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Optimization of Hybrid Solar PV and Diesel Generator System for an Efficient Electricity Supply

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ABSTRACT: *The operation and maintenance cost associated with running diesel generator autonomously is capital intensive and unfriendly to the environmentally. The paper examined hybrid diesel generator and solar* (PV) *based technology as an effective way to power an off grid facility. Solar PV integration impacted significantly on the energy production, thereby reducing the high operation and maintenance cost associated with diesel generator. Two scenarios were considered and implemented in HOMER software. The result obtained in the base case scenario when diesel generator was used shows [Cost of Energy: N0.712], [Net Profit Cost: N39.7M], [Operating Cost: N2.99M], [Fuel Cost: 1,857,800] and [O & M: N551880]. Also, the GHG emission [CO2:4863006Kg/yr], [CO:30.654kg/yr], [Unburned Hydrocarbon: 3,650kg/yr], [Particle matters: 507kg/yr], [Sulphur dioxide: 26811kg/yr], and [Nitrogen oxides: 78586kg/yr]. However, with the modified system, when diesel generator and PV system are integrated [Cost of Energy: N0.378], [Net Profit Cost: N21.1M], [Operating Cost: N886527M], [Fuel Cost: 530,555] and [O & M: N144, 660]. Similarly, the GHG emission [CO2: 1388788Kg/yr], [CO: 8,754kg/yr], [Unburned Hydrocarbon: 382kg/yr], [Particle matters: 53.1kg/yr], [Sulphur dioxide: 3,401kg/yr], and [Nitrogen oxides: 8224kg/yr]. Solar PV integration impacted significantly in mitigating GHG emission and high O&M cost associated with autonomous operation of diesel generator set.*

KEYWORDS: Renewable Energy, Diesel Generator, Converter, Battery and Solar PV

INTRODUCTION

The significance of a reliable and effective electricity supply cannot be overstated because it is the primary metric for assessing the socioeconomic and technological advancement of any nation (Gupta, 2016).
In Nigeria, the amount of power available does not match the amount that is needed. In order to address this problem, load shedding has become an alternative strategy for the management of the electricity utility firm.

Indeed, lack of energy has caused small firms to fail and the government to lose money. Many homes and businesses utilise generators to supply their everyday needs for electricity.In most cases, diesel generators are used for power generation which can impact negatively on the environment by increasing the greenhouse gas emission and noise pollution. In addition to the environmental pollution associated with diesel power generation, the operation and maintenance cost is excessive.

According to the World Energy Council Trend and Outlook (2016), lack of generation flexibility is responsible for the country's declining trend in terms of global energy security. Its ranking in terms of global energy security has suffered as a result. Nigeria shouldn't have an energy shortage based on its abundant oil reserves and solar radiation.

Shaaban and Pentrin's (2014) noted that Nigeria has abundant of renewable potentials such as hydro, solar, wind, and biomass energy to power anywhere in the nation. With an average solar irradiance is about 2000kWh/m^2, and 144 million tonnes of biomass are produced annually renewable energy can be fully implemented. Nevertheless, the results also indicate that the country's renewable resources have not yet been fully discovered and put to use.

The integration of solar PV renewable energy with an existing diesel generator is proposed in this paper. The model if fully implemented will not only mitigate the high operation and maintenance cost associated with diesel generator will also provide an improved alternative power supply with little or no greenhouse gas emission. Hybrid Optimization of Multiple Electric Renewable software (HOMER 3.11.2) developed by the National Renewable Energy Laboratory (NREL).

REVIEW OF RELATED LITERATURE

Gevorkian (2015) noted that the use of solar technology in the US has drastically reduced the cost power generation and also increase efficiency of the technology in the solar power industry. However, it was further noted that the use of solar technology has some associated effects which could impact negatively on the system if not checked. Tester (2015) in his presentation reviewed that photovoltaic technology permits the integration solar collectors and can also use external walls, windows and roof for solar collectors. However, it was noted that the excessive use of materials can impact negatively on the environment also health concerns.

Gordon (2018) in his work optimally sized a standalone solar generation for cost effectiveness as an alternative for fossil fuel generator. The result obtained after implementation shows significant improvement using solar technology for lightening small towns and villages that are off grid.Raugei and Frankl (2019) in their presentation, three scenarios were proposed as an alternative for future development of solar technology. It was further argued that the proposed scenarios may be beneficial in the future energy mix.In the same vein, Feltrin and Freundlich (2018) in their work critically observed dissimilar solar technology used for large scale generation of electricity. The result obtained shows that to overcome the material challenge both improvement and modernization are needed. In their research on hybrid gas turbine and PV systems, Okedu and Uhunmwagho (2015) were able to lower the high percentage of energy consumption, reducing both the high cost of electricity and GHG emissions. This can only be achieved with the use of renewable energy.The feasibility of employing HRES - Solar PV - Diesel and battery to power

Ofubu-New Patani, a distant community in Bayelsa State, Nigeria, was examined by Omorogiuwa and Ekiyor (2017). The data gathered was entered into HOMER software for analysis and optimisation. The community load was estimated to be 80.76kWh/d with a peak load of 12.01kW. It was determined that the Hybrid Renewable System (HRES) is economically feasible for a remote area with challenging terrain that is removed from the traditional grid.

