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Research Article

Developing Sustainable Power Supply for Rural Communities in Akassa of Bayelsa State Using Photovoltaic System and Battery

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Abstract: The study analyses the use of photovoltaic standalone AC system employing a battery and an inverter, which will supply continuous electricity in rural communities of Bayelsa State. It showcases the enormous potential of solar radiation in Bayelsa State and the benefit of taping it to solve the growing energy demand of rural communities. The analysis looks at the need to power a building load demand in Akassa community of Brass Local Government Area (BLGA) of Bayelsa State in order to solve the increasing energy demand of the community. The technology is based on a Photovoltaic (PV) system, a battery and an inverter to solve the building load demand for 24 h. This enormous potential of solar radiation estimated, can be explored with the use of photovoltaic modules to address the problem of inadequate rural communities' electrification of Bayelsa state.

Keywords: Hybrid system, irradiation, photovoltaic cell, photovoltaic module, renewable energy

INTRODUCTION

Bayelsa state is located at the center of the Niger Delta region in the southern part of Nigeria with a latitude of 4.75 (4/45' 0 N) and longitude of 6.08 (6/4' 60 E). It is one of Nigerian fastest growing state with an almost daily increasingly energy demand spreading from the state capital to every part of the state. Bayelsa has a riverine setting with almost 70% of her communities situated in the creeks. Most of her communities are almost or in some cases totally surrounded by water, hence, making these communities inaccessesible by road. It was the only state in Nigeria that was not connected to the national grid before and after its creation until in 2007 when the state was connected to the national grid. The only means of power supply in the state was through a state own gas turbine which was used to power the state capital and its environs, leaving out the rural communities in the creeks. However, the connection of Bayelsa State to the national grid did not solve the growing energy demand of the state because the rural communities were not connected due to their location and terrain which makes it practically difficult to transmit electricity in such communities. Examples of such communities are Akassa, Lobia, Ezetu, Nembe etc. The source of energy in these communities is through diesel generating sets and sometimes these generator set operate almost 24 h which result in massive discharge of CO_2 and CO which are not environmentally friendly and the emission rate does not agree with the Kyoto agreement of December 11, 1997. Since the Kyoto agreement, European countries have become very serious about manufacturing and using photovoltaic devices, particularly in building integrated systems (Richard, 2001; Barr and Thomas, 2005). But the insurgence of solar technology in 1839 and subsequent research, development and application in the 1970s paved the way for rural communities to be powered via photovoltaic solar technology from the massive sun's energy. Renewable energy is growing rapidly and it is becoming significant in our world today and in the future to come. Photo Voltaic (PV) is one of the most important area in the field of renewable energy and has attracted lots of research inits application both as a standalone and grid connected (Zuhairuse *et al*., 2009; Sambo, 2006; Togola, 2005). In the past years, PV power generation systems have attracted attention due to the energy crisis and environment pollution. Photovoltaic power generation systems can mitigate effectively environmental issues such as the green house effect and pollution (Zhang *et al*., 2009; Olesen, 2004). The long lasting solution to solve the growing energy demand in rural communities in the state is to adopt photovoltaic technology with backup to address this problem which is in line with the federal

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government commitment to solving the long lasting energy crisis in Nigeria through the adaptation of Renewable Energy Master Plan (REMP) with a target of increasing power generation capacity from 5000 to 16000 MW by the year 2015 through the exploration of renewable energy to realize this goal (Dike *et al*., 2011; Sambo, 2008). This study present a simple estimation of solar radiation, estimation of photovoltaic array area and analysis of powering a building load demand in Akassa community in Bayelsa state of Nigeria.

Calculation and estimating solar irradiation: The calculation and estimation of solar irradiation varies with climatic data and methods. However, in this research, the Duffie and Beckman method (Duffie and Beckham, 1980) was used to determine the solar radiation on an inclined surface, having in mind the climatic conditions of Akassa. Declination, δ:

$$\delta = 23.45 \sin (360(284+n/365) \quad (1)$$

Calculation of sunset hour angle (W_s) and daylight hours: Sunset hour angle (W_s) is the solar hour angle corresponding to the time when the sun set.

Cos W_s =-tanNtan*, the day length is 2 W_s, therefore the number of daylight hours (N):

$$N = 2/15*(\cos^{-1}(-\tan\varphi \tan\delta) \quad (2)$$

Then sunrise hour = 12.00 (noon)-N/2 and Sunset hour = 12.00 (noon) +N/2

Solar hour angle is now given by ω = 15 (12-t) degree, where t is solar time (24 h format) from sunrise to sunset.

