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Optimization of a hybrid energy system for GSM station: a case study of Aba transceiver station

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Abstract
The work presented in this paper explores the Modeling and Optimization of a Hybrid Energy system for a Global System for Mobile Communications (GSM) station located in Aba on$(5^0 7.3'N,\ 7^0 22.4'E)$. The proliferation of telecommunications in rural areas has increased reliance on Diesel Generators leading to significant consumption of non-renewable energy. The combination of fossil fuels with renewable energies would give a better quality, reduced cost and environmentally friendly system for the supply of the telecommunication base stations. GSM network operators can reduce their operating expenses and create a positive impact on the environment by the reduction of gas emissions through the optimization of cost of operation and the adoption of renewable energy. The Hybrid Optimization Model for Electric Renewable (HOMER) software was adopted for the optimization of the hybrid energy system located in Aba on$(5^0 7.3'N,\ 7^0 22.4'E)$. The hybrid Energy data set was collected from a GSM hybrid station located in Aba and used as input to the simulation programme. This study was based on simulation and mathematical modeling of the hybrid system through the use of the Hybrid Optimization Model for Electric Renewable (HOMER) software. The hybrid Energy System is a Grid- connected system that consists of the combination of the Diesel Generator, the Grid, the PV panels, the Batteries and the Converter. Different hybrid design configurations were considered in the optimization process and the most optimum configuration with the least Operating Cost, least Net Present Cost, least Cost of Energy and least amount of CO_2 gas emission was chosen after optimization. After optimization, the PV/Grid/Battery/Converter configuration was chosen as the most optimum configuration with the least Net Present Cost of #8.469,248,000, Least Operating cost of #9,173,536 and Least Cost of Energy of 10,832#/KWh. From the simulation result, the PV/Grid/Battery/Converter configuration gave the least CO_2 gas emission which reduced by 40% from the measured value thereby reducing the greenhouse effect. The chosen optimum configuration also has the least NO_x gas emission of 72.9Kg/yr compared to other configurations which has high NO_x emission. The total renewable energy production from the PV panels is 8,296KWh/yr. The total electric Energy production increased by 52% while the excess electric Energy production increased by 40.64% in the optimized system.

Keywords: Cost, Optimization, Homer, Diesel Generator, Hybrid Energy System

1. Introduction

One of the major critical challenges telecommunication operators confront in deploying their networks is power supply. According to Gielen *et al* (2019), the use of fossil fuel contributes to approximately 75% of the electricity produced in the world. Over the past two decades, Nigeria has been faced with electricity shortage. According to Ogujor and Orobor (2018), the utility grid has a high unreliability index with power supply reliability varying from 39 to 66%. Whenever the grid is available the supply voltage fluctuates. This consequently gives rise to load shedding, which affects the domestic, commercial and industrial activities. This has resulted in the use of fossil-powered sources. However, the use of fossil fuel generators has adverse effect on the environment as well as on the economy. This has triggered the rapid increase in greenhouse gas emissions to the atmosphere and a consequential rise in fuel price. The greenhouse effect has the potential of creating dangerous climatic changes with devastating effects on the ecosystem. Compared to the utility grid, the cost of electric power generation for fossil-fuel generators is significantly high. According to Adegoke and Babalola (2019), the operation and maintenance of diesel generators is also high and is responsible for about 78% of the overall cost of operation of the GSM sites. Countries are using the integration of renewable energy in their energy policies to reduce their dependence on fossil fuel. As a result of numerous evidence of global warming phenomena, coupled with the depletion of fossil fuel resources and fast escalated growth in world's population has caused widespread attention to shift towards the use renewable energy sources.

Consequently, the unit cost of running GSM stations tends to increase through the use of fossil-fuel generator. According to Kosai (2019), the easiest way to reduce the use of fossil fuels is through the use of renewable energy sources. According to Azam, Khan and Ali (2022), the use of clean energy is gaining wide acceptance. To achieve Long-term development, energy security, and environmental preservation there is need to incorporate renewable energy technologies. Thus a hybrid system can be said to consist of different energy sources which has varying energy conversion technology connected together to generate power to a local load or grid. Its advantages include reduction in line transformer losses, increase in system reliability, reduction in transmission and distribution congestion, and improvement in the power quality as well as increase in the overall efficiency of the system. Rinaldi, Moghaddampor, Najafi and Marchesi (2020), carried a study on the optimal configuration of hybrid PV-Wind-Diesel system for three small communities without grid connection in remote Peruvian village using Homer. They modeled the system using single component stand-alone system and the hybrid component system. Homer was used to determine the optimal sizing of the system by considering the configuration that has the least Operating Cost, least Cost of Energy (COE) and the least amount of CO_2 emitted. Their result showed that the best Configuration was the Solar-Wind-Diesel system. In selecting the objective function for certain configuration studies, economic index is usually considered.

Ryohei, Yuji, Syusike, Masahi and Tetsuya (2015), worked on PV panels and wind turbine system using the least cost of operation as their objective function. Yi, Jitian, Qingzhao and Jiahui (2022), set the least annual cost as their objective function using a solar-assisted natural gas Distributed Energy System (DES) coupled with energy storage device. They carried out the economic evaluation of the system using the least annual cost as their objective function. Their conclusion was based on the fact that the economic impact index tends to increase the contribution of the renewable energy. Pragya, Nema and Saroj (2015), worked on a PV solar-Wind Hybrid system located in Bhopal central India. Their simulation result gave the PV-Wind-Diesel Generator as the best optimal configuration. Their conclusion was that the PV-Wind-Diesel Generator configuration was more cost effective and environmentally friendly than the use of Diesel Generator alone. From their study, the new configuration had approximately 70%-80% fuel cost reduction and 90% reduction in CO_2 and other harmful gas emissions. They concluded that the payback period could reach as low as 2-4 days given a good sunny and wind location. Ramli, M., Bouchekara, H., Alghamdi, A. (2018), used Matrix Laboratory (MATLAB) and HOMER to carry out the cost and production of energy comparison in a Wind turbine and PV panels Hybrid energy system. Their study showed that the PV system was more economical and has more electricity production than the wind turbine system in the western area of Saudi Arabia.

