Improved Off-Grid PV System for a Small Community in Niger Delta Case Study of Opobo Town in Rivers State.

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ABSTRACT: Renewable energy potential of the Niger Delta Region of Nigeria was properly investigated and the use of active solar power technique was employed in this work. A typical community in Rivers State in the Niger Delta Region was used as case study. The work considered the essential loads in a typical three (3) room apartment in a clustered of an ideal community of the Niger Delta area. The materials and methods involved in the design included five (5) numbers of photovoltaic (PV) panels of 200W/12V, four (4) numbers of 12V deep cycle batteries connected in parallel giving a total power of 957.5AH to serve a total daily load of 3,516kw/h considering three (3) days of continuous power supply in a continuous raining days. Analytical mathematical models were applied to evaluate the solar penal daily demands and cost analysis was effected using solar power system. The economic cost for this provision and considering little or no service charge, this arrangement is best suitable for this region where environmental/cost factor can hinder extension of the national grid. Replacing the deep cycle batteries with heavy duty batteries reduces the cost by 8.3%. This is more affordable, obtaining the same services and long life span.

Key: *Renewable, Solar Power, PV Systems, Off-grid, national grid*

I. INTRODUCTION

Nigeria is a country whose Electrical Energy Generations come from hydropower stations and a few thermal gas power stations. Two main categories namely grid and off-grid supplies. The urban areas are supplied from the grid system while some rural communities are supplied off-grid system. Over the years the country has suffered a lot of setbacks in terms of development due to poor and insufficient energy production and transmission.

In the past there were no serious National plan and lay down frame work as to meet the huge energy demands with our teaming population. The power supply to on grid in the urban areas are inadequate, let alone the off grid rural areas. Most part of the year the rural areas never have power supply from the National Grid. This has been the scenario year in and year out, and we wonder how long this situation would continue. Study was carried out in the Opobo Town Communities; it was found that the national grid is absent there.

According to [5], Nigeria is fortunate to be endowed with abundant and enormous natural resources of renewable energy, such as: the Sun, Wind, Hydro and Biomass etc. as alternative energy sources. The objectives of the study are to design a durable solar energy power supply system using PV cells and Heavy Duty Batteries. To determine the total power usage for a 3 bedroom apartment using power equations. To estimate cost and benefits analysis. That analysis shall be used to advise the government to attract local and foreign investors to invest and establish solar panel manufacturing industries in Nigeria.

II. Related Works

The large magnitude of solar energy available makes it a highly appealing source of electricity. The United Nations Development Programme in US 2000 World Energy Assessment, found that the annual potential of solar energy was 1,575 to 49,389 Exa Joules (EJ) which is several times larger than the total world energy consumption, which was 559.EJ. for 2012(3) (4). The [7], stated that the development of affordable, inexhaustible and clean solar energy technology will have long time benefits. It will increase countries security through reliance on an indigenous inexhaustible and mostly impart-dependent resource. It will sustainably, reduce pollution and lower cost of mitigating global warming. The followings sub sections review related works in this study.

[6], investigated the impact of some implemented renewable energy projects including but not limited to Solar PV for single homes and micro- hydro power plants. Through the Remote Area Power Supply System (RAPS), mini scale amounts of power can be generated that is just suitable for single home rural dwellers.

A Solar Home System (SHS) is an economical-friendly photovoltaic electrification kit typically used in homes where sunshine is sufficient and where access to the public power utility is unavailable. Such kits typically power light loads such as small black and white televisions, radio cassette players, mobiles etc. In [4], the econometric impact of this form of electrical power in the Bangladesh was carried out using a questionnaire based field surveys. [1] performed hypothetical investigations on the feasibility of providing a renewable energy system to a small suburban area in Hargeisa, a major urban center in Somaliland.
The architecture of their proposed system is as shown in Figure 1.

