FEASIBILITY ANALYSIS OF A GRID CONNECTED PV/WIND OPTIONS FOR RURAL HEALTHCARE CENTRE USING HOMER

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ABSTRACT

Renewable energy system (RES) is the cost effective and reliable option for reducing energy bills and GHG emissions. The purpose of this study is to carry out a Feasibility Analysis of a Grid-Connected PV/Wind options for a Rural Healthcare Centre Using Hybrid Optimization Model for Electric Renewables (HOMER). The renewable energy feasibility study was conducted using HOMER optimization tool to evaluate the most appropriate renewable energy systems for the Clinic. Wind speed and solar radiations from NASA Surface Meteorology and Solar Energy web site are used along with the hourly load data for the Clinic to perform Simulation, Optimization and Sensitivity analysis for the RES. The RES feasibility study shows that the optimal grid-connected PV/Battery system is the most economically feasible option for the Healthcare Centre. The system consists of the Grid, 2kW PV Panels, two 6FM200D batteries and a 1kW converter. The Total Net Present Cost (NPC) for this system is $8,901 with initial Capital Cost of $2,800 and Levelized Cost of Electricity (COE) per kWh of $0.096. This system will save 542.753kg (0.5427 tonnes) of carbon dioxide per annum. The result of this research shows that 43% of the electricity production is from renewable which means that the clinic will still get electricity supply even if the grid is interrupted for a long period of time.

INTRODUCTION

Micro-generation is inevitably one of the most promising ways for ensuring the security of supply and reducing greenhouse gas (GHG) emissions. In Nigeria, the ever-increasing population leads to a large increase in energy consumption. This coupled to the intermittent nature of electricity supply and the rising public awareness about the environment make renewable energy the most needed alternative in the country.

In 2003, The Nigerian Government had reviewed its National Energy Policy (NEP) by integrating together the various policy documents for the different energy sub-sectors into a comprehensive energy policy. The policy identifies renewable energy (wind and Sun) as one of the sub-sectors of the nation's energy sector that is pivot to meeting the nation's energy demand and such is encourages greater indigenous participation (ECN, 2003).

Solar and Wind energy potential of Nigeria are enormous and varies considerably from the north to the south (ref). Solar radiation ranges from 7.0KW/m/day in the northern part of the country to 3.5KW/m/day in the south respectively. While the Wind speed is in the range of 2 to 4 m/s at 10m from low to high land (Chilakpu, 2015). These energy sources, if fully harness, especially in the northern part is enough to electrify remote villages that are not connected to the grid.

This paper will present a Feasibility Analysis of a Grid-Connected PV/Wind options for a Rural Healthcare Centre Using HOMER (Hybrid Optimization Model for Electric Renewables).

Methodology

The feasibility analysis was performed using HOMER Software. HOMER is a hybrid micro-power system optimization tool developed by National Renewable Energy Laboratory (NREL) of the US Department of Energy (DOE). It is widely used for both the off-grid and grid-tied micro-power systems analysis. It contains a mix of conventional generators and renewable energy systems (Sadique et al., 2012). Simulation, Optimization, and Sensitivity analysis, are performed on the system in order to compare the results of different energy systems, and get a realistic projection of their capital and operating costs.

Site Location and Climate

Murke is Village in the Central Senatorial District of Adamawa State, North Eastern Nigeria on the Latitude 9.25^{o} and Longitude 12.46^{o}. The climate of Adamawa state is a Tropical one which is characterized by dry and wet (rainy) seasons. Rainy season begins from April till late October, while the dry season lasts from November to March. Geographical and Meteorological influences cause local variations (Alexander, 2015). The maximum daily temperature may rise as high as 43^{o}C and the minimum may fall as low as 11^{o}C.

Figure 1: Map of Murke Village in the Central Senatorial District of Adamawa State

Input Data

Simulation in HOMER Software requires a number of data input which include the Load data, Wind resource data and solar radiation data. Others are prices and running costs of the equipment considered and air temperature data. However, this study will not take air temperature into consideration.

Load Profile

A standard health clinic in rural Nigeria requiring 19kWh per day to run and this was used to establishment a hypothetical study for the electrical load data (Vincent and Bahijjahtu, 2015).

The hourly load data was obtained by considering the equipments that are in the healthcare centre and their power rating as well as their predicted hourly usage. The usage of the equipments differs slightly from hour to hour but remains almost constant from month to month.