Olatomiwa, Mekhilef, Huda and Sanusi (2015), performed an economic analysis of a PV-diesel-battery and PV-Wind-Diesel-Battery power system for BTS. Their study presents the results of technical and economic feasibility of employing Hybrid Renewable Energy Systems (HRES) to power a mobile telecom BTS in Nigeria. The aim of their study was to find out the most economical and environmentally friendly configuration for the BTS site in Nigeria. Their analysis was based on the configuration with the least Net Present cost (NPC), Cost of Energy (COE) and renewable energy fraction obtained from HOMER simulation software. Their result showed that best configuration for a solar radiation of 5.8KWh/m2 per day and an average wind of 3.2m/sec for Doka-Saria area of Kaduna was the PV-Diesel-Battery system. Siddaiah, and Saini (2016), worked on the techniques for optimization of a stand-alone hybrid energy station. They used the minimum cost of operation as their objective function and used it to analyze various mathematical models for an off-grid hybrid energy system. Their study showed that for a system to have good performance it is necessary that it should be reliable.

Amutha and Rajini (2016), configured a PV-Wind-Hydro-Battery hybrid energy system for a household as well as industrial and farmland energy consumption in Southern India using HOMER. Their result showed that the PV-Wind-Hydro-Battery system has the advantage of a reduced CO_2 gas emission when compared to the grid. The increased energy demand and energy shortage problems can be solved by the adoption of the renewable energy sources which are capable of providing the required energy needed to power up the BTS stations. The formation of hybrid energy power system through the integration renewable and non-renewable energy sources has helped in achieving dependability, sustainability, scalability, reliability and cost-effectiveness in power system either as a grid-connected system or as an off-grid system. The use of hybrid energy sources has proven to be a very cost-effective approach towards providing health care system, standardized mechanized agricultural system as well as enhanced educational system to the rural areas. According to Gbenai, Bettayeb, Brdjanin and Hamid (2019), the implementation of renewable energy sources is a major stride to mitigate climatic change and energy security. According to Zhai Wang and Chuang (2019), the use Diesel Generators (DG) in powering base transceiver stations has proven to be less viable for network companies for the following reasons. High operating and maintenance cost of the diesel generator as well as high cost of fuel. Environmental effect of harmful emission of gases such as carbon dioxide, sulphur dioxide and nitrogen oxides from diesel fuel which causes depletion of ozone layer, acid rain, genetic mutation and global warming.

Global warming is caused by the emission of carbon dioxide (CO_2,) gas, a byproduct of fossil fuels. CO_2 has the ability to trap infrared radiation (IR) in the atmosphere. CO_2 causes vibrations by absorbing the reflected radiation from the earth's surface. These drawbacks have made network operators to seek for ways of reducing capital and operational cost as well as promoting an environmentally friendly system. Cost-effectiveness, efficiency, reliability and sustainability which are the basic power requirements of the BTS system can be effectively met through the optimization of cost of operation and through the utilization of the various technological advancements in renewable energy systems. Network operators can therefore reduce their operating cost and create a positive impact on the environment by the reduction of harmful gas emissions through the optimization of cost and adoption of renewable energy sources. In order to maximize the benefits of hybrid systems, a thorough optimization and complex design, control, planning and cost optimization method should be adopted in the BTS stations to save energy and provide best services.

2.0 Material and methods

2.1 Levelized Cost of Energy (LCOE)

The Levelized Cost of Energy is defined as the cost of power produced by solar energy throughout the lifetime of the PV system. It is used to calculate the present value of the total cost of building and operating a power plant over an assumed lifetime and creates avenue for the comparison of different technologies (wind, solar, natural gas etc) of varying life span, project size, different capital cost, risk, return and capacities.

The levelized Cost of Energy is expressed as

$$\text{LCOE} = \frac{\textit{Total net present cost}}{\sum_{t=1}^{T} P_{Load(t)}} \text{ X CRF} \tag{1}$$

Where

CRF = the total recovery factor which can be written as

$$\text{CRF} = \frac{i(1+i)^N}{i(1+i)^N - 1} \tag{2}$$

Where

i = the interest rate (Discount rate = 17.71%)

N = System life period =25 Years

2.1.1 Net Present Cost (NPC)

The Net present Cost (NPC) is also known as the life-cycle cost. It is defined as the present value of the total cost of installing and operating the component over the projected lifetime, minus the present value of all the revenues that it accrued over the projected lifetime. It is expressed as

$$NPC = C_{investment} + OM_{npv} + R_{npv} - S_{npv} \tag{3}$$

Where

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

OM_{npv} = the cost of maintenance and operation

R_{npv} = the cost replacement

S_{npv} = the salvage value
The OM_{npv} is modeled using the formula

$$OM_{npv} = F_I \times OC \times \left[\left(\frac{1+F_e}{d-F_e}\right) \times \left(1 - \left(\frac{1+F_e}{1+d}\right)^N\right)\right] \quad (4)$$

F_I = (5%) of Initial Cost
F_e = Escalation rate, assumed to be 20%
D = Discount rate, assumed to be 17.71%
N = Number of years (25 years)

The replacement cost is given by

$$R_{npv} = P \times (1+i)^N \quad (5)$$

Where
P = Initial Capital Cost for replaced Component
i = Rate of interest assumed as 15.37%
N = System life period =25 Years
The salvage value is given by

$$S_{npv} = R_{npv} \text{ x } \frac{R_{rem}}{N} \quad (6)$$

Where
R_{npv} = Replacement cost
R_{rem} = Remaining life of the component
N = System life period =25 Years.

