Nigerian Research Journal of Engineering and Environmental Sciences 6(1) 2021 pp. 87-95

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

Power Generation through Photovoltaic and Hybrid System in Babalmidila, Adamawa State, Nigeria: Design and Economic Feasibility

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ARTICLE INFORMATION

Article history:
Received 02 Mar 2021
Revised 11 May, 2021
Accepted 12 May, 2021
Available online 30 Jun 2021

Keywords:
Electricity
Rural
HOMER
Renewable energy
Population
Diesel generator

ABSTRACT

Electricity generation from the conventional (through fossil fuel) means or renewable energy sources currently generated and supplied to meet the energy requirements across the globe is grossly in-adequate. The population living in the rural areas are the most affected. The grid extension cost depends on the location of the area, its terrain, the number of households, and distance of the area from a grid point. However, based on these factors and in-adequate supply of electricity to even the areas connected to the national grid, renewable energy sources may provide an alternative means of electricity generation in rural areas. This work investigated the design of a power generation system (micro grid) through a renewable energy source and hybrid system for providing electricity to rural BabalMidila, Adamawa state in Nigeria using a HOMER tool. Eighty (80) houses and three (3) shops in the area were considered in the investigation. Results showed that solar panels of 113 kW, 156 pieces of AGM 12 V 200 AH batteries and an inverter of 59.9 kW will be enough to meet the calculated load of 372.19 kWh/d with a cost of energy (COE) at \$0.570/kWh. However, COE when a 9.6% of a diesel generator was introduced stood at \$0.531/kWh.

1. INTRODUCTION

Electricity supply to any community is a necessity in improving the life of a man, increasing his awareness and reducing the gap between the rural dwellers and the urban communities. However, studies showed that about 862 million people are living without access to any electricity and that these populations are compelled to depend on the out-dated means like the use of kerosene lamps, candles and solid fuels to be able to get their electricity needs despite the side effects these sources contribute to human health and the environment because these sources emit poor and dangerous light which if mishandled could result into fire and burn appliances or even houses (Valickova and Elms, 2021).

Nigeria is a Sub-Saharan African country and has 924,000 km^2 land area, accounting for about 3.1 % land area of Africa, and lies between 4.32 ^{o}N and 14 ^{o}N on the latitude and 2.72 ^{o}E and 14.64 ^{o}E on the longitude (Sambo, 2010). The country was estimated to have only 40% of its population connected to her electricity source (national grid) through grid extension, and even these population are left to experience everyday epileptic electricity supply (Aliyu et al., 2015). Nigeria possesses ample renewable energy sources everywhere in the country which are yet to be harnessed (Aliyu et al., 2015). The current means of providing electricity for the large number of the rural dwellers through grid extension is not successful, as many places have not been connected and those connected have frequent power outages or low voltage supply which cannot power even a bulb sometimes (Aliyu et al., 2015).

Realizing clean energy that is inexpensive in compliance with the 7th Sustainable Development Goal (SDG 7) is a problem in the country and other African countries as most energy policies presently in used are either ill managed or unsustainable (Adewuyi, 2020). The energy demand in Africa is rapidly increasing as also her population particularly Nigeria having an estimated population of about 200 million persons, and these requirements for the electricity demand is hardly achieved because most of the population are faced with issues of poor health, shortages in income (poverty), ill health conditions and in-adequate research and development (Adewuyi, 2020). With the numerous number of the population living without adequate access to good and consistent electricity supply across the globe, even with the sufficient renewable energy resources that are yet to be cultivated, it is essential that decentralised or off grid based rural power supply will be a good and reliable option of giving electricity to rural settlement (Breyer and Gerlach, 2013; Valickova and Elms, 2021).

Nigeria has abundant energy sources ranging from coal, petroleum, natural gas, solar, small hydropower, large hydropower, and biomass (Sambo, 2010). The economy of the country (Nigeria) relies mostly on the revenue generated from the export of crude oil. Nigeria depends largely on fossil fuel to achieve her energy demand. The generation of electricity in Nigeria obtained from hydro power and fossil fuel is 38.1 % and 61.9 % respectively (Sambo, 2010). The estimated reserve of some fossil fuel types as obtained from Sambo (2010) are 36.2 billion barrels of crude oil, 18.7 trillion SCF of natural gas, 2.7 billion tonnes of coal & lignite and tar sand of 31 billion barrels of oil equivalent. However, with the gains in the sales of crude oil and the abundant reserves of fossil fuel couple with the dependence of products of petroleum for the provision of electricity, there are the possibilities that fossil fuel usage may continue to be the most suitable means of energy resources in Nigeria for some time (Oji et al., 2012; Oisamoje and Oisamoje, 2013).