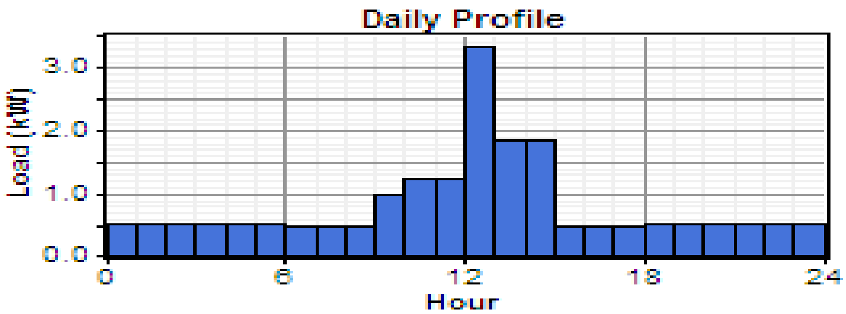

Figure 2: Daily load profiles for the health clinic

Wind Resource Data

The Wind resource data was sourced from the NASA Surface Meteorology and Solar Energy web site. The average annual wind speed for the area was 4.40m/s, and the anemometer height was 10m.

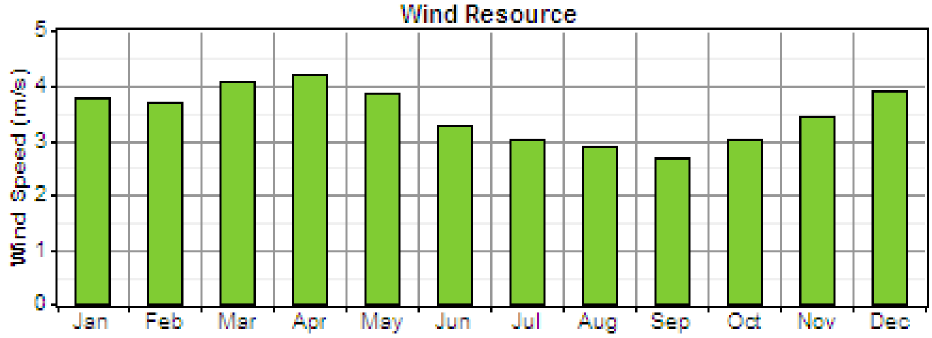

Figure 3: Annual wind speed profile for the area

For sensitivity analysis, Sensitivity values were introduced to performed sensitivity analysis in-other to make the results suitable for other places around Yola in Adamawa State of Nigeria. The values are 3.8, 4.0. 4.40 and 4.80m/s.

Solar Radiation Data

The solar radiation data was also obtained from the NASA Surface Meteorology and Solar Energy web site. The average annual solar radiation for the area was 5.51kWh/m^2/d.

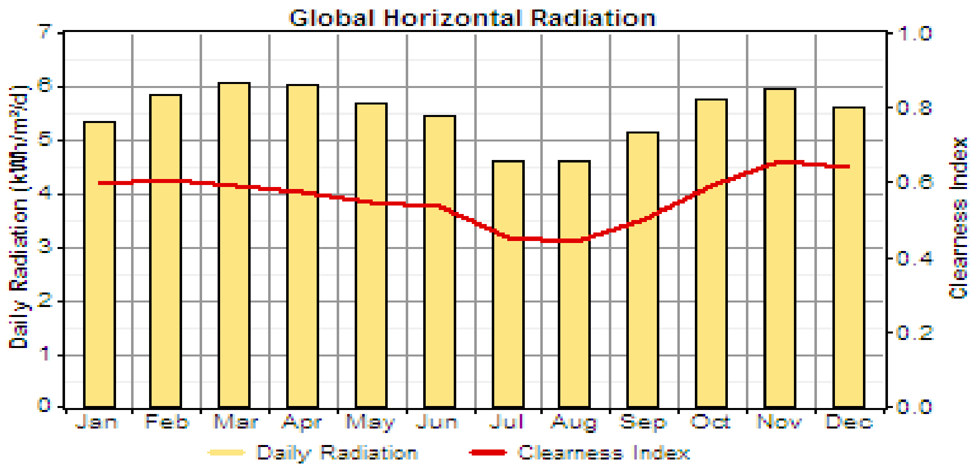

Figure 4: Annual Solar resource profile for the area

The sensitivity values of 4.5, 5.0, 5.5, 6.0 and 6.5kWh/m^2/d were introduced to perform sensitivity analysis.