MATERIALS AND METHOD

Load Assessment

The electric load of a commercial building complex consisting of six (6) office facility that makes use of domestic appliances such as radio sets, television sets, lights, fans, phones and refrigerators and computers was assessed. The total load was estimated to be about 11830watt. Currently, the complex is powered by a diesel generator which is operated for 10hrs each day from 8am-6pm.

Table1: Load Demand

Facility	Device	Qty	(W)	Total
1	Light	3	40	120
	Fan	3	70	210
	20" led tv	3	20	60
	Pos	2	10	20
	Aux device	4	100	400
2	Light	30	20	600
	Fan	15	70	1050
	32" led tv	1	90	90
	Aux device	3	100	300
3	Light	3	40	120
	Fan	4	70	280
	Aux device	3	100	300
4	Light	4	40	160
	Fan	4	70	280
	40" led tv	1	90	90
	Computer	40	100	4000
	Router	1	50	50
	Printer	1	150	150
	Aux device	1	150	150
5	Light	4	40	160
	Fan	4	70	280
	Aux device	1	100	100
6	Light	48	40	1920
	Fan	12	70	840
	Light	5	20	100
	Total			11830

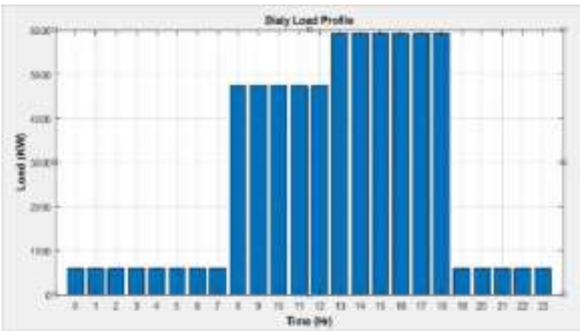

Figure 1: Daily Load Profile

Figure 1 displays the load profile of the load data supplied into HOMER from the data acquired at the commercial office complex. The commercial complex is open from 8 am to 6 pm, and 1 pm to 6 pm has been selected as the peak time. Due to the increased commercial activity in the commercial building, this time is thought to have the highest load demand.

Solar GHI Resources for PV System

The national renewable energy database was used to obtain the solar GHI resources for Eagle Island, which is located at Latitude 4°25.4'N and Longitude 7°14.6'E. Figure 2 below shows the average yearly irradiance of 4.24kWh/m2/day and the average clearness index of 0.438.

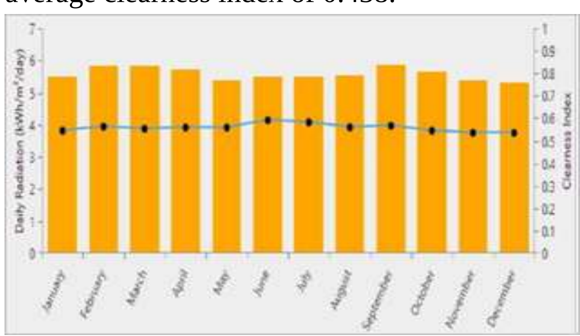

Figure 2: Monthly Average Solar GHI

Solar PV Array Characteristics

For this investigation, Suniva ART245-60 modules made by Suniva® Inc were employed. The module has a rated output, high efficiency monocrystalline cells, and a design that makes it perfect for high power applications. The characteristics of the Suniva ART245-60 solar module under typical test settings are displayed in Table 2 below.

Table2: PV Array Parameter

Model	**suniva ART245-60**
Maximum Power	250W
Voltage@ Max. Power	31.6V
Current @ Max. Power	7.91A
Open Circuit Voltage	37.4V
Short Circuit Current	8.58A
Temp. coefficient of I_{SC}	0.10899
Temp. coefficient of V_{OC}	-0.37799
Cell per Module	60

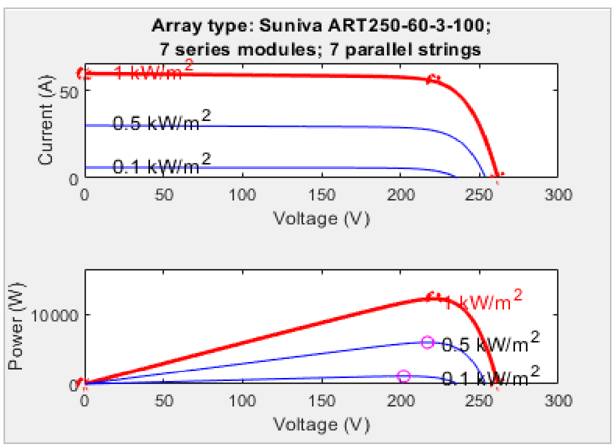

Figure 3: I-V and P-V Characteristics Curve

The PV module's I-V and P-V properties are crucial for maximising solar insolation. The suggested photovoltaic cell's I-V curve and P-V curve, respectively, are shown in figure 3 above at various irradiance levels.