2.1.1.1 Cost of Energy (COE)

The Cost of Energy (COE) is defined as the net present value of the unit cost of electricity throughout the lifetime of the system. The Cost of Energy is modeled using the equation

$$COE = \frac{\sum_{i=1}^{n} \frac{OC+OM+R+F}{(1+d)^t}}{\sum_{i=1}^{n} \frac{E_t}{(1+d)^t}} \quad (7)$$

Where
OC = Cost of Capital Investment
OM = Operation and Maintenance Cost
R = Replacement Cost
F = Cost of Fuel
E_t = Electrical Energy Produced in t years
t = System life period =25 Years

2.2 Economic and Environmental Impact Assessment

2.2.1 Carbon Emissions

The effect of the impact of the hybrid energy system on the environment is evaluated by calculating the carbon emissions associated with each energy source.

$$CO_2 \ Emissions = Egen(t) \times CO_2 \ Emissions \ Factor \quad (8)$$

Where:

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

The mass of CO_2 emission is calculated by summing CO_2 emission rate of 2.68 Kg/KWh of Energy generated by the Generator and 0.5Kg/KWh of Energy generated by the utility grid.

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} (9)

The cost of fuel is calculated using the unit cost of a liter of diesel as #1,300.
Where the cost of fuel consumed is given by
Cost of Fuel Consumption = Liters of Fuel Consumed x #1,300 (10)

2.2.1.1 Energy Balance Equation

The energy balance equation ensures that the total electrical energy production by the hybrid system must meets the total energy demand of the BTS site.

$$E_{total}(t) = E_{grid}(t) + E_{gen}(t) + E_{solar}(t) + E_{battery}(t) \quad (11)$$

Where
$E_{total}(t)$ = The total energy demand at time t
$E_{grid}(t)$ =The energy produced by the grid
$E_{gen}(t)$ = The energy produced by the generator
$E_{solar}(t)$ = Energy supplied by the solar panels
$E_{battery}(t)$ = Energy supplied or absorbed by the battery

2.2.1.2 Battery State Of Charge (SOC)

The battery state of charge is crucial for maintaining energy balance and ensuring reliability. The SOC at any time t is given by:

$$SoC(t) = SoC(t-1) + \frac{E_{charge}(t) - E_{discharge}(t)}{C_{battery}} \quad (12)$$

Where
$SoC(t)$ = the state of charge of the battery at time t
$SoC(t-1)$ = the state of charge of the battery at the previous time step
$E_{discharge(}t)$ = the energy discharged from the battery
$C_{battery}$ = the battery capacity

2.2.1.3 Optimization Algorithms

The aim of the objective function is to minimize the total cost of energy generation and also maximize the system reliability and efficiency.

Minimize $J = \sum_{t=1}^{T} \left(C_{total}(t)\right)$ (13)
Subject to:

- Energy balance constraints.
- Battery SOC constraints.
- Generator operational constraints.
- Renewable energy availability constraints

2.2.1.4 Constraints

- Energy balance constraints.
-

$$E_{total}(t) = E_{grid}(t) + E_{gen}(t) + E_{solar}(t) + E_{battery}(t) \quad (14)$$

- Battery SOC constraints.

$$SoC_{min} \leq SoC(t) \leq SoC_{max}$$

- Generator operational constraints.

$$E_{gen}(t) \leq E_{gen}^{max}$$

- Renewable energy availability constraints.

$$E_{solar}(t) \leq E_{solar}^{max} \quad (t)$$

2.3 Modeling of the Hybrid System in HOMER.

The hybrid system configuration is shown in Figure 1. The system is a Grid-connected system that deals with the combination of the Grid, the Diesel Generator, the PV panels, the Batteries and the Converter. The PV panels and the Batteries are
connected via a DC bus, while the Grid and the Diesel Generator are connected through an AC bus. The connection of the converter is between the AC and DC buses. The output of the AC is connected to the load.

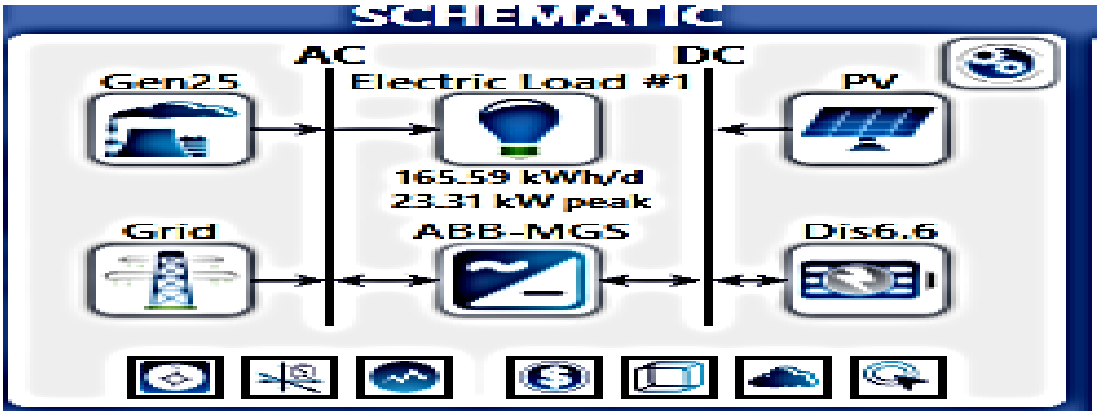

Figure 1: Model of the Hybrid Energy System

3.0 Results and Discussions

The detailed results and discussion of the study on the optimization of hybrid energy systems for a GSM base transceiver station (BTS) located in Aba is presented in this paper. The analysis aims to identify the most suitable energy sources and storage solutions based on factors such as cost, reliability, and environmental impact. The hybrid energy system models and optimization algorithms are implemented using HOMMER. The input data set was obtained from a GSM Base Transceiver Station in Aba with the station name AB 8946. The data set was collected for a period of one year from August 2023 to July 2024. Table 1 depicts the Financial Cost Analysis of the station for a one-year period depicting the various cost accrued by the station including utility cost, installation cost, fuel cost as well as amount of CO_2 gas emitted. The capital cost was #8,333,550,000; cost of fuel was measured as #94,066,245 while CO_2 gas emission was measured as 57,322.41Kg. Table 2 depicts the yearly energy data set

