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Optimization of Hybrid Renewable Energy System for Improved Alternative Power Supply Operation

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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 only 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 importance of a stable and efficient power system cannot be overemphasized as it is the key indicator for determining the socio-economic and technological development of any country (Gupta, 2016).

In Nigeria, the supply of electricity is not commensurate to the demand. Consequently, this has steered the management of power utility company in resulting to load-shedding as an alternative means to mitigate this challenge. Indeed, electricity deficit has led to the collapse of small-scale businesses and loss of revenue by the government. Many households and commercials use generators to meet their daily electricity demand.

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. it is therefore important to mitigate the excessive cost of diesel power generation using renewable energy system. With an average solar irradiance is about 2000kWh/m2, renewable solar PV energy can be fully implemented.

This paper proposes integration of solar PV renewable energy to an existing diesel generator. 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. The hybrid optimization model for electric renewable (HOMER) software environment was used to analyze the system.

Empirical Review

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.

Okedu and Uhunmwagho (2015) in their study on hybrid PV, gas turbine system reduced the high rate of fuel consumption. Thereby mitigating GHG emission and high electricity cost. It was further stated that this could be achieved with the use of renewable energy.

Methodology

Materials Used

1. **Load Data**

Table 1 shows the existing demand of the facility under study. Similarly, the load profile of the facility is shown in figure 1. Based on the calculation, an average of 11828.26kWhis consumed per day with a peak load of 1888.93kW.

Table1: Existing Load Demand

Facility	**Device/load**	**Qty**	**Watt**	**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
	Internet 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 Load (W)				11830

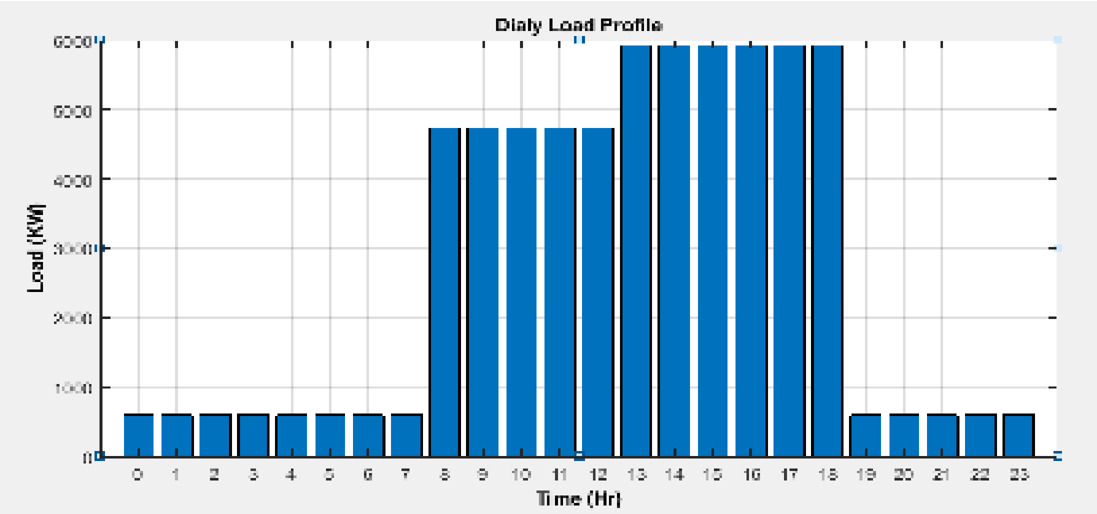

Figure 1: Load Profile

2. PV Data

For this paper, suniva ART245-60 modules manufactured by Suniva® Inc. are used. The module is made of high-efficient monocrystalline cells with rated output and design ideally suited for high power applications such as grid-tied systems. Table 1 shows the characteristics of suniva ART245-60 solar module under standard test conditions.

Table2: suniva ART245-60 solar module

Maximum Power	Pmax (W)	240
Volt @ Max Power	Vmp (V)	30.65
Current @ Max Power	Imp (A)	7.82
Open Circuit Voltage	Voc (V)	37.08
Short Circuit Current	Isc (A)	8.33
Voltage-derat factor	β,Voc	-0.332
Current-deratfactor	α,Isc	+0.035
Power-derat factor	γ,Voc	-0.465
Cell per Module		60
Max. System Voltage	Vdc	1000
Module Temperature	°C	-40 to +90
Module Efficiency		14.9%
Fill Factor		77.6%
Irradiance		1000w/m^2

3. Solar GHI

The solar GHI of the study area was obtained from NASA data base using GPS satellite at 4.50°N and 6.54°E shown in figure 2.

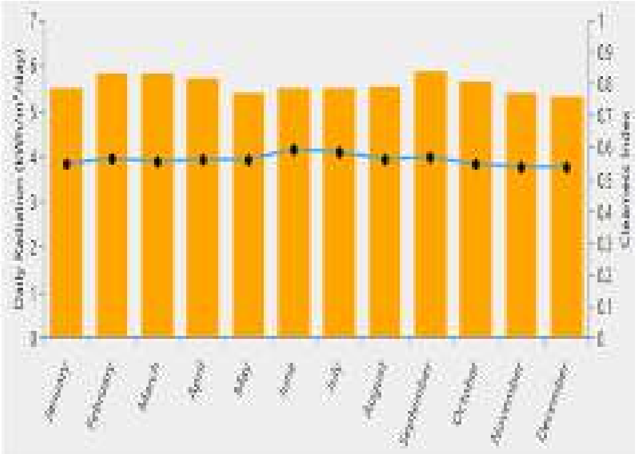

Figure 2: Solar GHI

4. Converter Data

For this paper, central inverter PVS800-57-1000KW-C manufactured by ABB was used. Table2 shows the main features of the converter model.