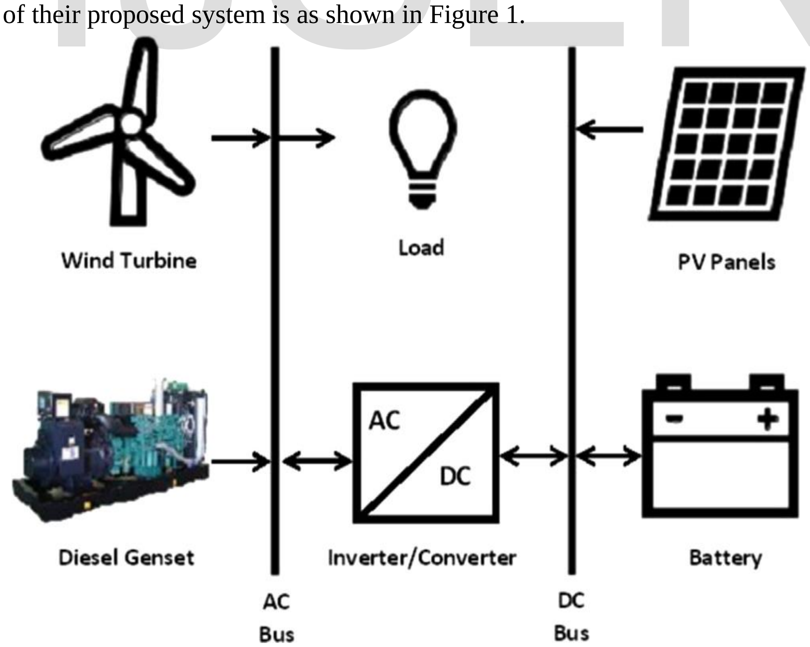


Figure.1 Hybrid system for renewable energy

[1] describes that system as useful, the added costs of fuel and inverter/converter equipment may not be comfortable for most inhabitants in the study region. Nonetheless, techno-economic analysis of the system based on cost and some design specified variables (size of PV array, number of wind turbines), gave a fair penetration level of about 58% for the RE scenario. Their findings also reveal an economical advantage of wind over solar PV with RE penetration levels of 56% and 2% respectively.

A. Optimal Siting and Sizing Of Solar Power Sources In Interconnection Grid System

Another instance of solar power review was done where [5], due to power losses in transmission wires considered proper sitting and sizing compensation Network using solar power sources.

In their work they used the mathematical model shown below:

$$\text{Minimize } f(x) = \sum_{i=1}^{n} P_{loss} \quad (1)$$

Where: P_{loss} is power loss in network

n is number of nodes

and

$$P_{loss} = \min \sum_{i=j}^{n} \sum_{i=j}^{n} = I_y^2 = Z_y \quad (2)$$

Where,

I_y is line current magnitude at node bus i^{th} to j^{th}

Z_y is line impedance at nod bus i^{th} to j^{th}

The objective was to propose model to decrease the power loss within the network by means of standard optimal sitting and sizing of solar power electricity assets in grid network. They emphasized that if power unbalance occurred at receiving end, it will generate power loss in network, and that power injection with the help of solar power at receiving end will reduce the power loss in network.

B. The Principle of Operation of Photovoltaic (Solar) Cell

In investigating the electrical characteristics of a solar under photovoltaic effect, a plot of current-voltage curve is made under various load conditions.

The solar cell is nonlinear device, so it is not convenient to use a mathematical expression for its characteristics, instead a family of graphic curves explains this better. In achieving this, the solar cell is connected in the circuit as shown

