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Solar Power Supply for a Developing Community in Rivers StateCase Study: Krakrama Community, Asari-Toru Local Government Area

Briggs IyenemiC.O. Ahiakwo, S.L.B. Braide,
Email Address: iyenemi_big@yahoo.com

ABSTRACT

Nigeria is blessed with lots of renewable energy potentials including solar energy which is an alternative source of energy. There is need for more research in the field of solar energy supply in other to reduce the unavailability of electricity supply. This study is focused on estimating the potential of building integrated standalone photovoltaic (PV) system for supplying electricity in Krakrama community in Rivers State, Nigeria. Equations based on optimization techniques were used to analyze the photovoltaic (PV) system for a total load of 1936.0176kWh/day. The solutions of the equations were made possible through HOMER. The result shows that the capacity of the photovoltaic (PV) panel obtained was 456kWp with 1kW/h battery capacity and 226kW inverter. Giving the Net Profit Cost (NPC) of $4,561,510.00 and operating cost of $169,086.70 for 25years project lifespan; this was based on the monthly solar irradiation of the study location. However, the system proved to be reliable and sustainable. To mitigate the initial cost, it was recommended that other renewable energy sources such as wind turbine be integrated into the system.

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Keywords: Controller, Converter, Grid, Homer, PV System

1. INTRODUCTION:

Solar energy is the core source of the earth's energy, which supplies it with daylight, heat and radiation. Electricity produced from sunlight does not exhaust the earth's natural resources and supplies the earth surface with unremitting energy. Two ways in which electricity is generated from sunlight are: Solar thermal and photovoltaic.The scope of this work is limited to supplying electricity to the residents of Krakrama community in Asari-Toru Local Government of Rivers State.

Justifications: This research will proffer solution to the inadequate power generationin the community, The PV system will provide reliable power supply to those using the grid and to those yet to be connected, Due to the challenge of inadequate power supply facing the Nigerian power sector; this research can make huge contribution in solving/tackling that challenge.The electricity challenges inKrakrama Community have remained prevalent. This is because electricity supply is insufficient to cope with the needed electricity demand.

The proposed solutions will be achieved in the following ways:- To determine the power consumption of each household in watts-hours/day, To construct the load profile, To simulate the system using Homer to obtain the PV capacity, Battery capacity and Electricity output of the community.

2. RELATED WORKS

Hundreds of generations have depended on a fairly short list of sources of energy to implement work. Coal, wood, natural gas and oil served well as fuels for providing heat and electrical energy. Some controls of the world ran out of resources faster than others in other regions, but they preserve their strong growing economies by importing resources from other resource-rich areas. (Maczulak, 2010).These resources became indispensible products of current society, and different approaches were employed to assure un-interruption of power supply.In the meantime, population has grown and increases the demand for plant energy resourcesand the persistence of such effects can effortlessly be foreseen.The energy sources distance is increasing, fossil reserves are being drained, pollution is becoming prevalent and material volumes are getting to their limits.(Farret et al.,2006).

According to Orodor et al (2010) the solar radiation energy received by Nigeria per day is projected to be 5.08×10^{12} kWh and this varies between a yearly average of 3.5 kWm^{-2} per day to 7.0 kWm^{-2} per day in the southern and northern parts of Nigeria respectively. With a PV system conversion efficiency of 5%, if 1% of the aggregate land area of Nigeria was covered with solar collectors or PV modules, it is easier to generate 2.54×10^{6} MWh of electricity annually.Study by Abbes and his associates applied the used in a triple multi-objective optimization to join the LCC. Embodied Energy (EE), and Loss of Load Supply Probability (LPSP). The optimal arrangement between hybrid wind PV and battery micro grid system can be establish by using the dynamic model and applying a controlled elitist genetic algorithm for the multi-objective optimization.The outcomes indicate that the hybrid system is greatly undersized when load shedding is tolerated. As a consequence, the environmental impact and cost of the system are reduced, (Abbess et al.,2014).Arabali and his colleagues applied Genetic Algorithm (GA) based optimization approach with fuzzy C-Means (FCM) to minimize the cost function that guarantees minimum PV, wind generation installation and storage requirements to Supply a controllable High Voltage Alternating Current (HVAC) load, the effectiveness of the system increases and the surplus energy production from renewable resources will decrease. This work shows that the cost of the system rises as the possibility of failure rises. (Arabali et al, 2013).In another vein, Askarzadeh developed a novel methodology by merging the three algorithms: Chaotic Search (CS), Harmony Search (HS), and Simulated Annealing (SA). These three algorithms were combined to know the best size of PV panels alongside the total number of wind turbine and batteries with minimum total annual cost.

3. MATERIALS AND METHODS:

I. **PV Panel:**A PV panel comprises of one or additional silicon cells (without any moving part or noise) to transform sunlight into DC electricity. It is rated in Watts and comes with various sizes. Individual cells are commonly quite small and typically producing one or two watts of power. In other to increase the power output of PV array, cells are united to form a module. The amount of modules in series or parallel makes the array nominal power at STC. To increase PV voltage, cells are coupled in series; and to increase current, they are coupled in parallel. There are three main types of solar PV cells available: polycrystalline, mono-crystalline and amorphous/thin film silicon solar cells. Monocrystalline and polycrystalline cells are more effective and rigidly framed for protection than amorphous silicon cells, but are also more costly to produce.