Mathematical Modeling

Modeling of generator fuel consumption

$$FC_G = A_G X P_G + B_G X P_R \qquad (1)$$

Where
FC_G: fuel consumption
PG: output power of the generator in kW
PR: the rated power of the generator in kW
B**G** and AG are coefficients of the consumption curve in (1/kWh) for the diesel generation
AG :0.246 1/kWh
BG: 0.08145

The power output of the PV array

$$P_{pv} = Y_{pv} * f_{pv}\left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right)\left[1 + \alpha_p(T_c - T_{c,STC})\right] \quad (2)$$

Where
P_{pv}: Output of the PV Array
Y_{pv}: Rated capacity of the PV array [kW]
f_{pv}: PV derating factor [%]
$\bar{G}_T$: Solar radiation incident on the PV array in the current time step [kW/m^2]
$\bar{G}_{T,STC}$: Incident radiation at standard test conditions [1 kW/m^2]
α_p: Temperature Coefficient Of Power [%/°C]
T_c: PV cell temperature in the current time step [°C]
$T_{c,STC}$: PV cell temperature under standard test conditions [25°C]

Minimum Number of PV Modules per String (N_{min})

$$\boldsymbol{N_{min}} = \frac{\boldsymbol{U_{mpp(DC)}}}{\boldsymbol{V_{mp}[1+(T_{high}-T_{stc})*\gamma]}} \quad (3)$$

Where
$U_{mpp\,(DC)}$: Maximum Inverter DC Voltage Range in V
V_{mp}: PV Module Voltage @ Maximum Power in V
γ: Temperature Coefficient (Power) in %
T_{high}: Maximum Operating Temperature of PV Module in ℃
T_{stc}: PV Module @ Standard Test Condition in ℃

Maximum Number of PV Modules per String (N_{max})

$$\boldsymbol{N_{max}} = \frac{\boldsymbol{U_{max(DC)}}}{\boldsymbol{V_{oc}[+(T_{low}-T_{stc})*\beta]}} \quad (4)$$

Where
$U_{max\,(DC)}$: Inverter Maximum DC Voltage in V
V_{oc}:PV Module Open Circuit Voltage in V
β: Temperature Coefficient (Voltage) in %
T_{low}:Minimum Operating Temperature of PV Module in ℃
T_{stc}: PV Module @ Standard Test Condition in ℃

Battery Bank Capacity Ampere-hour

$$BB_{Wh} = \frac{(Wh_{AD})*(DOA)*(BM_{Temp})}{V_L*V_{Sys}} \quad (5)$$

Where

Wh_{AD}: average daily [Wh]
DOA: days of autonomy
Vsys: system voltage
BM_{Temp}: battery temperature multiplier [1.19]
DL: Discharge limit [0.50]

Storage Bank Autonomy

$$A_{batt} = \frac{N_{batt} * V_{nom} * Q_{nom}\left(1 - \frac{q_{min}}{100}\right) * \left(24hr/_{d}\right)}{L_{prim,ave}\left(1000Wh/_{kWh}\right)} \qquad (6)$$

where
N_{batt}: number of battery in the storage bank
V_{nom}: nominal voltage of a single storage [V]
Q_{nom} : nominal capacity of a single storage [Ah]
Q_{min}: minimum state of charge of the storage bank [%]
$L_{prime,ave}$: average primary load [kWh/d]