A study conducted by Enongene et al. (2019) on about 150 residential houses in three local government area in Lagos State, Nigeria found that the levelized cost of energy/electricity was between US$0.398/kWh to US$0.743/kWh and that using the renewable energy resource (solar photovoltaic system) has a high chance of lowering the value of the emitted greenhouse gases thereby making Nigeria arriving at her climate change reduction mark. Another study by Esan et al. (2019), showed that for an optimized results obtained from HOMER tool consisting of a solar photovoltaic (PV) system, batteries, and diesel generator, the levelized electricity cost stood at US$0.396 per kWh.

In some households' research conducted in six areas of the South-South Nigeria, some location results provided that the diesel generator - PV solar system – wind – battery systems are more suitable for the provision of electricity to those areas, and in other locations of the zone, solar PV – Wind – Battery system are best suited for the power supply with no CO_2 emission. Results obtained from the hybrid system provided a payback period ranging from 3.7 to 5.4 years and the cost of energy ranging between US$0.459/kWh to US$0.562/kWh (Diemuodeke et al., 2019).

Consequently, this study employed the micro grid option due to the flatness of the landscape possessed by the area and the nearness of those eighty houses considered. HOMER tool which is an optimization software was used in the design and sizing of the solar PV system configuration in order to get the levelized cost of electricity. This software was developed by Mistaya Engineering, Canada for the National Renewable Energy Laboratory (NREL) USA to assist in the design of a power system, sizing of components used and other parameters involved.

2. METHODOLOGY

2.1. Collection of Data

In this study, the method used in collecting data was a personal survey of numerous visits made and my familiarization with the study area. The estimated load was evaluated from the assumptions made on the basic appliances found in a rural household, the appliances used by the village, bordering villages that are connected to the national grid and from studies conducted on rural electrification within the last three years. The cost of components (inverter, PV panel, diesel generator, battery etc.) was obtained by taking an average market price from online shops and suppliers. The appliances considered include lighting bulbs, DVD, television, fan, radio and phone charger. It was assumed that the study area will not go beyond the basic electricity need for lighting and entertainment.

2.2. Location of the Study Area

BabalMidila is a rural area of Hong local government in Adamawa State, Nigeria positioned on latitude 10° 10’ 48” N (10.18° N) and longitude 12° 54’ 36” E (12.91° E) (NASA, 2019). The area was estimated based on immunization count provided by the primary health care unit in that area and personal survey to have a population of about 1500 people with 215 houses. The available sources of power in the locality presently are grid extension (irregular supply), petrol generators, kerosene powered lamps, torchlights, candles and battery lanterns.

2.3. Average Daily Radiation and Temperature inputs

The solar radiation data was extracted from NASA surface meteorology and Solar Energy Data base. The data provided an annual average daily solar radiation and annual average clearness index of 5.59 kWh/m^2/day and 0.56 respectively as shown in Table 1.

Table 1: Average daily radiation and temperature data

Months	Average daily solar radiation (kWh/m^2/d)	Clearness index	Ambient temperature (°C)
January	5.69	0.566	27.09
February	6.02	0.580	28.21
March	6.26	0.596	34.46
April	6.05	0.593	33.40
May	5.80	0.601	28.47
June	5.66	0.608	25.97
July	4.51	0.478	24.56
August	4.30	0.434	23.96
September	5.33	0.516	24.49
October	6.07	0.586	24.50
November	5.99	0.593	24.30
December	5.43	0.548	25.49
Average	5.59	0.558	27.08

2.4. Estimated Electricity Load demand/Inputs

The personal survey found that the electricity needed in the area is for lighting, entertainment few community loads needed at the primary health care unit, primary school and shops. However, this study investigated eighty houses and three shops, and the load parameter put into consideration was the hourly load demand which was calculated from the appliances with their corresponding power ratings and the numbers needed in a household. The sum of the hourly load in kilowatt was used in the design and sizing of the components. The total hourly load and daily load profile considered are shown in Table 2.