A silicon PV cell consist of a tinny wafer containingultra thin layer of phosphorus doped (N-type) silicon on the uppermost of a denser coating of boron doped (P-type) silicon. Electrical field is produced close to the top exterior of the cell in which these two materials are connected, called P-N junction. When sunlight shine onto the surface of the PV cell, this electric field produces electrons, causing the movement of current when connected to electrical load (FSEC, 2007).

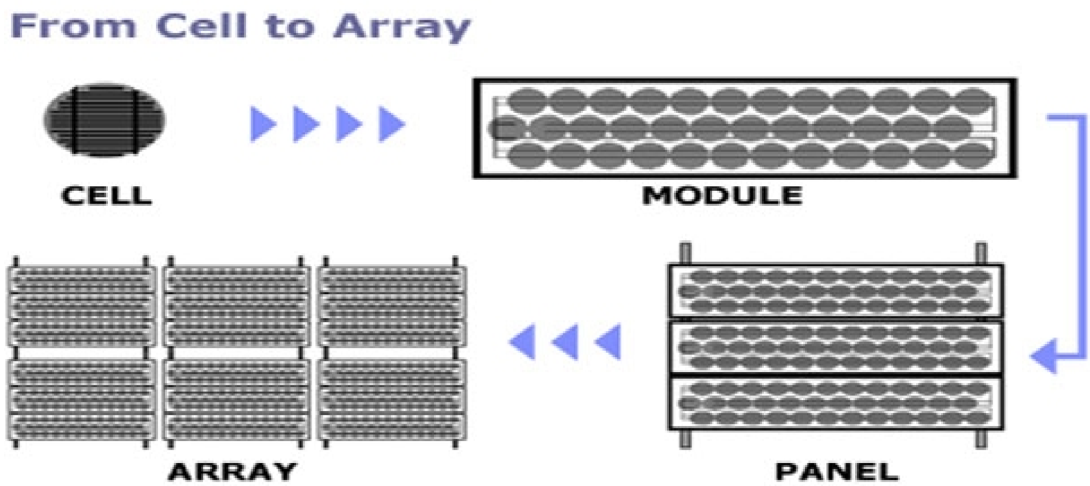

Fig. 1: PV cells, modules, panel and arrays (Opus, 2010)

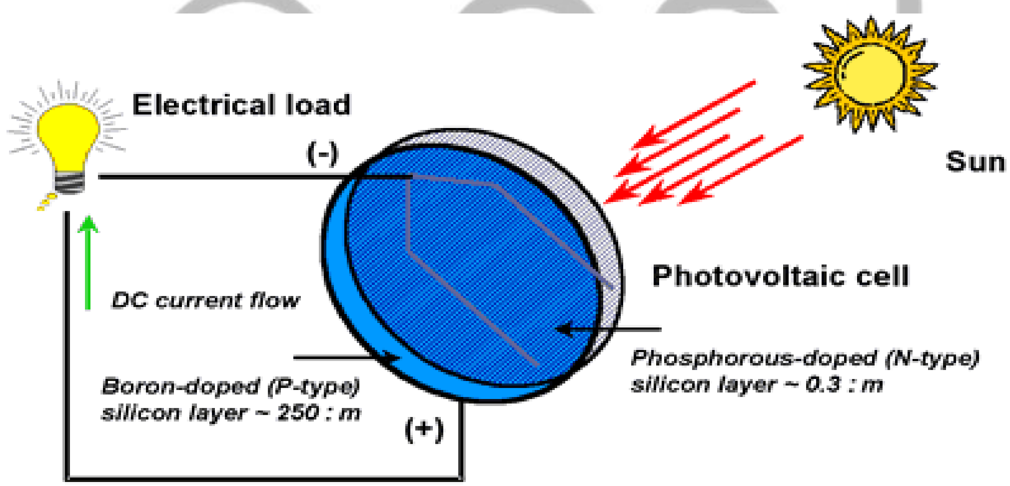

Fig. 2: Diagram of a PV cell (FSEC, 2007)

II. **Battery:** Batteries are of different types according to their technologies and applications: lithium-manganese dioxide, lithium-sulphur dioxide (Li-SO2), lead acid batteries and Nickel-cadmium (Ni-Cd) are some battery types. The standard batteries used in solar systems are 24VDC lead-acid batteries.The block diagram below shows example of a stand-alone PV system with battery storage powering both direct current and alternating current loads (Solar Direct, 2010). The system uses battery storage to generate electrical energy to the load whenever the PV panel isn't producing electricity.

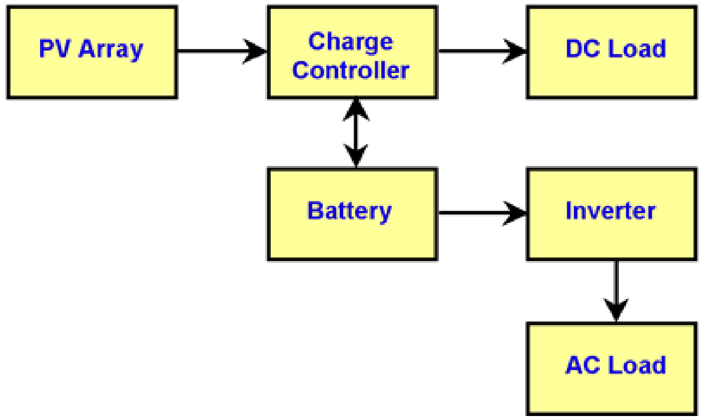

Fig. 3: Stand-Alone PV system with battery storage powering DC and AC loads (FSEC, 2007)

III. **Inverter:**Single-inverter-system is used as power converter on whole array. The purchasing cost is small. However, a certain number of failures are always expected during the lifespan of the system during operationand any fault in the inverter may lead to total system failures. To ensure maximum system availability, regular preventive maintenance of the inverters is required throughout the lifetime.

