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Economic Justification of Hybrid Renewable Energy over Fossil Fuel systems,Nigeria.

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ABSTRACT: *The work is about the Development of Hybrid Renewable Energy System for the Electrification of rural areas in cross River State, Nigeria.A Hybrid model comprising Diesel Generator, Battery banks, photovoltaic Panels and wind turbine Generator was proposed to serve remote communities at Yakurr Local Government Area, Cross River State. The human problem of generating individual electricity using private generators at a high cost due to no access to the national grid has been solved. The procedure of this work was the measuring and collection of the basic meteorological data of solar radiation from NASA for Ugep, and then performing components modeling and simulation. Wind speed of 3m/s, regional solar irradiance of 3.697kWh/m^2/d andtotal energy demand of 198kwh/d from the rural community were used as input in the study. The method of incremental conductance was used to achieve maximum power output.Comparative economic analysis of Hybrid Renewable Energy System and the diesel generator system was performed. The implementation of the HRES for two weeks cost ₦42,000 only thus saving the community ₦365,500. A total of 2,266kWh/d of electric energy was generated as against, 1,890.8kWh/d using generator at a cost of ₦407,500.Using HRES with a battery bank of high amp-hour capacity for storage is capable of supplying the required electric energy including peak period. Pollutant emissions were reduced due to the penetration of solar renewable energy. An Automatic power transfer Device utilizing voltage monitoring relay was introduced to function only during period of bad weather.*

KEY WORDS:*Photovoltaic, HOMER, Irradiance, Net Present Cost, Unmasking*

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I. INTRODUCTION

Cross River State is experiencing epileptic power supply due to low voltage profile and shortage of megawatts to meet up with the teaming population and industrial growth.

Industries are not depending on the National grid to run the day to day business in order to produce goods and services.

This endemic challenge has led to the research on alternative source of energy for private industries; given this background, we need to exploit the Renewable Energy Resources to meet up with these challenges. Cross River Statepromotes tourism in Nigeria,and attracts investment opportunities;the staterequires power supply to maintain thegrowing population and economic growth. Eighty percent of Nigeria's present power generation is coming from fossil fuel (gas powered plant) and few hydro power plants,thus, it is imperative to augment the expensive generation of power usingdiesel with renewable energysource.

The concern over the generation of adequate electricity to drive economic development is a global concern in Nigeria. More so, the need to produce such magnitude of needed electric energy from environmentally friendly and non-toxic sources has further heightened the desire [1]

[2]Used HOMER simulation tool to find out the best technically viable renewable based energy system for the consumers located in Akwa Ibom State. In his study, "Comparative Study of on and off Grid Tied Integrated Diesel Solar PV Generation system'was done. The paper showed clearly that the cost of running diesel generator due to epileptic power supply in a small rural community that is not grid connected is highly expensive and not environmentally friendly

II. HYBRID RENEWABLE ENERGY SYSTEM

Hybrid systems require more than one source of energy combined together to produce electric energy. Renewable Hybrid Energy Systems (RHES) are preferred to other sources of energy due to environmental concerns of climate change, air pollution, and depleting fossil fuels. Moreover, HESs can be cost effective in comparison with conventional power plants [3] The use of hybrid PV/wind-diesel generator battery system in producing electric energy for a small Ethiopian village called Sassu was presented [4],he opined that a PV-diesel generator hybrid system is a more viable energy system compared to a diesel engine or stand-alone PV system seen elsewhere and can integrate along with the diesel power plants found in rural area. In this remote area the only means of power changeover is by manual means, which could be dangerous considering human error.[5] developed a means of connecting two generators in parallel referred to as synchronizing technique, he explained that the equipment is reliable and fast. However, the automatic changeover device [6] did not address the need to safely transfer power from Renewable energy source in case of power failure in rural areas.A hybrid power model of renewable energy sources for on-grid power supply was analysed by [7],where diesel-PV-battery system was modeled, considering different methods to enhance the performance of the proposed model system and Energy Efficiency using HOMER. A study performed in a village called Amirgadhtaluka in India [8] shows that the hybrid system with photovoltaic, diesel generator, wind turbine gives better performance in terms of cost and sensitivity.The Hybrid renewable energy system (RES) requires effective preventive maintenance to prolong the life of the critical components in the system. This has encouraged researchers to design remote monitoring methods[9] , where remote monitoring system was utilised to enhance maintenance. In all these works, the need to provide automatic control is desirable in line with safety, [10]designed and implemented a Microcontroller BasedProgrammable Power Changeover to replace the traditional means of manual operation. A system that is sustainable should be maintenance free, hence the need for remote monitoring; and automation should form part of the design as well.