This paper aims at providing a comprehensive examination of the hybrid energy system's performance, optimizing the cost of operation, Levelised Cost of Energy, and the Net present Cost and, highlighting the benefits and challenges of integrating renewable energy sources. We explore the potential for optimizing energy usage to ensure cost-effectiveness and reliability within the power supply chain of the GSM BTS sites. The findings and recommendations presented in this paper are intended to guide future improvements and advancement in the operation and design of the hybrid energy systems, contributing to the sustainable growth of telecommunications infrastructure in developing regions. By systematically addressing each aspect of the study, this offers valuable insights into the practical application of hybrid energy systems and lays the groundwork for future research and development in this critical field. The hybrid system is a Grid connected system. The hybrid energy system optimization algorithms are implemented using Homer Optimization software. 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 545W and the site has16 panels. The Battery capacity is 150AH, 48V. The total number of batteries in the site is 16 while the Generator is a 20KVA Mikano sound proof Generator. The Converter is a 2.5KW, 48V/230AC, 50Hz bi-directional converter.

Table 1: Cost Analyses of the Aba (AB 8946) Base Transceiver Station

MONTH	SITE NAME	UTILITY COST(#)	LITER OF FUEL CONSUMED (L)	TOTAL COST OF FUEL(#)	CAPITAL COST (#)	CO_2 Gas Emission (Kg)
AUGUST	AB 8946	23,987.75	7,412.88	9,636,744	8,333,550,000	4,710.914
SEPTEMBER	AB 8946	0	7,653.23	9,949,199		4,589.99
OCTOBER	AB 8946	17,298.42	8,730.04	11,349,052		6,184.72
NOVEMBER	AB 8946	14,908.02	13,279.31	17,263,103		3,508.39
DECEMBER	AB 8946	0	4,124.98	5,362,474		5,278.12
JANUARY	AB 8946	0	749.02	978,926		3,819.59
FEBUARY	AB 8946	0	14,989.07	19,485,791		3,574.44
MARCH	AB 8946	0	12,322.39	16,019,107		6,540.60
APRLL	AB 8946	0	499.34	649,142		3,281.62
MAY	AB 8946	0	1,030.11	1,339,145		6,514.18
JUNE	AB 8946	0	687.96	894,348		5,067.12
JULY	AB 8946	0	876.32	1,139,216		4,252.71
TOTAL		56,194.19	72,354.65	94,066,245	8,333,550,000	57,322.41

Table 2: 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	30,143.99KWh/yr
Total Solar KWh/yr	652.08KWh/yr
Total Fuel Cost	#94,066,245
Total CO2 Gas Emissions	57,322.41Kg

Meteorological Data

Meteorological data is of great importance in the modeling and optimization of a hybrid energy system and is needed before a hybrid energy system can be effectively modeled and optimized. It is therefore required so as ascertain if the available amount of the renewable energy source will be able to meet the load requirements of the BTS station.. It is therefore necessary to determine the amount of sunlight available that can strike a particular location at any given point in time. Figure 2 and Table 3 below shows the average monthly solar irradiance data for the station in Aba located on $(5^0 7.3'N,\ 7^0 22.4'E)$

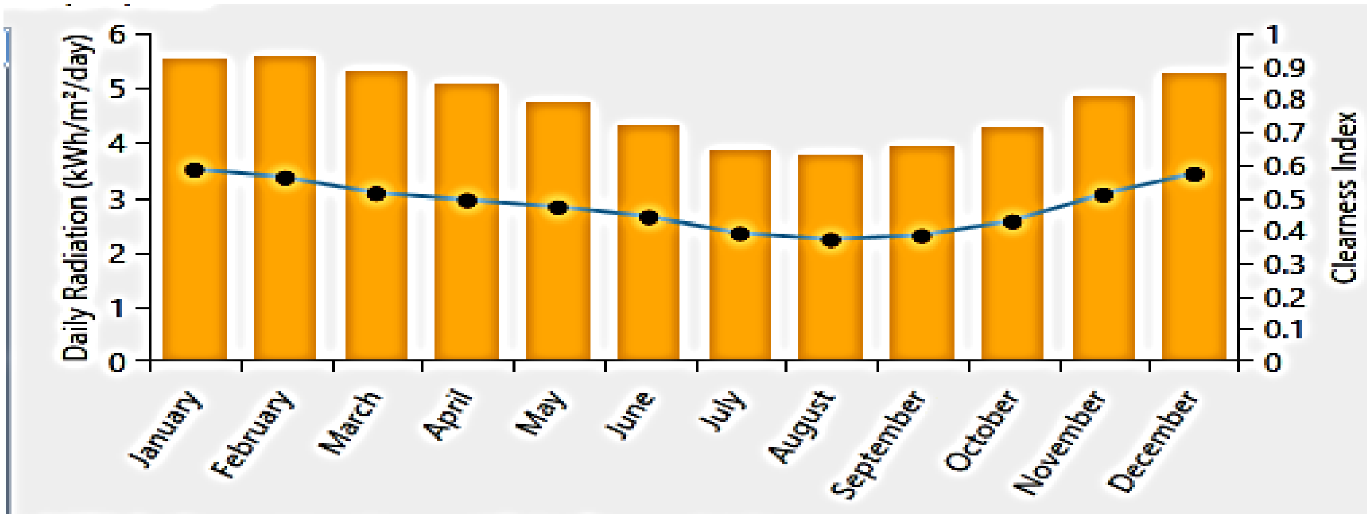

Figure 2: Monthly Average Solar Global Horizontal Irradiance (GHI) for Aba

Table 3: Monthly Average Solar Global Horizontal Irradiance (GHI) for Aba

Month	Clearness Index	Daily Radiation (KWh/m^2/Day)
January	0.583	5.530
February	0.558	5.590
March	0.511	5.320
April	0.490	5.090
May	0.469	4.720
June	0.439	4.310
July	0.388	3.850
August	0.369	3.770
September	0.381	3.940
October	0.425	4.270
November	0.507	4.840
December	0.570	5.290