IV**System Load:**Loads such as fridges, water pumps, lighting points, electronics appliances, etc. The power produced by the PV is fed into these loads for consumption. For this investigation, AC loads were chosen since they are commonly available and they are less costly compared to DC appliances.The AC loads are utilized by the residents of community.

Table 1: Daily Energy Demand for Each Resident in Krakrama Community

Appliance A[1]	Quantity A	Power(Watts) B	Total(watts) C	Average Daily Use(h/day) D	Daily Consumption (Wh/day) E	kWh/day F
Security Lighting	5	8	40	13	520	0.52
House Lighting	8	8	64	6	384	0.384
Toilet Lighting	2	8	16	4	64	0.064
Fridge	1	300	300	8	2400	2.4
TV	1	120	120	6	720	0.72
Radio/CD Set	1	120	120	4	480	0.48
Fan	4	80	320	10	3200	3.2
Total	22	644	980	51	7768	7.768

Calculations on the different values/parameters, Given A, B and D:

i. $C = A \times B$ ------------------------------------ Eq.1

ii. $E = C \times D$ -- Eq.2

iii. $F = \frac{E}{1000}$ ------------------------------------ Eq.3

Using 10% Increase Factor (IF) of the total load, we had:
IF= (0.1 x 7.768 = 0.7768) + 7.768 = 8.5448kWh/day.
The number of houses is 223, so,
The total number of required load per day is 223 x 8.5448 = 1905.4904kWh/day

- **Governing Mathematical Equations**

Using the iterative method of optimization and analysis, the energy generated by the PV panels is given by Equation 4 (Daud, 2012):

$$P_{PV-OUT} = P_{R-PV}\ X \left(\frac{G}{G_{ref}}\right) X \left[1 + K_T(T_C - T_{ref})\right] \text{ ------------Eq.4}$$

Where;
P_{PV-out} is the output power generated from the PV panel,
P_{R-PV} is the PV rated power at reference conditions,
G is solar radiation (W/m²),
G_{ref} is solar radiation at reference conditions (G_{ref} =1000 W/m²),
T_{ref} is the cell temperature at reference conditions (T_{ref} =25°C),
K_T is temperature coefficient of the PV panel [K_T = - 3.7 x 10-3 (1/°C)] for mono and poly crystalline silicon.

Equation.5 is used to calculate the cell temperature T_c such that:

$$P_C = T_{amb} + (0.0256\ X\ G) \text{ ---------------------------- Eq.5}$$

Where T_{amb} is the ambient temperature in °C. The rated power P_{R-PV} can be calculated using equation 6

$$P_{R-PV} = (E_L\ X\ S_L)/(\eta_R\ X\ \eta_V\ X\ PSH) \text{ ----------------------Eq.6}$$

Where E_L is daily load energy, S_F is stacking factor considered to compensate for resistive and PV-temperature losses, η_R, η_V are efficiencies of solar charging regulator and bi-directional inverter respectively, and PSH is the peak sun shine hours (numerically equals to daily average of solar radiation at the specified location).

The storage capacity of the battery (C_{Wh}) is calculated using Eq. 7 (Khatib, 2011):

$$C_{Wh} = (E_L\ X\ AD)/(\eta_V\ X\ \eta_B\ X\ DOD) \text{ ---------------------- Eq.7}$$

Where DOD is allowable depth of discharge of the battery, AD is number of autonomy days, and η_B is battery efficiency.

Homer Software Sizing: A computer sizing software known as Homer was used for the design of the required voltage and current ratings of the structure components and matching them with the system load demand. HOMER is a micro power optimization model; developed to help simplify the duty of design and analysis of ON and OFF-grid distributed generation, for a range of applications. HOMER performs energy balance calculations for every system configuration that is considered. It then determines whether a configuration is feasible under the conditions that are specified. HOMER is able to model both conventional and renewable energy as in the case of this research. This is essential because the performance and reliability of the system will be based on the choice of components ratings, such as PV nominal power rating. Alternatively, calculation could be done manually, but using technically suitable tools eliminate human errors,

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and ensure projects are completed within the given time frame. HOMER is a micro power optimization model; developed to help simplify the duty of design and analysis of ON and OFF-grid distributed generation, for a range of applications. It was initially developed at the National Renewable Energy Laboratory (NREL) for a village power program. HOMER performs energy balance calculations for every system configuration that is considered. It then determines whether a configuration is feasible under the conditions that are specified, and estimates the cost (capital) of installation and operation of the system over the lifetime of the project. HOMER is able to model both conventional and renewable energy as in the case of this research. Centered on these, the design and optimization of the solar power supply system will be done using HOMER amongst the available tools.

- **Table 2: Monthly Solar Radiation of Krakrama Community at Location: 6°27'0" North,**

3°16'0" East, Elevation: 7 Meters above Sea Level (MASL)

Month	H_h
January	5770
February	6020
March	6220
April	6010
May	5390
June	4560
July	4470
August	4860
September	5050
October	5200
November	5630
December	5470

H_h: Irradiation on Horizontal Plane (Wh/m^2/day). (PVGIST, 2010).

