EVALUATIVE ASSESSMENT OF A HYBRID RENEWABLE ENERGY UTILIZATION OF A RURAL AREA IN NIGERIA.

C.S. Esobinenwu and C.O. Omeje

Abstract: The recent advancement in the alternate form of power generation using renewable energy source has indeed brought many rural dwellers that are deprived of direct energy supply from the grid or utility to the limelight. The importance of hybrid renewable energy system has grown rapidly as they appeared to be the right solution for a clean and distributed energy production. In this technical report, a hybrid renewable energy system consisting of Photovoltaic (PV) and Micro-hydro power supplies were analyzed with major emphasis on Ichama community in Benue State of Nigeria. The proposed hybrid renewable energy systems (Photovoltaic and Micro-hydro power supplies) were simulated using Hybrid Optimization Model for Electric Renewable (HOMER) software. The hybrid data were presented and simulation was carried out in three different cases such as case 1, case 2 & case 3. From the simulation results obtained, case 2 (stand-alone hybrid system) showed the best optimized solution due to its reduced operating and maintenance cost (O & M) and minimal gaseous emission as compared to cases 1 & 3. The total energy produced amounts to 2,384,840kwh/yr with PV contributing 14% while Hydro turbine contributed 84%. Excess energy valued at 192,222kwh/yr was realized in the analysis of this paper as presented herein for clarity.

Keywords: Energy Optimization, HOMER, Micro-Hydro Power Supply, Photovoltaic Supply, Hourly Load Demand, Load Factor, Annual Energy Demand and Consumption Rate.

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1.0 INTRODUCTION

Hybrid renewable energy systems (HRES) are becoming very expedient for remote area power applications due to advances in renewable energy technologies and a consequential rise in prices of petroleum products. A hybrid energy system usually consists of two or more renewable energy sources combined to provide an increased system efficiency as well as greater balance in the magnitude of energy supply. Energy unequivocally is vital for the progress of a nation and public-private enterprise, thus, it has to be conserved in a most efficient manner and must be developed through environmentally benign technologies. One of such technology is the hybrid renewable technology. In the past few years, the use of renewable energy technologies (such as wind, photovoltaic, wind-solar, or hydro-solar hybrid systems) to meet energy demands has been on a steady increase since the resources are naturally available, free, inexhaustible and pollution free. However reliability of these renewable sources poses a challenge since resources availability is seasonal. According to the international energy agency, renewable energy is derived from natural processes that replenishes constantly. In its various forms, it is derived directly from wind, solar, hydro power, biomass, geothermal resources, bio-fuel and hydrogen gas. These renewable resources can therefore be replenished over time and are inexhaustible. It also poses less risk to the environment. Each of these renewable sources has unique characteristics which influences how and where they are used. Globally, in 2006, about 18% of global final energy consumption came from renewable, with 13% coming from traditional biomass which is mainly used for heating, and 3% from hydro-electricity. New renewable (small hydro, modern biomass, wind, solar, geothermal and bio-fuel) accounted for another 2.4% and are growing very rapidly. The share of renewable energy in electricity generation is around 18%, with 15% of global electricity coming from hydroelectricity and 3.4% from new renewable as reported in [1].

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In Nigeria, having a population of about 160million, the amount of electricity generated from the grid is grossly inadequate, unreliable and insufficient to meet the growing energy demand. While some cities in Nigeria are connected to the grid, others especially in the rural areas or villages are partially or completely isolated, thereby depending on this alternate form of energy for sustenance.

2.0 Related work.

A hybrid wind/solar systems using battery banks and an optimal model for designing such systems was developed and reported in [2]. The stand-alone system was designed to power a telecommunication station along the coast of China. The slope angle of the photovoltaic (PV) array was studied to find the optimal power-producing angle, as well as the optimal values of other variables such as the number of wind turbines and battery capacity. The annual cost of the system was minimized while meeting the specified loss of power supply probability (LPSP). The model was analyzed using a genetic algorithm as reported in [3] with a good comparison of the two energy sources without emphasis on micro hydro power and HOMER simulations. The optimal sizing method was then used to calculate optimal system configurations that achieve a given loss of power supply probability (LPSP) while at the same time minimizing the annual cost of the system (ACS). In [4], an optimal sizing procedure was carried out for a similar system in Turkey with no reference to micro hydro power supply and Hybrid Optimization Model for Electric Renewable (HOMER). The technical report in [5] presented a hybrid system model that included fuel cell generation along with wind and solar power. The fuel cell system was used as a backup resource, where as the main energy sources were the Solar and wind systems. Results demonstrate that the system is reliable and can supply high-quality power to the load, even in the absence of wind and sun but no emphasis was made on the hybrid optimization and total energy loss.

The feasibility of meeting the energy demand of a seawater greenhouse in Oman using a hybrid wind/solar energy system was assessed and presented in [6]. This was achieved by analyzing the hourly wind speed and solar radiation measurements. Thus, optimization of the hybrid was not comprehensively evaluated in terms of the best optimized solution with reference to reduced operating and maintenance cost (O & M).

In reference [7], [8] an assessment of the feasibility of providing power to a building and also meeting the load requirements of a typical commercial building was carried out. This was done using a hybrid solar-wind energy system with different combinations of wind energy systems, photovoltaic panels with battery storage, and a diesel backup energy system. The optimization process was not reflected in this analysis.

The feasibility of a grid-independent hybrid wind/solar system for a particular region of Australia was studied and reported in [9]. This design featured a compressed hydrogen gas storage system. The optimization technique did not apply HOMER and was not carried out in annual basis.

The reports in [10], [12] assessed the long-term performance of a hybrid wind/solar power system for both standalone and grid-dependent applications by using a probabilistic approach to model the uncertainty in the nature of the load and renewable energy resources.

Dihrab and Sopian [13], proposed a hybrid PV/wind system that would be used for grid-connected applications as a power source in three cities in Iraq. A simulation of the model was carried out on MATLAB, where the input parameters were determined by meteorological data from the three locations, as well as the sizes of the wind turbines and the PV arrays. Their results showed that their hybrid system would provide sufficient energy for villages in rural areas [9].

A novel method of sizing hybrid wind/solar energy systems using battery storage was proposed in [14]. It includes a designed parameter such as the fraction of time that the system can satisfy the load and the cost of the system.

The analysis of the technical and economic feasibility of using a grid-connected hybrid wind/solar system to meet the energy demands of a typical residence in Xanthi, a city in Greece, through electrical and thermal energy production was presented in [15]. The absence of comparing the optimization of the two hybrid renewable sources limits this study.

Borowy and Salameh developed a graphical construction technique for determining the optimal sizes of the battery bank and the PV-array in a hybrid wind/solar system. Only paired combinations of the three subsystems were considered in the optimization process which introduces a limitation to this study [16].

In this paper, a comprehensive study was carried out on a proposed hybrid renewable energy system which include Photovoltaic and Micro-hydro power supplies using Hybrid Optimization Model for Electric Renewable (HOMER) software to simulate and analyze the effect of the two sources with pertinent to the maintenance and operating cost, rate of gaseous emission and total energy contributed by the two renewable energy sources. The hybrid data were presented and simulation was carried out in three different cases such as case 1, case 2 & case 3.

3.0 Researched Area.

Okpokwu LGA is located in Benue state which is situated in the middle belt region of Nigeria. It is made up of Okpoga; Edumoga and Ichama communities with Okpoga as it's headquarter. It has an area of 731km^2 and a population of 176,647 as at 2006 census. The local government area shares boundary with Otukpo, Ogbadibo, and Ado local government area of Benue State; Olamaboro local government area of Kogi state and Isi-Uzo local government area of Enugu state. Okpokwu LGA is transversed by three big rivers namely river-okpokwu, river-oma and river Ideme. There is also a stream flowing from Ogbadibo LGA as shown in the Fig. 1.

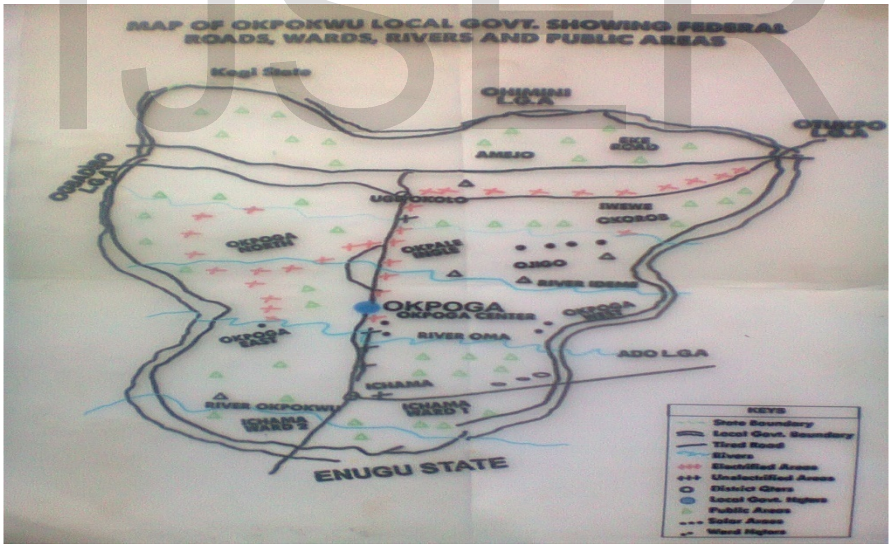

Fig.1. Map of Okpokwu LGA of Benue State

Source: Benue State Town Planning and Estate Management 2008.

4.0 Major Forms of Renewable Energy Resources in Okpokwu LGA.

Feasibility study carried out in the research area showed that the following renewable energy resources are available. They include: wind, hydropower, biomass combustion and photovoltaic (solar) renewable energy sources. However, the suitable renewable energy technologies that can be applied efficiently to this area are the hydropower and photovoltaic (solar) energy.

4.1 Hydro-Power

Hydropower technology is a proven and well developed technology that is capable of providing electricity for 24 hours a day due to the availability of water. Hydropower systems are derived from the hydrological climate cycle, where water precipitated in high regions (mountains) develops high energy potential. This energy potential through water flow turns water turbine that is mechanically coupled to generators to produce electricity. The Energy potential of a hydro-system is a function of height difference and water volume. Thus, in order to produce higher output of electricity supply, this can be achieved by increasing the volume of water or creating larger height difference. Using dams as water storage can raise volume and level of water to compensate the water supply fluctuation. According to J. Thake, there are 3 main types/options of hydropower systems, namely **impoundment**, **diversion** and **pumped storage** [17].

The impoundment uses a dam to store water from the river and the water released can be controlled to meet the fluctuating load demand. Diversion or run-of-the-river facility diverts some of the water from the river that is channelled along the side of a valley through a penstock before being dropped into the turbine. The working principal of a pumped storage facility is storing energy by pumping water from a lower reservoir to an upper reservoir when the load demand is low and during period of high load demand, the water is released back to the lower reservoir for generating electricity. For a rural area such as Okpokwu, using run-of-river method would be the best choice because it requires no water storage that will reduce the complexity and the development cost of the system. When using this method, the production of electricity power obviously depends on the topographical and hydrological condition of the area. While the power produced by this method is not sufficient for covering the whole load demand, then developing a small dam also could be an option to increase power output. Parameters that were identified for calculating the electrical power production of hydropower are the head through which the water flows and the flow rate of the water. There are three rivers that traversed the area. However, the data regarding flow rate of the river and real topographical situation where the rivers flows for determining the head is difficult to access due to the lack of real data. But based on the normal surface land without any hills, we assumed the flow rate of the water river to be (0.5-1.5) m^3/s and the head as 25 meter in height since no mountain exists. These values were be used as the flow rate and head in the ensuing calculation. The shape of the river path could be assumed that there is a barrier that obstruct the free flow of the water but rather causes the water flow turned towards the lowest surface. So it can be assumed that the bigger the curly shape of the river flow, the higher the available height. Moreover, the advantage of building hydropower on the curly shape is to reduce the distance for diverting some of the water and releasing back this water to the river while reducing materials for the channel. The calculation of hydropower output was achieved by (1).

$$P = H_{gross} \times S_{water} \times g \times Q \times T_{total} \quad (1)$$

Where: P = Power output (Watt), H_{gross} = Gross hydraulic head (meter)

S_{water} = density of water (kg/m^2) = 1000 kg/m^3 g = acceleration due to gravity (m/s^2) = 9.81 m/s^2

Q = flow rate of the turbine (m^3/s) T_{total} = total system efficiency.

The micro hydro power model in HOMER software is not designed for a particular water resource. Certain assumptions are taken about available head, design flow rate, maximum and minimum flow ratio and efficiency of the turbines. The life time of the micro hydro model in simulation is chosen as 25 years. The details of micro hydro parameters used are given in table 1.

Table 1. Micro-Hydro Parameters applied in the Hydro Turbine

Nominal power (KW)	276

Quantity considered	1
Lifetime	25 yrs
Available head	25m
Design flow rate	(500-1500)L/s
Minimum flow ratio	25%
Maximum flow ratio	100%
Turbine efficiency	75%
Pipe head loss	15%

4.2 Solar/Photovoltaic (PV) Energy Resource

Solar energy is freely available in abundance and is the primary energy source. There are two different ways to convert solar energy into electricity. The first is converting solar energy directly into electricity with the aid of semiconductor devices or modules of solar cells in a panel connected to a boost converter and a multilevel converter to produce an a.c voltage as detailed in [18]. The second way is the accumulation of heat using solar collectors to rotate the generator which yields electricity. This paper therefore considered a PV technology and the utility level of the battery bank as a reserve for power supply when solar irradiance is depleted. Hence ensuring the reliability of the whole system. The photovoltaic cell is also referred to as photocell or solar cell. The common photocell is made of silicon, which is one of the most abundant elements on earth, being a primary constituent of sand. A Solar Module is made up of several solar cells designed in weather proof unit. The solar cell is a diode-like structure that allows incident light to be absorbed and consequently converted to electricity [18]. The assembling of several modules will give rise to arrays of solar panels whose forms are electrically and physically connected together. To determine the size of PV modules, the required energy consumption must be estimated. Therefore, the PV module size in Watts is calculated using (2).

$$\text{PV module size in Watt} = \frac{\text{Daily Energy Consumption}}{\text{Isolation} \times \text{Efficiency}} \quad (2)$$

Where Isolation is in KWh/m^2/day and the energy consumption is in watts or kilowatts. The storage batteries that are used in solar energy generation are the deep cycle motive type. Various storage batteries are available for use in photovoltaic power system. These batteries are meant to provide power backups when the sun irradiance is low especially in the night hours and cloudy weather. For better performance, these storage batteries must have the following features;

(a) Must be able to withstand several charges and discharge cycle

(b) Must have a low self-discharge rate

(c) Must be able to operate with the specified limits.

The battery capacities are dependent on several factors which includes age and temperature.

Batteries are rated in Ampere-hour (Ah) and the sizing depends on the required energy consumption. If the average value of the battery is known, and the average energy consumption per hour is determined. According to Adejumobi in [19], the battery capacity BC is determined by (3a).

$$\mathrm{BC} = \frac{2 \times \mathrm{F} \times \mathrm{W}}{\mathrm{V_{batt}}} \quad (3a)$$

Where; BC – Battery Capacity

F= Factor for reserve

W = Daily energy utilization

V_{batt} = System DC voltage

The ampere-hour (Ah) rating of the battery is calculated by (3b)

$$\mathrm{Ah} = \frac{\text{Daily Energy Consumption (KW)}}{\text{Battery Rating at a specified voltage (Amp} - \text{hr)}} \quad (3b)$$

The Charging Controller is a very important tool. It is an electronic circuitry that helps to control charging of the storage batteries. It serves as a sensor to prevent overcharging of the batteries. Thus resulting in longer lifespan of the battery cells. The controllers have the following features;

- Prevention of feedback from the batteries to PV modules
- It has a connector for DC loads
- It has a working model indicator

A voltage converter is an electric power device that changes the voltage of an electric source. It is combined with other component to generate a power supply. Ac voltage conversion is shown in figure 2.0

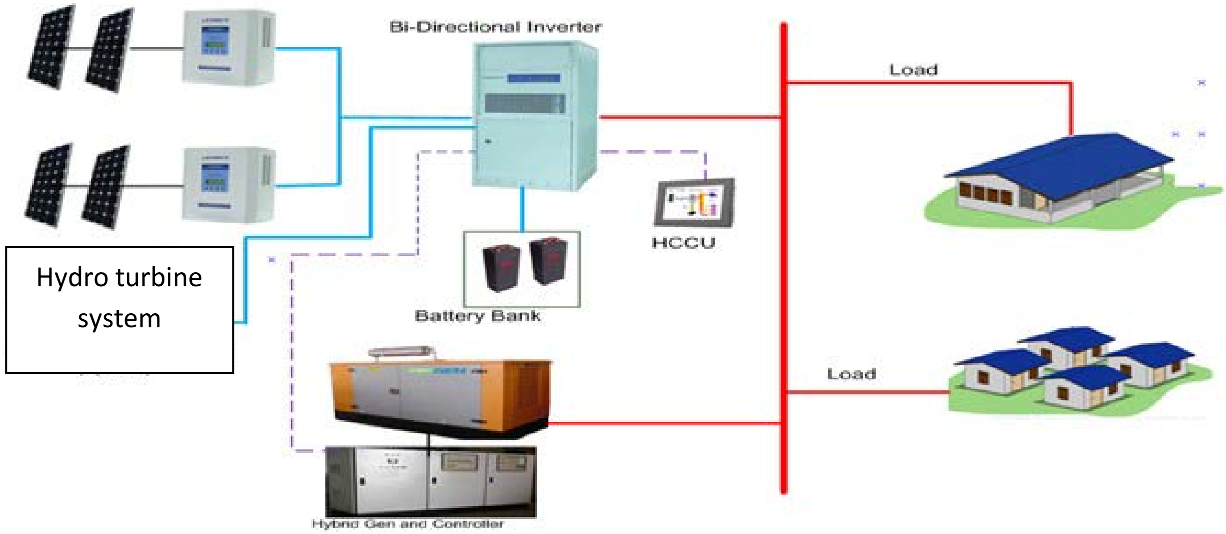

Figure 2.0 Overall system schematic diagram of a hybrid energy system

Solar energy is the radiant light and heat from the sun. The sun creates its energy through a thermal process that converts about 650 million tons of hydrogen to helium every second as presented in [20]. Nigeria lies within a high sunshine belt and thus has enormous solar energy potentials. The mean annual average of total solar radiation varies from 3.5 kWh/m^2-day in the coastal latitudes to about 7 kWh/m^2-day along the semi arid areas in the far North. On the average, the country receives solar radiation at the level of about 19.8 MJ/m ^{2}-day. Average sunshine hours are estimated at 6hrs per day. Solar radiation is fairly well distributed. The minimum average is about 3.55 kWh/m^2 -day for Katsina on January, and 3.4 kWh/m^2-day for Calabar in August and the maximum average is 8.0 kWhm-^{2} per day for Nguru in May. Given an average solar radiation level of about 5.5 kWh/m^2-day, and the prevailing efficiencies of commercial solar-electric generators, then if solar collectors or modules were used to cover 1% of Nigeria's land area of 923,773km2, it is possible to generate 1850x10^3 GWh of solar electricity per year. This is over hundred times the current grid electricity consumption level in the country [21] (Sambo, 2009).

Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute sunlight. Active solar techniques include the use of photovoltaic panels and solar thermal collectors (with electrical or mechanical equipment) to convert sunlight into useful outputs. Passive solar techniques include orienting a building to the sun, selecting materials with favourable thermal mass or light dispersal properties, and designing spaces that naturally circulate air.

5.0 Estimation of Load Demand in Okpokwu Local Govt Area

At present, some areas/communities in Okpokwu LGA are not connected to the grid. Feasibility study of the area showed that there is an ongoing installation of electrical poles and overhead power cables linking to some towns/communities within the local government. These off-grid areas are marked as non-electrified areas in the key presented in the map shown in figure 1. As such, it is practically impossible to determine an accurate load demand for these non-electrified and off-grid areas. In the grid connected areas, there is a variation in the load demand and energy consumption over time. This is due to diversity factor on the load during the day. Another reason for this is the presence of suppressed load in the system which cannot be mathematically determined but can only be assigned a factor less than unity (suppressed factor < 1).

Consequently, an estimate of the hourly load demand or approximate load demand can be realized as shown in table 1. While for non-electrified and off-grid areas, a rough estimate of load demand can be forecasted considering the present structure available in that area.

Table 2 Installed Power and % Loaded Capacity for the Electrified areas in Okpokwu LGA

Communities	Installed capacity	Approximate loaded capacity
Ugbokolo	2.5 MVA	30% loaded
Okpoga	2.5 MVA	46% loaded
Ede	200 KVA	32% loaded
Ojapo	2x300 KVA	10% loaded
Ai-dogodo (College of Education and communities)	500 KVA	30% loaded
Eke-Nobi	200 KVA	15% loaded
Eke District	4x200 KVA	57% loaded

Source: Jos Electricity Distribution Company (Ugbokolo Branch)

5.1 Hourly Load Demand

Load demand curves have been made by using logical assumption, referring that load demand varies in time, depends on season, and also on the inhabitant presence in a room; that is why load demand curves are erratic and quite choppy over the time. In the tropical area, there are only two seasons namely the dry season (November to March) and the rainy season (April to October). Nevertheless, these two different seasons are assumed will give different usage of electricity especially in rural area whereas the electricity is mostly used for lighting.

Apparently, load demand variation for each season in sub tropics area which has four different seasons (summer, fall, winter and spring) is highly significant especially in developed countries which many automatic controlled electric appliances are used.

Moreover, during winter, many heaters will be used while air conditioned will be used in summer period.

Making exact forecasting for load demand is rather impossible since too many parameters are involved. However, the roughly load demand patterns in one area should be determined for knowing approximately about the base load, peak load, load factor and also how long the peak load duration would be. Mathematically;

$$\text{Load Factor} = \frac{\text{Average Load (Watts)}}{\text{Maximum Load (Watts)}} \quad (4)$$

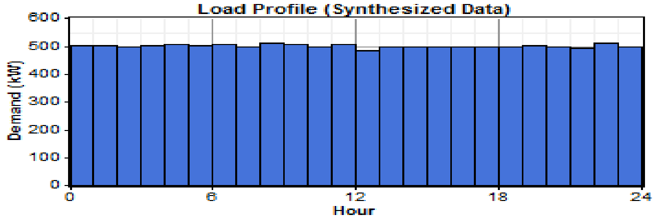

Figure 3. Projected hourly load demand for Okpokwu LGA

Different renewable technologies options were explored; this includes solar, hydro, wind, and biomass. But the most suitable renewable resources (solar and hydro) were chosen due to the high degree of resource availability in the area. Also a generator was also selected for non-electrified areas to help augment power supply in the case of insufficient renewable energy at certain periods in the month. Effort was made to simulate and analyze the hybrid system using HOMER (Hybrid Optimization Model Electric Renewable) software. This software (HOMER) is designed to assist in optimizing a hybrid power system based on comparative economic analysis. The HOMER software determines optimal hybrid system using combination of photo-voltaic (solar), micro-hydro, fuel generation, battery storage, and inverter (bi-directional converter) capacity. Therefore, optimization of the hybrid system was required to determine the best possible sizing system configuration.

5.2 Hybrid System Components Calculations

A. Photovoltaic (PV) power calculation

The power output of PV arrays is computed using (5)

$$P_{PV} = F_{PV} \times Y_{PV} \times \frac{I_T}{I_S} \qquad (5)$$

Where; F_{pv} is the PV's derating factor in percentage. Y_{pv} is the rated capacity in kilowatts

I_T is the solar radiation incident on the array in KW/m^2

I_S is the standard amount of radiation used to test the capacity of the PV array [$1kw/m^2$]

B. Storage Battery Calculation

The battery capacities are dependent on several factors which include age and temperature.

Batteries are rated in Ampere-hour (Ah) and the sizing depends on the required energy consumption. If the average value of the battery is known, and the average energy consumption per hour is determined. The battery capacity is determined by (3a). The ampere-hour (Ah) rating of the battery is calculated using (3b)

C. Micro Hydro Power Output Calculation

The calculation of hydropower output is efficiently done using (1) as stated above.

D. Diesel Generator

In HOMER, (6) was used to determine a generator's fuel consumption rate over a given period:

$$\mathrm{F} = \mathrm{F_0 Y_{gen}} + \mathrm{F_1 P_{gen}} \qquad (6)$$

Where: F_0 is the fuel curve intercept coefficient. F_1 is the fuel curve slope

Y_{gen} is the Rated Capacity in kW. P_{gen} is the electric output in kW

Similarly, (7) was applied in Homer to determine the generator's fixed cost of energy:

$$C_{fixed} = C_{O\&M} + \frac{C_{replacement\ cost}}{life\ time\ (hrs)} + F_0 \times Y_{gen} \times C_{fuel} \qquad (7)$$

Where: $C_{O\&M}$, and C_{fuel} are the operation and maintenance cost and fuel price.

F_0 is the fuel curve intercept coefficient

Y_{gen} is the Rated Capacity in kW

To determine a generator's marginal cost and additional costs for every KWh, (8) was applied.

$$C_{marginal} = F_1 \times C_{fuel} \qquad (8)$$

6.0 Simulation Data

In this chapter, the electrical data that is employed for the proposed photo-voltaic (PV)-hydro power hybrid system is presented in table 3 while table 4 shows the cost of off grid solar power.

As earlier discussed, the hybrid system was simulated using the software called Hybrid Optimization Model Electric Renewable (HOMER). In order to achieve a fairly accurate simulation result, certain assumptions were made. Particularly in the daily load demand parameter and these parameters were assigned values for which the system was optimized.

Therefore, the hybrid renewable energy system will be simulated in the three different cases. From table below, the input parameter for the converter (bi-directional inverter system), battery storage and all other system constraints are contained in each of the cases. This is elaborated in tables 5-10 as presented below:

Table 3 Solar radiance parameter for Benue state

Month	Solar radiance (KWh/m^2/day)	Solar radiance (MJ/m^2/day)
January	4.47	16.09
Feb.	4.90	17.65
March	5.01	18.05
April	5.16	18.56
May	4.98	17.93
June	4.33	15.59
July	3.95	14.23
August	3.99	14.37
Sept.	4.23	15.24
Oct.	4.05	14.58
Nov.	4.80	17.29
Dec.	4.57	16.46

The above table shows the monthly solar parameters for Benue state. The data shows the variations in the amount of sunshine radiating in the state.

Table 4. Tabulated cost for off grid solar power system

PV Manufacturer	Array size (kw)	Monthly output (kwh)	Price ($)
Solar World	7.5	1,018	16,627
	8.1	1,081	19,207
	9.0.	1,222	17,923
	11.25	1,528	25,750
	12.15	1,621	29,434
	13.50	1,833	27,690
	14.58	1,946	32,025
Astro-Energy	7.5	1,018	16,627
	9.0	1,222	1,7923
	11.25	1,528	25,750
	13.5	1,833	27,690

ONLINE SOURCE: Astro-Energy and Solar-World

Table 5: HOMER input parameters for the three different cases for Hydro-Turbine

	CASE 1 (hybrid + gen)	**CASE 2 (hybrid only)**	**CASE 3 (hybrid + grid)**
	HYRDO-TURBINE		
SYSTEM LIFETIME (Yrs)	25	25	25
AVAILABLE HEAD (m)	25	25	25
DESIGN FLOW-RATE (L/s)	750	1,000	1,500
MIN. FLOW RATIO (%)	50	50	50
MAX. FLOW RATIO (%)	150	150	150
EFFICIENCY (%)	75	75	75
PIPE HEAD LOSS (%)	15	15	15
CAPITAL COST ($)	50,000	50,000	50,000
REPLACEMENT COST ($)	50,000	50,000	50,000
OPERATION AND MAINTENANCE COST (O&M) $/Yr	1,000	1,000	1,000
NORMINAL POWER (KW)	138	184	276

Table 6: HOMER input parameters for the three different cases for Solar Power

SYSTEM LIFETIME (Yrs)	25	25	25
AVERAGE ANNUAL RADIANCE (KWh/m^2/day)	4.53	4.53	4.53
CURRENT OUTPUT TYPE	DC	DC	DC
DE-RATING FACTOR (%)	80	80	80
SLOPE (DEGREE)	0	0	0
SIZE (KW)	50	250	50
GROUND REFLECTANCE (%)	20	20	20
AZIMUTH (DEGREE W OF S)	0	0	0
CAPITAL COST	100,000	100,000	100,000
REPLACEMENT COST	100,000	100,000	100,000
O&M ($/YR)	1,000	1,000	1,000
TRACKING SYSTEM	None	NONE	NONE

Table 7: GENERATOR POWER

SYSTEM LIFETIME (OPERATING HOURS)	15,000	N/A	N/A
CURRENT OUTPUT TYPE	A/C	N/A	N/A
SIZE (KW)	1,000	N/A	N/A
CAPITAL COST ($)	65,000	N/A	N/A
REPLACEMENT COST ($)	65,000	N/A	N/A
O&M ($/hr)	100	N/A	N/A
MINIMUM LOAD RATIO (%)	30	N/A	N/A

Table 8: GRID POWER

EMISSION PARAMETER	N/A	N/A	
* Carbon monoxide (g/kwh)			632
* Carbon monoxide (g/kwh)			0
* unburned hydro-carbon (g/kwh)			0
*particular matters (g/kwh)			0
* Sulphur dioxide (g/kwh)			2.74
* Nitrogen oxide (g/kwh)			1.34
RATE TYPE	N/A	N/A	SCHEDULED RATES
PRICE ($/KWh)	N/A	N/A	0.1
SELLBACK ($/KW)	N/A	N/A	0.05

Table 9: Battery Parameter

BATTERY TYPE	SURRETTE 4KS25P (4V, 1,900AH)	SURRETTE 4KS25P (4V, 1,900AH)	SURRETTE 4KS25P (4V, 1,900AH)
Quantity	150	150	150
Capital Cost ($)	46,900	46,900	46,900
Replacement Cost ($)	46,900	46,900	46,900
O$M ($/Yr)	1,000	1,000	1,000
No. Of Strings	2	2	2
No Of Batteries Per String	75	75	75
Min. Battery Lifetime (Yr)	4	4	4
Initial State Of Charge (%)	100	100	100

Table 10: Converters parametric properties (BI-DIRECTIONAL INVERTER)

Lifetime (Yrs)	25	25	25
Size (Kw)	500	500	500
Capital Cost ($)	37,500	37,500	37,500
Replacement Cost ($)	37,500	37,500	37,500
O&M ($)	2,000	2,000	2,000
Size To Consider	250	250	250
Inverter Efficiency (%)	90	90	90
Rectifier Efficiency (%)	85	85	85
Rectifier Capacity Relative To Inverter (%)	100	100	100

7.0 Simulation Results and Discussion

This chapter present the simulation and optimization results obtained for the different cases of the hybrid renewable energy system. The different cases of possible hybrid system combination were simulated and optimized with their different cost and sizes in kilowatt as presented below The summary of the simulation results for case 1 shows that the system's total energy production is 4,530,504kwh/yr with generator contributing 79% of its total production resulting to high fuel cost as shown in table 15. There seem to be an excess energy of 145,625kwh (table 17) produced by the system as compared to the total energy consumption of 4,379,998kwh shown in table 16 with the entire system emission contributing to a total value of 4,316,904kg/yr shown in table 30.

Table 11: System Architecture

PV Array	50 kW
Hydro	138 kW
Generator 1	1,000 kW
Battery	150 Surrette 4KS25P
Inverter	50 kW
Rectifier	50 kW
Dispatch strategy	Cycle Charging

Table 12: Cost Summary

Total net present cost	$ 32,448,166
Levelled cost of energy	$ 0.580/kWh
Operating cost	$ 2,515,088/yr

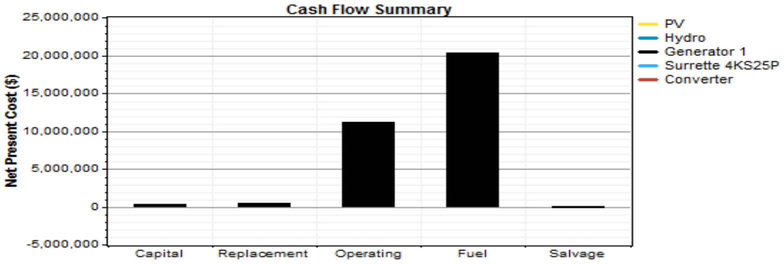

Figure 4 Net Present cost of Hybrid Variables

Table 13: Net Present Costs

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	($)	($)	($)	($)	($)	($)
PV	100,000	0	12,783	0	0	112,783
Hydro	50,000	0	12,783	0	0	62,783
Generator 1	62,500	465,908	11,184,164	20,406,018	-6,336	32,112,250
Surrette 4KS25P	46,900	34,891	12,783	0	-10,017	84,558
Converter	37,500	15,647	25,567	0	-2,912	75,802
System	296,900	516,447	11,248,083	20,406,018	-19,265	32,448,184

Table 14: Annual Variable Costs

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)
PV	7,823	0	1,000	0	0	8,823
Hydro	3,911	0	1,000	0	0	4,911
Generator 1	4,889	36,446	874,900	1,596,296	-496	2,512,036
Surrette 4KS25P	3,669	2,729	1,000	0	-784	6,615
Converter	2,934	1,224	2,000	0	-228	5,930
System	23,226	40,400	879,901	1,596,296	-1,507	2,538,315

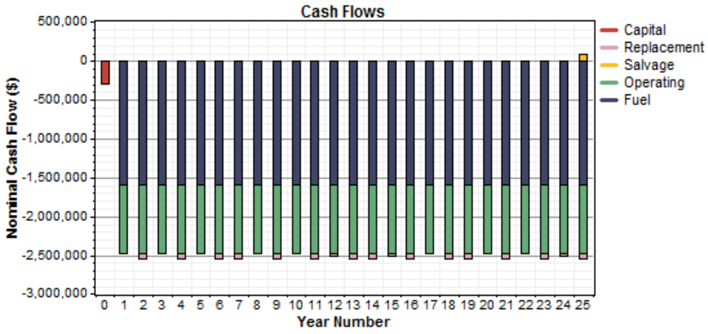

Figure 5 Nominal Cash Flow against Years

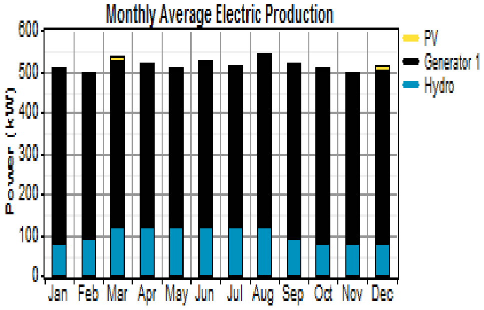

Figure 6 Monthly Average Electric Productions.

Table 15: Annual Production Costs

Component	Production	Fraction
	(kWh/yr)	
PV array	66,113	1%
Hydro turbine	879,282	19%
Generator 1	3,585,504	79%
Total	4,530,899	100%

Table 16: Annual Consumption Costs

Load	Consumption	Fraction
	(kWh/yr)	
AC primary load	4,379,998	100%
Total	4,379,998	100%

Table 17: Annual Energy consumption

Quantity	Value	Units
Excess electricity	145,625	kWh/yr
Unmet load	0.00665	kWh/yr
Capacity shortage	0.00	kWh/yr
Renewable fraction	0.181	

Table 18: Annual Power Rate

Quantity	Value	Units
Minimum output	0.00	kW
Maximum output	47.5	kW
PV penetration	1.51	%
Hours of operation	4,380	hr/yr
Levelled cost	0.133	$/kWh

Table 19: Photovoltaic Characteristics

Quantity	Value	Units
Rated capacity	50.0	kW
Mean output	7.55	kW
Mean output	181	kWh/d
Capacity factor	15.1	%
Total production	66,113	kWh/yr

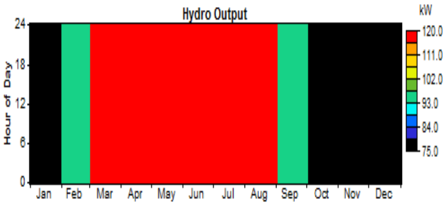

Figure 7 Monthly Hydro Power Output.

Table 20: Fuel Consumption Rate

Quantity	**Value**	**Units**
Fuel consumption	1,596,295	L/yr
Specific fuel consumption	0.445	L/kWh
Fuel energy input	15,707,545	kWh/yr
Mean electrical efficiency	22.8	%

Table 21: Hydro Power Characteristics

Quantity	**Value**	**Units**
Nominal capacity	138	kW
Mean output	100	kW
Capacity factor	72.8	%
Total production	879,282	kWh/yr

Table 22: Hydro Power Characteristics

Quantity	**Value**	**Units**
Hours of operation	8,749	hr/yr
Number of starts	12	starts/yr
Operational life	1.71	Yr
Capacity factor	40.9	%
Fixed generation cost	184	$/hr
Marginal generation cost	0.250	$/kWh/yr

Table 23: Hydro Power Characteristics

Quantity	**Value**	**Units**
Minimum output	78	kW
Maximum output	117	kW
Hydro penetration	20.1	%
Hours of operation	8,760	hr/yr
Levelled cost	0.00559	$/kWh

Table 24: Hydro Power Characteristics

Quantity	**Value**	**Units**
Electrical production	3,585,504	kWh/yr
Mean electrical output	410	kW
Min. electrical output	300	kW
Max. electrical output	855	kW

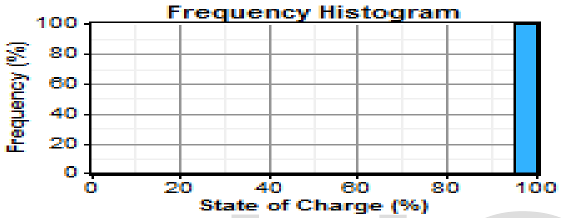

Figure 8: Frequency Distribution of Charge

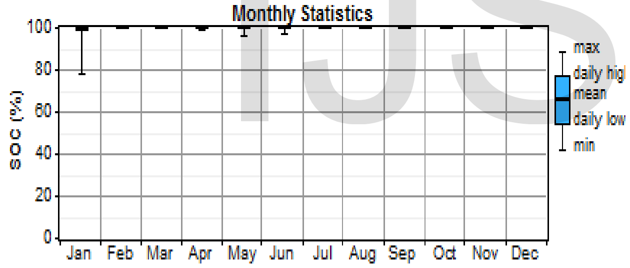

Figure 9 Monthly Distribution of Charge.

Table 25: Generator Characteristics

Quantity	**Value**
String size	75
Strings in parallel	2
Batteries	150
Bus voltage (V)	300

Table 28: Battery Characteristics

Quantity	**Value**	**Units**
Nominal capacity	1,140	kWh
Usable nominal capacity	684	kWh
Autonomy	1.37	hr
Lifetime throughput	1,585,290	kWh
Battery wear cost	0.033	$/kWh
Average energy cost	0.329	$/kWh

Quantity	Value	Units
Energy in	371	kWh/yr
Energy out	297	kWh/yr
Storage depletion	-2.07	kWh/yr
Losses	76.5	kWh/yr
Annual throughput	332	kWh/yr
Expected life	12.0	yr

Table26 Battery Characteristics

Quantity	Inverter	Rectifier	Units
Hours of operation	3,469	3,702	hrs/yr
Energy in	51,508	389	kWh/yr
Energy out	46,357	331	kWh/yr
Losses	5,151	58	kWh/yr

Quantity	Inverter	Rectifier	Units
Capacity	50.0	50.0	kW
Mean output	5.3	0.0	kW
Minimum output	0.0	0.0	kW
Maximum output	50.0	45.3	kW
Capacity factor	10.6	0.1	%

Table 27: Battery Characteristics

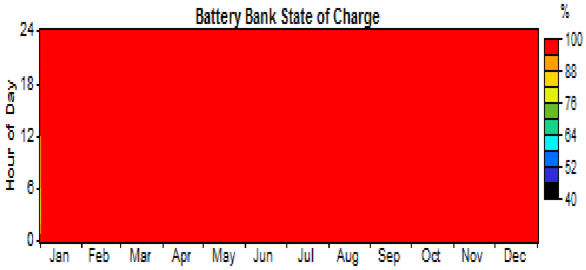

Figure 10: Monthly Battery Bank State of Charge

Table29: Converter Characteristics

Table 30: Gaseous Emissions

Pollutant	Emissions (kg/yr)
Carbon dioxide	4,203,570
Carbon monoxide	10,376
Unburned hydrocarbons	1,149
Particulate matter	782
Sulphur dioxide	8,442
Nitrogen oxides	92,585
Total Emission	4316904

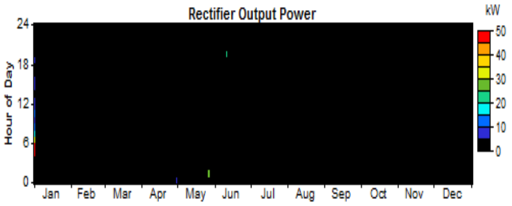

Figure 11: Monthly Battery Bank State of Charge

From the simulation result obtained for case 2 as presented below, the summary shows that the Total Hybrid Energy Production per annum was 2,384,840kwh/yr, hydro turbine contributes about 86% as shown in table 33 .The system produced excess energy amounting to 229,486kwh/yr as shown in table 37 with a zero gaseous emission as presented in table 47.

Table 31: Hybrid Wattage Limit.

PV Array	250 kW
Hydro	184 kW
Battery	150 Surrette 4KS25P
Inverter	250 kW
Rectifier	250 kW

Table 32: Annual Energy Cost

Total net present cost	$ 185,803
Levelled cost of energy	$ 0.007/kWh
Operating cost	$ 5,449/yr

Table 33: Hybrid Energy Production per annum

Component	Production (kWh/yr)	Fraction
PV array	330,564	14%
Hydro turbine	2,054,276	86%
Total	2,384,840	100%

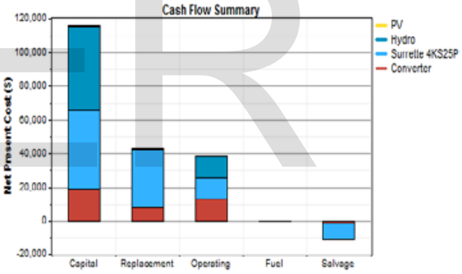

Fig. 12: Net Cost of Hybrid material

Table 35a: Annualized Costs

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	500	140	0	0	-79	562
Hydro	50,000	0	12,783	0	0	62,783
Surrette 4KS25P	46,900	34,891	12,783	0	-10,017	84,558
Converter	18,750	7,824	12,783	0	-1,456	37,901
System	116,150	42,855	38,350	0	-11,552	185,803

Table 35b: Capital Costs

Component	**Capital**	**Replacement**	**O&M**	**Fuel**	**Salvage**	**Total**
	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)
PV	39	11	0	0	-6	44
Hydro	3,911	0	1,000	0	0	4,911
Surrette 4KS25P	3,669	2,729	1,000	0	-784	6,615
Converter	1,467	612	1,000	0	-114	2,965
System	9,086	3,352	3,000	0	-904	14,535

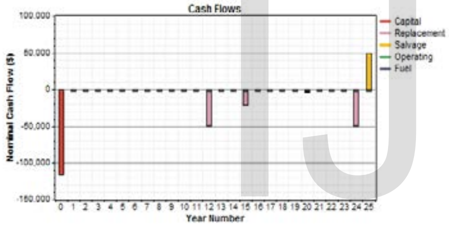

Fig.: 13 Net Cost of Renewable Energy.

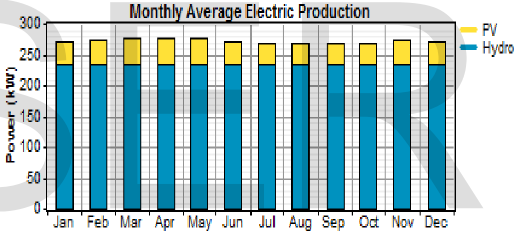

Fig.:14: Power Chart for Hybrid Renewable Energy.

Table 35c: Annualized Energy Output

Quantity	**Value**	**Units**
Energy input	144,855	kWh/yr
Energy output	116,496	kWh/yr
Storage depletion	683	kWh/yr
Losses	27,676	kWh/yr
Annual throughput	130,246	kWh/yr
Expected life	12.0	yr

Table 36: Load Consumption per annum

Load	**Consumption** (kWh/yr)	**Fraction**
AC primary load	2,096,246	100%
Total	2,096,246	100%

Table 37: Energy utilization per annum

Quantity	**Value**	**Units**
Excess electricity	229,486	kWh/yr
Unmet load	93,742	kWh/yr
Capacity shortage	159,441	kWh/yr
Renewable fraction	1.000	

Table 38: Photovoltaic total production

Quantity	**Value**	**Units**
Rated capacity	250	kW
Mean output	37.7	kW
Mean output	906	kWh/d
Capacity factor	15.1	%
Total production	330,564	kWh/yr

Table 39: Photovoltaic Output

Quantity	**Value**	**Units**
Minimum output	0.00	kW
Maximum output	238	kW
PV penetration	15.1	%
Hours of operation	4,380	hr/yr
Levelled cost	0.000133	$/kWh

Table 40: Hydro total production

Quantity	**Value**	**Units**
Nominal capacity	184	kW
Mean output	235	kW
Capacity factor	127	%
Total production	2,054,276	kWh/yr

Table 41: Hydro penetration level

Quantity	**Value**	**Units**
Minimum output	235	kW
Maximum output	235	kW
Hydro penetration	93.8	%
Hours of operation	8,760	hr/yr
Levelled cost	0.00239	$/kWh

Table 42: Hydro Energy level

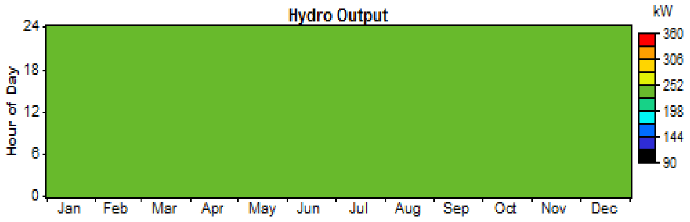

Fig.:15: Power Chart for monthly Hydro Energy output.

Table 43: Nominal Battery Value

Quantity	**Value**
String size	75
Strings in parallel	2
Batteries	150
Bus voltage (V)	300

Table 44: Battery Wattage capacity.

Quantity	**Value**	**Units**
Nominal capacity	1,140	KWh
Usable nominal capacity	684	kWh
Autonomy	2.74	hr
Lifetime throughput	1,585,290	kWh
Battery wear cost	0.033	$/kWh
Average energy cost	0.000	$/kWh

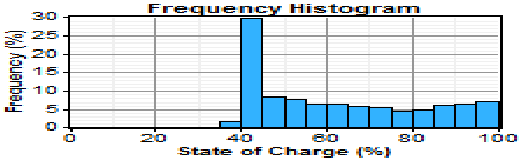

Fig.: 16: % distribution of Battery Charge

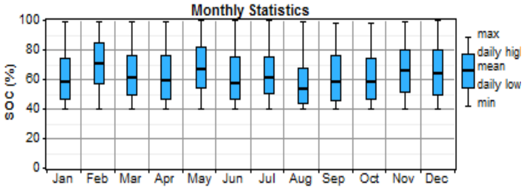

Fig.: 17: Monthly distribution of Charge

Table 45: Battery Wattage capacity.

Quantity	**Inverter**	**Rectifier**	**Units**
Capacity	250	250	kW
Mean output	23	6	kW
Minimum output	0	0	kW
Maximum output	219	45	kW
Capacity factor	9.0	2.3	%

Table 46: Converter Energy Level.

Quantity	**Inverter**	**Rectifier**	**Units**
Hours of operation	4,479	2,323	hrs/yr
Energy input	219,852	59,200	kWh/yr
Energy output	197,866	50,321	kWh/yr
Losses	21,986	8,880	kWh/yr

Table 47: Gaseous Emission Level.

Pollutant	**Emissions (kg/yr)**
Carbon dioxide	0
Carbon monoxide	0
Unburned hydrocarbons	0
Particulate matter	0
Sulphur dioxide	0
Nitrogen oxides	0

From the simulation results presented below, the summary of the results showed that the individual contribution (PV-1%, Hydro-47% and Grid 52%).Total energy production amounted to 4,393,144kwh/yr as clearly shown in table 52. The system recorded a very negligible excess electricity production (0.000121Kwh/yr) as shown in table 54, but had a total emission of about 1,444,875kg/yr presented in table 64 with an operating cost of $236,513/yr shown in table 49.

Table 48: Hybrid Power Level.

PV Array	50 Kw
Hydro	276 Kw
Grid	1,000 kW
Battery	150 Surrette 4KS25P
Inverter	500 Kw
Rectifier	500 kW

Table 49: Energy Cost Summary.

Total net present cost	$ 3,257,830
Levelled cost of energy	$ 0.058/kWh
Operating cost	$ 236,513/yr

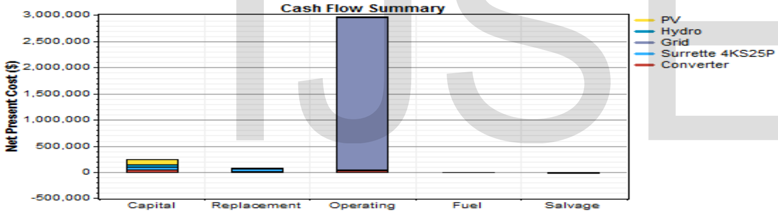

Fig.: 18: Net Present Cost of Hybrid Devices.

Table 50: Hybrid Variables Cost Summary.

Component	**Capital**	**Replacement**	**O&M**	**Fuel**	**Salvage**	**Total**
	($)	($)	($)	($)	($)	($)
PV	100,000	31,181	12,783	0	-17,475	126,489
Hydro	50,000	0	12,783	0	0	62,783
Grid	0	0	2,908,201	0	0	2,908,201
Surrette 4KS25P	46,900	34,891	12,783	0	-10,017	84,558
Converter	37,500	15,647	25,567	0	-2,912	75,802
System	234,400	81,719	2,972,117	0	-30,404	3,257,832

Table 51: Annual Variable Cost Summary.

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)
PV	7,823	2,439	1,000	0	-1,367	9,895
Hydro	3,911	0	1,000	0	0	4,911
Grid	0	0	227,499	0	0	227,499
Surrette 4KS25P	3,669	2,729	1,000	0	-784	6,615
Converter	2,934	1,224	2,000	0	-228	5,930
System	18,336	6,393	232,499	0	-2,378	254,849

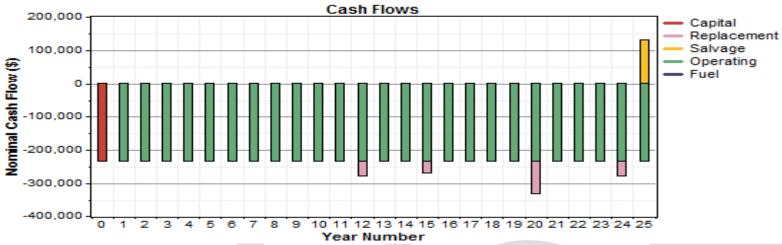

Figure 19: Nominal Variable Cash Flow.

Table 52: Annual Hybrid Energy Production.