System Configuration

The block diagram of the proposed system is shown in Figure 5. The system consists of the Grid, PV panels, wind turbine generator, and storage batteries as well as a converter. The PV panels and wind turbine generator generate DC power and are connected to the DC bus. The converter converts the Direct Current produced to Alternating Current. The system supplied power to the load and when the generation exceeds the load demand, the storage batteries are charged. The batteries will then supply power to the load when demand exceeds generation. When the batteries are fully charge but generation still exceeds the load, the excess available power is sold to the nearby community.

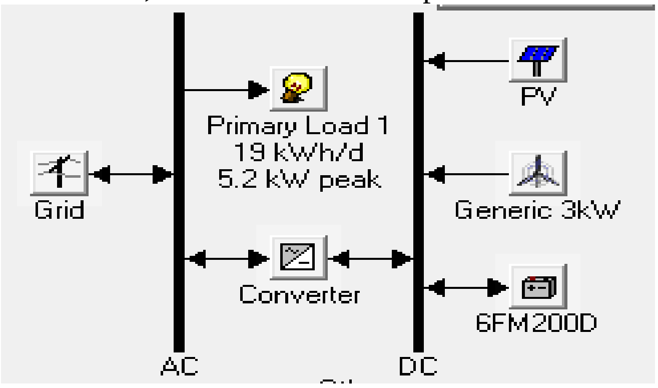

Figure 5: Block diagram of the proposed system

Table 1: List of system component sizes and cost considered for the analysis

Component	PV Panel	Wind Turbine	Battery	Converter
Size/Type	4kW	Generic 3kW	Vision 6FM200D 200 Ah / 12 volt, 2.4KW	3kW
Capital Cost ($)	$3975/kW	$9,000	$200	$800/kW
Replacement Cost ($)	$3975/kW	$8,000	$160	$700/kW
O&M Cost ($)	0	$15/year	$10/year	0
Lifetime	25 years	20 years	10 years	15 years
Derating factor (%)	90	-	-	-
Sizes/Quantity/String Considered for Sensitivity Analysis	0, 2, 4 and 6kW	0, 1, 2	2, 4, 6, 8, 10 and 12	1, 2, 3 and 4

RESULTS AND DISCUSSION

Optimization Result

Figure 6 shows the best solutions (from the economic perspective) per system design. These optimization results are obtained based on a solar radiation of 5.51kWh/m^2/d, a wind speed of 4.40m/s and an average load of 19.2kWh/d.

There are four different feasible system designs; Grid/PV/Battery, Grid/Battery, Grid/Wind/Battery and Grid/PV/Wind/Battery systems.

	PV (kW)	G3	6FM200D	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
	2		2	1	1000	$ 2,800	477	$ 8,901	0.096	0.36	0.00
			2	1	1000	$ 1,300	656	$ 9,685	0.108	0.00	0.00
		1	2	1	1000	$ 3,550	668	$ 12,084	0.127	0.31	0.00
	2	1	2	1	1000	$ 5,050	561	$ 12,223	0.123	0.53	0.00

Figure 6: List of the Best Solutions per System Design for the power system

From the figure, the Grid, 2kW PV Panels, two 6FM200D batteries and a 1kW converter is the most economical (optimal) combination. The Total Net Present Cost (NPC) for this system is $8,901 with initial Capital Cost of $2,800 and the Levelized Cost of Electricity (COE) per kWh is $0.096. The renewable fraction is 36% meaning that 36% of the power delivered to the load originated from renewable source (Solar).

Result of the Sensitivity Analysis

Sensitivity variables were introduced to study the effect of changing average daily load, solar and wind resources. Figures 7, 8, 9 and 10 show the sensitivity results for the system at a fixed wind speed of 3.8, 4, 4.4 and 4.8m/s respectively.

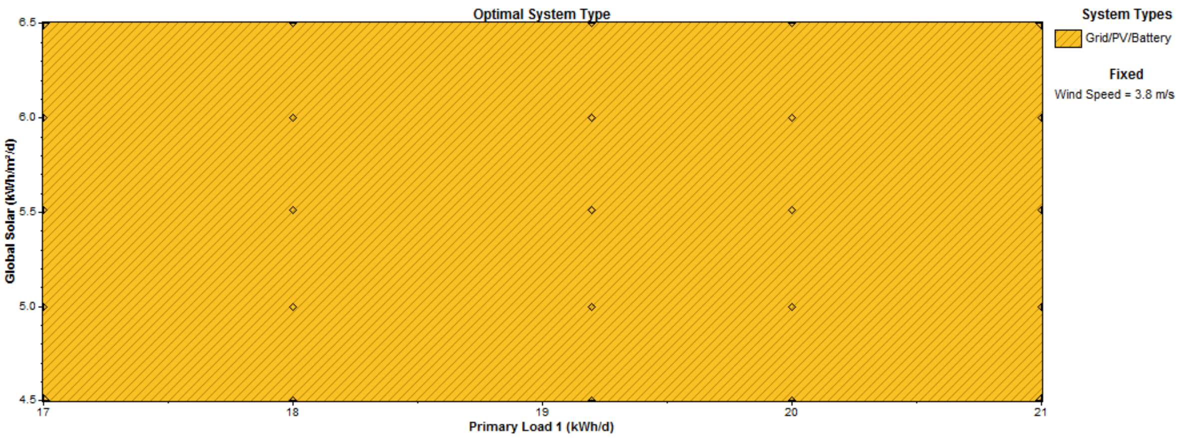

Figure 7: Optimal System Type (OST) over increasing Global solar and Load at wind speed of 3.8m/s

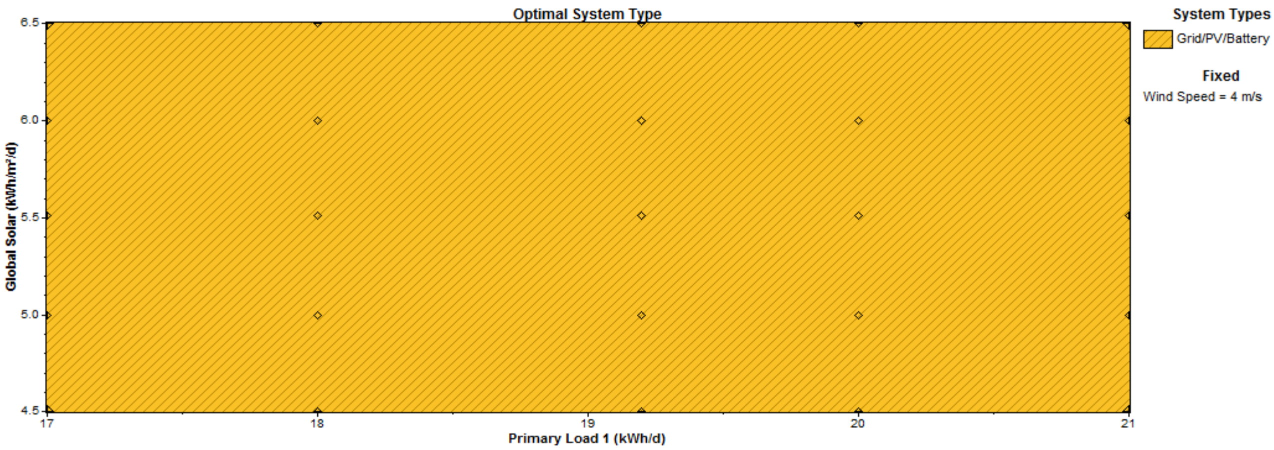

Figure 8: Optimal System Type (OST) over increasing Global solar and Load at wind speed of 4m/s