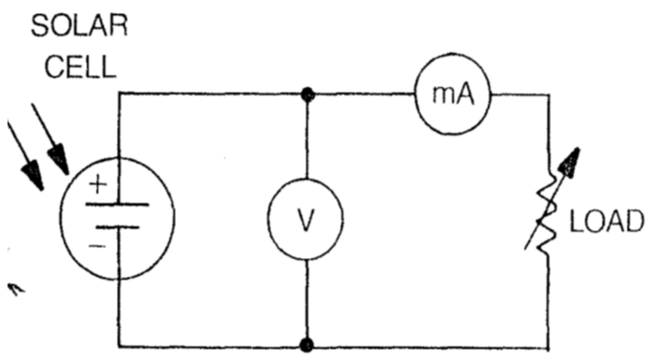


Fig. 2: Circuit for plotting voltage-current curves

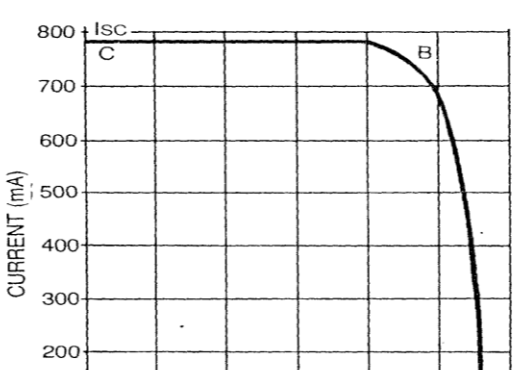
The load resistance is varied over a wide range while noting the values of the voltages and current as indicated on the meters in the circuit. Considering silicon cell being in connection in the circuit and is subjected to an amount of light approximately equally to the amount of the maximum value of sunlight as the surface of the earth-about 100mW/cm. considering that the load resistance is taken so high that practical it is made an open circuit ie no current is indicated in the mili-ammeter. The terminal voltage under this condition will be about 0.570 volts. This point is indicated as Voc- the open circuit voltage on the graph.

Now when the load resistance is gradually decreased, the terminal voltage drops very slowly, and the current increases rapidly. This continuous until point ‘B’ is reached on the curve. At this point, the voltage drops to about 0.45 volts and the current has increased to about 780 mill amperes. That is point, the shape of the curve changes rather drastically and is referred as the knee of the curve. If the decrement of the load is continued, the voltage will continue to drop, but the current will remain nearly constant. When the load resistance becomes zero, the voltage on the voltmeter becomes zero. At this instance there is a short-circuit, and this is referred to as point c on the curve. It is also referred as I_{sc} – short circuit current of the cell.

C. Maximum Power

To establish the maximum or optimum power on the current voltage curve, the voltage is divided by the current at a particular point on the curve. Interestingly the power to be delivered to the load will be maximum when the cell is operated about the knee in the characteristic curve. Arrays were obtained when the cell was subjected to maximum value of solar rays.

In fig 3 the Dash line shows the curve of the power output. At the maximum power output indicated on the curve, the voltage does not vary so much, the power is proportional to the current, and the current will decrease linearly with the amount of solar rays incident on the cel



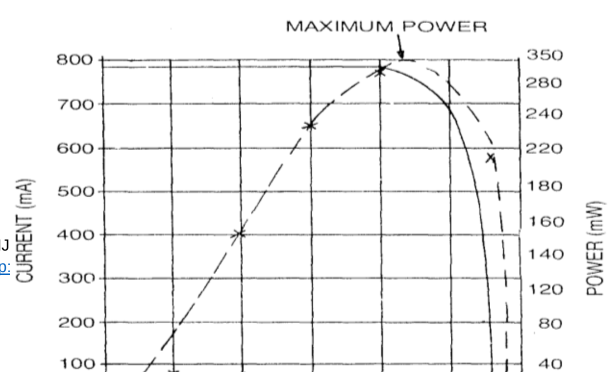


Fig. 3a: Voltage-current curve for a solar cell

Fig. 3b: Voltage-current curve for a solar cell With power plotted also

Graphs from Solarex Cooperation Experimental Values

Inferences reached from the curve characteristics are that, solar cells with larger areas will produce more current, and that the voltage produce by a solar cell is approximately 0.45V (450mV) irrespective of the area of the cell.

III. MATERIALS AND METHOD

Application of active solar technique PV panels involve the use of the following materials, the conducting wires take the current off the modules may contain silver, copper or other non-magnetic conductive metals. The cells must be connected electrically to one another and to the rest of the system. Externally, popular terrestrial usage photovoltaic modules use MC3 (older) or MC4 connectors to facilitate easy weatherproof connections to the rest of the system. Bypass diodes may be incorporated or used externally, in case of partial modules shading, to maximize the output of module sections still illuminated.

Some recent solar module designs include concentrators in which light is focused by lenses or mirrors onto an array of smaller cells. This enables the use of cells with a high cost unit area (such as gallium arsenide) in a cost-effective way.

There is also hotspot effect in solar modules in which two sides of cells are connected two diodes, this prevents solar modules or panels from short circuit.

A. Electrical Load Estimates of 3 Bedroom Rural Apartment

Electrical load of a 3 bedroom apartment of typical rural dwellers is stated below, in table 1

Load Type	**No. of Unit**	Load Wattage (w)	Operating Period/Day in Dry Season (HR)	Operating Period in Raining Season (HR)	Total Energy (w)
Energy Saving Bulb	**13**	23	4	4	1,196

TV	**1**	80	4	4	320
Electric Fan	**4**	40	6	4	800
Refrigerator	**1**	100	12	12	1,200
Average Energy Needed (kwh/day)			**3.516**		

The total energy in the last column is a multiple of the number of units load wattages and the average operating Hours in the dry and raining season in each row.

The family house of 3-bed room flat apartment does not require much energy, as their most consumable energy is on lighting, fan and refrigeration. The need of providing power for pumping of water does not arise, as it is expected that the community water resources is available.

B. DETAILED CALCULATIONS

Energy Consumed = No of units x wattage x (period of dry season + period of wet season) /2

(i) Lighting points = 13 x 23 x (4+4)/2 = 1,196W

(ii) TV = 1 x 80 x (4+4) /2 =320W

(iii) Fans = 4 x 40 x(6+4)/2 =800W

(iv) Refrigerator = 1 x 100 x (12+12)/2 = 1200W

C. Sizing of Photo-Voltaic (PV) Generator

The size of PV generator can be estimate as follows:

$$\text{PV (Area)} = \frac{E_L}{H \times TCF \times \eta pv \times \eta B \times \eta Nv} \qquad (3)$$

Where: E_L = Average daily load energy (kwh/day)

H = Average solar energy input/day (kwh/m^2/day)

TCF = Temperature correction factor.

η_{PV} = Efficiency of PV module

η_{B} = Efficiency of storage battery

η_{INV} = Efficiency of inverter

From standard values:

E_L = 3.516kwh/day

H = 5.30kwh/m^2/day

η_{PV} = 0.12,

TCF = 0.8,

η_{B} = 0.85

η_{INV} = 0.9

Therefore we have:

$$PV \quad (Area) = \frac{3.516}{5.30 \times 0.12 \times 0.8 \times 0.85 \times 0.9} \tag{4}$$

= 3.516/0.389 = 9.04m^2

$$\text{Peak power} = \text{PV (Area)} \times \text{PSI} \times \eta_{PV} \tag{5}$$

Where PSI = peak solar intensity at the earth surface

= 1000w/m^2

∴ Peak power = 9.04 x 1000 x 0.12 = 1,084.8W

Choosing a standard PV module of 200W peak power, 14V the number of solar panels (modules) required is expressed as:

$$N_m = \frac{PV\ peak\ \ power\ (W)}{Maximum\ \ power\ \ ouput\ of\ \mathrm{mod}\,ule\ (W)} \tag{6}$$

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N_m = 1,084.8/200 = 5.4 ≈ **5Nos of PV Panels of 200W/14V**

Thus 5 modules of 200W/14V Photo-Voltaic (PV) panels are required to be installed in parallel to supply the house the required electrical energy. The modules can be connected in serried to give the desire voltage or the specification required.

IV. Results and Discussions

A. Economic Analysis/Estimation of PV System

The economic analysis/estimation of PV system associated the parameters and cost of various components of the system is stated in the table 2 below.

Table 2 Economic Analysis/Estimation

S/No	Description	Qty	Unit Rate (₦)	Cost for Deep Cycle Battery System(₦)	Cost for Heavy Duty Battery System(₦)
1	200W PV Array	5	45,000.00	225,000.00	225,000.00
2	Deep Cycle Battery System (60A)	4	45,000.00	180,000.00	—
3	Heavy Duty Battery System (60A)	4	35,000.00	—	140,000.00
4	Battery Charger Controller	1	30,000.00	30,000.00	30,000.00
5	Inverter Unit (4KW)	1	30,000.00	30,000.00	30,000.00
6	Accessories	Lots	8,000.00	8,000.00	8,000.00
7	Solar System Installation	1	10,000.00	10,000.00	10,000.00
8	Sub Total			483,000.00	443,000.00
9	10% Discount Rated(d)			48,300.00	44,300.00
	Total			**434,700.00**	**398,700.00**

Initial cost of installation is

= PV Array Cost + Battery Bank Cost + Battery Charge +

Controller Cost + Inverter Cost + Accessories Cost + Cost of Installation – 10% Discount.