Incident angle (θ) and solar zenith angle (θ_z) starting from sunrise hour to sunset hour:

$$\cos\theta=\sin\delta\sin\varphi\cos\beta-\sin\delta\cos\varphi\sin\beta\cos\gamma+\cos\delta\cos\varphi\cos\beta\cos\omega+\cos\delta\sin\Phi\sin\beta\cos\omega+\cos\delta\sin\beta\sin\gamma\sin\omega \quad (3)$$

$$\cos \theta_z = \sin\delta\sin\varphi+\cos\delta\cos\varphi\cos\omega \quad (4)$$

Calculation of the beam Radiation (R_b) on the tilted plane and horizontal plane is given by:

$$R_b = \cos\theta/ \cos \theta_z \quad (5)$$

Calculation of the global solar radiation (G_o):

$$G_o = G_{sc}[1+0.033\cos(360/365n)] \cos \theta_z \quad (6)$$

$$G_{sc} = 1367 W/m^2$$

The total daily extraterrestrial radiation on a horizontal plane H_o is given by integrating the Eq. (5) from sunrise to sunset. Hence H_O = G_O* time, time in every 1 h Olesen (2004).

Calculation of solar radiation at earth surface with use of clear index K_t which is determining by location:

$$\text{Clear index } K_t = H/H_O \quad (7)$$

Calculation of diffuse and beam radiation: When the solar hour angle is less than 81.4° and K_t lies in between 0.3 and 0.8

We use this equation to calculate the diffuse radiation given by

$H_d/H = 1.391-3.56K_t+4.189K_T^2-2.137K_t^3$ and when solar hour angle is greater than 81.4 and K_t lies in between 0.3 and 0.8 we use this equation:

$$H_d/H = 1.311-3.022K_t+3.427K_T^2-1.821K_t^3$$

Therefore the average beam radiation

$$H_b = H-H_d \quad (8)$$

The solar radiation on an inclined surface is given by:

$$H_T = H_bR_b+H_d(1+\cos\beta/2)+H\rho(1-\cos\beta/2) \quad (9)$$

With ρ as ground reflectivity which varies from 0.3 to 0.8

METHODOLOGY

The design system is made up of the photovoltaic array, inverter, battery and charger as shown in Fig. 1.

To design the photovoltaic system the following factors were considered:

- The load of the building
- Daily solar radiation of the location
- Battery capacity (Lead acid or Nickel Cadmium)
- Area of the photovoltaic array
- Photovoltaic cell type and efficiency

