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EVALUATION OF SOLAR ENERGY POTENTIALS FOR OPTIMIZED ELECTRICITY GENERATION AT ANYIGBA, NORTH CENTRAL NIGERIA

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Abstract:
This paper is aimed at evaluating solar energy potentials at Anyigba, North Central Nigeria, latitude $7^0$29.6'N (7.49^0N), longitude $7^0$10.6' (7.17^0E) and at an altitude of 420m above sea level for optimized electricity generation. The solar radiation data was collected at 4m height using the Campbell scientific automatic weather station of Tropospheric Data Acquisition Network (TRODAN), operated and managed by the Centre for Atmospheric Research (CAR), National Space Research and Development Agency (NASRDA), Anyigba. The instrument measures at an interval of five minutes update cycle for a period of five years (2011-2015). The solar radiation in the area fell between 8.4 kWh/m^2/day and 11.4 kWh/m^2/day. Analysis of the irradiance data was conducted using MATLAB software. The preliminary results showed that Anyigba is viable for solar energy generation. Using the results of the solar analysis, a stand-alone photovoltaic PV power system was designed to power the Ozone monitor Laboratory at Anyigba to be used for air quality research and climatic change studies using hybrid optimization model for electric renewable (HOMER) software. The software simulates off-grid system, as well as checking the technical and economical criteria of the system. The performance of each component of the stand-alone system was analyzed and sensitivity analysis performed to optimize the system at different initial conditions. Based on the simulated result, it was found that 4 kW size PV panel, 4 No. 60A charge controller, 16 No. 200AH battery and 1No. 1 kW inverter is the optimal solution for this system at the cost of ₦5,573,760:00 ($17 418.00). The optimized off-grid system would lead to the reduction pollution emission as well as ensuring a stable power supply.

Key words: *Solar energy, Electricity generation, PV power system, HOMER software, Stand-alone system.*

I. INTRODUCTION

Energy is the mainstay of any economy. It is one of the most important tools for national development. Energy has a major impact on every aspect of our socio-economic [1, 2]. Nigerian energy is supplied from hydro and thermal power stations. Despite the abundance of energy resources in Nigeria, the country is still in short supply of electrical power.

The concern over the production of adequate electricity to drive economic development is a global issue. Moreover, the need to generate such magnitude of needed electricity from environmentally friendly and non-toxic sources has further heightened the concern. This has led to various efforts at measuring and assessing the potentials and viability of generating electricity from renewable and reliable energy resources. One of the major challenges of developing countries is the global demand of energy, in which is a major problem in Nigeria for both critical and large areas and small scale purposes. This is as a result of dependency on hydropower and gas which is susceptible to seasonal variation of water level of the dams and insurgency problem in Niger-Delter region. The use of fossil fuel contributes to global warming, which is one of the most serious problems facing the global community. The use of clean renewable energy sources such as solar systems would help to curb the effect of global warming [3].

Solar energy has unique characteristics of being clean, inexhaustible, unlimited and environmental friendly. Such characteristics have attracted the energy sector to use renewable energy sources. Solar source is dependent on unpredictable factors such as weather and climatic condition. This brings us to the evaluation of it potentials at Anyigba located in Kogi State-Nigeria so as to provide an alternative source of electricity generation. These energy sources having proven to be advantageous for decreasing the depletion rate of fissile, as well as supplying energy to remote rural areas, without harming the environment.

II. LITERATURE REVIEW

This paper aimed at evaluating and optimizing the energy potentials of solar radiation for electricity generation at Anyigba, Kogi State - Nigeria. Various renewable energy assessment studies have been conducted around the world to determine the potentialities of local site for it potentials for power/electricity generation [3]. The increasing global demand and the adverse effect of non-renewable fossil fuels on environment hat motivated considerable research. Attention in wide range of engineering application of renewable sources such as solar, geothermal and wind [4, 5].

Solar thermal is the direct application of solar energy to produce heat. This is dated back to ages, exemplified by sun drying and so on. In Nigeria, solar thermal have been developed for various application; such as solar cookers, solar pulverizes, chick brooding devices [6].