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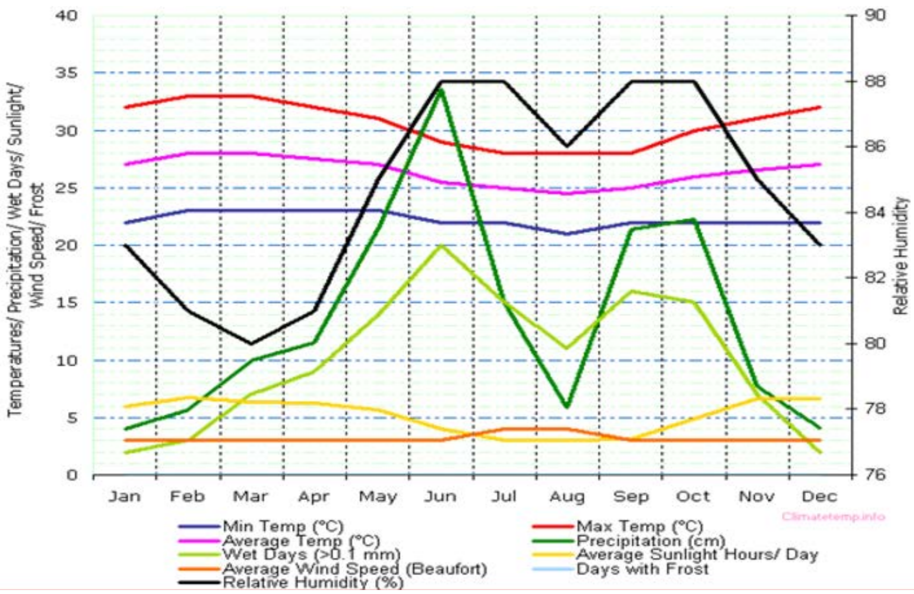

Fig 4. Graph Showing Weather and Climate of Krakrama (Nigeria Climate MPs, 2018)

4. RESULT AND DISCUSSION:

It is obvious that HOMER prepares both economic and technical calculation of renewable system, with limitation on electrical transient and additional dynamic effects of components. The result obtained is centered on Total NPC, which HOMER performs for optimal system comprises all charges and incomes that occur inside the project period, with upcoming cash movements reduced to the current. With this awareness, the optimal system is selected and analyzed. But since one single renewable energy resources is used, comparative analysis is not conducted.

The type of load applied is AC, though the supply is DC. Figure 5 shows the seasonal load profile result of the solar PV structure. Seasonal load input was used because deferrable loads are taking into consideration in this work. Deferrable loads are loads that need a definite volume of energy supplied, but cannot wait until power is accessible and do not need to be supplied at any specific moment. So therefore, the load outline varies on monthly basis.

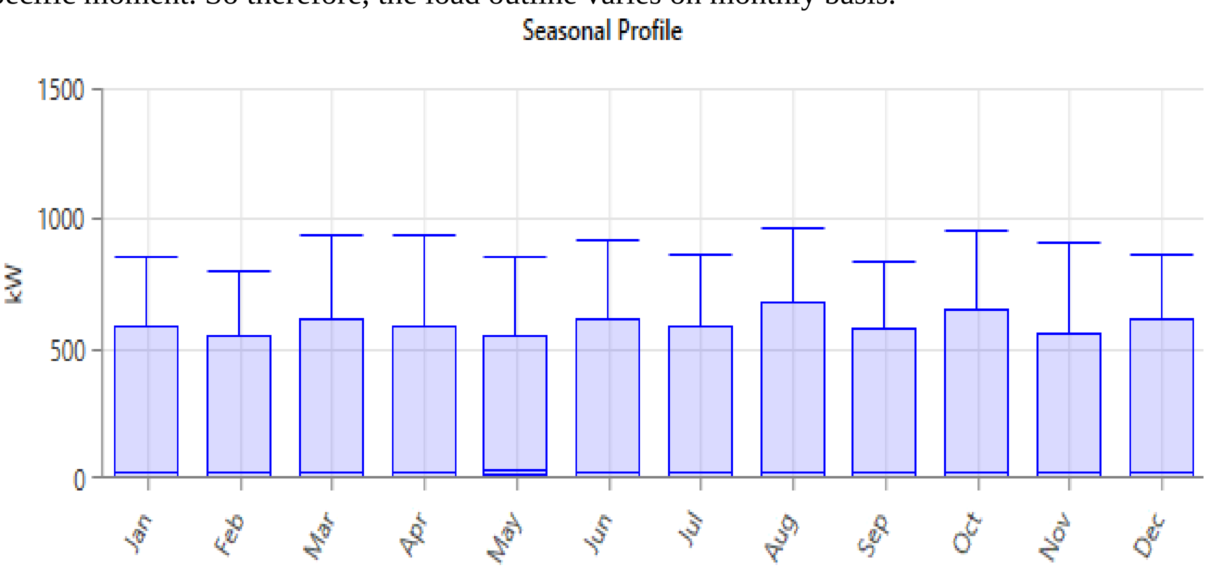

Figure 5: Load Input for the Solar PV Renewable Energy System

TABLE 3: Scaled Annual Average (kWh/d) of Load Input for the Solar PV Renewable Energy System

Metric	Baseline	Scaled
Average (kWh/d)	1,949.5	1,949.5
Average (kW)	81.23	81.23
Peak (kW)	165.94	165.94
Load Factor	.49	.49

Load Type: AC DC

The system location and solar monthly data obtained was entered to obtain annual average data as revealed in Figure 4.3. The data was evaluated with respect to 1000W/m^2 which is the irradiation at Standard Temperature Condition (STC). The idea of entering this data is to choose a PV array that will produce the equivalent solar energy. An average solar irradiation of 5,387.50 kWh/m^2/day was obtained.