Table3: ABB PVS800-57-1000KW-Inverter

Input DC		
DC Voltage Range	$V_{mpp(DC)}$	600-850V
Maximum DC Voltage	$V_{max(DC)}$	1100V
Maximum DC Current	$I_{max(DC)}$	1710A
Output (AC)		
Nominal Power	$P_{N(AC)}$	1000KW
Maximum Output Power		1200KW
Power @ CosΦ		950KW
Nominal AC Current	$I_{N(AC)}$	1445V
Nominal Output Voltage	$V_{N(AC)}$	400V
Out Frequency		50/60Hz

Mathematical Model

PV Generator Array Output

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

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]

Total Number of PV Modules (N_T)

$$N_T = \frac{P_{pv}}{PV_{max}} * N_A \qquad (2)$$

Where
P_{pv}= Power Output of PV Array in KW
PV_{max}=Maximum Power of PV Module in W
N_A= Number of Arrays

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

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

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

$$\boldsymbol{N_{max}} = \frac{\boldsymbol{U_{max(DC)}}}{\boldsymbol{V_{oc}[+(T_{low}-T_{stc})*\beta]}} \quad (5)$$

Where
N_T=Total Number of PV Modules
N_{max}= Maximum Number of PV Module per String

Generator Fuel Consumption

$$FC_G = A_G X P_G + B_G X P_R \qquad (7)$$

Where
FC_G = fuel consumption
PG = output power of the generator in kW
PR = the rated power ofthe 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

Battery Bank Capacity Watt-hour

$$BB_{Wh} = \frac{(Wh_{AD})*(DOA)*(BM_{Temp})}{DL} \qquad (8)$$

Where
Wh_{AD}=Average daily [Wh]
DOA=Days of autonomy
BM_{Temp}= Battery temperature multiplier [1.19]
DL=Discharge limit [0.50]

Result and Discussion

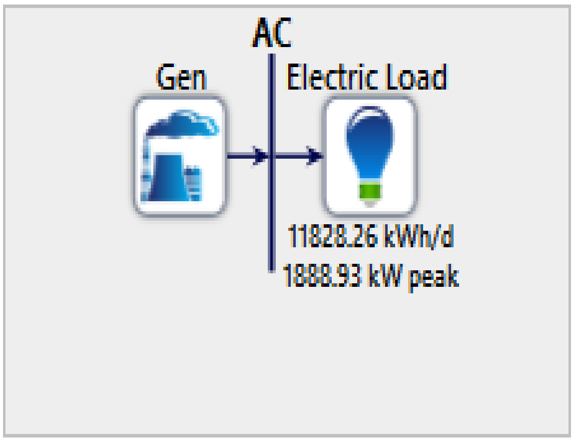

Figure 3: Base Case System Model

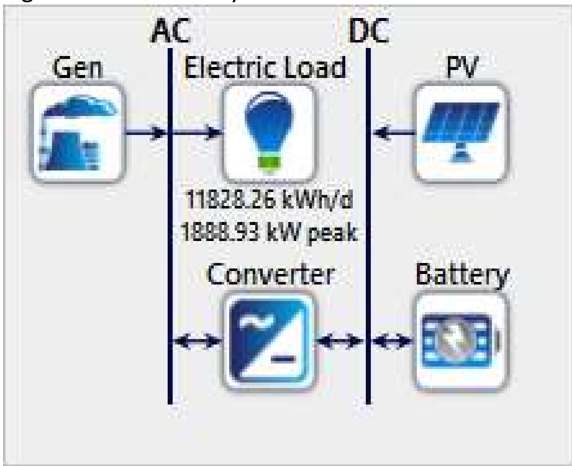

Figure 4: Modified System Model

Optimization Result

Table4: Economic Analysis

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

Table5: Greenhouse Gas Emission

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

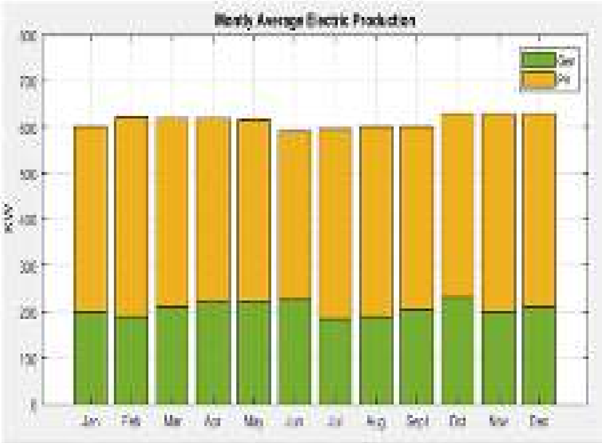

Figure 5:

Result Discussion

The following are the simulation result obtained for this study in HOMER software environment. Two (2) scenarios were adopted for the simulation. Figure 3 and 4 shows the base case and modified case scenario respectively. In the base case, the daily electrical energy is supplied by diesel generator only. Similarly, in the modified system PV system with backup battery was integrated to the system.

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 greenhouse gas emission for both systems. A look at table5 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%].

Finally, figure 5 shows the monthly average electric power production for different system models. A quick at the monthly average electric power production from 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.

Based on the finding, it is concluded that the hybrid renewable technology is economically achievable for power generation. 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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