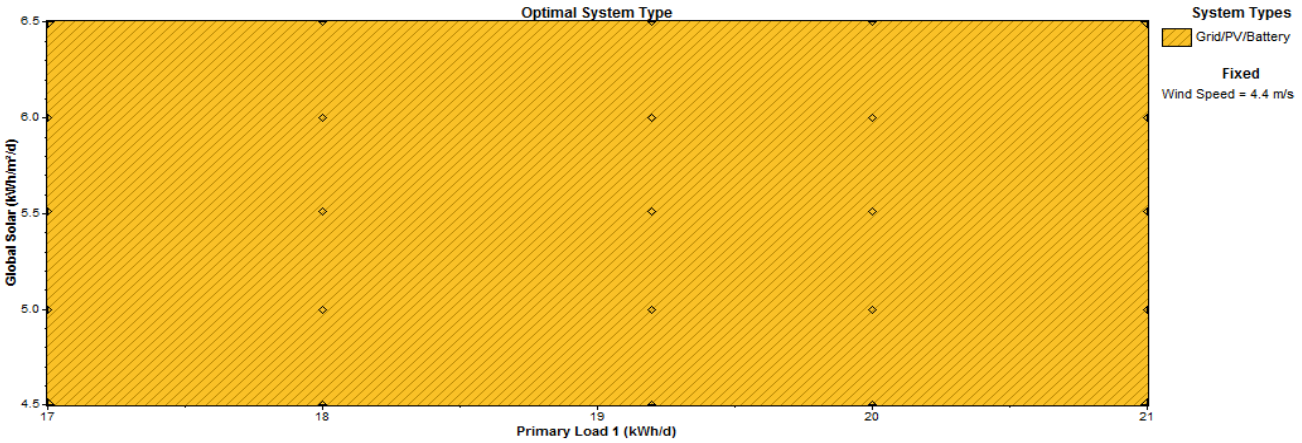

Figure 9: Optimal System Type (OST) over increasing Global solar and Load at wind speed of 4.4m/s

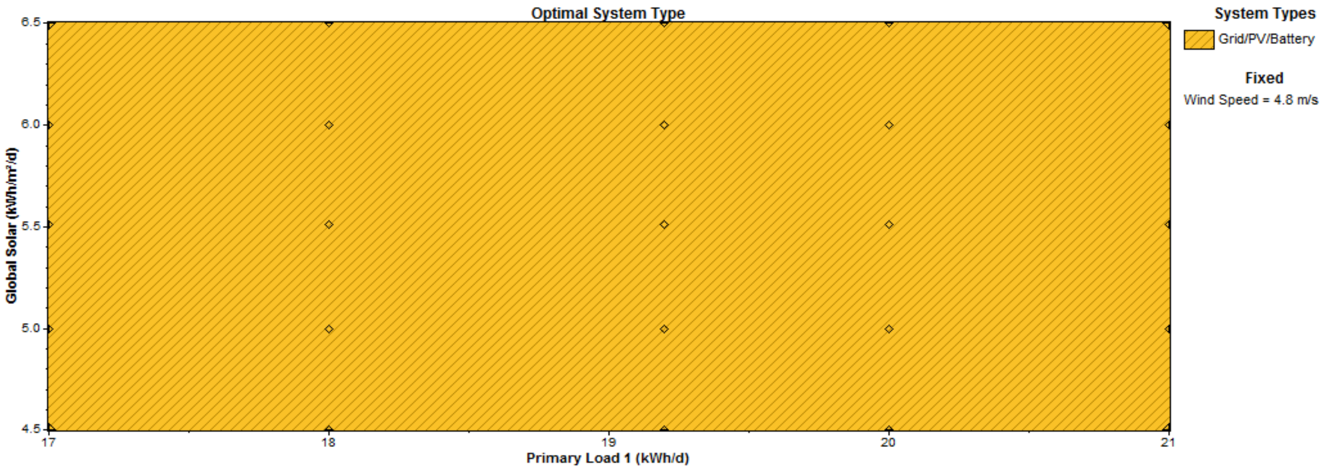

Figure 10: Optimal System Type (OST) over increasing Global solar and Load at wind speed of 4.8m/s

As can be seen from the figures, at all points over the range of global radiation used, the Grid/PV/Battery system is the most cost effective throughout the load range irrespective of the variation in the wind speed.

Simulation Result

The cost summary in figure 11 indicated that the Grid contributed to 53.58% ($4769) of the NPC followed by the PV with 19.17% ($1706). The Batteries and the converter contributed 15.59% ($1388) and 11.66% ($1038) respectively.

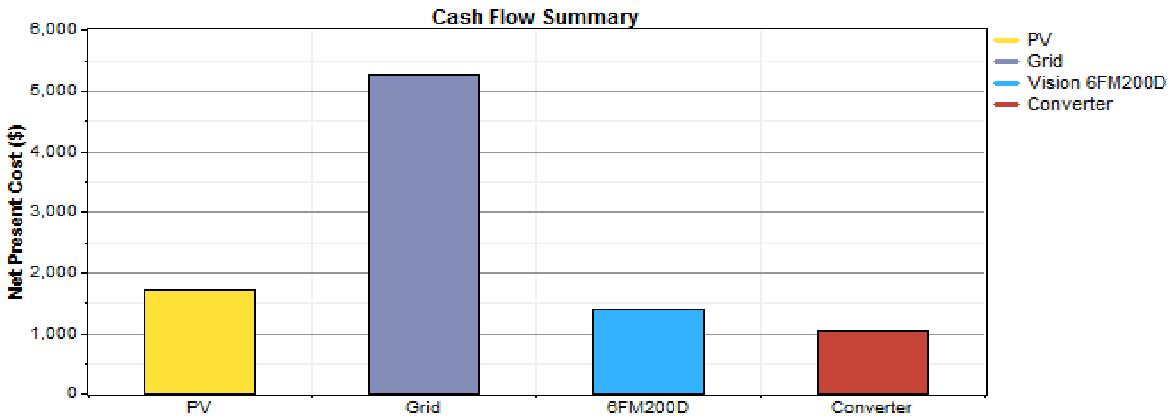

Figure 11: The cost summary for the optimal system (Grid/PV/Battery system)

Figure 12 shows the cash flow order for this system design. A large capital expenditure in year zero and the subsequent small Operation and Maintenance (O&M) cost that occurs in every year. There is a small battery replacement cost after the tenth year and a converter replacement cost after 15 years. It also shows a large PV and Battery replacement cost after 20 years and a large salvage value at the end of the project.

