Energy Crisis Way-Forward: Diesel Generator-Micro Hydro-Solar Hybrid Power System of Off-Grid Power Station for Rural Development

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***Abstract*—**There are several benefits for using renewable energy sources such as emission reduction, lowering of cost and technological gain. In many remote communities in the world, standalone power systems utilizing renewable sources of energy are widely deployed to counter the widespread of energy shortage conditions. The present days' quest for emission reduction from energy systems couple with the intention for rural electrification has fostered aggressive research directives for renewable energy for sustainable development. The major contributions to the existing body of knowledge in this study are to establish the large renewable energy sources usage and the optimal cost allocation of hybrid system components. For the off-grid electrification of the village under study, various combinations have been obtained for the hybrid systems with PV, micro-hydro turbines, batteries, convertors and generators from the HOMER optimization simulation. The optimal simulation result table shows that the most cost effective system configuration, i.e. the system with the least net present cost, is the PV micro hydro battery converter system configuration and the cost of energy (COE) at that scenario observed to be 0.044$/kWh, and renewable resources segment is around 99%. This shows that practically the total ratio of energy production is from renewable energy sources. Hence it has become a way forward for solving rural and off-grid communities' energy needs.

***Keywords*—**Energy Crisis; Hybrid Power System; Osochokodo Community; Sustainable Development.

***Abbreviations*—**Automated Teller Machines (ATMs); Cost Of Energy (COE); Hybrid Optimization Model for Electric Renewable (HOMER); National Aeronautics Space and Administration (NASA); National Renewable Energy Laboratory (NREL); Renewable Energy (RE).

I. INTRODUCTION

STATISTICS made available in recent years shows that almost 33% of the world's population do not have access to electrical energy in the form of electricity [Omari et al., 1; Phuangpornpitak & Kumar, 2]. Virtually all of the non-electrified areas are found in developing countries of the world. These areas can be electrified by extending the grids systems of the existing electrical power systems or by building standalone new power systems for sustainable development, which are alternative energy sources in nature. Preferably, going for the extension of the existing grids system is easy but they are unaffordable due to the fact that most of the non-electrified regions in developing countries are remotely located and in difficult terrains, like forests, hilly regions, islands and deserts, which requires huge investments for existing power grid extension.

Thus, this study investigates the techno-economic analysis of integrated hybrid Solar/Micro-

hydropower/diesel/battery based on a case study of rural community (Osochokodo) in Nigeria using the localized site data and data from the website of National Aeronautics Space and Administration (NASA).

In a study conducted by [Okundamiya et al., 3], the performance of six solar radiation models was carried out to ascertain the most accurate model for estimating global solar radiation on a horizontal surface in Nigeria. Twenty-two years meteorological data sets obtained from the Nigerian Meteorological agency and the National Aeronautics and Space Administration for the three regions, covering the whole climatic zones in Nigeria were exploited for calibrating and validating the designated models for Nigeria. The precision and applicability of various models were investigated for the three locations (Abuja, Benin City, and Sokoto), which spread across Nigeria using seven viable statistical indices. This study established that the estimation results of deliberated models are statistically significant at the 95% confidence level, but their accuracy differs from one location to the other. Though, the multivariable regression link assumed in terms of sunshine ratio, air temperature ratio, maximum air temperature, and cloudiness performs better than other relationships.

II. MOTIVATION

In many remote places, particularly in developing Nations where grid supply systems have not captured due to economic constraints but still with more availability of solar-hydro hybrid systems and other renewable energy sources needed to be harnessed. The reliance of economy on depleting fossil fuels and the adverse environmental challenges of conventional power generation methods created renewed interests in renewable energy sources as alternative towards achieving a sustainable energy and economic development. As presented in [Onar et al., 4; Setiawan et al., 5], hydro-solar hybrid energy is the world's quickest growing energy sources, growing globally at a rate of 25–35% annually over the last decade. The *benefits* of using renewable energy sources for generating power in isolated regions are obvious such as the cost of transported fuel are often high-priced fossil fuel and that there is growing concern on the subjects of climate change and global warming. The system of generating electric power, which comprises of renewable energy and fossil fuel generators composed with an energy storage system (ESS) and power conditioning system (Convertors), is referred to as a hybrid power system. A hybrid power system has the capability to provide 24-hour grid quality of electricity to satisfy the load demands. This system offers a higher efficiency, flexibility of planning and environmental benefits paralleled with the diesel generator stand-alone system. The costs of maintenance of the diesel based generator can be reduced as a consequence of taming the efficiency of operation and plummeting the operational time which also means less usage of fuels. The system also provides the prospect for expanding its capacity in order to handle the increasing energy demand in the future. This can be achieved by increasing either the rated power of diesel generator, renewable generator or both of the generators.

III. RELATIONSHIP BETWEEN ENERGY AND ECONOMIC DEVELOPMENT

Understanding the linkage between economic growth and energy needs is significant to energy policies of any Nation. It is known that energy consumption and economic growth are related, but the path of this relationship is not always understandable, for instance, when does a country's economic growth stimulate energy consumption or when does increased energy consumption of a country promote its economic growth?

It is believed that a growing segment of renewable energy in the energy mix of a country can help meet the growing future of energy demand while influencing economic development. As well as decreasing the environmental negative impact associated with fossil fuels, renewable energy sources can encourage diversity of energy sources and, possibly, contribute to energy security and to the long-term availability and reliability of energy supply. Renewable energy sources can also encourage regional development as they can be used in fewer developed areas without conventional energy sources need, and could decrease costs associated with climate change significantly [Pirlogea & Cicea, 6].

In the voltage-time characteristics of solar panel investigated by [Evbogbai et al., 7], range of time of the day when maximum terminal voltage from the solar panel is established was studied from the experiment and noted to be between 7:30 am to 6:00 pm and the terminal voltage of the panel during the hours (7:00 pm to 6:00 am) is noted to be zero. Hence the need for energy storage device arises in the form of battery for off-peak period. It is also established that the voltage obtained from the solar panel greatly depends on the period of the year, climatic conditions and the geographical locations of the study site.

Energy is a critical feature in poverty decline and wealth amelioration, and access to modern energy (defined as electricity, safe and clean fuels, and mechanical power) is known as a requirement for the achievement of the Millennium Development Goals [Modi et al., 8; AGECC, 9].

Access to energy permits people to accomplish the operations of domestic needs like heat, cools and cook, use telephones, televisions and radios and to transport themselves and their goods from one place to another, benefits from better health and education facilities, and gets the ends meet. Accessing modern energy for cooking expands energy efficiency, grows the health status of women and children (most vulnerable) by reducing their problem of accumulating fuel (inform of firewood) and reducing indoor air pollution. Access to energy increases people's livelihood selections from needs and supports their flexibility in the aspect of climatic condition changes [Gaye, 10].

IV. HYBRID ENERGY STRUCTURE

A hybrid energy structure shown in Figure 1 is the one that uses the method of combining one or more of renewable energy resources such as wind, micro/mini-hydropower, solar and biomass with other related technologies such as diesel generator and batteries. Off-grid hybrid power generation as it is, the hybrid system offers efficient, sustainable and clean power that will in numerous situations be more cost-effective compare to a system utilizing autonomous energy resource for electric power generation [Ali et al., 11].

An investigation presented in the work of [Okundamiya et al., 12] for the optimum size of a hybrid energy system for reliable operation of automated teller machines (ATMs) to identify an arrangement amid a set of power generation opportunities that can consistently meet up with the power demand of the remote loads at the lowest available energy cost taking into account of the availability and vibrant nature of energy sources are projected and renewable energy sources take the lead in terms of cost ahead of other energy sources [Evbogbai et al., 13]. Three primary energy sources (solar, wind and diesel) are measured. The optimum design configuration is achieved by making energy balance calculations based on HOMER (hybrid optimization model for electric renewable) software.

A work conducted by [Elhassan et al., 14] focused on the design and implementation of renewable based energy system for domestic application in Khartoum (Sudan) for electric power generation. The study focused on hybrid PV-battery integrated energy system and presents that there is situation of high cost of the system for single users but however, established that for cluster of users the system is economically viable. In the framework, optimization and simulation was carried out for individual households in addition to a cluster of other households comprising of 10 to 25 in numbers for techno-economic benefits. Results revealed that the cost of energy (COE) for individual home energy user is about 49.5 SP/Wh, for 10 households it is approximately 25.8 SP/Wh while the value of about 20.1SP/Wh is obtained for 25 households.

Run-of-river hydropower projects have limited project construction activities due to their suitable economic issues [Gondwe, 15] in addition to environmental benefits over other hydroelectricity generating systems of the same installed capacity [Perez-Diaz et al., 16; Douglas, 17].

A research carried out by [Elhadidy & Shaahid, 18] centred on isolated wind/diesel generator hybrid power systems to meet energy demand for settlements in the warm coastal regions of Dhahran. It considered the provision of energy essentially from wind source of energy for a community containing 100 households. Results obtained established that wind/diesel and battery hybrid system is the best solution for the rural residents.

In the work of [Schmitt et al., 19], a design of solar-diesel hybrid system in the range of 10, 15, and 30 kW was carried-out and the micro-grid is anticipated to provide energy to 90% of the villages in developing countries upon execution.

In [Getachew & Gelma, 20], designed a hybrid system comprising photovoltaic-wind system for power generation for a remote community in Ethiopia. In the context, a software tool is used to examine data with reference to the potential of solar and wind in the location of research interest.

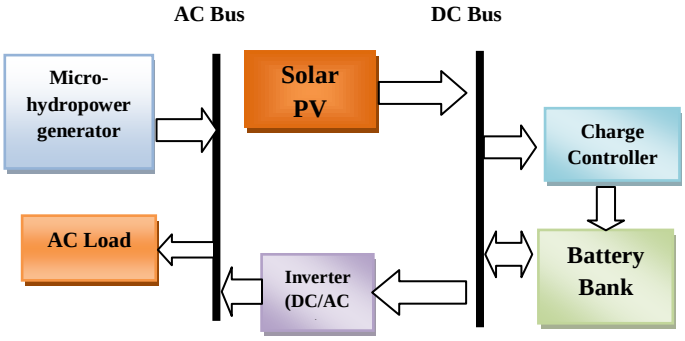

Figure 1: The Hybrid System Structure with Energy Storage System (ESS)

V. RESEARCH METHODOLOGY

The methodology of sizing the hybrid power system study in this work is to review the existing literature resources on renewable hybrid power system and thereafter followed by system input data considerations based on the localized site data and system configurations design component selection. HOMER software is used to carry out simulation, optimization and sensitivity analysis.

VI. RESEARCH INSTRUMENT DESCRIPTION

Hybrid Optimization Model Electric Renewables (HOMER) is a computer software model for the purpose of designing a remote area distributed generation comprising renewable energy systems in a grid-connected or off-grid operational mode. The software package was developed by the National Renewable Energy Laboratory (NREL) in the United States of America (USA). The purpose of developing the computer based programme is to help integrate renewable energy into a small-scale power system. Specific areas of applications of the software are optimization, simulation and system sensitivity analysis for techno-economic feasibility. The conventional behaviour of the HOMER software is such that it simulates a power system based on the input parameters (electrical load, renewable energy resources, conventional energy source, component technical costs and specifications, system dispatch strategy and controls). These enable it design an optimal configuration of a micro power plant with potential capability to serve a desired load in a rural districts. In the optimal design strategy, effective result is such that ensure most excellent feasible matching between supply and demand of electric load obtained on the circumstance of low cost of energy dispatch. Therefore, the possible means of getting the most excellent result using HOMER is to allow the software perform three basic computer programmes of

simulation, optimization and sensitivity analysis of the model inputs in the design. Additionally, there is other renewable energy software but the purpose of choosing HOMER is based on reliability and multi-objective nature.

Table 1: Average Flow Rate of Stream across the Year (KSMEWR)

Month	Flow Rate (Litre/Sec.)
January	690
February	610
March	880
April	1,040
May	1,590
June	10,990
July	34,080
August	46,640
September	36,750
October	12,240
November	2,240
December	1,440
Flow Rate Average	**12,433**

VII. Solar Radiation of the Study Community

Energy exploitation using solar based energy system is one of the vast and growing RE technologies in the world today with characteristic environmentally friendly potential. Solar based electricity is being pursued across different regions in the world but depending on solar radiation of the area. Utilization of solar energy can cushion the endeavour to reduce the current level of global dependence on fossil fuels for electricity generation. Solar radiation of tropical countries is sufficiently high to sustain electric power generation. The solar data for the site investigated in this study is not available locally but obtained from the National Aeronautics and Space Administration (NASA), United States of America, based on the geographical latitude 7.55^{o}N and longitude 6.23^{o}E of the local site. Thereafter, monthly clearness index and daily radiation with respect to monthly average for a period of one year is generated by the HOMER as shown in Figure 2. The solar radiation data simulated by the HOMER indicated that solar radiation range is 4.13 kWh/m^2/day in August to the peak value of 5.77 kWh/m^2/day in January. The pattern observed is such that the scale annual average of solar radiation of the study area is 5.09 kWh/m^2/day. The majority of the months with high solar radiation correspond to dry season (November-April) and consequently, the period of high energy demand resulting from hot weather. The clearness index is equal to the ratio of the global solar radiation on the surface of the earth to the extraterrestrial radiation at the top of atmosphere. The value estimated by HOMER depend on the variation of the magnitude of clearest weather conditions which is usually attributed to the highest value of 0.8 to the worst case overcast weather conditions with a typical value of zero.

Table 2: Clearance Index and Daily Radiation of the Study Site (NASA)

Month	Clearance Index	Daily Radiation (kWh/m^2/day)
January	0.623	5.770
February	0.582	6.480
March	0.521	6.320
April	0.572	6.120
May	0.586	6.050
June	0.535	5.430
July	0.458	4.680
August	0.479	4.130
September	0.536	5.550
October	0.620	6.180
November	0.740	6.460
December	0.736	6.660

VIII. Data Collection and their Sources

The design of autonomous PV/ micro hydro/battery hybrid power supply system for rural electrification of about eight hundred and twenty one (821) households presently living in the case study community (Osochokodo, Kogi-Central, Nigeria), with an average of seven (7) members per household considering the data obtained from Kogi State Ministry of Rural and Infrastructural development is the cardinal point of this research. Importantly, the timing of deferrable load is not very important such that it could be utilized at any point of time. The primary load in the study area mainly consists of lighting points, portable DVDs, pressing iron, televisions, mobile charger, PC, radio receivers and refrigerators. It is assumed that the load consumption of the villagers during the working days will be different from weekends and holidays. The electric load proposals for the households have been categorized into two as large consumer houses and low consumer houses respectively based on their means of income. Two hundred and twenty one (221) houses have been classified as large consumer houses and six hundred (600) houses as low consumer houses. Presently, there is no electricity supply to the rural area but energy consumed at individual household is supplied on self-maintained household petrol generators. Traditionally, electricity demand in the area will increase with time especially when electricity is made available to the area which could thereby attract some socio-economic activities.

Table 3: Primary and Secondary Data Collected for the Village under Study

S/N	Data Collected	Value	Source of Data
1	Number of worship centres	2	Okene L.G.A administrative Office
2	Number of primary school	2	Okene L.G.A education office
3	Number of health facility	2	Okene L.G.A health office
4	Net head of stream	22 m	Measurement using GPS
5	Cost of renewable energy equipment	-	Sourced from online mart websites
6	Village population density	3,010	Population commission, Lokoja Office-2006
7	Village present population	5,856	Population commission, Lokoja Office-2006
8	Flow rate of stream (1985-2010)	31 years average	Kogi State Ministry of water resources
9	Solar radiation data	20 years average	NASA

Table 4: Analysis of Load Demand of the Case Study Community

Large Consumer Houses (221)						
S/N	**Device Description**	**Rated Power (W)**	**Quantity**	**Load for 221 Large Houses (kW)**	**Operating Hours (Hr/day)**	**Daily Energy Demand\ (kWh/day)**
1	Radio at working days	25	1	5.525	4	22.100
2	Radio at weekends	25	1	5.525	9	49.725
3	TV(29'')	100	1	22.1	6	132.600
4	Lighting	15	5	0.075	7	116.025
5	Heating panel	3000	1	663	2	1326
6	Cooking stoves	1000	1	221	3	663
7	Miscellaneous	18	1	3.978	24	95.472
	Sub-Total			921.203		2404.922
Low Consumer Houses (600)						
S/N	**Device Description**	**Rated Power (W)**	**Quantity**	**Load for 600 Low Houses (kW)**	**Operating Hours (Hr/day)**	**Daily Energy Demand (kWh/day)**
1	Radio at working days	25	1	15	3	45
2	Radio at weekends	25	1	15	8	120
3	TV(29'')	100	1	60	4	240
4	Lighting	15	4	36	7	252
5	Miscellaneous	18	1	10.8	24	259.2
	Sub-total			136.8		916.2
General Public Loads Demand						
(1) Worship Centers Loads Demand						
S/N	**Device Description**	**Rated Power (W)**	**Quantity**	**Load for 2 Worship Centers (kW)**	**Operating Hours (Hr/day)**	**Daily Energy Demand (kWh/day)**
1	Megaphone	16	8	0.256	4	1.024
2	Lighting	15	20	0.6	4	2.4
3	Miscellaneous	18	1	0.036	24	0.864
	Sub-total			0.892		4.288
(2) Primary Schools Load Demand						
S/N	**Device Description**	**Rated Power (W)**	**Quantity**	**Load for 2 Primary Schools (kW)**	**Operating Hours (Hr/day)**	**Daily Energy Demand (kWh/day)**
1	Computers	100	5	1	5	5
2	Lighting (Offices)	15	8	0.24	5	1.2
3	Lighting (Classrooms)	15	28	0.84	3	2.52
4	Miscellaneous	18	1	0.036	24	0.864
	Sub-total			2.116		9.584
(3) Primary Healthcare Loads Demand						
S/N	**Device Description**	**Rated Power (W)**	**Quantity**	**Load for 2 Healthcare (kW)**	**Operating Hours (Hr/day)**	**Daily Energy Demand (kWh/day)**
1	Water Heater	1000	1	2	8	16
2	Microscope	20	1	0.04	8	0.32
3	Vaccine Refrigerator	65	1	0.13	24	3.12
4	Lighting	15	8	0.24	10	2.4
5	Medium Refrigerator	250	1	0.5	24	12
6	Miscellaneous	18	1	0.036	24	0.864
	Sub-total			2.946		34.704
Other Loads Demand						
S/N	**Device Description**	**Rated Power (W)**	**Quantity**	**Load for Other Demands (kW)**	**Operating Hours\ (Hr/day)**	**Daily Energy Demand (kWh/day)**
1	Flour Mill	8500	1	8.5	8	68
2	Pump	1500	3	13.5	6	81
3	Tomato Paste processing plant	4500	2	9.0	3	27
	Sub-total			31		176
	Total Daily Energy Demand			1094.957		3545.698

IX. Discussion of Results

The inputted data into the HOMER simulation software described the primary load, and hybrid system components and its costs (PV module, Hydro turbine, Battery bank, converter and Generator 1) and different sizes as mentioned so far in the previous sections. The system's simulations are performed by HOMER for each of the 8,760 hours in a year. The simulation output consists of several combinations of each source, with initial capital and net present cost of each of them. The monthly average solar radiation of the village is fed into HOMER as shown in Figure 3. Energy exploitation using solar based energy system is one the vast and growing RE technologies in the world today with characteristic environmentally friendly potential. Solar based electricity is being pursued across different regions in the world but depending on solar radiation of the area. Utilization of solar energy can cushion the endeavour to reduce the current level of global dependence on fossil fuels for electricity generation. Solar radiation of tropical countries is sufficiently high to sustain electric power generation. The solar data for the site investigated in this study is not available locally but obtained from the National Aeronautics and Space Administration (NASA), United States of America, based on the geographical co-ordinates of the local site. Thereafter, monthly clearness index and daily radiation with respect to monthly average for a period of one year is generated by the HOMER as shown in the Figure 2 while Figure 3 shows hydro resource of the rural village.

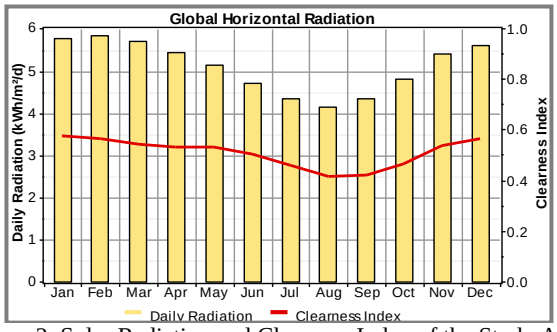

Figure 2: Solar Radiation and Clearness Index of the Study Area (NASA)

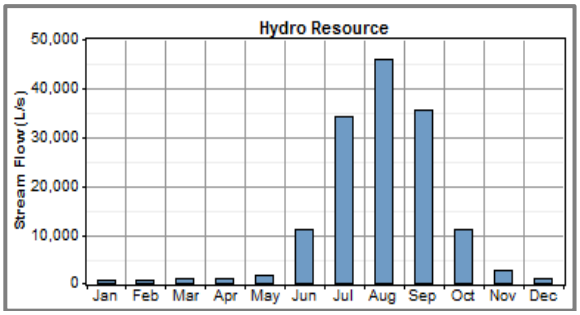

Figure 3: Stream Flow Average of the Study Community Site (NASA)

X. Research Findings

a) Technically, the results of the hybrid system study in this project revealed that 94% of the energy is supplied by hydropower generator and the PV module covers only 6% of the total load consumption. Thus, the PV may not be considered as a priority electricity generator in this case.
b) The hybrid system studied in this project is cost competitive with 0.044$/kWh, which is less than the present 0.05$/kWh in Nigeria.
c) The hybrid system exhibited a very large fraction (99%) of renewable, thereby has high tendency to contribute to sustainable environmental dignity from the point of emission reduction.

It is no doubt that increasing demand for global energy consumption in the coming years is apparent due to soaring demand for socio-economic activities. In addition, rapid global increase in human population coupled with depleting fossil fuel sources is undisputedly validating the necessities for pursuing alternative approaches to conventional power generation in order to increase the global capacity for energy supply.

XI. Optimization Results

For the off-grid electrification of Osochokodo village, various combinations have been obtained for the hybrid systems with PV, micro-hydro turbines, batteries convertors and generators from the HOMER optimization simulation. From the optimal simulation result Table 5, the most cost effective system, i.e. the system with the lowest net present cot, is the PV micro hydro battery converter configuration the cost of energy (COE) is 0.044$/kWh, and renewable resources fraction is 99% from this we can easily observe that almost the total portion of energy production is from renewable energy sources. This setup could be a good choice for implementation because the system is almost from renewable energy sources.