From the average monthly solar irradiance data we saw that the months of July and August recorded the least daily radiation with July having a daily radiation of 3.850KWh/m^2/day and August recorded a daily radiation of 3.770KWh/m^2/day. This implies that the Energy produced by the solar panels within these months will be minimum. However the month of February recorded the highest daily radiation implying that the electrical Energy produced by the solar panel will be maximum in the month of February

Table 4: The Homer Optimization Result

Configuration	Net Present Cost(#)	Operating Cost (#/Yr)	Cost of Energy (#/KWh)	Initial Capital Cost(#)	Fuel Cost (#/Yr)	Grid Energy Purchased (KWh)	Renewable Fraction (%)	Energy Production (KWh/Yr)	CO_2 Emissions (Kg/Yr)	SO_2 Emissions (Kg/Yr)	NO_x Emissions (Kg/Yr)	CO (Kg/Yr)
PV/Grid/Battery/Converter	#8.469B	9,173,536	10,832	#8.350B	0	54,417	9.97	8,296	34,391	149	72.9	0
PV/Grid/Converter	#8.460B	9,617,072	10,832	#8.336B	0	59,847	0.983	1,191	37,824	164	80.2	0
Battery/Grid/Converter	#8.464B	9,827,776	10,832	#8.336B	0	60,435	0.00956	0	38,196	166	81	0
PV/Grid/Battery/Converter	#8.464B	9,431,952	10,832	#8.336B	0	57,411	5.02	3,498	36,284	157	76.9	0
PV/Generator/ Battery/Converter	#8.673B	13,174,944	11,104	#8.496B	7,625,600	0	74.7	69,242	15,356	37.6	90.1	0
Generator/Battery/Converter	#8.778B	32,123,184	11,232	#8.368B	29,164,800	0	0	0	58,730	144	345	367
Generator	#8.817B	37,178,400	11,280	#8.336B	34,766,400	0	0	0	70,010	171	411	437
PV/Generator/ Converter	#8.817B	37,061,552	11,296	#8.336B	34,608,000	0	0	1,191	69,691	171	409	435
PV/Battery /Converter	#8.987B	13,766,400	11,504	#8.816B	0	0	100	214,889	0	0	0	0
Generator/Grid	#8.474B	10,655,520	10,848	#8.336B	0	60,442	0	0	38,199	166	81	0
PV/Generator/ Grid/Converter	#8.475B	10,601,600	10,848	#8.336B	0	59,847	0.983	1,191	37,824	164	80.2	0
Generator/Battery /Grid/Converter	#8.479B	10,812,624	10,848	#8.336B	0	60,436	0.00956	0	38,196	166	81.0	0
PV/Generator/ Battery/Grid/Converter	#8.479B	10,416,784	10,848	#8.352B	0	57,411	5.02	3,498	36,284	157	76.9	0

Table 4 depicts the simulation result as obtained from HOMER software. HOMER performs simulation in hourly basics so as to obtain an optimal result with the most optimum configuration. In executing the simulation, HOMER considers all possible outcome of the system through energy calculation. At the end of the simulation result, HOMER makes decision for the best result with combination of power sources which will be ranked from top to bottom with most optimum configuration to least optimum configuration. From the result, the PV/Grid/Battery/Converter system gave the most optimum result with a Net Present Cost of #8.469 ,248,000, Operating cost of #9,173,536 and Cost of Energy of 10,832#/KWh. From the result, it was observed that the optimized configuration (PV/Grid/Battery/Converter) gave the least Operational Cost, the least Cost of Energy, has the least amount of Grid power purchase and also gave the least amount of CO_2 gas emission apart from other configurations that does not include Grid and Generator thereby reducing the Green House effect. It was also observed that the CO_2 gas emission was considerably reduced from 57,322.41Kg to 34,391Kg giving a percentage reduction of about 40%.

Table 5: Grid Rate Schedule of the Optimized System

Month	Energy Purchased (KWh)	Net Energy Purchased (KWh)	Peak Demand (KW)	Energy Charge (#)
January	3511.261607	3511.261607	15.524794	561,808
February	3223.425805	3223.122031	13.418968	515,728
March	4189.199087	4189.199087	16.144679	670,272
April	4444.943826	4444.943826	18.416640	711,184
May	5039.328137	5038.658382	20.363544	806,240
June	5369.886047	5369.886047	21.909080	859,184
July	5639.226421	5639.226421	23.176289	902,272
August	5774.274440	5774.274440	20.776222	923,888
September	5076.426436	5076.426436	19.700984	812,224
October	4538.261218	4538.261218	16.553600	726,128
November	3933.362985	3932.875987	17.131974	629,296
December	3677.296057	3677.265667	14.509285	588,368
Annual	54416.892064	54415.401149	23.176289	8,706,576

