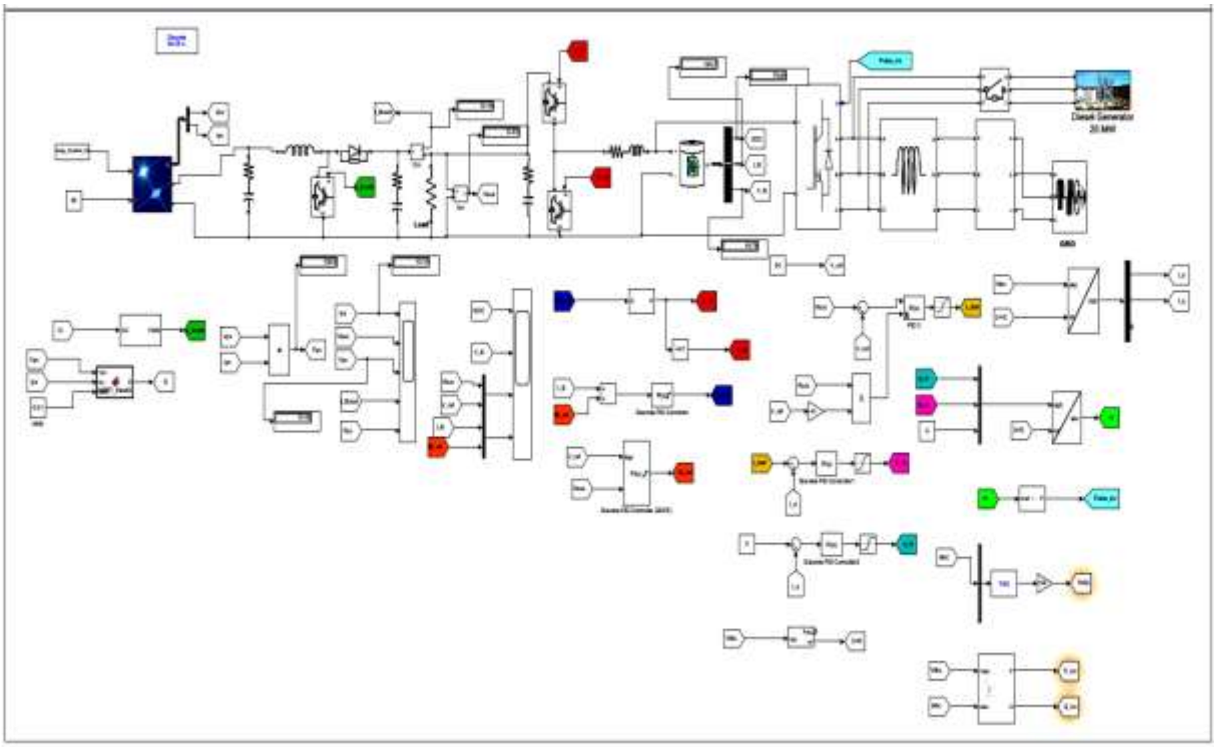

Figure 6 Simulink Model of the Hybrid Energy System

The simulated hybrid energy system comprises the following key components.

i. A photovoltaic (PV) array
ii. DC to DC Converter
iii. Battery Energy Storage System
iv. Bidirectional DC to DC converter for the charging and discharging of the battery
v. An inverter
vi. The Grid system
vii. An auxiliary Diesel Backup Generator.

This configuration enables optimal energy management between generation, storage and grid support while ensuring DC bus voltage stability. The DC bus serves as the central power exchange node between the generation units, storage system, and load. Each subsystem is interfaced to the DC bus through appropriate power electronic converters to achieve efficient energy conversion and control. The system operates on a hierarchical energy management strategy with the following power supply priority.

During daylight conditions, the PV array supplies power directly to the load. Any excess generation is used to charge the battery. When the PV output is insufficient to meet the load demand, the grid automatically supplements the power deficit maintaining supply continuity. When both the PV generation and grid supply are unavailable (e.g, grid outage at night), the battery discharges through the bidirectional converter to sustain the load until its SOC reaches the lower limit. The generator starts only when the battery is depleted below the critical SOC level and both PV and grid are unavailable. This ensures energy reliability while minimizing fuel consumption and emissions.

3.2 Transient Simulation Observation.

The result of the hybrid system model simulation is shown in figure 7 and 8

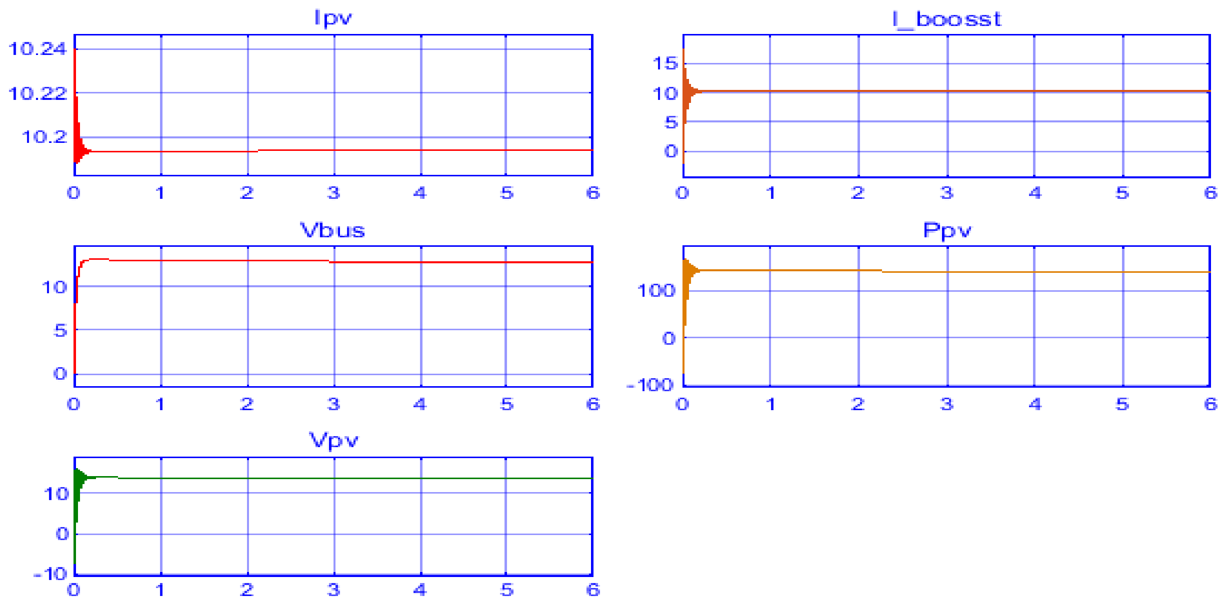

Figure 7 Hybrid Model Result of Bus Voltage, PV voltage, PV Current and Power

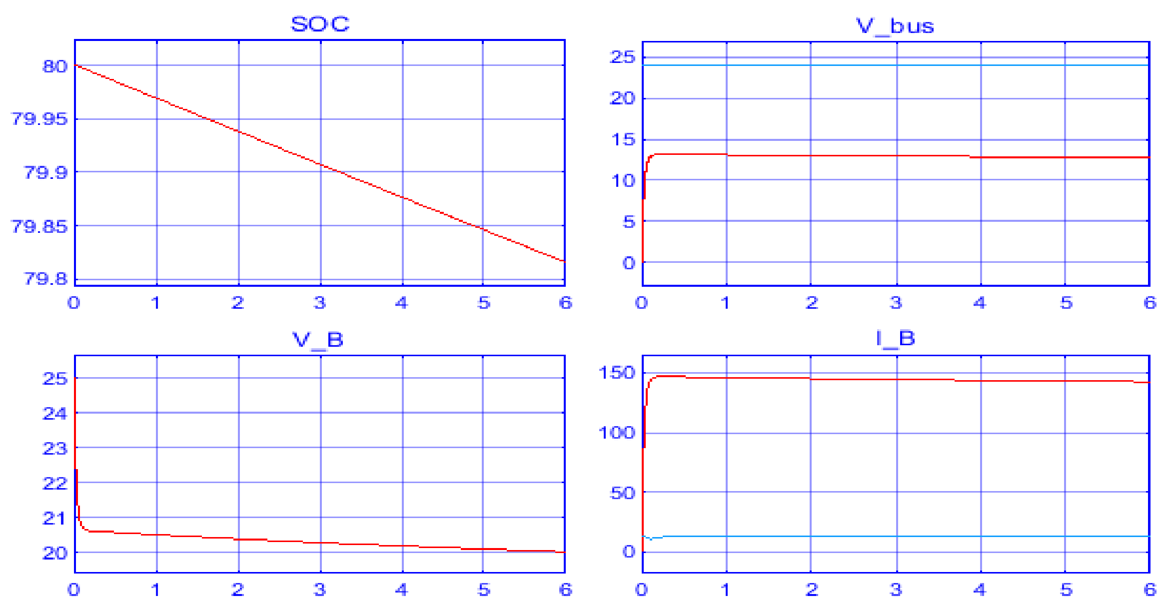

Figure 8 Hybrid Model Result of Battery Voltage, Battery Current and Battery state of charge

The system was subjected to a step change or initial load/generation condition and the following key metrics were observed through the simulation scope. From figure 7, it was observed that there was a slight reduction in the PV current from 10.24A to 10. 19A.This slight reduction in the value of Ipv from 10.24A to 10.19A suggests that the PV output is closely following its maximum power point (MPP).