Table 5: Overall Optimization Results

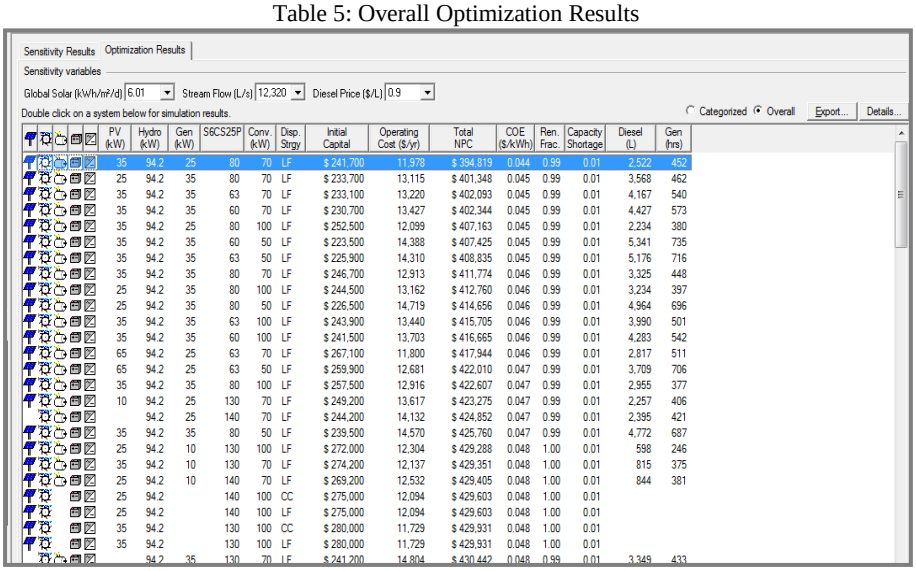

Figure 4 shows the energy produced by percentage by the hybrid sources. An overview of the figure exhibits that the most important part of the energy comes from hydropower which is as high as 94% and just a share of 6% produce by the PV array and 1% from diesel power plant. This scenario implies that even if the major part of the energy is produced by hydro power, the photovoltaic system covers 6% of the total energy demand by the village. Based on optimization result the most feasible hybrid configuration is 35kW PV, 94.2kW hydropower, 80 Surrett6CS25P battery and 70kW inverter and 52.5kW rectifier. The NPC of the hybrid system is $394,819 and the cost of energy for the hybrid system is 0.044$/kWh, which is relatively lower than the current electricity tariff of Nigeria, that is $0.05/kWh.

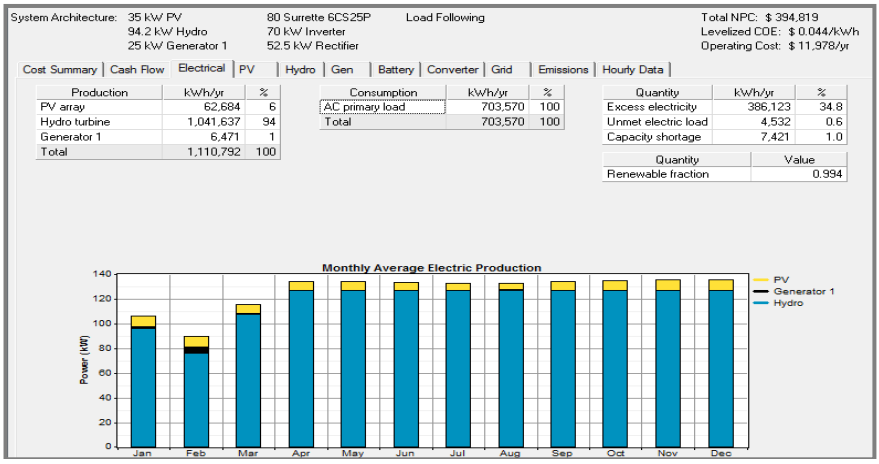

Figure 4: Energy Produced by Percentage in the Hybrid Sources

XII. CONCLUSION

This project work aimed to explore the techno-economic feasibility and design a hybrid power generation system which comprises of PV arrays, Micro hydro with battery banks using a conventional diesel generator as back-up system.. The study of the renewable potentials of the site is based on the data sourced from the average solar radiation data obtained from the NASA surface metrology, and the average stream flow obtained from Ministry of Rural and Infrastructural development, Kogi State. HOMER does the analysis of the renewable energy resources. From the results, the hydro potential of the site is found to be considerably high, and adequate for supplying the village in the current and near future electric power demands of the village. However, incorporating a PV panel also ensure the unforeseen increase in energy demand for the rural community. The results obtained confirmed the availability of ample solar energy at the site with an average radiation. The results obtained from the software gave numerous alternatives of feasible hybrid systems with different levels of renewable resources penetration, which their choice sorted by changing the net present cost of each set up. In General, this study demonstrates the technical, economic and environmental impact of the off-grid system.

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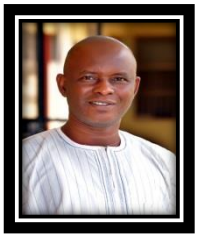

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