RESULT AND DISCUSSION

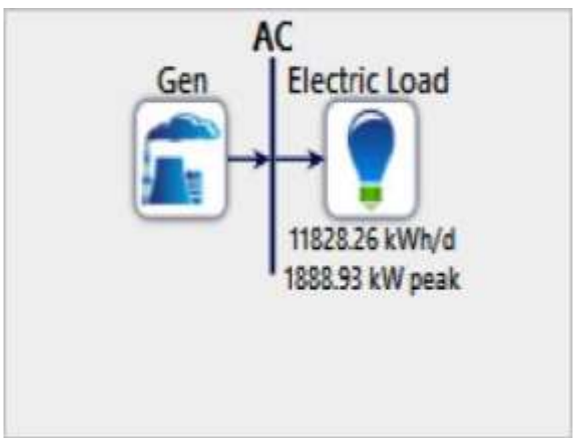

Figure 4: Base Case System

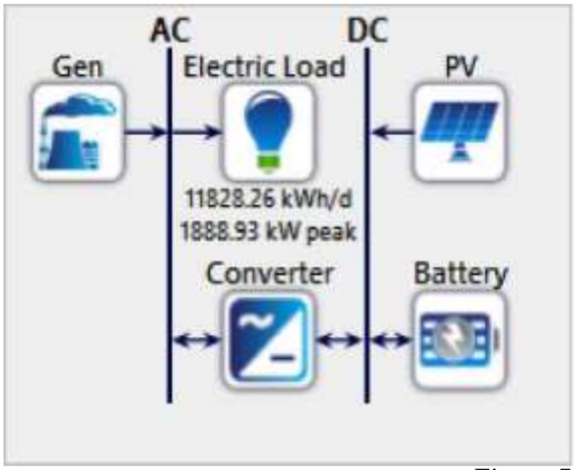

Figure 5: Improve System

Table3: Green House Gas Emission

Pollutant	Base Case (kg/yr)	Improve Case (kg/yr)
Carbon dioxide	4,863006	1,388788
Carbon monoxide	30,654	8,754
Unburned Hydrocarbon	1,338	382
Particle matters	186	53.1
Sulphur dioxide	11,908	3,401
Nitrogen oxides	28,796	8,224

Table 4: Cost Analysis

	Base Case (N)	Improve Case (N)
Cost of Energy	0.712	0.378
Net Present Cost	39.7M	21.1M
Operating Cost	2.99M	886,527
Fuel Cost	1,857,800	530,555
O & M Cost	551,880	144,660

Table5: Electricity Production

Component	Production (kWh/yr)	%
Generator	82,929	34.3
PV	158,577	65.7
Total	241,506	100

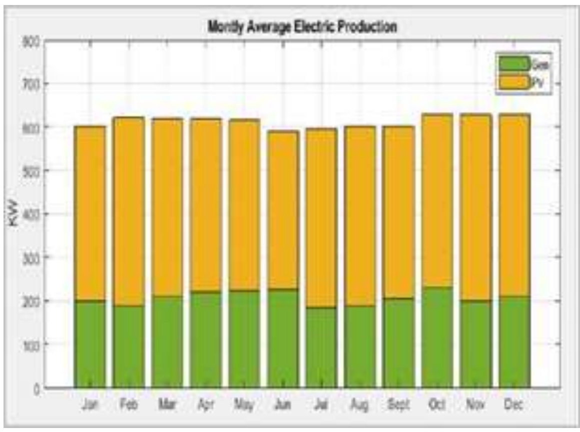

Figure 6: Graph of Electricity Production

The following are the simulation result obtained for this study in HOMER software environment. Two (2) scenarios were adopted for the simulation. Figure 4 and 5 shows the base case and improve case scenario respectively. In the base case scenario, the daily electrical energy was supplied by diesel generator only. While in the improve case scenario, a PV system with backup battery was integrated to the system as alternative source of daily electricity supply.

Table 3 shows greenhouse gas emission for both systems. A look at table3 shows significant reduction in GHG emission when PV was integrated to the system. [CO2: 46.2%], [CO: 65.2%], [Unburned Hydrocarbon: 47%], [Particle matters: 53%], [Sulphur dioxide: 45%], and [Nitrogen oxides: 55.4%].

Table 4 shows the economic analysis of both system model. A quick look at table 4 shows significant reduction in the system economics when PV was integrated. [COE: 46.9%, NPC: 43.2%, Operating Cost:70.4%, Fuel Cost: 74.4% and O&M cost 73.9%]

Table 5 shows the electricity production after Homer software optimization. The solar is actually the most preferred source of renewable energy with a contribution of 156,577 kWh/yr. Similarly, the diesel generator contributed 82,929kWh/yr. The fraction of the energy delivered renewable sources in a year is 65.7% while that of the diesel generator is 34.3%.

The average monthly generation of electric power for various system configurations is shown in Figure 6. Taking a brief look at the average monthly generation of electricity in January to December shows in the modified 40% of the power was produce by diesel generator while 60 % by PV.

CONCLUSION

The main goal of this paper is to design a hybrid renewable energy system for improved alternative power supply operation. In the design, two (2) scenarios were considered and implemented in HOMER software. Findings from this work indicates that the cost of electricity and GHG emission are far reduced compared to the conventional diesel generator.

From HOMER simulations and optimization, it is confirmed that solar is one of the most viable renewable sources for the location with a generating capacity of 65.7%; which means, standalone wind turbine generator- when properly designed can meet the commercial complex load demand.

Based on the findings, it can be concluded that the hybrid renewable technology is economically feasible and achievable for power generation. Also, the integration of the solar PV system impacted significantly in reduction of GHG emission and high O&M cost associated with autonomous operation of diesel generator.

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