A. Stand-Alone Photovoltaic System

Stand-alone photovoltaic system is a collection of interconnected electrical components, which can generate electricity from sun-light and satisfy our daily energy requirements without worrying about any interval when the sun-light may not be available [7,8]. The photovoltaic system consists of the following components; Solar PV array, Cables, Charge controller, Inverter, Battery and Protection devices.

Figure 1 shows a schematic diagram of interconnection of components of a typical stand-alone photovoltaic power system. Depending on load requirement and radiation intensity at the site, the components of the system will have to be specified [9].

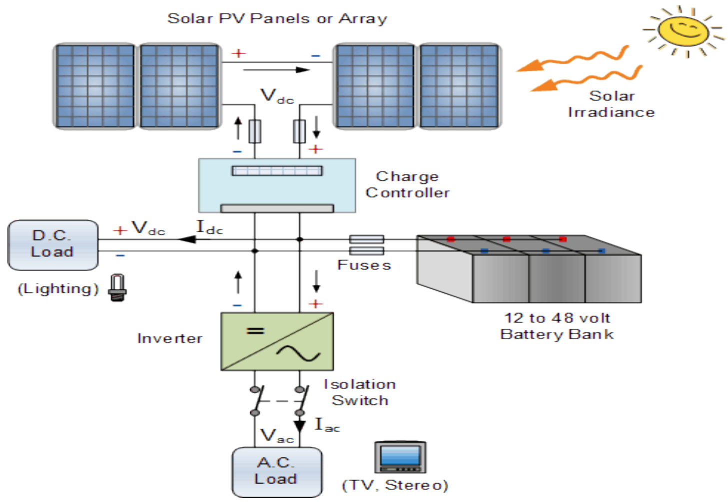

Figure 1: Stand-Alone Photovoltaic System Components (Source: Alternative-Energy-Tutorials.com)

III. MATERIALS AND METHODS

A. Materials

Some of the materials and equipment's used in carrying out this research are highlighted below.

3.1 Sources of data

The metrological data were collected from Centre for Atmospheric Research (CAR), sited at the Kogi State University, Anyigba Campus, Nigeria. The Centre is under the supervision of the National Space Research and Development Agency (NASRDA).The data was obtained from Tropospheric Data Acquisition Network (TRODAN).This is a network of automatic weather station over entire Nigeria initiated to provide atmospheric data to Engineering and science communities in Nigeria and the world at large for research purpose. The collection was done using Campbell automatic weather station shown in Figure 2. It is located at Kogi State University, Anyigba on the coordinates (7.49333^{o}N, 7.173332^{o}E) in North-Central Nigeria. Five years data from 2011 to 2015 of solar radiation and wind speed data were collected and their potential for electricity generation was evaluated over Anyigba.

3.2 Instrumentation of Campbell scientific automatic weather station

The standard station is a fully configured, solar powered, automated weather station. It consists of a weather proof enclosure which contains highly reliable Campbell scientific data logger, barometric pressure sensor, 12 V battery and charge controller. The weather station is equipped with a standard set of sensors which takes records of: air temperature, relative humidity, wind speed and direction, soil temperature and moisture etc. The data logger is programmed using Campbell Routines data logger basic. Additional sensors especially dual-sensor can be added as options. It was designed for long term unmanned or unattended operation and is ideal for meteorological, weather monitoring and climate study applications. The CR1000 data logger type is used for measurement and data storage in this station at five-minute update cycle as shown in Figure 2.