Table 2: Total hourly load required

Time	Residential load (kW)							Commercial load (kW)					
	Light LED (10W)	Fan (55W)	TV (80W)	DVD (35W)	Radio (40W)	Phone charger (6W)	Security light (40W)	Light LED (10W)	Fan (55W)	Radio (40W)	Phone charger (6W)	Security light (40W)	Hourly load (kW)
00:00-01:00		8.8					3.2					0.12	12.12
01:00 -02:00		8.8					3.2					0.12	12.12
02:00 -03:00		8.8					3.2					0.12	12.12
03:00 -04:00		8.8					3.2					0.12	12.12
04:00 -05:00					3.2	0.96	3.2					0.12	7.48
05:00 -06:00	2.4				3.2	0.96	3.2					0.12	9.88
06:00 -07:00	2.4		6.4		3.2	0.96		0.06					13.02
07:00 -08:00	2.4	8.8		2.8	3.2			0.06			0.09		17.35
08:00 -09:00		8.8			3.2				0.165	0.12	0.09		12.375
09:00 -10:00		8.8			3.2				0.165	0.12	0.09		12.375
10:00 -11:00		8.8			3.2				0.165	0.12			12.285
11:00 -12:00		8.8			3.2	0.96			0.165	0.12			13.245
12:00 -13:00		8.8	6.4	2.8	3.2	0.96			0.165	0.12			22.445
13:00 -14:00		8.8	6.4	2.8	3.2	0.96			0.165	0.12	0.09		22.535
14:00 -15:00		8.8	6.4	2.8	3.2				0.165	0.12	0.09		21.575
15:00 -16:00		8.8			3.2				0.165	0.12	0.09		12.375
16:00 -17:00		8.8			3.2	0.96			0.165	0.12	0.09		13.335
17:00 -18:00		8.8			3.2	0.96			0.165	0.12	0.09		13.335
18:00 -19:00	2.4	8.8	6.4			0.96	3.2	0.06	0.165	0.12	0.09	0.12	22.315
19:00 -20:00	2.4	8.8	6.4	2.8		0.96	3.2	0.06	0.165	0.12		0.12	25.025
20:00 -21:00	2.4	8.8	6.4	2.8		0.96	3.2	0.06				0.12	24.74
21:00 -22:00	2.4	8.8	6.4	2.8			3.2	0.06				0.12	23.78
22:00 -3:00		8.8					3.2					0.12	12.12
23:00 -00:00		8.8					3.2					0.12	12.12
						Total							372.19

2.5. Design and Components Sizing

Hybrid Optimization Model for Electric Renewables (HOMER), uses some inbuilt modelled equations to calculate input data. The design uses 16.11% as the value for the annual real interest rate in the economic input window, 25 years' project lifetime, \$30,000 system fixed cost to serve for battery storage house/area and cost of distribution and \$2,000 estimated as the system fixed operation and maintenance in a year (HOMER Pro, 2016).

2.6. Selection and Specification of Photovoltaic Solar panel

Photovoltaic array power was calculated using the inbuilt equation as shown in Equation 1 (*HOMER Pro,* 2016).

$$P_{pvao} = PV_{RC} \times PV_{DF} \left(\frac{G_{i,PV}}{G_{i,STC}}\right)\left[1 + \tau_p\left(T_{Cell} - T_{Cell,STC}\right)\right] \quad (1)$$

Where:

$PV_{RC} =$ Photovoltaic array rated capacity (kW)
$PV_{DF} =$ Photovoltaic array Derating factor (%)
$G_{i,PV}$ = Incident radiation on the array at that time (kW/m^2)
$G_{i,STC}$ = Incident radiation at standard test condition (1kW/m^2)

τ_p, = Temperature coefficient of power (% / °C)
T_{Cell} = Cell temperature of PV (°C)
$T_{Cell,STC}$ = Cell temperature of PV at standard test conditions (25 °C)

The selection of 3000 W monocrystalline PV cell at $339.72 capital cost was made in this design and was chosen over other types of PV cells like polycrystalline and amorphous cells due to some of the following advantages it possesses:

- Has the highest efficiency between 15% - 20%
- They are space-efficient (acquire the use of small space)
- Live longer
- Perform better than same capacity of polycrystalline at low-light conditions
- They have greater heat resistance

The specifications of the 300 W selected for the design is shown in Table 3.