= ₦ (225, 000 +140,000 + 30,000 + 30,000 + 8,000 + 10, 000 – 44,300) **= ₦398, 700.00**

The life span of the system components is considered for 25 years, except for the batteries which have a life time of 5-8 years. The initial cost of installation is relatively high, but it pays off over a long period of time.

However, there different sizes of photo-Voltaic panels such as **100W, 150W, 175W and 200W,** which have different cost components. And depending on the financial capacity of individuals and their power consumptions, he can make different choices of PV system installation to get their maximum daily power demands.

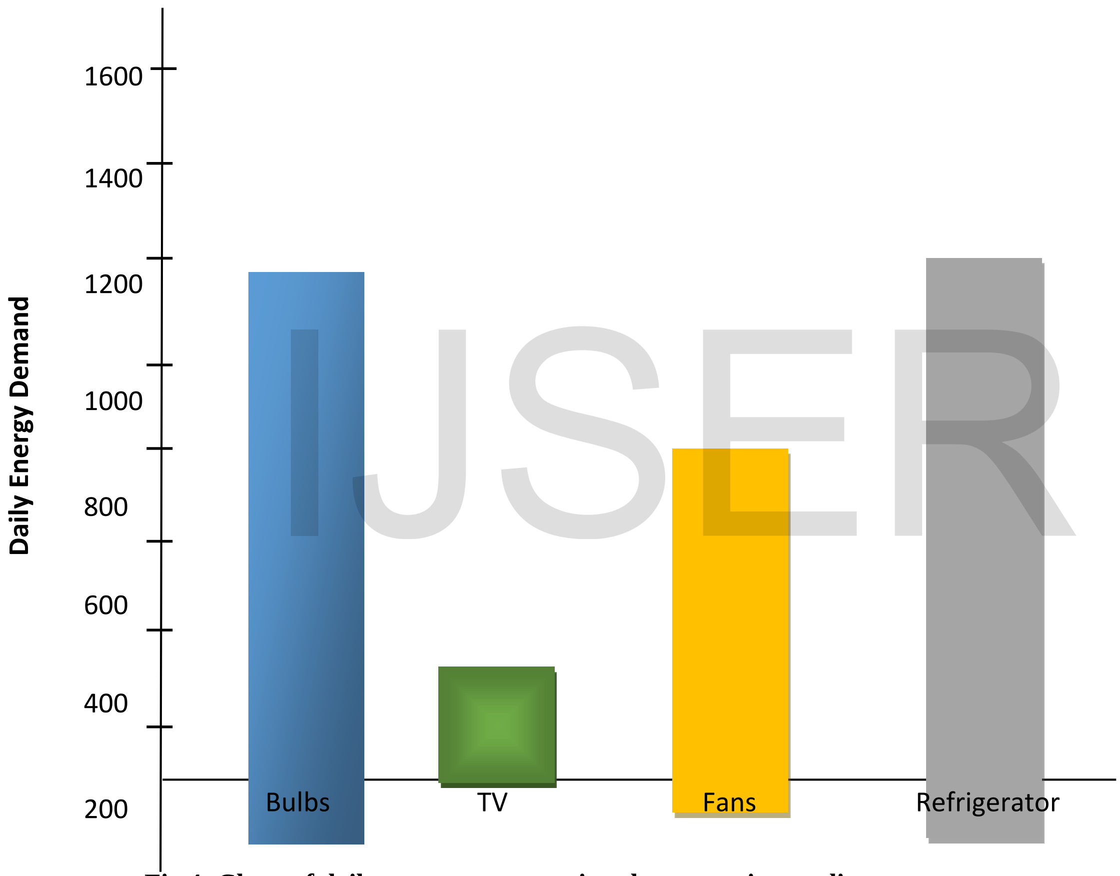

Fig 4: Chart of daily energy consumptions by respective appliances

From the bar chart of the energy consumption profile above, it is seen that the lighting points consume the highest energy daily demand. Seconded by the refrigerator, the fans and lastly the television set. In a three bed room apartment, an occupant can regulate the usage of his refrigerator down wards, this will invariably reduce his daily energy consumption profile.