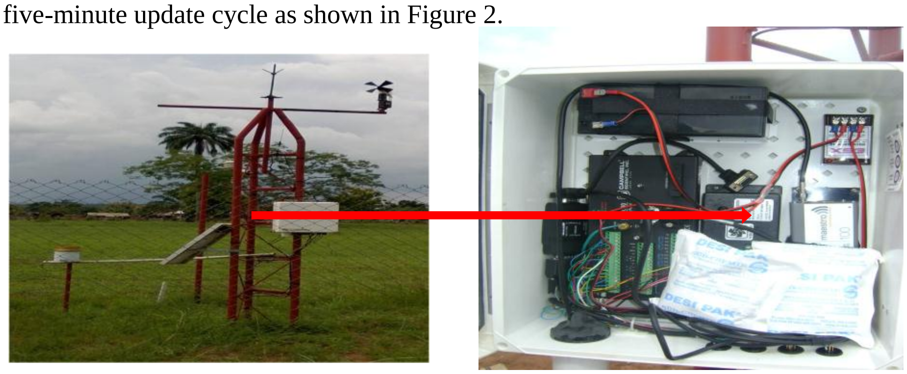

Figure 2: Installed Campbell Scientific Automatic Weather Station and Enclose Box Interior (2011)

3.3 Methods of Measurement

In-situ measurement of meteorological parameter of solar radiation was employed. The data was collected from (January 2011- December 2015). The records cover 24hours each day from 0000 hours to 2300 hours local time at five minutes update cycle. The value of solar radiation is in W/m^2.

The data is at twenty-four hours interval local time, it was then processed into monthly average for every month of the years using MATLAB software R2010a as shown on Figure 3. This was achieved by first, averaging the five minutes interval data into hourly values then into daily values and lastly into monthly values for each within the study period. The analysed solar radiation was used as source irradiance for the photovoltaic system.

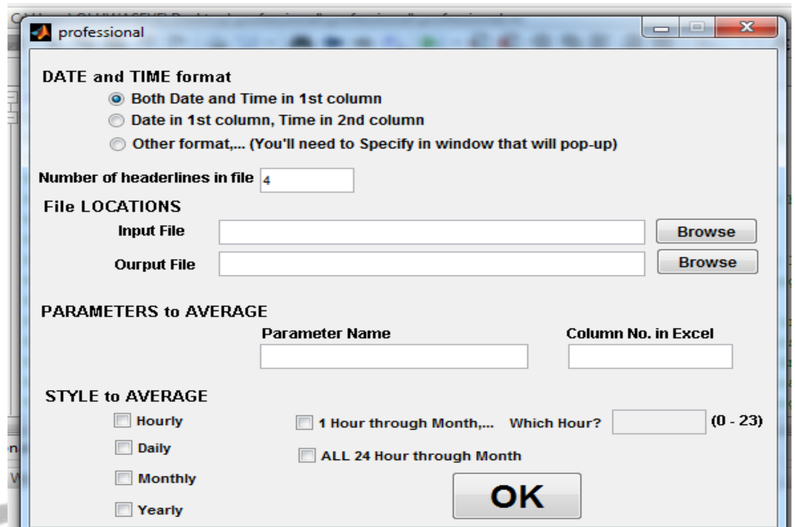

Figure 3: MATLAB Graphics user Interface Software for Averaging Solar Radiation

B. Design Methodology for PV System Using HOMER Software

HOMER software was basically used for the design because this software gives better result than other software available for renewable energy simulation, optimization and sensitivity. In simulation process, HOMER simulates the hybrid system for each hour for the year and determines its technical feasibility and its life cycle cost. In optimization process, HOMER simulates many configurations to find the best combination that fulfil the criteria of technical feasibility along with minimum life cycle cost. In sensitivity analysis HOMER performs many optimizations with some input assumptions to determine the effect of uncertainty and variation in model input [10].

This is the process of determining the PV system capacity which is basically in terms of power, voltage and current of each component of a stand-alone PV power system with the aim of meeting the load requirements of the building (ozone monitor laboratory.) for which the design was made.

IV. RESULTS AND DISCUSSIONS

The results and findings of this work are obtained by analysis of the data collected from the Centre for Atmospheric Research data catalogue. The results for solar energy analysis and the design of the photovoltaic power system using HOMER software are presented as follows;

4.1 Solar radiation results

The success of any solar energy installation depends largely on the availability of solar radiation at that location, making detailed knowledge of solar resource data critical for planning, as such the solar radiation data of Anyigba was obtained and analysed. