HYBRID SOLAR AND WIND POWER: AN ESSENTIAL FOR INFORMATION COMMUNICATION TECHNOLOGY INFRASTRUCTURE AND PEOPLE IN RURAL COMMUNITIES

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ABSTRACT

One of the primary needs for socio-economic development in any nation in the world is the provision of reliable electricity supply systems. This work is a development of an indigenous technology hybrid Solar -Wind Power system that harnesses the renewable energies in Sun and Wind to generate electricity. Here, electric DC energies produced from photovoltaic and wind turbine systems are transported to a DC disconnect energy Mix controller. The controller is bidirectional connected to a DC-AC float charging-inverter system that provides charging current to a heavy duty storage bank of Battery and at the same time produces inverted AC power to AC loads. The 2002-2009, 8years wind velocity data for Abeokuta and its environs were collected. The two parameters Wielbull distribution was used to simulate power in W/m^2 densities for the 8-years period. The step by step design of 1000W solar power supply system's was done as a sample case. Load estimates of a typical rural community and for rural ICT infrastructures were estimated. Simulation of wind power capacity in W/m^2 in Abeokuta, Ogun State Nigerian was done based on the obtained wind data. The results showed that the average exploitable wind power density between $4W/m^2$ and $14.97W/m^2$ is realizable and that development of hybrid wind-solar system for off- grid communities will go a long way to improve socio-economy lives of people.

Keywords: *Socio –Economic development, Nigeria, Hybrid system, Solar and Wind Power, Rural Communities ICT infrastructure, Simulation*

1. INTRODUCTION

One of the primary needs for socio-economic development in any nation in the world is the provision of reliable electricity supply systems. In Nigeria, the low level of electricity generation in Nigeria from conventional fossil fuel, has been the major constraint to rapid socio-economic development especially in rural communities. Moreso, about sixty-five percent(65%) of 140million Nigeria populace are rural dwellers with majority of them living far-off grid areas [1]. These rural dwellers are mostly farmers whose socio-economic lives can only be improved when provisions are made to preserve their wasting agricultural products and provide energy for their household equipment such as refrigerator, fan, lighting etc. There is also such a need to provide electricity for e-information infrastructures in our rural communities to service school, rural hospital, rural banking and rural e-library. Hence, there is the need to develop an indigenous technology to harness the renewable energies in Sun and Wind to generate electricity.

1.1 Importance of Renewable energy

The global search and the rise in the cost of conventional fossil fuel is making supply-demand of electricity product almost impossible especially in some remote areas. Generators which are often used as an alternative to conventional power supply systems are known to be run only during certain hours of the day, and the cost of fueling them is increasingly becoming difficult if they are to be used for commercial purposes. There is a growing awareness that renewable energy such as photovoltaic system and Wind power have an important role to play in order to save the situation. Figure 1 is the schematic layout of Solar-Wind Hybrid system that can supply either dc or ac energy or both.

2. SOLAR ENERGY

Solar energy is energy from the Sun. It is renewable, inexhaustible and environmental pollution free. Nigeria, like most other countries is blessed with large amount of sunshine all the year with an average sun power of $490W/m^2/day$ [2]. Solar charged battery systems provide power supply for complete 24hours a day irrespective of bad weather. Moreso, power failures or power fluctuations due to service part of repair as the case may be is non-existent.

2.1 Solar Systems

There are two types of solar systems; those that convert solar energy to D.C power, and those that convert solar energy to heat.

2.2 Solar-generated Electricity – Photovoltaic

The Solar-generated electricity is called Photovoltaic (or PV). Photovoltaics are solar cells that convert sunlight to D.C electricity. These solar cells in PV module are made from semiconductor materials. When light energy strikes the cell, electrons are emitted. The electrical conductor attached to the positive and negative scales of the material allow the electrons to be captured in the form of a D.C current. The generated electricity can be used to power a load or can be stored in a battery.