Table 3: **Energy and the Number of Batteries Required**

S/No	No of Day(s)	Energy Required (KWH)	No of 12V, 60A Batteries Required
1	1	5.745	2
2	2	11.490	3
3	3	17.406	5
4	4	22.980	7

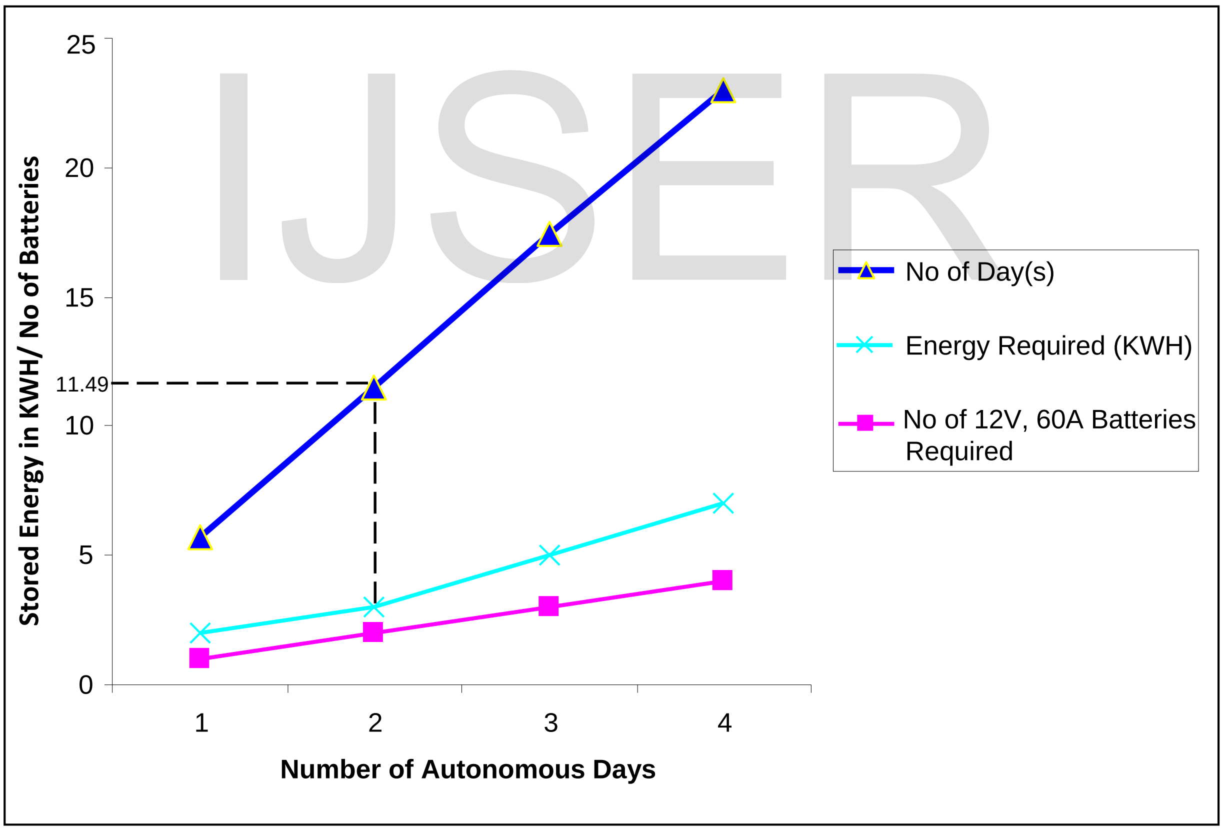

Figure 5: A graph of energy/Autonomous day's profile of the batteries

From the energy autonomy graph, it shows that the average of two days autonomy gives the minimum number of storage batteries required for long sustenance of the battery that will avoid over drained of the cells. Therefore, 11.490KWH energy is the minimum of autonomous energy required for typical three bedroom dwelling apartment for the Niger Delta Area.

Conclusion

From the study, its analysis and implementation show that the solar power system is the easiest, cheapest and continuous means of deploying power to the Niger Delta Rural Areas, where the natural grid is not in existent. The deep cycle batteries can be replaced with the heavy duty batteries if properly sized and thus reducing the initial cost of installation by 8.3%. The sizing of the batteries for storage of solar power, the autonomous (sunless) days must be put into consideration for the longevity of the batteries.

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