Automatic Solar Powered device using Wireless Sensor Network Technology was presented [11]. Using the solar power in that location, an agricultural pump can run during the day hours without depending on grid power; the objective is to generate electricity and use it to power water pumps for irrigation in the farm. The design of aLoad Tuning Photovoltaic system Using ILP was carried out [12],

This direct coupled PV system eliminates the battery and unnecessary power conversion devices and it has been successfully applied to many applications; the design eliminates the use of battery banks as storage device. The limitation here is for low power domain environment.

A study of Autonomous and Non Autonomous Diesel-Solar PV system was performed using HOMER software to optimise a suggested PV/diesel hybrid system in Eket that has the same weather withthat at Ugep cross River State. The conclusion in that paper is that the most optimal configuration is the scenario that involves PV and diesel [13]. Also, a similar research wascarried out to optimised the efficiency of a typical Hybrid electrical power system [14], recommending different configurations of the desired hybrid Model using different types and sizes of components to select the optimal solutions. He further concluded that among the many modeling software available today, HOMER is the best in sensitivity and optimisation analysis.The development and distribution of small wind turbines (SWTs) requires great expectations in the field of Eco energy production. Some stakeholders suggest that without the dissemination of SWTs, the fulfillment of legal requirements for energy efficiency and energy production from renewable sources will be ineffective [15]. In Nigeria, small wind turbine sector can efficiently contribute to generate electricity to millions of people in rural areas.When the stand alone energy system having photovoltaic panels only or wind turbine only are compared with the hybrid PV/wind energy systems, the hybrid systems are more economical and viable according to variation in climate..[16].The use of an operational smart grid has the potential to mitigate some of the difficulties encountered by renewable energy generation.[17],designed and simulated a transformer-less single phase photovoltaic inverter without battery for domestic application;, this has added advantage to future users of this system as the need for battery storage may be eliminated thereby having edge in costs savings. The system however, does not consider days of autonomy which makes this design not user-friendly to smaller homes.[18,Used HOMER simulation tool to find out the best technically viable renewable based energy system for the consumers located in Akwa Ibom State. In his study, "Comparative Study of on and off Grid Tied Integrated Diesel Solar PV Generation system' was done. The paper showed clearly that the cost of running diesel generator due to epileptic power supply in a small rural community that is not grid connected is highly expensive and not environmentally friendly.

WIND TURBINE MODELING

The mathematical relation for the mechanical power extracted from the wind can be expressed as follows [19]$Pw = 0.5p\pi R2VwCp(Cp(\lambda,\beta\ )$ The power Pw is extracted from the wind,ρ is the air density [kg/m3], and R is the blade radius [m], V_w is the wind speed [m/s] and Cp is the power coefficient which is a function of both tip speed ratio, λ , and the blade pitch angle, β [deg]. The wind turbine characteristic for this study is shown in Figure 2.1.One of the most used wind farm concepts in power systems is based on fixed speed wind turbines (FSWT) with directly grid coupled squirrel cage induction generator connected to the wind turbine rotor through gearbox. This generator presents very small rotational speed variations because of the only speed variations that can occur due to changes in the rotor slip, and therefore these wind turbines are considered to operate at fixed speed.

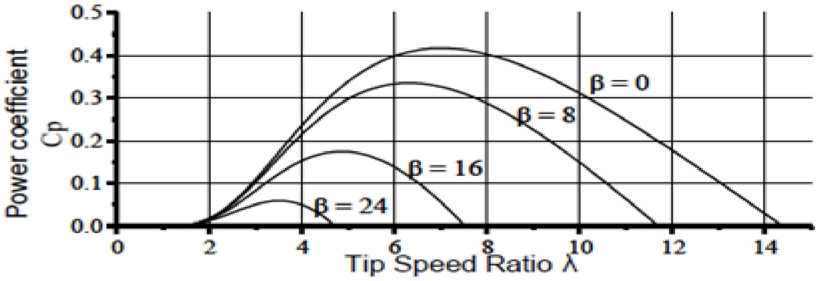

Fig. 2.6:Cp-λ Curves for different Pitch Angles (for FSWT) (Okedu,2015)

Energy in the wind was summarised [19] (RWE, 2014), it was explained that energy available in wind depends on density (ρ) and air velocity (v). The density changes with temperature and pressure, and depends on the elevation above sea level. The kinetic energy (E_o) of mass of air which is dis-placed through area (A) is $E_0=1/2pAV^3$

III. MATERIALS AND METHOD

3.1 **Components description**

Meteorological Instruments/materials

Cup generator anemometer, Radiation sensor and thermometer.Data logger and power module, tripod kit.

Electric power Generating materials. Electromechanical contactors and timer Relay
Control Relay,Fuses,chargecontrollers,solar panels, wind turbine generators, power and control cables.

System capacity sizing:

To determine the capacity of the PV and Battery banks required in the design
Load estimation was done and the energy consumed was estimated to be 198kWh/d.
Average power was 8.25Kw.

Given inverter efficiency as 0.9, it means that it will draw energy from the battery. The battery bank is designed to take care of the 10% of loss. 198000Wh x (100/90) =220,000Wh.

198,000wh is load consumed by customers. 220,000Wh is the energy drawn by the battery
Photovoltaic component depends on the area of the panels, Peak Solar Intensity and the efficiency of the PV Module. It is designed based on the energy requirement to charge the battery bank; the required energy obtained is then divided by the average sun-hours per day for Ugep to obtain the peak power. The peak power is then divided by the selected system DC voltage to obtain the total DC current. The work is presented thus,
Considering the average sunlight hours in a day as 8 hours in a year.
Hence, $\frac{220{,}000Wnx\ 1.25}{8h} = 34{,}375w$
(220,000Wh x1.25)= 275,000Wh. PV array is (275,000wh) / (8) = 34,375W minimum PV array Watts. The factor 1.25 is to take care of battery charge and discharge efficiency losses throughout the life of the battery. When we consider a module of 200 Watts (BP Solar SX)
34375W/200w = 171.875 modules approximately, 172 modules.

3.2Meteorological and Load data

The periodic and seasonal variation in wind and solar energy was recorded and the chronological weather data of Yakurr over the last four years was chosen during the power potential analysis. These data were recorded by a cup generator anemometer, radiation sensor and thermometer at a height of 10m courtesy of NIMET, Calabar. Weather data was processed in advance; in this work, these solar intensity level and wind speed data were calculated hourly and daily in each season. The time zone is 24 hours a day starting at 8:00am until 8:00am of the next day. This approach to estimate the total power required in that location involves a record of a long-period of wind speed data and global insolation data. This is incident on a south-facing Photovoltaic array by the site latitude angle ϕ for every day of a month in one year.

The total energy consumption of all required loads that need to be supplied by the Hybrid system were obtained as shown in worksheet table 3.5 load estimation.

3.3.**(i) Battery Specification and Sizing**

The battery bank size and energy storage requirements are determined based on the days of autonomy and load requirement of the rural area.

Our bus voltage is 24 Vdc, Energy/Voltage = Ah, 220,000Wh/24V= 9,166.66Ah. Considering one day of Autonomy at 50% Depth of Discharge (DOD) we have (9,167 x 1)/0.5 =18,333Ah for a battery bank. If a battery of 200Ah, 12 V is selected, the number of batteries required will be 18333/200 = 92 Batteries. The wiring arrangement will be series –parallel connection, two in series to give 24 V and 46 in parallel.

(ii) Sizing of Charge Controller

The module short circuit current is multiplied by the number of solar modules that will give the desired rating. The short circuit current from the chosen Panel is 8.56 A. This will amount to8.56 x 172 =1,471.A.

(iii). Inverter Sizing

The inverters must be greater than the PV peak power; hence a factor of 20% should be added to the value of PV Peak power. We have 1.2 x 34375 = 41,250 Watts. 10 number inverters are recommended rated 5 kVA each to share the load.

(iv). Wind Turbine specification

Wind Turbine specification

The magnitude of the converted mechanical energy depends on air density and wind velocity. The equation gives the wind power (Pm) that is developed by the turbine:

$PM = 1/2 C_p(\lambda,\beta)\rho A W^3$ Where

Pm power captured by wind turbine

ρ=Air density,β=Pitch angle (in degrees), R= Blade radius (in meters)

W= Wind speed (in m/s), the term λ is the tip-speed ratio, given by the equation

A= area of Turbine blades (m^2)

λ= tip speed ratio of the

C_p = Performance coefficient of turbine

β=blade pitch angle (deg.)

(v). Switching Circuit:

All subsystems or components are interconnected in the Hybrid system; with an introduction of Automatic Change over Device (ACD) having an intelligent voltage monitoring and regulating unit.

IV. CHARACTERIZATION OF THE AREA UNDER STUDY

The area under study is a geo-ecological area which occupies the south-East zone of Nigeria, located between latitude 5^0 48'N and longitude 8^0 4.3'about 90 kilometers to Calabar, Nigeria.

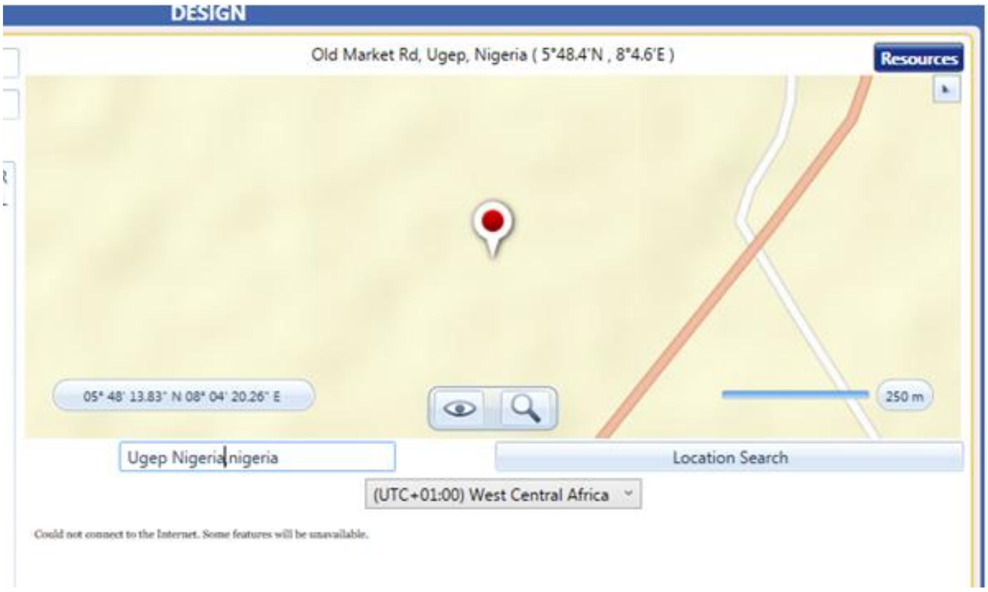

Fig. 3.1: Area of research work from longitude and latitude coordinates.

The people living in Ijiman community where this project is carried out are utilizing diesel and petrol engine-driven generators. The average quantity of fuel consumed weekly is about 826 litres equivalent to 118 litres per day. The Diesel Engines provided by the Cross River State Rural Development Authority under Niger Delta Development Commission (NDDC) are not cost effective. The Government has stopped the fuel subsidy provided initially to run the two giant Generators rated at 1.5 megawatts each. The three megawatts mini- power plant has ceased to function immediately after the 2019 general elections. On that basis the community has been using the 50kVA Diesel generator from communal efforts. When the generators were in operation an average of

825 litres of diesel are usually consumed weekly as shown in table 3.1 below. The cost of running the diesel Generator in a month amounts to ₦ 796,250 (seven hundred and ninety-six thousand, two hundred and fifty naira only.)

Table 3.1 Electric Energy Generated from Diesel Generator for the month of January and courtesy of NGS Nigeria Limited, RC-663076, Calabar

Month January	Diesel Litres	Unit cost Naira	Duration Hours	Total Cost Naira	Average kWh/d Energy/Day	Average Kw Power
1	110	250	24	27500	180	7.5
2	120	250	24	30000	180	7.5
3	115	250	24	28750	180	7.5
4	120	250	20	30000	140	7
5	125	250	20	31250	140	7
6	110	250	20	27500	140	7
7	115	250	12	28750	93.0	7.8
8	115	250	12	28750	96	8
9	115	250	12	28750	96	8
10	115	250	13	28750	104	8
11	115	250	13	28750	104	8
12	115	250	13	28750	104	8
13	120	250	18	30000	135	7.5
14	120	250	18	30000	135	7.5
15	120	250	18	30000	135	7.5
16	120	250	22	30000	165	7.5
17	120	250	22	30000	176	8
18	120	250	22	30000	176	8
19	120	250	20	30000	160	8
20	125	250	24	31250	198	8.25
21	125	250	20	31250	165	8.25
22	125	250	20	31250	165	8.25
23	125	250	20	31250	165	8.25
24	125	250	20	31250	130	6.5
25	110	250	10	27500	65	6.5
26	110	250	10	27500	65	6.5
27	110	250	10	27500	65	6.5
Total	**3185**		**481**	**796250**	**3657.6**	**204.3**

The burden has now been shifted to the communities; Residents have been asked to pay N2,200 monthly to cover the running cost ;the Environmental Hazard due to air pollution is high, as shown in table 3.2, emissions from unburned hydrocarbons (Courtesy of ministry of Health and Environment.)The Presence of unburned hydrocarbons are easily seen and felt in the region, this has over time constituted environmental pollution. Environmental Impact Assessment (EIA) carried out by ministry of health and environment in collaboration with Niger Delta Development Commission (NDDC) gave the following key indices.

Table 3.2 Emissions from Diesel Generator only, Courtesy of Ministry of Health, Occupational Safety and Health section, Calabar

Pollutant	Emissions (kg/yr.)
Carbon Dioxide	156,152
Carbon monoxide	385
Unburned hydrocarbons	42.7
Particulate matter	29.1
Sulphur dioxide	314
Nitrogen oxides	3,439

The area is known for its rocky terrain and bad roads with gully erosion affecting the tropical rain forest. This location has an average sunshine of 9 hours which could be a technical reason for implementing Hybrid renewable energy power system with the potential of connecting it to the national grid in future. The wind speed is in the range of 2.93m/s to 3m/s. The Presence of unburned hydrocarbons are easily seen and felt in the region, this has over time constituted environmental pollution. Environmental Impact Assessment (EIA) carried out by ministry of health and environment in collaboration with Niger Delta Development Commission (NDDC) gave the results shown in Table 3.2.

4.1. Diesel Generator system

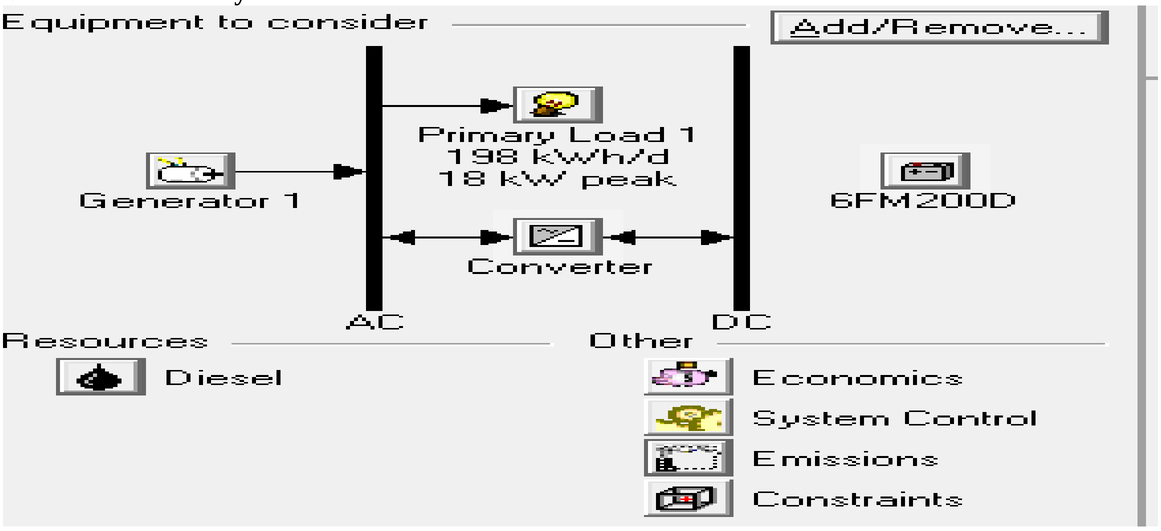

Fig.3.2: Diesel generator system only

The figure above is the connection of the generating set feeding the rural load as shown below. When the generator is in use for two weeks, table 3.1 above shows the fuel consumed and the energy generated per unit cost.

4.2 Renewable Energy System

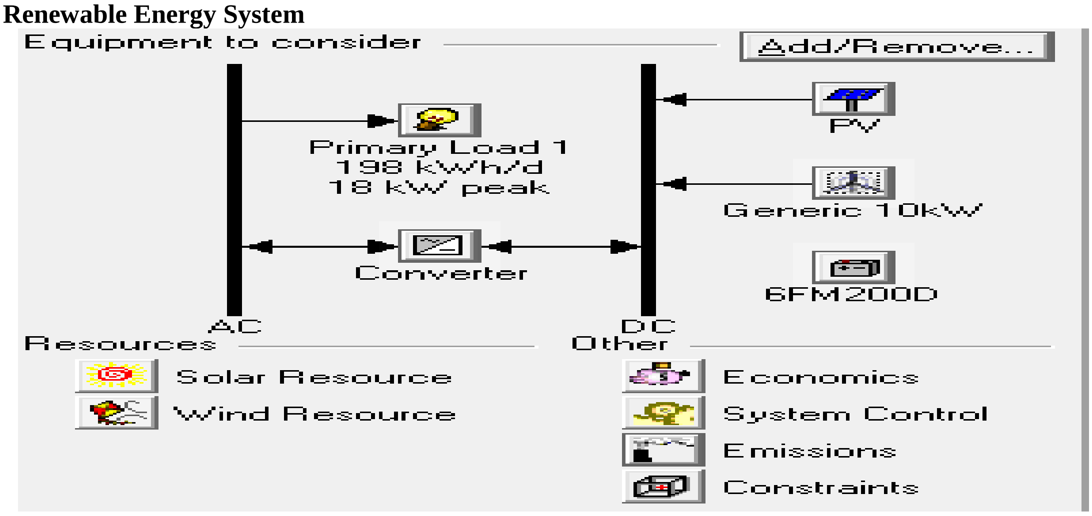

Fig.3.3: configuration of Hybrid Renewable energy PV/Wind only

The configuration above is that of Hybrid Renewable Energy system comprising of photovoltaic modules and wind turbine without diesel generator. Table 3.3 below shows the generated energy and operation and maintenance cost.

Table 3.3 Hybrid Renewable Energy System (HRES) implementation.

Month February	HRES HOURS	Ave. kW Power	Energy kWh/d		Running Cost Naira
1	19	8	152		3000
2	19	8	152		3000
3	19	8	152		3000
4	20	7	140		3000
5	20	7	140		3000
6	20	7	140		3000
7	21	7.8	164		3000
8	21	9	189		3000
9	21	9	189		3000
10	20	9	180		3000
11	20	8	160		3000
12	20	8	160		3000
13	20	7.5	150		3000
14	24	8.25	198		3000
Total	284	111.55	2266		42000

4.3 Economic analysis of both systems

Economic analysis of the diesel generator system and Hybrid Renewable Energy system with statistical Techniques was performed to validate and evince the justification for implementing the work in rural communities. This aspect is very necessary in order to unmask the key performance indices of both generating systems; by so doing, it will attract counterpart funding from private investors and government funding. The table below compares the energy generated and cost of production at the same consumption rate.

Table 3.4 Economic Analysis of Generator and Hybrid Renewable Energy System.

Configurations	**Bi-weekly Fuel used(Litres)**	**Total Cost(Naira)**	**Total Energy(kWh/d)**	**Hours Run**	**Total Power kW**
Renewable Energy (February)	**Nil**	**42,000 (Running Cost)**	**2266**	**284**	**111.6**
Diesel Gen only (January)	**1630**	**407500**	**1890.6**	**249**	**107.6**
Economic Advantage	**1630**	**365,500**	**375.4**	**35**	**4**

Worksheet Table 3.5 Load estimation

.
Location: Cross River state, Yakurr LGA,Ugep.
Coordinates:
Latitude 5^0 48.4'N
Longitude 8^0 4.3'

U. Loads					
U1=Inverter Efficiency	.85				
U2=Battery Bus Voltage	24volts				
U3=Inverter Ac Voltage	220 volts				
	U4	**U5**	**U6**	**U7**	**U8**
Appliance	Rated wattage	adjustment factor 1.0 for DC (U1) for AC	Adjusted wattage (U4/U5)	Hours per day used	Energy per day (U6*U7
(200) 30w lights	6000	.85	7058.8	2	14117.64
(40)Refrigerator	20000	.85	23529.4	5	117647
(100) 45w fans	4500	.85	5294	8	42352.9
(60)TV	12000	.85	14117.64	4	56470
(10)Blower 1000w	10000	.85	11765	0.25	2941
(10)Washer 1500w	15000	.85	17647	.86	15176
U9	Total Energy demand in a day(sum of U8)			197904.54Watt-hours	
U10	Total amp-hour demand per day (U9/U2			8246 amp-hours	
U11	Maximum ac power requirement (sum of U4)			67500 Watts	
U12	Maximum dc power requirement (sum of U6			79411.84 Watts.	
	Design Temperature		30^0C		

A visit to the rural community Ketabana was undertaken during the field assessment. Over 500 homes were assessed and estimated using the available records from the contractor in charge of generator maintenance. The information was used in the computation of the load profile. (NGS Nigeria Limited, Calabar). The information was used in HOMER environment to generate the plot of the load profile shown in figure 3.2.

V. RESULT AND DISCUSSION

Results were taken from the data/records monitored for two weeks in the field by the electricity service provider, NGS Limited for the duration.Both cases using the configuration systems in figures 3.2 and 3.3 respectively were compared.

5.1 Case 1 and case 2 (Diesel generator and Hybrid Renewable Energy System.)

The data in Table 3.1 is the record of the energy generated from a 50kVA diesel generator used in the rural community of ketabana-Ijiman, in Ugep Yakurr Local Government of Cross River State, Nigeria This information was provided by an Indigenous company (NGS Nigeria Limited) whose responsibility is to perform preventive and break down maintenance of all private generators supplied by the state government. The graph of the table plotted and displayed in figure 3.4 showed that the use of the generator in the rural community for a period of two weeks amounted to ₦407,500 (Four Hundred and seven thousand, five hundred naira only).A total of 1,630 litres of fuel at the cost of ₦250 per litre was consumed. Hybrid Renewable Energy System was introduced into the rural community at the same consumption rate. It was recorded in table 3.3 displayed graphically in figures 3.4 and 3.5 respectively. The average running cost for preventive maintenance and security services was fixed at ₦3000 daily. This amounted to ₦42,000 (forty -two thousand Naira only).The economic analysis in table 4.4 showed that ,for a given period of two weeks a total of N365,500(three hundred and sixty-five thousand five hundred naira only had been saved for using Renewable Energy source for supply. Excess of 44 hours has been gained without breakdown, a total of 111.6kW of electric power had been produced. Total energy gained was 375.4kwh/d and excess of 4kw of power gained for using renewable energy. Emissions that were usually monitored and recorded by Ministry of Health, Occupational Health and Safety section had been completely eliminated table 4.1.For testing the capacity of the design, the generated power was used to supply a rural equivalent load up to 10kW as shown in Fig. 4.12.The generated output power was able to supply the rural load equivalent of 10kW without overloading the power system components. This has again validated the design and tested the capacity of the power station designed in accordance with the load profile of the rural area and energy demand per day. Figure 4.13 demonstrated the changing positions of the two contactors M1 and M2 when the voltage monitoring relay gives a command from input variable.

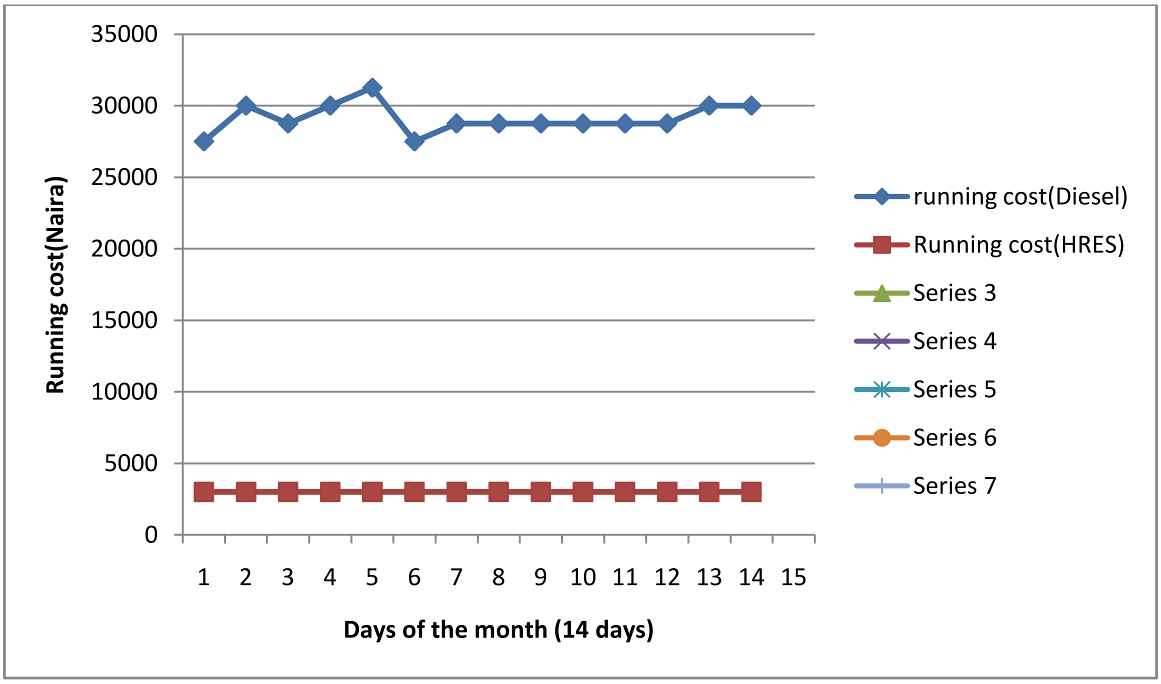

Fig. 3.4: Graph ofhybridand diesel generator showing cost of energy production for two weeks.

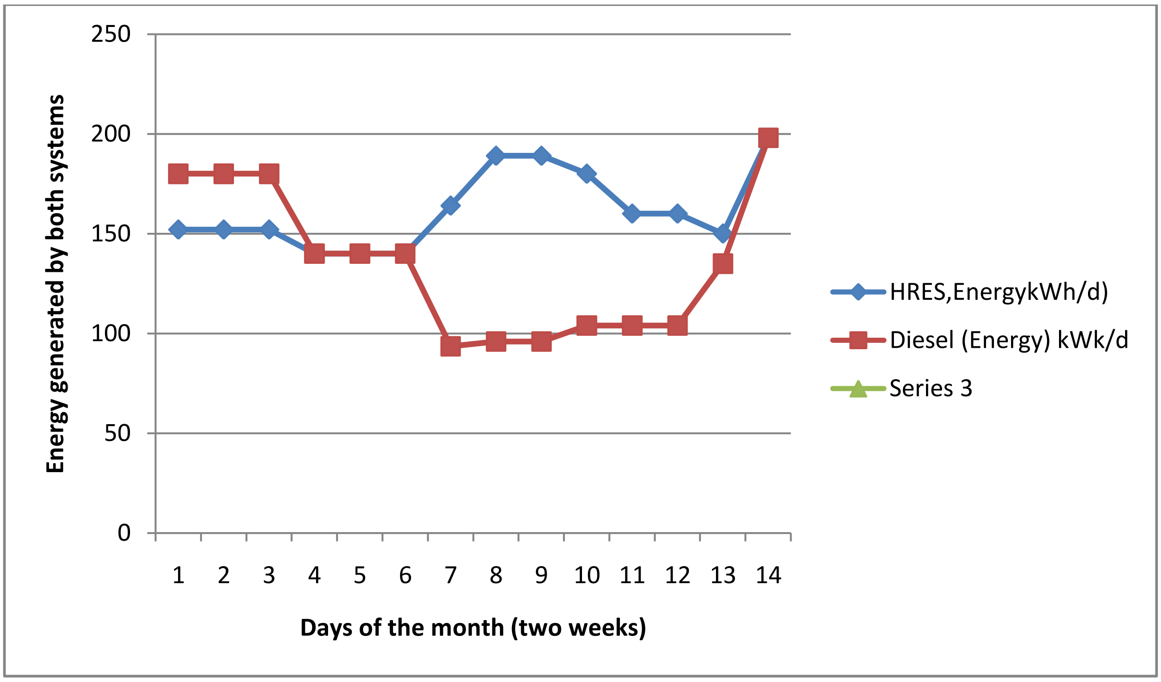

Fig 3.5: Graph of hybrid diesel and renewable Energy showing total energy generated by both systems.

VI. CONCLUSION

Solar photovoltaic (PV) power system has a great potential in future as one of the renewable energy technologies for power generation. This work has presented an off- grid connected diesel, Generator, solar PV/WTG for electrification of Rural areas in Cross River State, with an option of interconnecting the stand-alone system with the Grid. The work has illustrated the technique to compare the two systems to show clearly the benefits of using Renewable Energy systems in rural communities. The State would achieve availability and sustainability of power supply eventually when his type of energy is injected into the energy mix. Renewable energy can bring electric power to remote villages currently left off the grid. This will attract investment opportunities to small scale industries and access to modern communications.

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