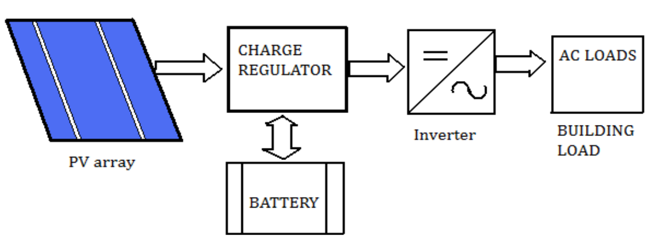

Fig. 1: Methodology and block diagram of design system

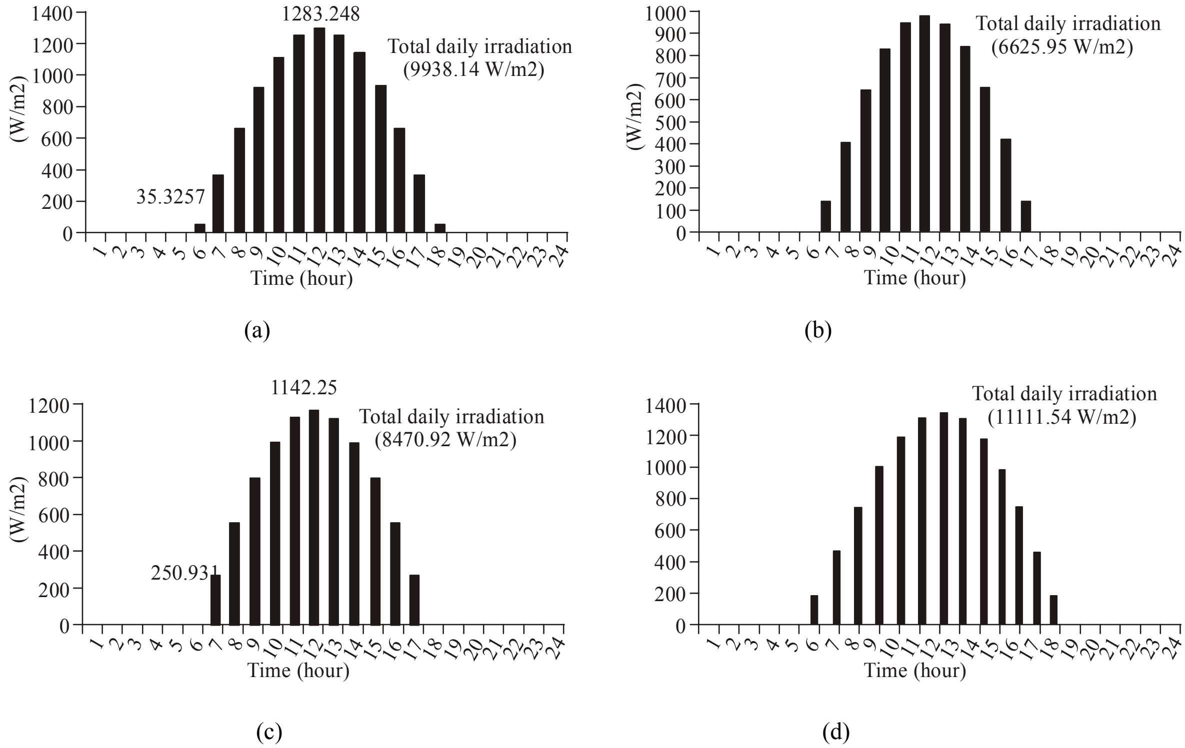

Fig. 2: Solar irradiation for month of March, June, September and December

The climatic data's used are δ (declination), β (Tilt angle) = 45, γ (surface azimuth) = 0, φ (latitude) = 4.75, K_t (clear index) = 0.7, ρ (ground reflectivity) = 0.6, n, (day number). Solar hour angle (ω) ranging from sunrise to sunset is also calculated. The solar irradiations (H_T) from January to December were estimated.

RESULTS

Results of solar radiation on an incline surface in akassa, bayelsa state from January to December: The result of solar irradiation (H_T) on an incline surface was estimated for a particular day in each month of 2011 and the estimated irradiation was assumed to be the average solar irradiation for that particular month in Akassa. The irradiation level for March, June, September and December are shown in Fig. 2.
The average monthly solar irradiation is shown in Fig. 3

Load evaluation: The load of the building is estimated per hour across 24 h of a day and the estimated load of the building is measured in Kilowatts hour (KWh). The total rural daily load of a building in Akassa is estimated at 2865 KWh and it is to be powered by the assumed solar irradiation estimated and a battery to address the energy demand of the building. The daily electrical load estimated is shown in Fig. 4.

From the parameters of solar radiation of 11078.94 W/m^2 in January, building load of 2865 kWh and cell efficiency of 12% (Monocrystalline), the area of

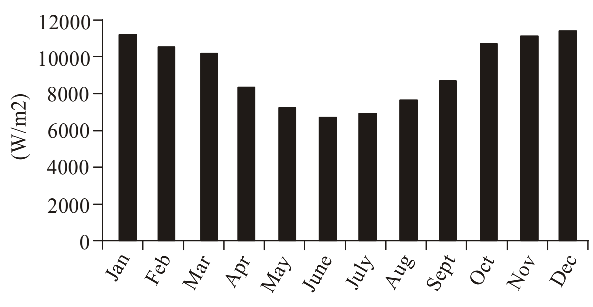

Fig. 3: Average monthly solar irradiation (W/m2) in Akassa kingdom

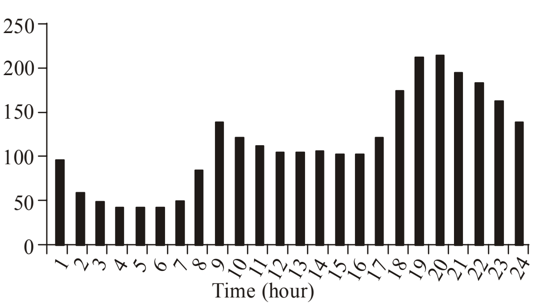

Fig. 4: Daily electrical energy (load) in Akassa community

photovoltaic array that would match the total load of the building was determined, Using Eq. (10):

$$\text{Area of photovoltaic array (A)} = \frac{\text{building load}}{\text{efficiency of cell}(\eta) * \text{solar radiation (Ht)}} \quad (10)$$