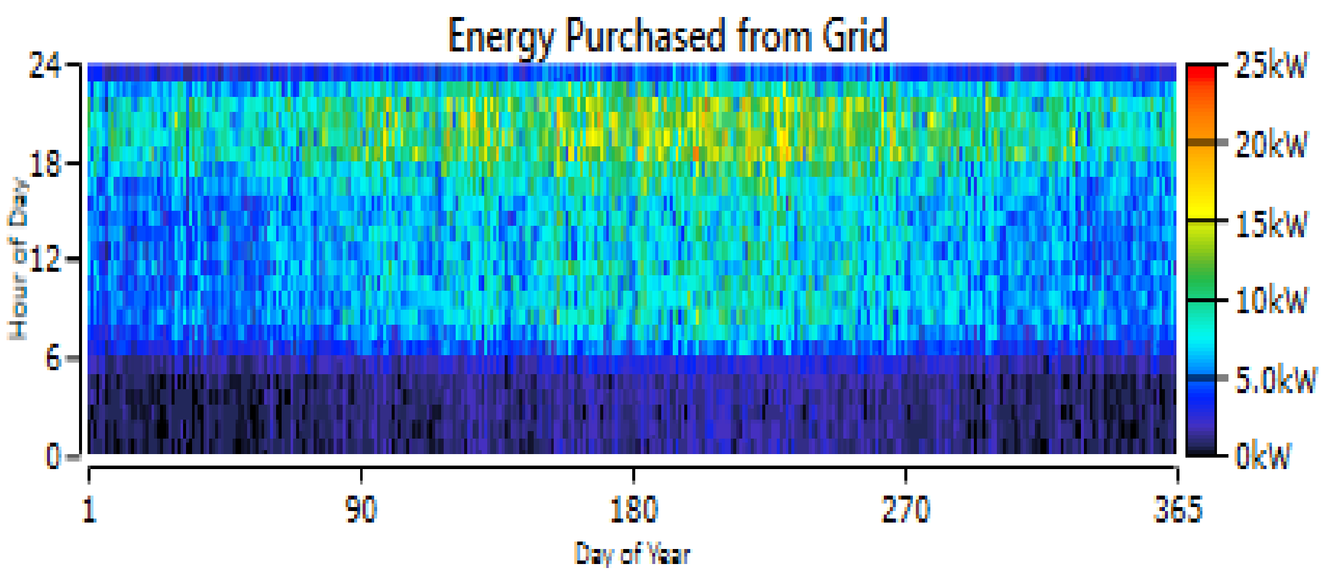

Figure 3 Energy Purchased from the Grid

From table 5 above we observe that the Energy purchase from the Grid is 54,417KWh at a cost of #8,706,578 from January to December. We also observed that the months of July and August recorded the highest Grid Energy purchase with the month of July recording a Grid Energy purchase of 5,639.23KWh while the month of August recorded a Grid Energy purchase of 5,774.27KWh. The least Grid Energy purchase was recorded in the month of February with a Grid Energy purchase of 3,223.42KWh. This values corresponds with the solar Irradiance data of table 5 which shows the months of July and August recording the least value of daily solar irradiance while the month of February recorded the peak value of daily solar irradiance which implies that while the daily irradiance was least in July and August, the system has to optimize the energy demand by increasing Grid Energy purchases within the months of July and August while the least Grid Energy purchase was recorded in the month of February because the GHI in this month was very high and the solar panel produced more Energy that was demanded by the system thus bringing the Grid Energy purchase to the minimum.

Table 6 Electric Output Energy Production of the Optimized System

Quantity	OUTPUT (KWh/Yr)	Percentage (%)
PV Plate	8,296	13.2
Grid Purchase	54,417	86.8
Total Energy Production	62,713	100
Excess Electric Load	1,793	2.86
Unmet Electric Load	0	0
Shortage Capacity	0	0

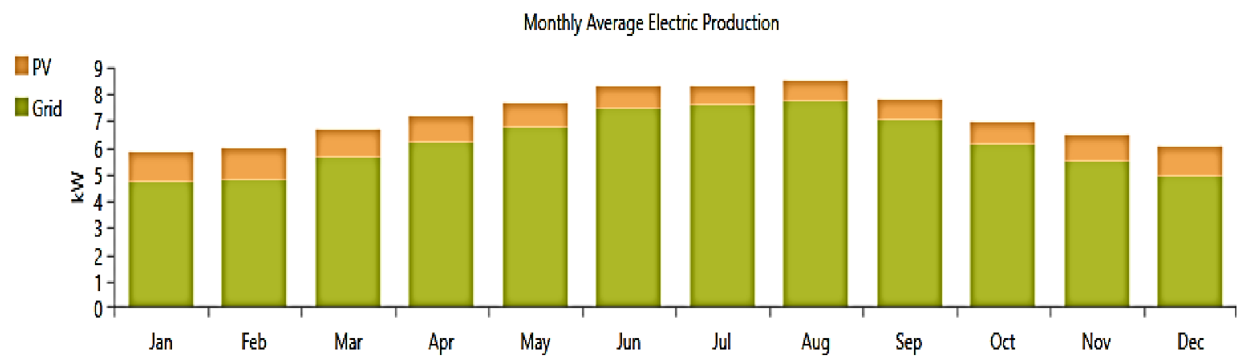

Figure 4 Monthly Average Electric Productions of the Grid and PV System

Table 6 depicts the Electric Energy output production of the optimized system, while figure 4 shows the monthly Electric Energy productions of the Grid and PV systems. From table 6, we observed that the PV plates of the optimized configuration had an output of 8,296KWh/yr representing 13.2% of the total Energy output while the Grid source had an output of 54,417KWh/yr representing 86.8% of the total output energy. The total electric Energy output comprising both the PV panels and the Grid Energy source is 62,713KWh/yr which is higher than the measured total electric production of 30,143.99KWh/yr from table 2. Also from Table 2, the measured surplus Energy was 1,064.31KWh/yr while the optimized configuration had an excess electric Energy output of 1,793KWh/yr representing a 40.64% increase in the excess electric energy produced and a 2.86% of the total electric Energy output. The optimized configuration had a zero unmet electric load and a zero capacity shortage.

Table 7 Cost Summary of the Optimized Configuration

Measured Quantity	**Measured Value**	**Optimized Value**
Total Electric Energy Production	30,143.99KWh/yr	62,713KWh/yr
Total Energy Surplus	1,064.31KWh/yr	1,793KWh/yr
Total Renewable Energy Contribution	652.08KWh/yr	8,296KWh/yr
Total CO_2 Gas Emission	57,322.41Kg	34,391Kg
Total Fuel Cost	#94,066,245	0

Table 8 Comparison Between Measured Values and Optimized Values

Component	Capital Cost(#)	Replacement Cost(#)	Operation & Maintenance Cost(#)	Fuel Cost(#)	Salvage (#)	Total Net Present Cost (#)
ABB MGS100	4,720,640	2,002,848	0.00	0.00	376,960	6,346,512
Discover AES 6.6kWh 48VDC	4,144,000	3,660,960	0.00	0.00	496,368	7,308,608
Generic flat plate PV	8,241,296	0.00	1,246,080	0.00	0.00	9,487,376
Grid	0.00	0.00	112,554,496	0.00	0.00	112,554,496
Other	8,333,550,000	0.00	0.00	0.00	0.00	8,333,550,000
System	8,350,655,936	5,663,808	113,800,576	0.00	873,312	8,469,246,992

Table 7 depicts the cost summary of the optimized configuration (PV/Grid/Battery/Converter). From table 3.6 above, we observed that the Total Net Present Cost was #8,469,246,992, the Operation and Maintenance cost was #113,800,576, the Replacement Cost was #5,663,808, the salvage value was #873,312 while the capital Cost was #8,350,655,936. Table 8 also shows the cost summary of the components of the optimized system such as the Converter, the Battery, the PV and the GRID system. The Converter has a Capital Cost of #4,720,640, Cost of Replacement was #2,002,848, a Salvage value of #376,960 and a Total Net Present Cost of #6,346,512. The Battery has a Capital Cost of #4,144,000, a Replacement Cost of #3,660,960, a Salvage value of #496,368 and a Total Net Present Cost of #7,308,608. The PV Panels has a Capital cost of #8,241,296, a zero Replacement Cost, an Operating Cost of #1,246,080 and a Net Present Cost of #9,487,376 while the Grid system has an Operating cost of #112,554,496 and a Net Present Cost of #112,554,496.

Table 8 above shows the comparison between Key Performance Index (KPI) values obtained before and after optimization, figure 4 depicts energy comparison between measured and optimized values while figure 3.4 shows the measured and optimized values of CO_2 gas emitted to the atmosphere. From table 8 above we observe that the total energy production increased from a measured value of 30,143.99KWh/yr to 62,713KWh/yr after optimization indicating a 52% increase in the total electric energy production. The total energy surplus also increased from 1,064.31KWh/yr to 1,793KWh/yr indicating an increase of 40.64%. Similarly, the total renewable energy contribution also witnessed an increase from 652.08KWh/yr before optimization to 8,296KWh/yr after optimization indicating a 92.14% increment in the optimized scenario while the CO_2 gas emission witnessed a reduction from 57,322.41 Kg before optimization to 34,391Kg after optimization indicating a 40% reduction in the amount of CO_2 gas emitted

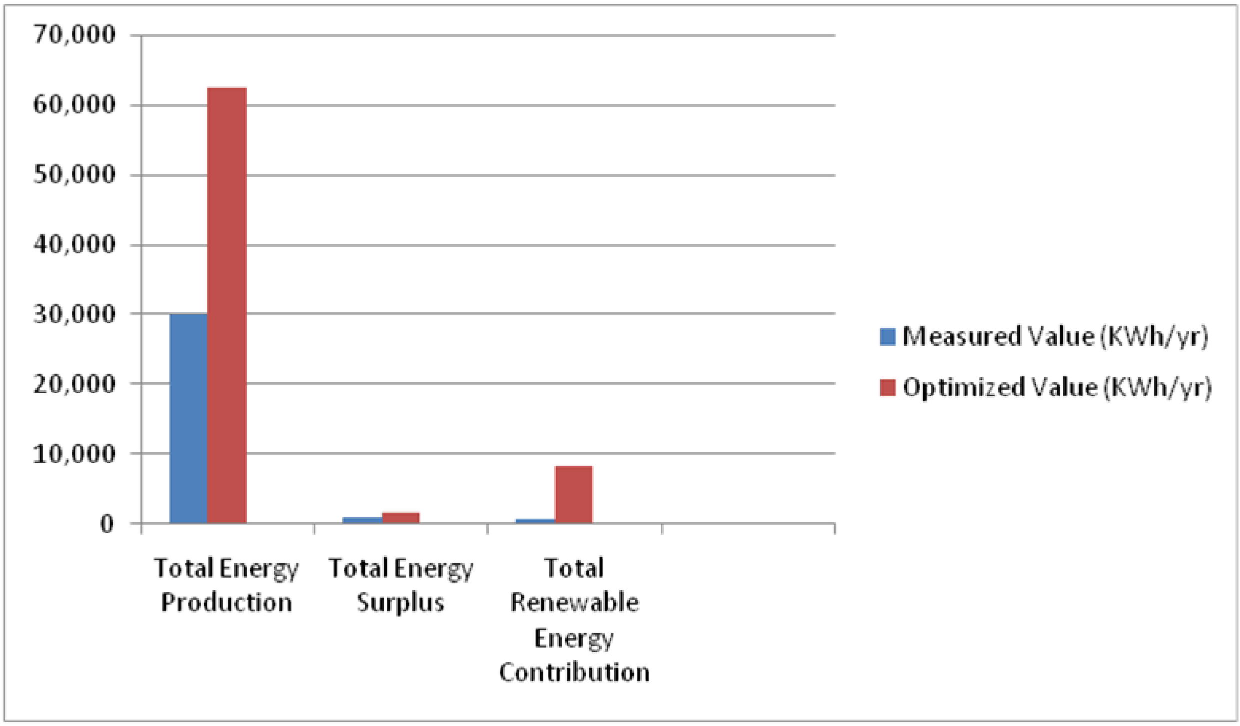

Figure 5: Energy Comparisons of Measured Values and Optimized Values

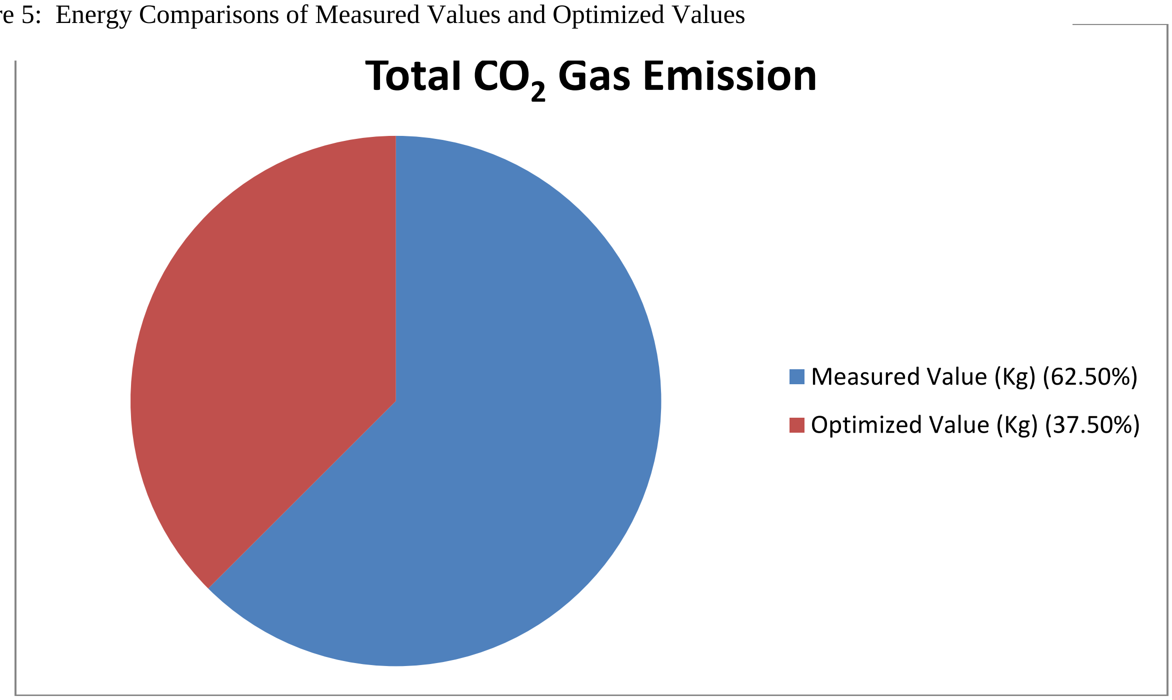

Figure 6: Measured and Optimized Values of CO_2 Gas Emissions

4.0. Conclusion

The optimization was carried out with the aim of identifying the most suitable energy sources and storage solution based on key performance factors such as cost, environmental impact and reliability. The hybrid energy system models and optimization algorithms were implemented using HOMER to evaluate some real time performance metrics such as environmental and economic impacts. The results of the simulation provided insights into the performance of the different configurations of the hybrid energy system. The result of the optimization can be seen in the key performance index (KPI). From the simulation result, the optimal system configuration was chosen as PV/Grid/Battery/Converter. This eliminates the Diesel Generation from the optimal configuration thereby bringing the total fuel cost from #94,066,247 to a zero level. The total energy production from the utility Grid was 54,417KWh/yr. representing 86.8% of the overall energy that was produced by the system. The CO_2 gas emission was also reduced from 57,322.41Kg to 34,391Kg of CO_2 emitted representing a 40% reduction while SO_2 gas emitted was 149Kg, $N0_x$ emitted was 72.9Kg. In the area of renewable energy contributions, the overall energy that was produced by the PV panels was 8,296KWh/yr while the Renewable energy fraction was 9.97% representing 13.2% of the overall energy that was produced by the system. The total electric Energy production of the measured system was 30,143.99KWh/yr while that of the optimized system was 62,713KWh/yr giving an increment in the total Energy production of 52% in the optimized system. The measured surplus Energy was 1,064.31KWh/yr while the optimized configuration had an excess electric Energy output of 1,793KWh/yr representing a 40.64% increase in the excess electric energy produced. The economic impact analysis showed that the optimized configuration has the least Net Capital cost of #8,350,000,000, the least Net Present Cost of #8,469,248,000 the least Operating Cost of #9,173,536 and the least Cost of Energy of 10,832 #/KWh which when converted to Naira by multiplying it by the total energy production in KWh/yr (62,713KWh/yr) gives the Cost of Energy as #679,307,216

5.0 Recommendation

From the analysis and optimization of the hybrid energy system, the recommended optimal energy configuration for the system is PV/Grid/Battery/Converter. Improvements should be made to increase the solar capacity and optimize battery usage. This underscores the potential for maximizing solar energy utilization while minimizing dependence on the grid and generators. Further research should be made in the area of advanced battery technologies and real-time energy management systems. This can provide innovative solutions for improving energy storage and distribution, thereby ensuring a more sustainable, reliable and cost-effective power supply for GSM base stations.

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Nomenclature

CO_2= Carbon iv Oxide
CO= Carbon ii Oxide
SO_2= Sulphur iv Oxide
NO_x= Nitrogen ii Oxide and Nitrogen iv Oxide

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