Table 3: Design and input parameters of solar photovoltaic module

Parameters	Values	Unit
Maximum power	300	W
Project lifetime	25	Yr.
Slope	10.18	°
Derating factor	80	%
Temperature coefficient of power	-0.41	%/°C
Azimuth	0	°
Ground reflectance	20	%
Nominal operating cell temperature	46	°C
Efficiency at standard test condition	17.89	%
Capital cost	339.72	$
Replacement cost	0	$
Operation and maintenance cost	0.32	$/yr.
Nominal voltage	24	V

The capital cost of the solar system includes the cost of the panel, wiring, installation, and mounting of circuit breakers connectors and fuses. 5% of cost of the component was used to get the installation cost, 2% of the coat of installation was used to get the operation and maintenance cost (Akinyele et al., 2015), no value was used for the PV system replacement cost due to the same warranty period the panel has with the project lifetime (*HOMER Pro*. 2016). A value of 27.8 % of total initial cost was used to get the cost for other balance of system (Rehman et al., 2007).

2.7. Selection of the Inverter

A 1.5 kW GP solar inverter with a 48 VDC, having an isolation transformer suitable for inductive loads and a capital cost of US$ 555.78 was chosen. This inverter has an inbuilt AC charger of 20 A which can charge up to 4 pieces of 200 Ah batteries and an inbuilt maximum power point tracking (MPPT) charge controller of 10-60 A which can regulate up to 8 pieces of 300 W solar modules.

2.8. Battery Sizing and Selection

The set-up of an off grid or micro grid needs a storage unit in order to store excess power produced from the solar energy so as to use it at night. It functions as a backup that provides electricity for the system in a situation where there is low generation of power and also when a constant voltage is required especially during peak load (Ugirimbabazi, 2015). However, two independent factors lessen the life time of a battery bank; these are either usage or old age. In this design, the model calculates the life of battery bank using Equation 2 (Lambert et al., 2004).

$$L_{bb} = MIN\left[\frac{N_b \times Q_{lt}}{Q_{tp}}, L_{bf}\right] \quad (2)$$

Where:
L_{bb} = Battery bank life (yr.), N_b = Number of batteries in the bank, Q_{lt} = Life time throughput of a single battery (kWh), Q_{tp} = Annual battery throughput (kWh/yr.) and L_{bf}= Float life of battery (yr.)

2.9. Generator Inputs

About 9.6% diesel generator input was introduced to support the system in an event of low capacity and in order to discourage the use of generators in the future so as to minimize gaseous emission. A value of 25 % generator cost was used as the installation cost with 5 % of the capital cost as the value of the operation and maintenance cost (Otasowie and Ezomo, 2014; Abdul-Salam and Phimister, 2016). The input parameters used in the design window are in Table 4. Figure 1 shows a simple set-up of a solar PV microgrid system.

Table 4: Diesel generator input data

Description	Value	Unit
Size	10	kW
Capital cost	3563.29	$
Replacement cost	3563.29	$
Lifetime	15000	h
Minimum load ratio	30	%
Fuel	Diesel	-
Fuel cost	0.54	$/L

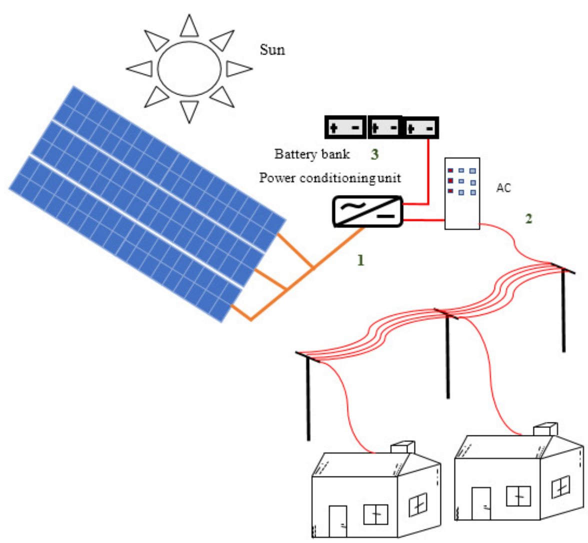

Figure 1: Components of a solar photovoltaic (PV) microgrid

2.10. Emissions Outputs

The emissions tab in the simulation results window shows the total amount of each pollutant produced annually by the power system in kg/yr. Pollutants originate from the consumption of fuel and biomass in generators (*HOMER Pro*. 2016).