Table 4: Solar Resources Input

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Month	Clearance Index	Daily Radiation (kWh/m^2/day
January	573.461	5,770.000
February	579.640	6,020.000
March	591.960	6,220.000
April	589.026	6,010.000
May	558.257	5,390.000
June	490.032	4,560.000
July	473.925	4,470.000
August	490.132	4,860.000
September	488.883	4,860.000
October	501.972	5,200.000
November	557.815	5,630.000
December	552.038	5,470.000

Annual Average (kWh/m^2/day)

The first approach used to carry out the PV arrangement sizing is to define the Solar Global Irradiation on horizontal plane (kWh/m^2/day) for the structure location. The system location and solar monthly data obtained was entered to obtain annual average data as revealed in Figure 6. The data was evaluated with respect to 1000W/m^2 which is the irradiation at Standard Temperature Condition (STC). The idea of entering this data is to choose a PV array that will produce the equivalent solar energy. An average solar irradiation of 5,387.50 kWh/m^2/day was obtained.

A baseline data is also produced with regards to the solar data entered. The baseline produced in this work is a one-year time series representing the average universal solar radiation on the plane surface, expressed in kWh/m^2, for each time step of the year. The location latitude value entered is also used to compute the average daily irradiation and clearness index. Clearness Index is a dimensionless fraction of solar energy that is transmitted through the atmosphere to raid the surface of the earth

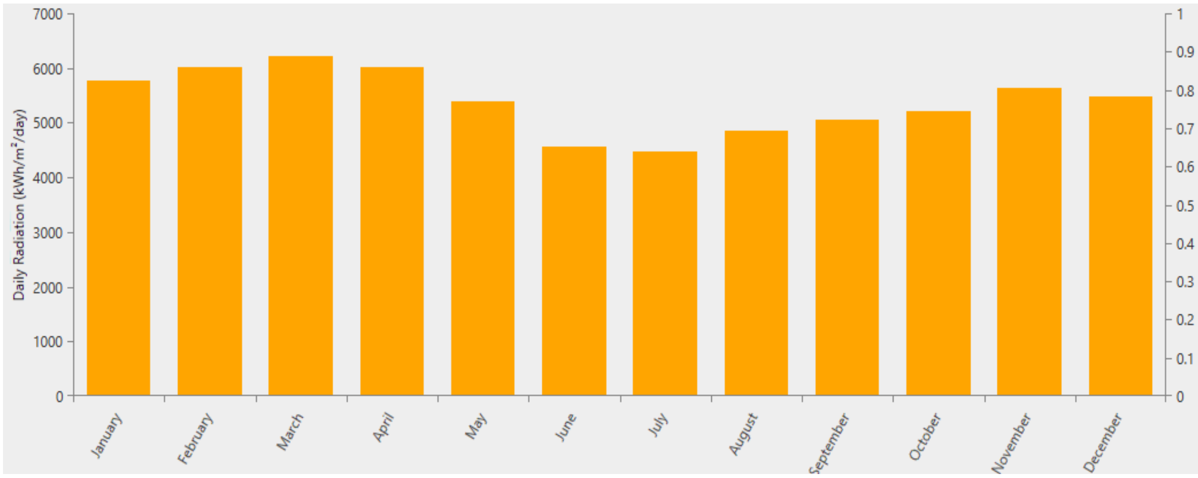

Figure 6: Solar Resources Inputs graph

A PV capacity of 456kW was designated based on the load and solar resources data entered.It was assumed there was no tracking since the design is a stand-alone system. 1kW/h battery and 226kW was selected.The cost component of this is revealed in figure below. The battery unit took the highest cost followed by the PV system and then the converter system. The total battery unit system cost is $3,042, 210.67 while the PV system cost is $1,428,104.18; and the converter system cost is $91,197.47.

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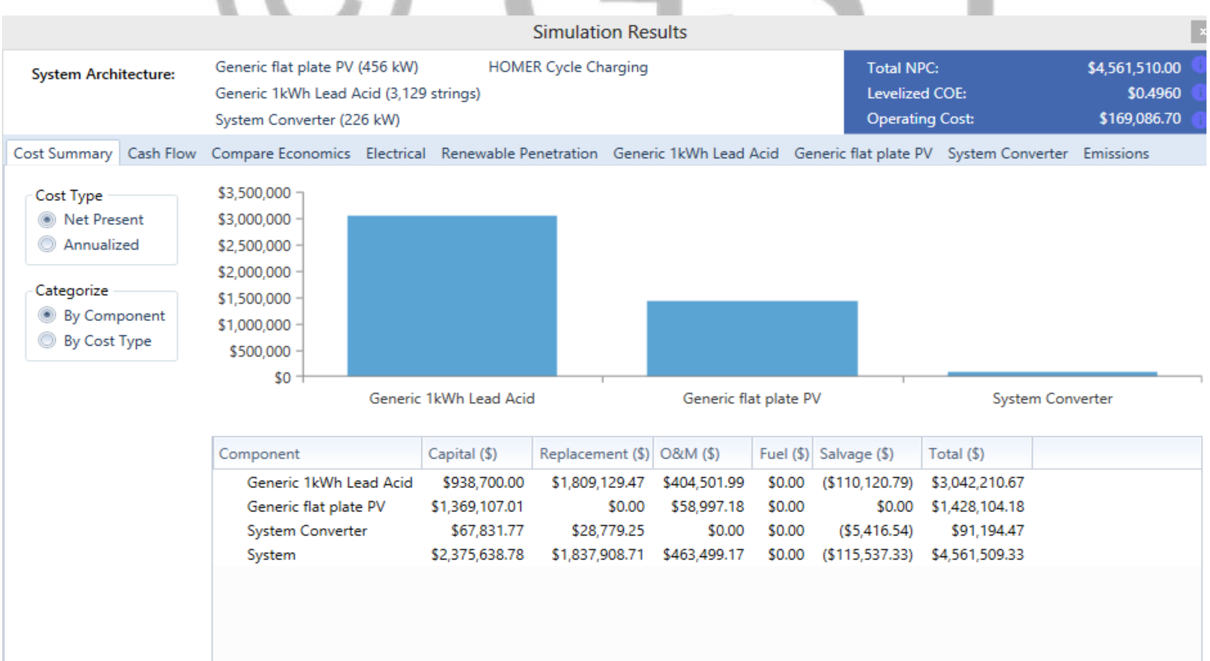