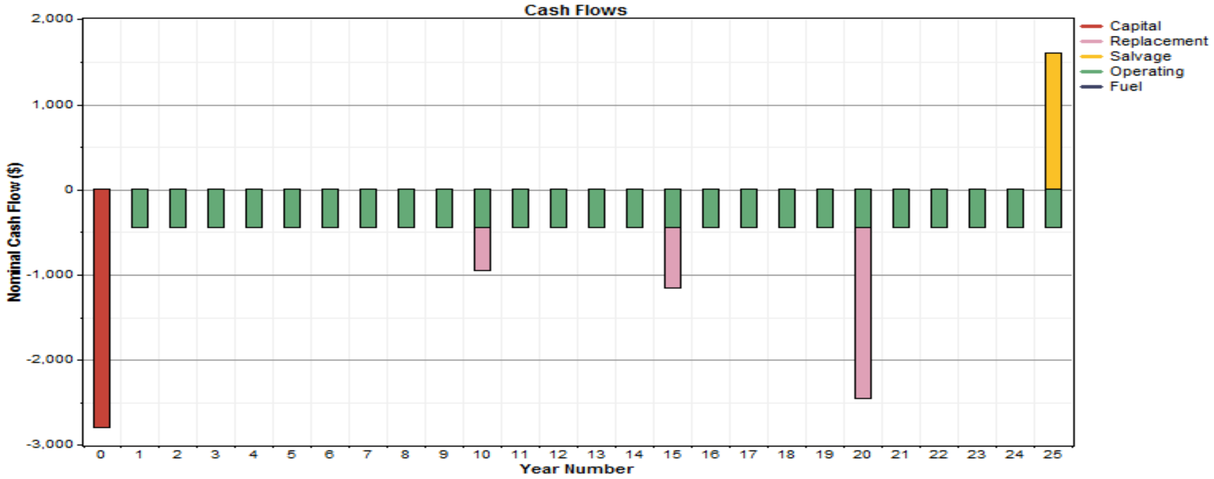

Figure 12: Cash flow order for this system design

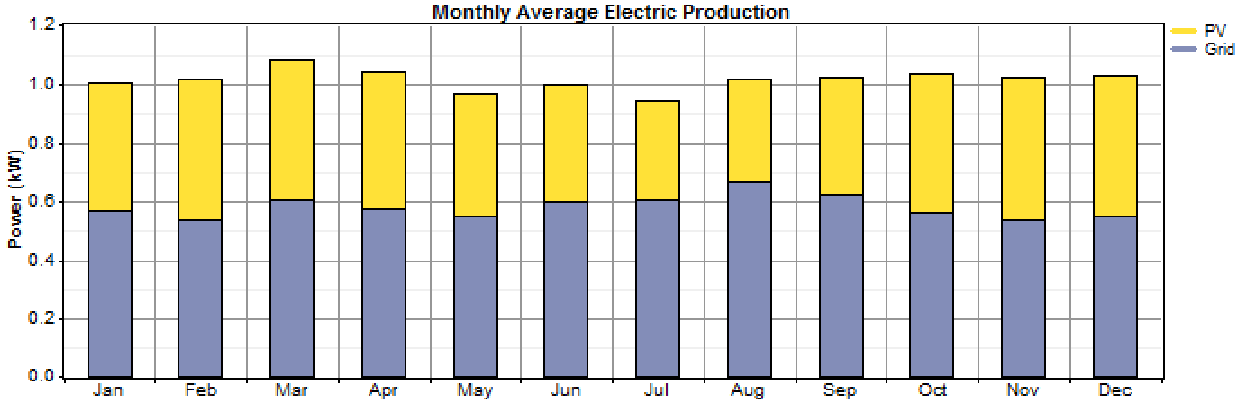

Figure 13: Monthly average electric production for the system

The power consists of the Grid purchased power and the PV generation. The breakdown of the electricity production from the system and the annual consumption is given in the Tables in figure 14. The result indicates that the system generates a total of 8,886kWh per annum, with the PV system producing 3,809kWh which represents 43% of the total annual production and the grid supplies the remaining 57% (5077kWh). While 250kWh representing 3% of the total electricity production is sold to nearby community. There is also an excess of 655kWh representing 7.37% of the total yearly production. There is no unmet load and the capacity shortage is zero. The maximum renewable penetration of this system is 204%.

System Architecture: 1,000 kW Grid, 2 kW PV, 2 Vision 6FM200D, 1 kW Inverter, 1 kW Rectifier

Total NPC: $ 9,391
Levelized COE: $ 0.093/kWh
Operating Cost: $ 516/yr

Cost Summary | Cash Flow | Electrical | PV | Battery | Converter | Grid | Emissions | Time Series

Production	kWh/yr	%
PV array	3,809	43
Grid purchases	5,077	57
Total	8,886	100

Consumption	kWh/yr	%
AC primary load	7,665	97
Grid sales	250	3
Total	7,915	100

Quantity	kWh/yr	%
Excess electricity	655	7.37
Unmet electric load	0.00	0.00
Capacity shortage	0.00	0.00

Quantity	Value
Renewable fraction	0.359
Max. renew. penetration	204 %

Figure 14: Breakdown of the monthly average electric production for the system

According to Adegunle et al, (2015), 0.486277966kg of carbon dioxide is emitted per kWh of electricity purchased from the Power Holding Company of Nigeria (PHCN). Base on that 3588.753kg (3.589 tonnes) could have been emitted if the grid electricity is used to serve the whole load (present scenario). But the resulting GHG emissions per annum from this system design, as shown in figure 15 is 3,046kg (3.046 tonnes) per annum which is less by 542.753kg (0.5427 tonnes).

Pollutant	Emissions (kg/yr)
Carbon dioxide	3,046
Carbon monoxide	0
Unburned hydrocarbons	0
Particulate matter	0
Sulfur dioxide	13.2
Nitrogen oxides	6.47

Figure 15: Emission per annum for the system

CONCLUSION

This paper presents a proposed hybrid electric power system for a remote health care center in Adamawa Nigeria. HOMER is used to identify the optimal hybrid system combination base on economic and environmental factors. Wind speed and solar radiations data from NASA Surface Meteorology and Solar Energy web site are used along with the hourly load data for the Clinic to perform Simulation, Optimization and Sensitivity analysis for the hybrid system. The optimization result has suggested 4 optimal combination of the different components (i.e Grid, Wind and PV) of the hybrid systems. Grid/PV/Battery system is identified, amongst the 4 combinations, as the best optimal solution with least NPC. It has the NPC of $8,901 and a Cost of Electricity (COE) per kWh of $0.096. This system is paramount to the clinic as the renewable system can power the most needed loads when the supply from the grid is interrupted as the electricity supply in Nigeria is still facing such problems. The excess power resulting from the system, when available, is sold to the nearby community. This system can save 542.753kg (0.5427 tonnes) of carbon dioxide per annum which is very good for the environment.

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