3. RESULTS AND DISCUSSION

3.1. Solar Photovoltaic (PV) Optimization Results

Results from the system architecture presented in Table 5 showed that the photovoltaic solar panels capacity for the 372 kWh/d load is 113 kW (about 378 pieces of 0.3 kW solar panels) with about 156 pieces of 12 V 200 AH AGM batteries and 59.9 kW inverter and a load following dispatch. The peak load demand of 25.025 kW is needed around 19:00h to 20:00h and this was increased in the day to day settings to 10 in order to accommodate for any change in additional load. The summary of the result for the PV configuration as shown in Table 5, presented that the cost of energy is \$0.57/kWh with a net present cost (NPC) of \$270,940 and an energy production of 167,390 kWh/yr. with no any emission. Some of the factors making the cost of energy and hampering the development of renewable energy sources include initial capital, politics, policy and strategy, programs on environmental support, legislation and regulation, fiscal incentives, technology and innovation among others (Emodi and Ebele, 2016). The cost of energy obtained as \$0.57/kWh is within the range obtained by Enongene et al. (2019) which is between \$0.398/kWh to \$0.743/kWh and Diemuodeke et al., (2019) that ranges between \$0.459/kWh to \$0.562/kWh.

Table 5: Solar PV optimization results

Architecture				Cost			PV
PV (kW)	Battery	Inverter (kW)	Dispatch	COE (\$/kWh)	NPC (\$)	Initial cost (\$)	Production (kWh/yr)
113	156	59.90	LF	0.57	270,940	245,288	167,390

3.2. Hybrid Optimization Results

The results from the configuration comprising 90.4 % solar photovoltaic (PV) and 9.6% Perkins diesel generator penetrations gave a total net present cost (NPC) and cost of energy (COE) at US\$ 274,853 and US\$ 0.531/kWh respectively as shown in Table 6. It further provided that PV panel of 109 kW together with a diesel generator of 10 kW, an inverter capacity of 53.9 kW and 156 quantities of 12 V 200 AH AGM batteries can be used to serve the load. It shows some of the component results that made up the system and also provided the summary of the replacement, operation and maintenance cost of the system throughout its lifetime.

Table 6: Hybrid optimization results

Items	Quantity	Unit
PV panel	109	kW
Battery	156	-
Inverter	53.9	kW
Total NPC	274,853	US\$
Cost of energy	0.531	US\$/kWh
Renewable	90.4	%
Diesel generator	10	kW
Replacement Cost	3,563.29	US\$

The hybrid optimization results were observed to have a reduction in the cost of energy, the quantities of solar PV panels required, and the total net present cost, just with a 9.6 % use of a diesel generator, in order to cater for the event of insufficient power output from the solar system configuration. Moreover, results show that it is economically advantageous to use hybrid system in remote areas than using diesel-only power generating set because, the hybrid system reduces the fuel consumption and carbon dioxide (CO_2) emission (Okeolu et al, 2015). From the hybrid optimization results, the emission in kg/yr. with the 9.6% penetration of the diesel generator in the system indicating carbon dioxide having the highest value of 11,029 kg/yr. while carbon monoxide, unburned hydrocarbons, particulate matter, sulphur dioxide and nitrogen oxides were released in the values of 83.4, 3.04, 5.06, 27.1 and 94.8 kg/yr (Table 7).

Table 7: Emissions

Quantity	Value (kg/yr)
Carbon dioxide	11,029
Carbon monoxide	83.4
Unburned hydrocarbons	3.04
Particulate matter	5.06
Sulfur dioxide	27.1
Nitrogen oxides	94.8

4. CONCLUSION

This paper investigated the generation of power for 80 residential houses and 3 shops in rural BabalMidila, Adamawa state - Nigeria. The design and optimization results for both the solar PV system and the hybrid configuration (comprising the solar PV and diesel generator) showed that solar PV technology and even the hybrid system are viable means of electrifying BabalMidila, Adamawa state as indicated by the electricity production rate of about 167,390 kWh/yr. The net present cost (NPC), the cost of energy (COE) between US$ 0.531/kWh to US$ 0.57/kWh, solar panels capacity of 113 kW, 156 pieces of AGM 12 V 200 AH batteries and an inverter of 59.9 kW provided a feasible configuration for the design and techno-economic analysis.

5. ACKNOWLEDGEMENT

The authors wish to acknowledge and thank the managements of Hybrid Optimization Model for Electric Renewables (HOMER) and Konga Online Shop for providing the necessary materials, information and cost values for this work.

6. CONFLICT OF INTEREST

There is no conflict of interest in this work.

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