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 1kWh Lead Acid	$938,700.00	$1,809,129.47	$404,501.99	$0.00	($110,120.79)	$3,042,210.67
Generic flat plate PV	$1,369,107.01	$0.00	$58,997.18	$0.00	$0.00	$1,428,104.18
System Converter	$67,831.77	$28,779.25	$0.00	$0.00	($5,416.54)	$91,194.47
System	$2,375,638.78	$1,837,908.71	$463,499.17	$0.00	($115,537.33)	$4,561,509.33

Figure 7: PV sizes Inputs by component

The system's input by cost type as demonstrated in Figure 4.6, the replacement cost is $0, 00. This implies that the PV will be sustained for the required project life span which is 25 years.

The Operation and Maintenance (O&M) cost is $58,997.18. This comprises the cost of cleaning the PV arrangement, which might be done two or three times a year.

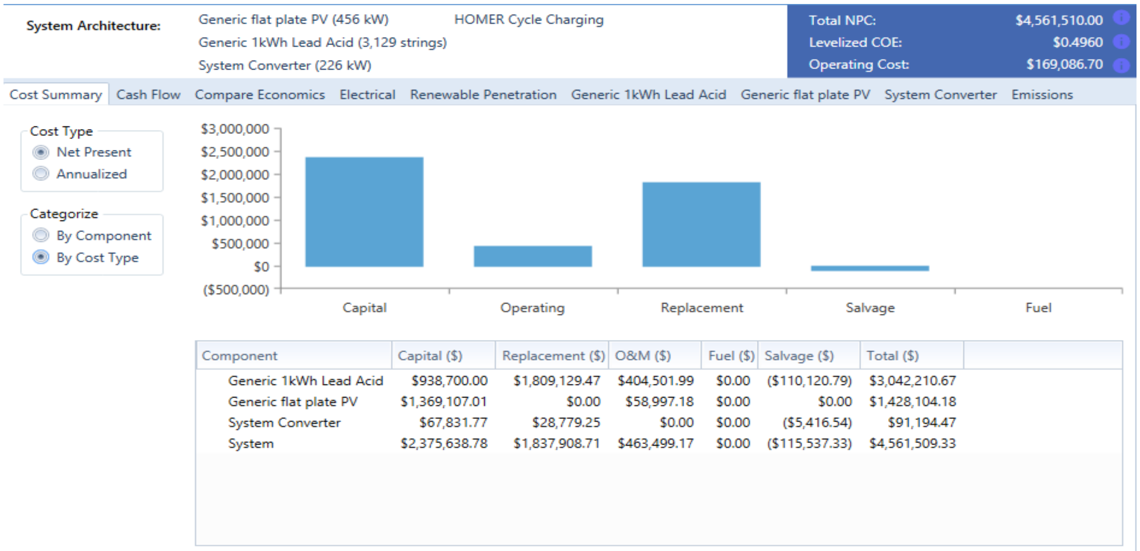

Figure 8: PV sizes Inputs by cost

Figure 9(a) shows the PV structure has a 1.887kW PV array. The PV operates for about 7 hours daily (between 0800-1600 hours); and no production between 0000-0700 hours and (1700-2400) hours. The PV has 25year and 2935 penetration per year; that is percentage renewable output divided by load. The total energy production is 1000,109 kWh/year. That is 15%. Surplus electricity is 151,283.1kWh/year. That is 15%. Unmet electricity is 161kWh/year while capacity shortage is 709kWh/year. This admirable output is owed to the PV contribution during the dry season months. As shown in Figure 9(b), 100% renewable energy productivity was achieved.