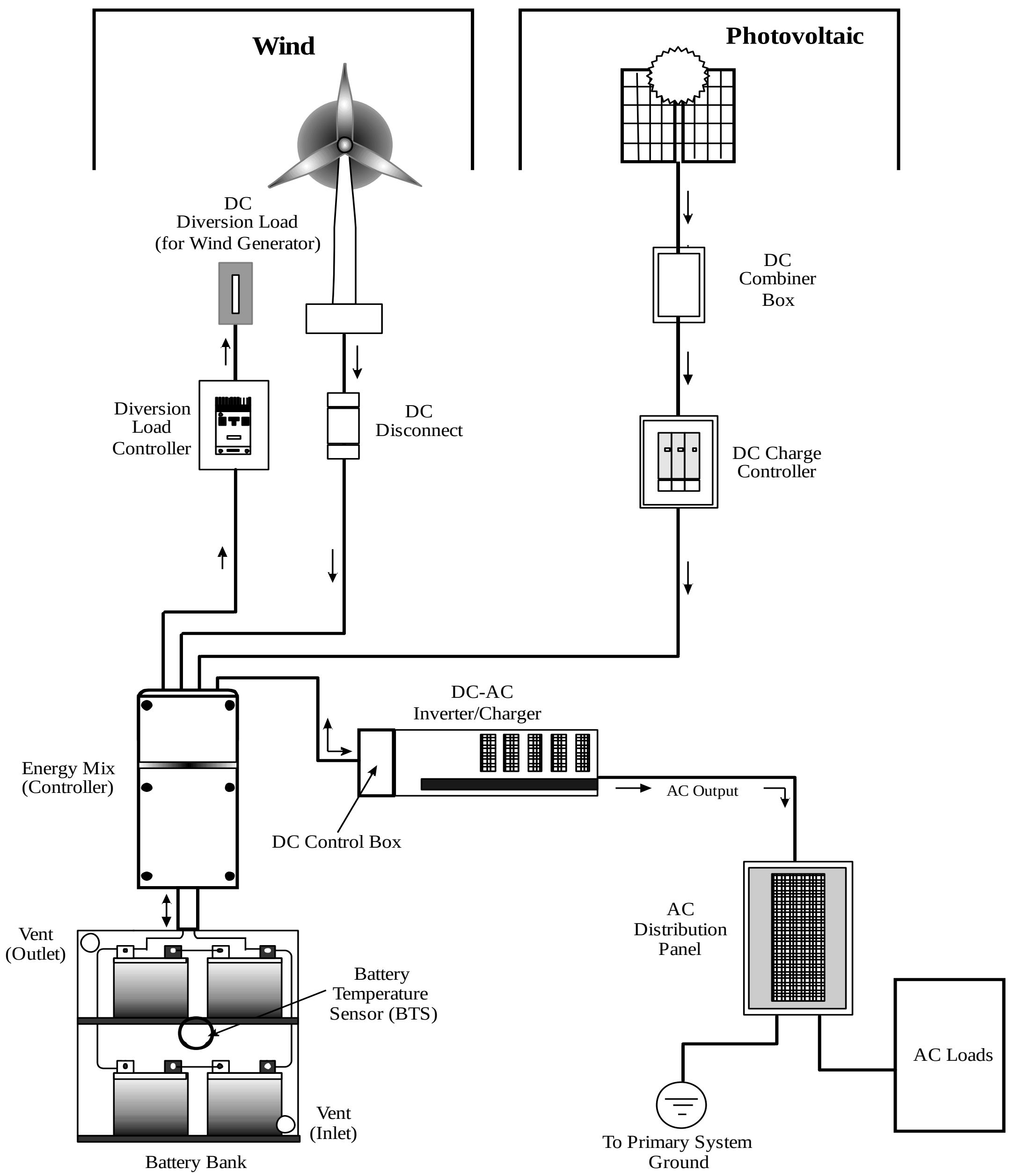

Figure 1: Schematic diagram of Hybrid (Renewable) Solar – Wind Power Source

Photovoltaic system is classified into two major types: the off-grid (stand alone) systems and inter-tied system. The off-grid (stand alone) system are mostly used where there is no utility grid service. It is very economical in providing electricity at remote locations especially rural banking, hospital and ICT in rural environments.