Component	Production	Fraction
	(kWh/yr)	
PV array	60,421	1%
Hydro turbine	2,054,276	47%
Grid purchases	2,278,447	52%
Total	4,393,144	100%

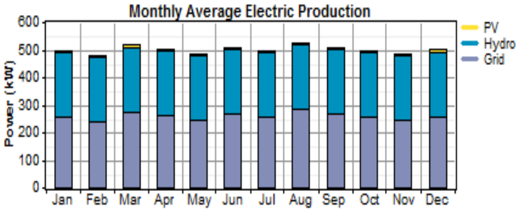

Figure 20: Hybrid Monthly Power Distribution

Table 53: Annual Consumption Summary.

Load	Consumption	Fraction
	(kWh/yr)	
AC primary load	4,379,998	100%
Grid sales	6,917	0%
Total	4,386,915	100%

Table 54: Annual Energy Distribution.

Quantity	Value	Units
Excess electricity	0.000121	kWh/yr
Unmet load	0.0144	kWh/yr
Capacity shortage	0.00	kWh/yr
Renewable fraction	0.481	

Table 56: Annual Component Cost.

Table 55: Annual Component Cost.

Quantity	**Value**	**Units**
Rated capacity	50.0	kW
Mean output	6.90	kW
Mean output	166	kWh/yr
Capacity factor	13.8	%
Total production	60,421	kWh/yr

Quantity	**Value**	**Units**
Minimum output	0.00	kW
Maximum output	43.4	kW
PV penetration	1.38	%
Hours of operation	4,380	hr/yr
Levelled cost	0.164	$/kWh

Table 57: Annual Hydro Power Production

Quantity	**Value**	**Units**
Nominal capacity	276	kW
Mean output	235	kW
Capacity factor	85.0	%
Total production	2,054,276	kWh/yr

Table 58: Hydro Power Ratings

Quantity	**Value**	**Units**
Minimum output	235	kW
Maximum output	235	kW
Hydro penetration	46.9	%
Hours of operation	8,760	hr/yr
Levelled cost	0.00239	$/kWh

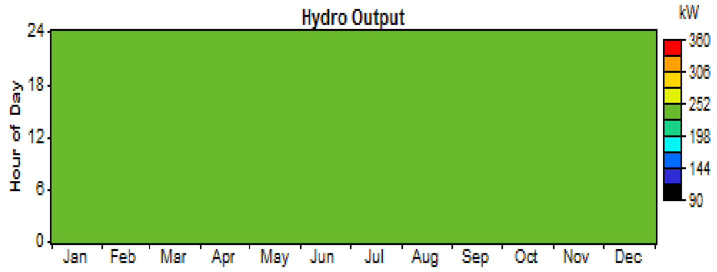

Figure 21: Hourly Output of Hydro Power

Quantity	**Value**

String size	75
Strings in parallel	2
Batteries	150
Bus voltage (V)	300

Table 59: Hydro Battery Ratings.

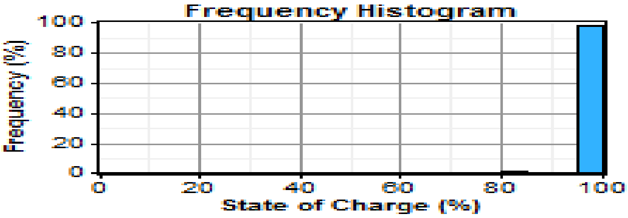

Fig.: 22: % distribution of Battery Charge

Table 60: Hydro Power Ratings.

Quantity	Value	Units
Energy input	759	kWh/yr
Energy output	607	kWh/yr
Storage depletion	8.09	kWh/yr
Losses	144	kWh/yr
Annual throughput	679	kWh/yr
Expected life	12.0	yr

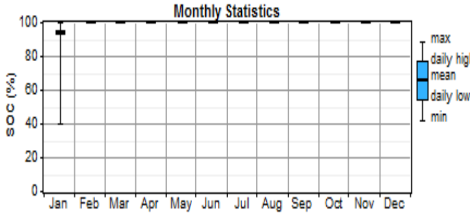

Fig.: 23: Monthly distribution of Charge

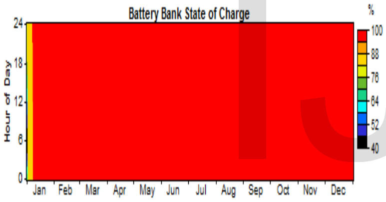

Fig.: 24: Monthly Battery bank state of Charge.

Table 61: Hydro Energy Ratings.

Quantity	Value	Units
Nominal capacity	1,140	kWh
Usable nominal capacity	684	kWh
Autonomy	1.37	Hr
Lifetime energy output	1,585,290	kWh
Battery wear cost	0.033	$/kWh
Average energy cost	0.099	$/kWh

Table 62: Hydro Power Converter's Ratings.

Quantity	Inverter	Rectifier	Units
Capacity	500	500	kW
Mean output	6	0	kW
Minimum output	0	0	kW
Maximum output	278	45	kW
Capacity factor	1.3	0.0	%

Table 63: Hydro Power Ratings.

Month	**Energy Purchased** (kWh)	**Energy Sold** (kWh)	**Net Purchases** (kWh)	**Peak Demand** (kW)	**Energy Charge** ($)	**Demand Charge** ($)
Jan	189,809	648	189,162	666	18,949	0
Feb	160,718	645	160,072	650	16,040	0
Mar	204,848	606	204,242	738	20,455	0
Apr	189,040	436	188,604	633	18,882	0
May	181,698	1,114	180,585	611	18,114	0
Jun	193,430	582	192,849	671	19,314	0
Jul	189,835	437	189,398	627	18,962	0
Aug	213,408	289	213,119	708	21,326	0
Sep	192,430	339	192,091	609	19,226	0
Oct	192,696	592	192,104	570	19,240	0
Nov	177,422	917	176,505	630	17,696	0
Dec	193,112	313	192,799	671	19,296	0
Annual	2,278,447	6,917	2,271,530	738	227,499	0

Table 64: Gaseous Emission Level.

Pollutant	**Emissions (kg/yr)**
Carbon dioxide	1,435,607
Carbon monoxide	0
Unburned hydrocarbons	0
Particulate matter	0
Sulphur dioxide	6,224
Nitrogen oxides	3,044
Total	1,444,875

Table 65: Converter’s Energy Rating.

Quantity	**Inverter**	**Rectifier**	**Units**
Hours of operation	4,369	92	hrs/yr
Energy input	60,921	767	kWh/yr
Energy output	54,829	652	kWh/yr
Losses	6,092	115	kWh/yr

8.0 CONCLUSION

From the results presented for the different cases, CASE 1 recorded a very high operating cost as compared to CASE 2 and CASE 3. This is due to high fuel and maintenance expenses incurred in the running of the system, although it produced excess electricity which could be supplied to other areas that needed power. But the system gaseous emission contributed to a high degree of environmental pollution, as compared to others (case 2 and case 3) which produced little emission. As such, we recommended case2 (stand-alone hybrid system) for the project. This is because of its reduced operating cost, net present cost and zero emission. The availability of different renewable energy sources is highly variable and the comparison suggests that there is a need of integrated renewable energy systems which will reduce the dependencies on diesel generating units and other conventional energy sources. These combinations showed the economic analysis of adopting each energy resource over a period of 25 years. However, it is important to note that this is most feasible where hydro and solar resources are in adequate supply. It is considered generally more suitable than systems that have only one renewable energy source for supply of electricity to off-grid applications. The Northern central part of Nigeria, with the largest land mass, has abundant (highest) supply of both wind, hydro and solar resources in Nigeria. This means that this proposed solution can be reliably deployed for base stations and local govt. areas around all the northern region and most southern regions of the country. This will drastically reduce the use of diesel generators for power consumption as well as reduce overhead costs inherently associated with the fossil fuel energy.

7.0 References

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