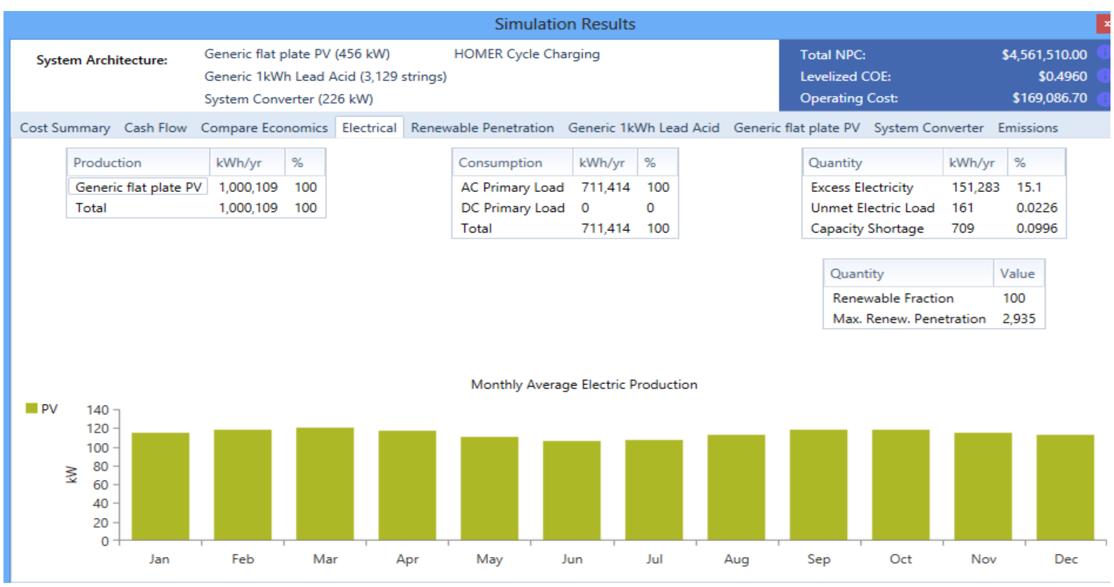

Figure 9(a): Electricity output of PV System

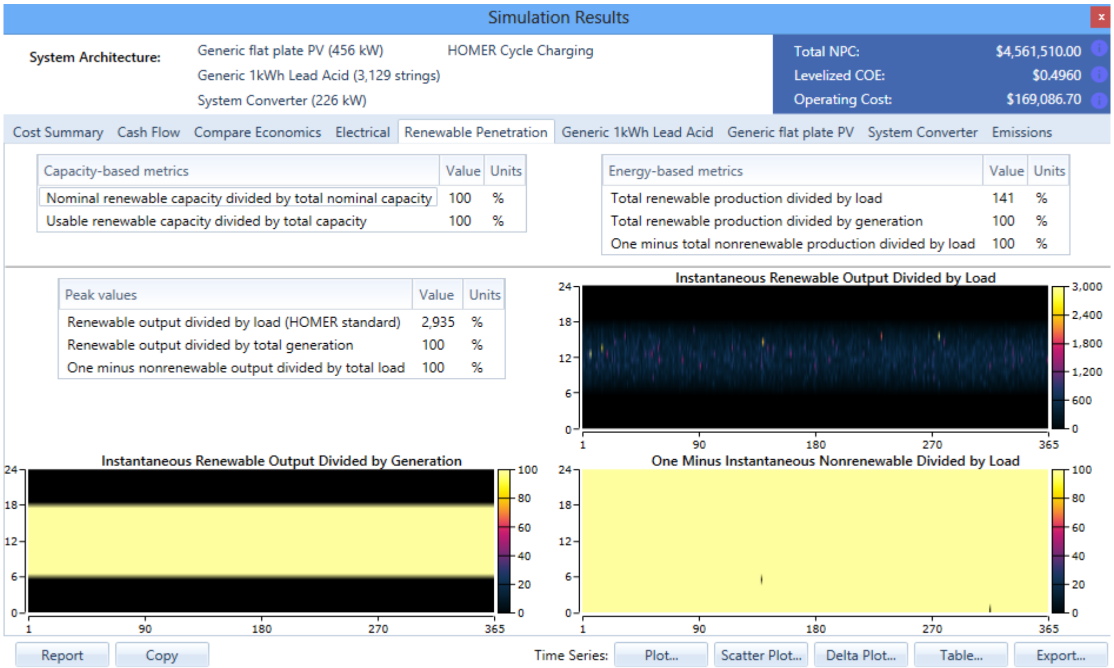

Figure 9(b): Electricity output of PV System

The figure below shows the battery energy production of the PV system of 12 volts battery with 35 strings connected in parallel. Batteries Nominal capacity is 3132kWh (i.e. 1*3 string of 3132). Usable nominal capacity is 1879kWh. This means about 70% of that was used, giving autonomy close to 23 hours/year. The autonomy is low because only PV is used as generator. The input energy is 503899kWh/year and the output energy 403903kWh/year. This means that the losses due to battery are less. The annual throughput is 451603kWh.