This behavior is expected once the maximum power point tracking (MPPT) algorithm stabilizes after start up transients. The PV voltage (Vpv) rose from zero as the system initializes and begins harvesting solar power. A final value of 13.57V indicates the operating point set by the boost converter to maintain optimal PV performance via MPPT control.

Similarly, the bus voltage rose from zero as the power electronics components (particularly the boost converter and the bidirectional converter) begins regulating power flow. The final voltage of 12.76V reflects the system's steady state DC bus set point. The initial oscillations of the boost converter current from 5A to 15A are typical during start up and indicate in rush of current as the converter charges the DC bus and responds to transient loading. The settling at 10.19A aligns with Ipv, showing stable power transfer from PV to the load/grid via the boost converter. It is also seen from figure 3.4 that Ppv rose from 0W to 138.4W which shows that the PV system begins generating power as solar irradiance is available and the MPPT algorithm engages. The final power output corresponds to the product of the final Ipv and Vpv values.

From figure 8, we discovered that there was a drop of about 9.2% in the battery voltage (from 24V to 20.02V) during the simulation. This implies that the battery was discharging to support system load or to maintain DC bus voltage stability. This suggests insufficient PV generation to meet load demand during part of the interval necessitating battery support. This is also seen in the drop of the battery voltage to 20.02V which could be due to high load or insufficient PV output.

This simulation confirms the successful integration and operation of the hybrid system under dynamic conditions and illustrates a typical startup and stabilization sequence in a hybrid renewable energy system. The DC voltage is well regulated and the battery demonstrates expected behavior by compensating the load demand

3.3 Modeling of the Hybrid System in HOMER.
Figure 9 displays the schematic diagram of the hybrid energy system. The system is a grid-connected system that manages the diesel generator, photovoltaic panels, batteries, converter and grid. An AC bus connects the grid with the diesel generator, while a DC bus connects the PV and batteries. The AC and DC buses are connected to the converter. The load is connected to the AC output. The diesel generator, photovoltaic panels, batteries, converter, and grid are all part of the system, which is grid-connected. The batteries are attached to the PV panels.

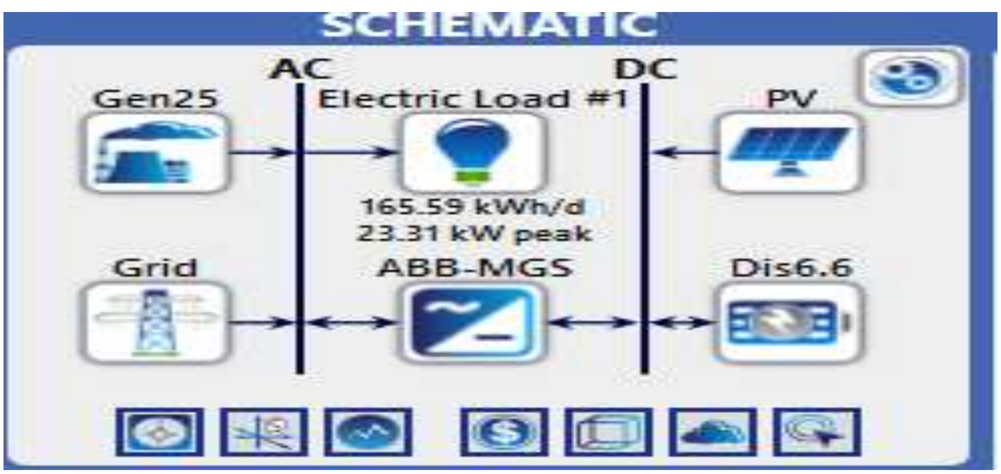

Figure 9 Schematic diagram of the Hybrid Energy System

In order to determine the best energy sources and storage option based on important performance criteria including cost, environmental impact, and dependability, optimization was done. HOMER was used to create optimization algorithms while MATLAB/Simulink was used in modeling the hybrid energy system and its financial cost models in order to assess real-time performance indicators including environmental and economic implications. Understanding the performance of the various hybrid energy system configurations was made possible by the simulation findings. The result of the optimization can be seen in the key performance index (KPI)

Figure 10 depicts the monthly average electric productions of the

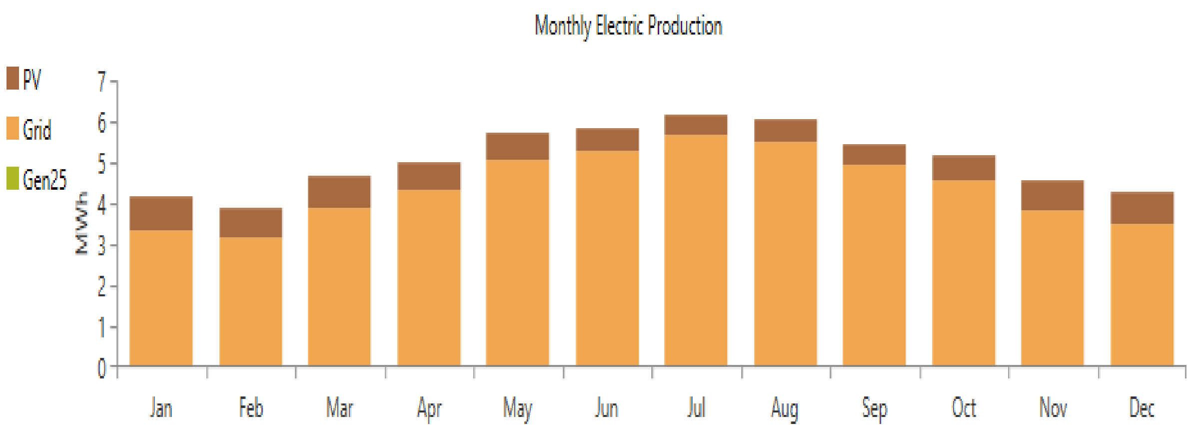

Figure 10 Monthly Average Electric Productions of the and PV System, Grid and Generator

From table 10, it was observed that the PV plates of the optimized configuration had an output of 7,884KWh/yr representing 12.9% of the total energy output while the Grid source had an output of 53,103KWh/yr representing 87.1% of the total energy output. The total electric energy output comprising of the PV panels, the Generator and the Grid Energy source is 60,986KWh/yr which is higher than the modeled value of total electric production of 60,440.35KWh/yr indicating a 0.9% increase.

Figure 11 shows a pie chart depicting the modeled and optimized values of carbon iv oxide gas emitted

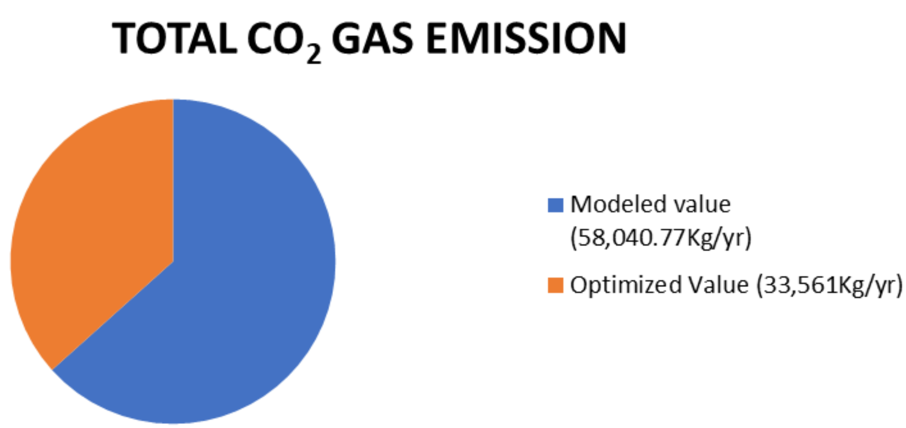

Figure 11 Modeled and Optimized Values of CO_2 Gas Emissions

From figure 11 it was discovered that the modeled value of the CO2 gas emitted was 58,040Kg/yr of CO2 while the optimized value of the percentage of CO2 gas emitted was 33,561Kg/yr of CO2 indicating a 42.18% reduction. Table 4.11 shows the cost comparison analysis of the optimized system and the modeled hybrid energy system describing the result of the optimization process.

3.4 Conclusion

From the simulation result, the optimal energy system configuration was chosen as PV/Grid/Generator. The total energy production from the utility Grid was 53,103KWhKWh/yr. representing 87.1% of the total energy produced by the system. The CO2 gas emission was also reduced from 58,040.77Kg/yr to 33,561.00Kg/yr of CO2 emitted representing a 42.18% reduction while SO2 gas emitted was 146Kg/yr; N02 emitted was 71.3Kg/yr while unburnt hydrocarbons, particulate matter and carbon monoxide had zero emissions because the Generator was only used in back up capacity and was not utilized. In the area of renewable energy contributions, the total energy produced by the PV panels was 7,884KWh/yr representing 12.9% of the total energy produced by the system while the PV penetration was 13%. The total electric Energy production of the modeled hybrid energy system was 60,440.35KWh/yr while that of the optimized system was 60,986KWh/yr giving an increment in the total Energy production by 0.9% in the optimized system.
The economic impact analysis shows that the optimized configuration has the least Net Capital cost of ₦8,259,553,666.67 the least Net Present Cost of ₦8,435,340,000.00, the least Operating Cost of ₦13,445,300.00 and the least Levelised Cost of Energy of ₦10,674.56/KWh

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