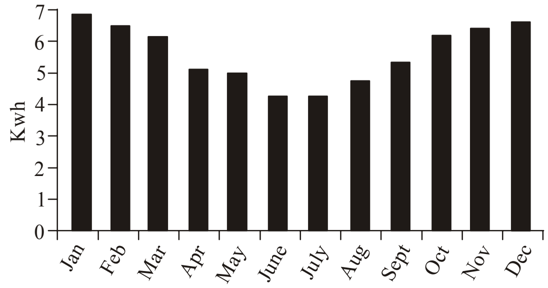

Fig. 5: Average monthly power generated by PV in KWh before inverter application

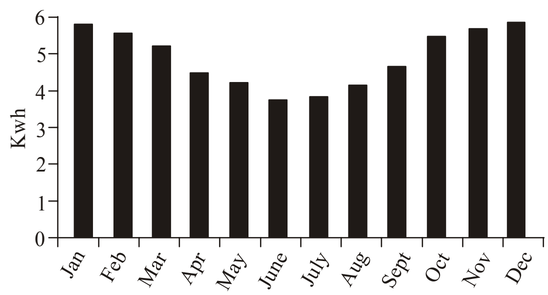

Fig. 6: Average monthly power generated by PV after inverter Application

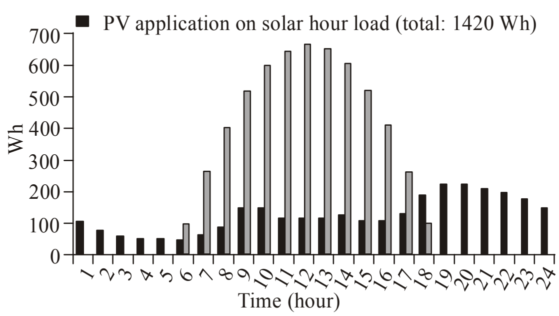

Fig. 7: PV application on solar hour load (Total: 1420 Wh) in dry season (12th January)

This area was estimated to be 2 m^2. To harness the varying solar radiation across the month of the year, the area of the array was altered to 6 m^2 to meet the load demand. With the area of 6 m^2, the DC power of the array was calculated in KWh from January to December as shown in Fig. 5.

Due to the fact that the building has AC load and the Photovoltaic (PV) array produces DC load, the PV system needs an inverter of about 85% efficiency to converter the DC power to AC power to enable the PV to power the load. The power produced by PV after inverter is shown in Fig. 6.

Batteries are necessary in this process because of the variable nature of solar radiation (daily and seasonally). The battery storage system balances the mismatch between the building electrical load and the photovoltaic production.

Photovoltaic and battery application:

Dry season: The solar hour of dry season is about 13 h that is 6 A.M to 6 P.M daily and the intensity of the solar radiation can be effectively harness without the assistance of backup with the solar hour total load of 1420 Wh as shown in Fig. 7.

The total energy from PV in January is 5700.07 Wh after the inverter application but the total solar hour load is 1420 Wh, which means that there was an excess of 4280.07 Wh. The building load of 1445 Wh was not directly powered by the Photovoltaic array as shown in Fig. 7.

The energy delivered to battery E_b (excess power generated) was

$E_b = E_d - E_L$

Where E_d is solar hour Energy and E_L is solar hour load

E_b = 5700.07Wh-1420Wh = 4280.07Wh.

Using battery efficiency of 80%, the Useable battery capacity

$E_{bu} = E\eta_b$ that is 4280 × 0.8 = 3424.05Wh

3424.056 Wh was used to power the non solar hour load with an excess energy of 1979.05 Wh, as shown in Fig. 8 (Considering solar hour load of 1420 Wh).

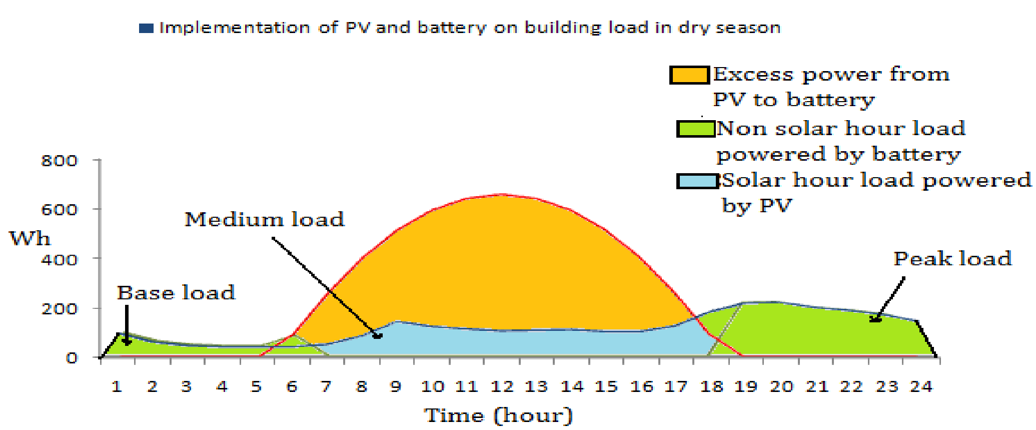

Fig. 8: Implementation of PV and battery to power building load in dry season (12th January 2011)

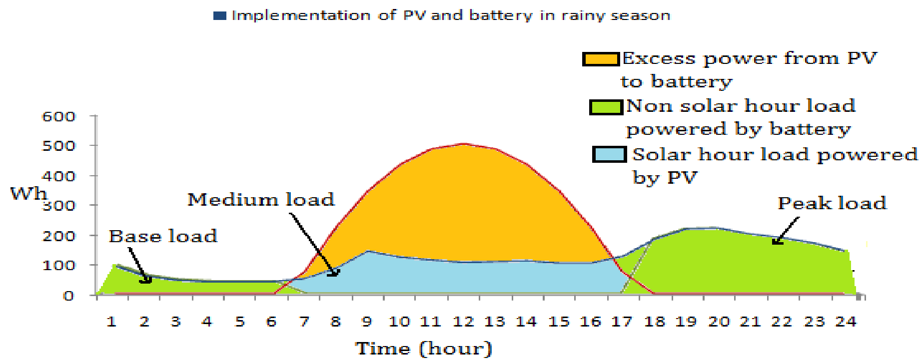

Fig. 9: Implementation of PV and battery to power building load in rainy season (15th June 2011)

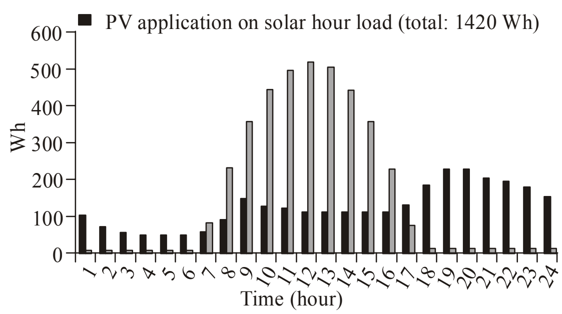

Fig. 10: PV application on solar hour (Total: 1420 Wh) in rainy season (15th June 2011)

Rainy season: The solar hour of rainy season was about eleven hours (11 h) that is from 7 am to 4 pm a day. Taking the month of June, the energy from the photovoltaic after the inverter application was 3663.485 Wh.

The solar hour energy is given by

$E_b = E_d - E_L$

That is, (3663.485-1420) Wh = 2243.485 Wh

The useable battery capacity is 2243.485×0.8 Wh. This load is used to power the non solar load (1420 Wh) with an excess of 349.78 Wh stored in the battery as shown in Fig. 9.

DISCUSSION

In Nigeria, there are two seasons, the rainy and dry seasons. From the geographical records each season duration is 6 months but due to the present climatic variations the records have changed with more dry season periods than it has ever been. From the experiment, the power generated by the PV array during the dry seasons (October-March), ranges from 4287 to 4765 Wh with the lowest in March and highest in December. During the rainy seasons (April-September), the generated power ranges from 3052.904 to 3817.426 Wh with lowest in June and highest in September.

From the solar irradiation calculated, the total irradiation (assumed average irradiation of a month) varies from January to December in 2011 with the higher irradiation in the dry seasons as shown in Fig. 3.

From the load calculation the lowest in the rainy season (June) and the lowest value in the dry seasons were used. This was necessary to guarantee adequate supply even at the worst seasonal effect. Due to this reasons, the cell area of 2 m^2 calculated was increased to 6 m^2 to give adequate irradiation to effectively power the given load at all seasons. Figure 7 and 10 demonstrate the sellable energy in January in the dry season as 1979.05 Wh and that of rainy season as 349.78 Wh in June.

CONCLUSION

Akassa community is situated along the Nun River of the Atlantic Coast. The population is about 200,000 spread sparingly in small villages. It is about 180 km away from the capital city of state and about 230 km from the National grid the same challenge of most rural electrification programmes (the dispersed populations, difficult terrain and the big river crossing resulting to High capital and operating cost). Such areas are characterized by poor load profile that is, using energy sparingly in the evening which leads to low cost recovery. Due to its location and terrain there is insufficient institutional capacity of main power companies to cope up with such challenges. In order not to ignore those at the last mile, the photovoltaic cell with battery becomes the best solution.

Nigeria is situated at the equator and has great potential in solar energy radiation in different part of the country. This immerse potential can be tapped to tackle the problem of rural community electrification in Bayelsa state.

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