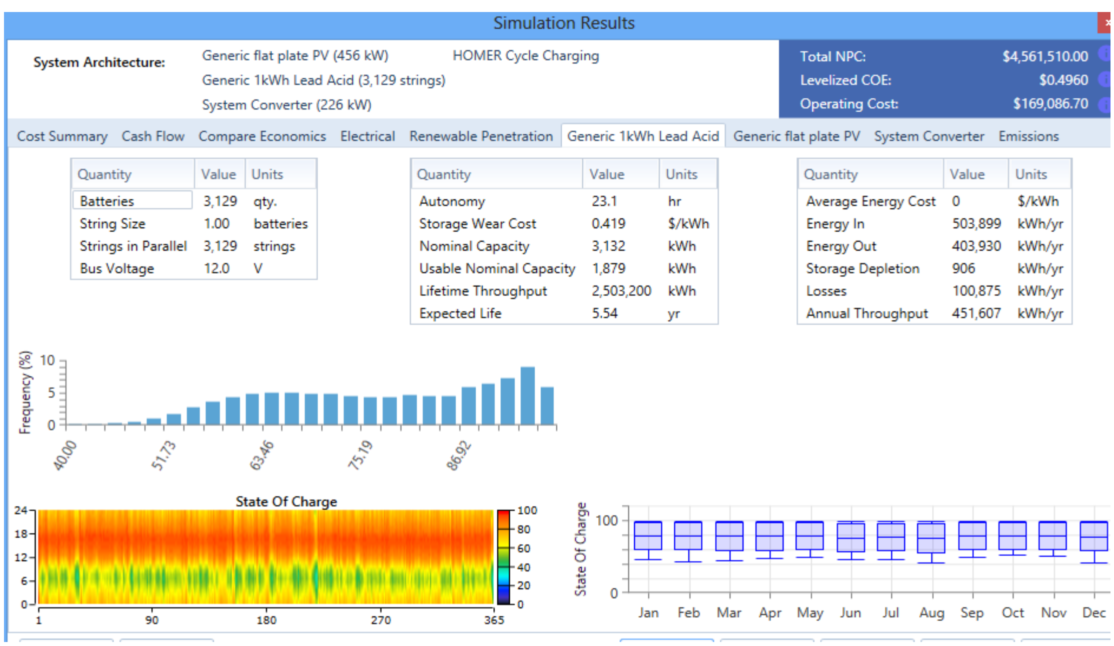

Figure 10: Battery Energy Contribution of PV System

A 226kW converter was selected in this configuration with PV and Battery Storage.The maximum inverter productivity is 166kW. The inverter is reasonably sized to aid the system average capacity, which is 81.23kW, and peak load of 165.94kW. This is one of the profits of a stand-alone system-meeting the sized load. The inverter losses are 37443kWh/year. For 8758 periods of operation in a year, the input energy from the inverter is 748857kWh/year while the output energy is 711414kWh/year.

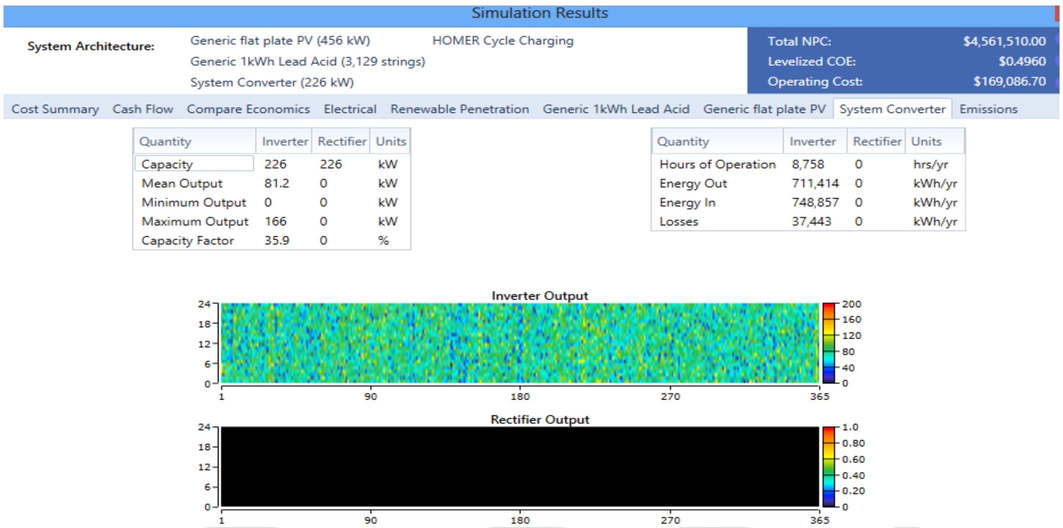

Figure 11: Converter Contribution of PV System

5. CONCLUSION

The optimization and investigation of a stand-alone solar power supply for developing community in Rivers State have been carried out in this work. The analysis was centered on relevant solar data and variables for the study site. Renewable energy software, HOMER was used to accomplish this. It was revealed that solar PV system can adequately power a communityin remote areas.

The advancement of renewable energy hybrid technology is a sustainable approach to fostering economic and ensuring electricity supply, particularly in remote locations where entrance to the national grid is limited. To contribute in solving electricity supply matters in Nigeria, the system can also be useful to other communities with similar load profile. It is also lucrative to any other applications where noise is tolerable.

With the application of optimization improving techniques, we have been able to carry out cost effective photovoltaic system based on Net Present Cost (NPC) for Krakama Community of Rivers State. This research showcases the benefit of using solar photovoltaic system at the considered location.

REFERENCES

Maczulak A. E. (2010) *Renewable Energy: Sources and Methods*. New York: Facts on File, Inc

Farret F. A. and Simoes M.G. (2006) *Integration of Alternative Sources of Energy*. New Jersey: John Wiley & Sons, Inc

Orodor N. P. and Ogujore. A. (2010) SAIDI Minimisation through Non-conventional Energy Resources: Opportunities and Challenges, Journal of Economics and Engineering, Department of Electrical/Electronic Engineering, University of Benin, Edo State, Nigeria. Available at: http://www.lit.az/ijar/pdf/jee/2/JEE2010(2-8).pdf (Accessed: 24 July 2010).

D. Abbes, A. Matinez and G. Champenois (2014) Life Cycle Cost, Embodied Energy and Loss of Power Supply Probability For the Optimal Design of Hybrid Power System.

A. Arabali, M. Ghofrani and M. Etezadi-Amoli (2013) Cost Analysis of a Power System using Probabilistic Optimal Power Flow with Energy Storage Integration with Wind Generation, International Journal of Electrical Power and Energy Systems.

Obasa R. (2010) Getting to Grips with the Power Problem. *Nigeria's Oil and Gas Monthly*, Available at: http://www.nigerianoilgas.com/?p=207 (Accessed: 26 August 2010)

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