PV systems generally can be much cheaper than installing power lines and step-down transformers especially to remote areas.
Solar modules produce electricity devoid of pollution, without odour, combustion, noise and vibration. Hence, unwanted nuisance is completely eliminated. Also, unlike the other power supply systems which require professional training for installation expertise, there are no moving parts or special repairs that require such expertise [3].

2.3 Basic Components of Solar Power

The major components include P.V modules, battery and inverter. The most efficient way to determine the capacities of these components is to estimate the load to be supplied. The size of the battery bank required will depend on the storage required, the maximum discharge rate, and the minimum temperature at which the batteries will be used [4]. When designing a solar power system, all of these factors are to be taken into consideration when battery size is to be chosen.
Lead-acid batteries are the most common in P.V systems because their initial cost is lower and also they are readily available nearly everywhere in the world.
Deep cycle batteries are designed to be repeatedly discharged as much as 80 percent of their capacity and so they are a good choice for power systems. Figure 2 is a schematic diagram of a typical Photovoltaic System.

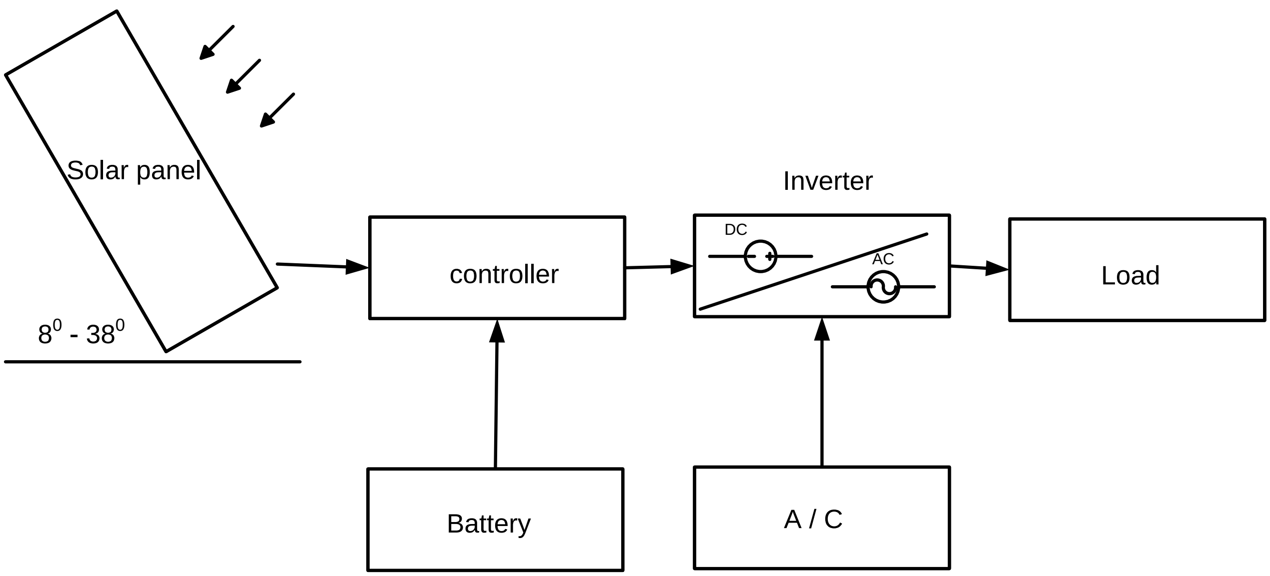

Figure 2: Photovoltaic System

2.4 Photovoltaic (P.V) Solar Modules

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 that allows incident light to be absorbed and consequently converted to electricity. 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 Wp is calculated as[5]:

$$\frac{\text{Daily energy Consumption}}{\text{Isolation x efficiency}} \quad (1)$$

Where Isolation is in $KWh/m^2/day$ and the energy consumption is in watts or kilowatts.

2.5 Batteries and Batteries Sizes of the Solar System

As mentioned above, the batteries in use for solar systems are the storage batteries, otherwise deep cycle motive type. Various storage are available for use in photovoltaic power system, The batteries are meant to provide backups and when the radiance are low especially in the night hours and cloudy weather. The battery to be used:

(a) must be able to withstand several charge and discharge cycle
(b) must be 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. The battery capacity is determined by the equations 2a and 2b[3]

$$BC = 2*f*W/V_{batt} \tag{2a}$$

Where BC – Battery Capacity
f – Factor for reserve
W – Daily energy
Vbatt – System DC voltage

The Ah rating of the battery is calculated as[3]:

$$\frac{\text{Daily energy Consumption (KW)}}{\text{Battery rating in (Amp-hr) at a specified voltage}} \tag{2b}$$

2.6 Charging Electronics (Controllers)

The need for Charging Controllers is very important so that overcharging of the batteries can be prevented and controlled.. The controllers to be used required the following features[4]:

- Prevent feedback from the batteries to PV modules
- It should have also a connector for DC loads
- It should have a work mode indicator.

2.7 Solar Inverters

The Solar inverters are electrical device meant to perform the operation of converting D.C from array or battery to single or three phase A.C signals. For P.V Solar Systems, the inverters are incorporated with some inbuilt protective devices. These include[3]:

- Automatic switch off if the array output is too high or too low.
- Automatic re-start
- Protecting scheme to take care of short circuit and overloading.

Generally the inverter to be used that would produce the quality output must have the following features[3,4,5]:

- Overload protections
- Miniature Circuit Breaker Trip Indicator(MCB)
- Low - battery protection
- Constant and trickle charging system
- Load status indicator

3. WIND POWER

Wind Power is energy extracted from the wind, passing through a machine known as the windmill. Electrical energy can be generated from the wind energy. This is done by using the energy from wind to run a windmill, which in turn drives a generator to produce electricity [6]. The windmill in this case is usually called a wind turbine. This turbine transforms the wind energy to mechanical energy, which in a generator is converted to electrical power. An integration of wind generator, wind turbine, aero generators is known as a wind energy conversion system (WECS)[7]

3.1 Component of a wind energy project

Modern wind energy systems consist of the following components[8]:

- A tower on which the wind turbine is mounted;
- A rotor that is turned by the wind;
- The nacelle which houses the equipment, including the generator that converts the mechanical energy in the spinning rotor into electricity.

The tower supporting the rotor and generator must be strong. Rotor blades need to be light and strong in order to be aerodynamically efficient and to withstand prolonged used in high winds[8].
In addition to these, the wind speed data, air density, air temperature need to be known amongst others.

3.2 Wind Turbine

A wind turbine is a machine for converting the kinetic energy in wind into mechanical energy. Wind turbines can be separated into two basic types based on the axis about which the turbine rotates. Turbines that rotate around a horizontal axis are more common. Vertical-axis turbines are less frequently used [8,9].
Wind turbines can also be classified by the location in which they are used as Onshore, Offshore, and aerial wind turbines [9]

3.3 Wind Power Modeling

The block diagram in figure 3 shows the conversion process of wind energy to electrical energy.

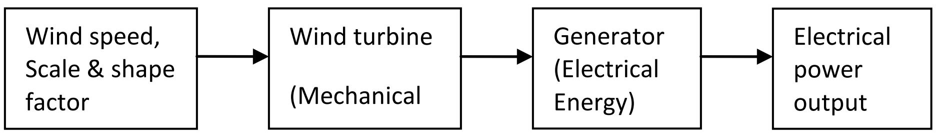

Figure 3: Energy conversions from Wind to Electrical

Various mathematical models have been developed to assist in the predictions of the output power production of wind turbine generators (WTG), A statistical function known as Wiebull distribution function has been found to be more appropriate for this purpose [10]. The function is used to determine the wind distribution in the selected site of the case study and the annual/monthly mean wind speed of the site. The Wiebull distribution function has been proposed as a more generally accepted model for this purpose [10,11].
The two-parameter Wiebull distribution function is expressed mathematically in equation 3 as [6,7],

$$F(v) = \frac{K}{C}\left(\frac{v}{C}\right)^{K-1} \exp\left[-\left(\frac{v}{C}\right)^{K}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

It has a cumulative distribution function as expressed in equation 4, and is given as:

$$M(v) = 1 - \exp\left[-\left(\frac{v}{C}\right)^{K}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where v is the wind speed, K is the shape parameter and C, the scale parameter of the distribution. The parameters K (dimensionless) and C (m/s) therefore characterized the Wiebull distribution.
To determine K and C, the approximations widely accepted are given in equations 5 and 6 respectively [11, 12].

$$K = \left(\frac{\sigma}{v'}\right)^{-1.09} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

$$C = \frac{v' \times K^{2.6674}}{\left(0.184 + 0.816k^{2.73859}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

where σ = standard deviation of the wind speed for the site (ms^{-1})
V´ = mean speed (ms^{-1})

3.4 Power Content of the Wind

The amount of power transferred to a wind turbine is directly proportional to the area swept out by the rotor, to the density of the air, and the cube of the wind speed.
The power P in the wind is given by [12]:
$P = ½\, C_p.\, \rho.A.\, V'^{3}$ …………………………………… (7)
Where C_p is the turbine power coefficient. A theoretical maximum value of 0.593 has been proposed for C_p [8,9]
ρ = air density (kg/m^3),

A is the rotor swept area $= \frac{\Pi D^2}{4}$ (m^2) , (8)

Where D is the rotor blade diameter (m) and V´ = mean wind speed (ms^{-1})

4. LOAD ESTIMATE OF A TYPICAL COMMUNITY INCLUDING INFORMATION COMMUNICATION TECHNOLOGY (ICT) SERVICES

In Nigeria, official definition of rural areas is one with a population of less than 20,000 [14]. In this study, a rural settlement with a population of ten families has been considered. The electrical energy demand for the domestic use is estimated as follows:

4.1 Lighting Circuit Assessment

Assume that each household will use 6, 40 W bulbs, therefore power demand for lighting is = 6 * 40 * 10 = 2.4kW

4.1.1 Power Circuit Assessment

Assume also that each household has 1 television set and 1 radio set at power ratings of 120W and 20W respectively. Therefore,

Power for the Television sets = 1 * 120 * 10 = 1.2kW
Power for radio set = 1* 20 * 10 =0.2kW

4.1.2 Power demand for water pumping

Assume that the entire village will use 1.5hp pumping machine
Power demand = 1.5 * 0.746 = 1.119kW
Total power demand = (2.4 + 1.2 + 0.2 + 1.119) kW
= 4.919kW

4.2 Information Communication Technology (ICT) and the Rural Development

In the recent times, ICT has been acknowledged as a means of fighting poverty and illiteracy in developing economics like Nigeria, if we are to meet Millennium development (MDG) targets. The ICT is one major key tool to facilitate e-service programmes, especially to those institutions such as banks, hospitals and schools in rural and unreached communities. When this is achieved, the socio-economic lives of rural citizens will be improved.

To provide ICT for Rural livelihoods, there is always the need to ascertain an enabling environment. The enabling environment has to do with the national policies, laws, physical infrastructure (roads, electricity e.t.c.) and others like access to education, access to banks, e.t.c., that need to be in place for people to use ICT infrastructure. It should be noted that without the availability of continual supply of electric energy, ICT provision to rural communities becomes almost impossible.

4.2.1 Rural Hospitals and Banking

Among the basic needs to actualize vision 2020 and MDGs are the provision of hospital and Banking facilities to rural environments.

As said earlier, one of the major needs to actualize functional and reliable rural banking and hospital is the availability of a continuous and reliable power supply system. Hence, the use of uninterrupted power source, solar energy would be advantageous to facilitate good rural banking, hospitals and ICT.

4.2.2 Energy Estimate For ICT facilities, Bank And Hospital In Rural Areas

In order to provide continuous electricity energy to the above mentioned facilities, the need to embrace Solar Power supply is more emphasized here. Since some of these rural communities suffer conventional electricity supply systems, the supply of these communities with alternative solar energy will be of great economic and technological values. Another advantage of using solar energy is that both D.C and A.C loads can be supplied. The output from the solar panel arrays is D.C while from the inverting battery banks, A.C voltage output is obtained.

Tables 1,2 and 3 show typical estimated energy to power ICT, Banks and hospitals in rural communities[15] .

Table 1: Energy needed for a typical ICT Center in Rural/Remote environments

Description of Item	Qty	Load (Watts per unit)	Load (Watts) Total	Weekly Hour of Actual Utilization (hours)	Weekly Watts Hours
Router	1	25	25	48	1,200
Port fast Switch	1	15	15	48	720
Wireless Access Point	2	12	24	48	1,152
Server (plus accessories)	1	150	150	48	7,200
RF (Radio Communication)	1	40	150	48	1,920
Laptops (with security cables)	10	40	400	48	18,200
VOIP Phones	2	20	40	16	640
HP desk jet 5943	2	44	88	8	704
Laser Printer	1	100	100	7	700
Lighting	4	15	60	48	2,880
Ceiling fans	4	60	240	48	11,520
		TOTAL	`		46,836Wh

Table 2: Energy needed for a typical Banking in Rural/Remote environment

Description of Item	Qty	Load (Watts per unit)	Load (Watts) Total	Weekly Hour of Actual Utilization (hours	Weekly Watts Hours
ATM Machine	2	1,000	2,000	12	24,000
Premises/Street Lightings	4	40W	40W	12	72
Internet Service	AS PROVIDED IN TABLE 1				

Table 3: Solar Energy needed for a typical Hospital Service in Rural/Remote environment

Description of Item	Qty	Load (Watts per unit)	Load (Watts) Total	Weekly Hour of Actual Utilization (hours	Weekly Watts Hours
Cold Chain Storage (fridge)	1	60W	60W	48	2,400
Lighting for the operating Theatre	3	15W	45W	48	2160
Lighting for Ward	6	15W	90W	48	4320
Premises Lighting/Street Light	2	40W	80W	12	960
Television Colour	1	150W	150W	6	900
Fans	6	15W	40W	48	1920
		TOTAL Weekly Watt hour			**12,660Wh**

5. RESULTS AND DISCUSSION

5.1 Choice of components for Solar Energy Power Supply For 1000 Watt Load:

The choice of 1000W is a sample case and this can be extended to any required capacity.

To achieve a solar power capacity of 1000watts the capacities of Solar panel, Charging Controller, bank of battery and Inverter are determined. The values cannot be picked abstractly and hence, their ratings and specification have to be determined through calculations in other for the system to perform to required specifications. For this design 12 hours was assumed for the duration of the operation and the calculations is done as indicated below:

5.1.1 Solar Panel:

Total load = 1000W

Period of operation or duration = 12 Hours

Then, Total Watt-Hour = 1000×12= 12000w-hr

The period of the solar panel exposed to the sun = 8 Hours (Averagely between 9am and 3pm)

Therefore solar panel wattage = $\frac{1200\,Wh}{8Wh} = 1{,}500W.$

Hence solar panel of 1,500W will be needed for this design.

If solar panel of 150W is to be use the number of panels to arrange in parallel to achieve 1,5000 Watt will be:

No of panel $=\frac{1500\,W}{150\,W} = 10$

This shows 10 of 150 Watt solar panel will be required for this design

5.1.2 Charging Controllers:

For this design of 1000W solar power supply P=IV

Where

I is the expected charging current and

V is the voltage of the battery and = 12 V

P is the power supply rating= 1000W

Hence I $=\frac{P}{v}=\frac{1000}{12} = 83Amps.$

Since the value 83.3 A Charging controllers is not readily available in the market then 1000A charging controller will be used.

5.1.3 Battery capacity:

Given that the total load P= 1000W and

Operational period = 12 Hours

Watt/hour capacity = 12,000 W/h

To make the chosen battery to last long it is assumed that only a quarter (¼) of the battery capacity will be made used of so that it will not be over discharged therefore hence the required batter capacity will be

12, 000 × 4 = 48,000 W/h

Now the choice of battery hour depends on A-H rating of the storage battery. For example, for 200AH, 12V battery the number of batteries that will be needed is $\frac{48000}{200} = 240$ batteries. Also for a 1500AH, 12V batteries the number of batteries that will be needed is $\frac{48000}{1500}$ = 32 batteries. Hence, for this design and to avoid too much weight and occupying unnecessary space, 15000AH 12V battery should be used, Therefore the total number of storage battery required for 1000W solar power supply system = 32

5.1.4 Inverter

Since the total load is 1000W it is advisable to size the required inverter to be 1500W as designed for solar panel ratings. Hence 1500W pure sign wave inverter is recommended in other to prolong the lifespan of the inverter.

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5.2 Wind Power Simulation:

The study area of Abeokuta have been chosen as sample case. Abeokuta is south-western Nigeria on Latitude 7^0 09'N and Longitude 3^0 21'E. The eight years (2002-2009) wind speed data were collected from the monitoring unit of the Department of Agricultural Meteorology and Water Resources (AGROMET), University of Agriculture, Abeokuta. From the average monthly wind speed data collected, the annual average was determined

With an assumed Aero generator Hub Height of 50m[7,16], and by applying expression 3 to 7, the annual mean speed and the average wind powers for various years were shown in Table 4. From this result, an average power output of 13.6.kW at a blade diameter of $300m^2$ can be obtained from the study site using equation 7.

Table 4 Wind Power Simulation Using available wind speeds in Abeokuta for 2002-2009

Year	Mean wind speed (m/s)	Standard deviation σ (m/s)	Shape parameter K	Scale parameter C(m/s)	Air density ρ (kg/m³)	Probability distribution function F(V′)	Cumulative distribution function M(V′)	Power coefficient C_p	Power density P_s (W/m²)
2002	1.525	1.799	0.835	1.3822	14.243	0.2007	0.6623	0.593	14..977
2003	0.4828	0.4359	1.117	0.1966	13.698	0.4125	0.9347	0.593	6.457
2004	1.444	0.92	0.452	0.1912	13..506	0.3448	0.7686	0.593	13.351
2005	1.636	0.1129	1.84	1.6293	12..901	4.1254	0.6599	0.593	16.749
2006	1.078	0.043	1.913	0.0879	12..901	8.8064	0.5487	0.593	4.018
2007	1.068	0.073	0.925	0.0655	12..552	5.0012	0.6449	0.593	4.117
2008	1.053	0.03	1.859	0.0596	12..707	12.6207	0.5525	0.593	5.020
2009	1.148	0.141	1.054	0.1511	12..683	2.6193	0.6241	0.593	4.012

6. CONCLUSION

There is the need for the provision of an alternative sustainable electric power supply system to provide electricity to rural and the unreached communities. The importance of Information Communication Technology for e-service to rural communities are inevitable in order to achieve the MDGs objective. Also there is the need for rural banking and hospitals if the social and economic lives of rural citizens in Nigeria are to be improved.

The provision of hybrid solar -wind energy system to power ICT infrastructures, banking and hospitals in rural and the unreached communities that are not connected to National Grid Power supply system is very important so as to maintain a continuous electricity supply.

When considering the cost and overall efficiency, it is advisable for all the stakeholders who have concern for the rural community development to embrace solar and wind power.

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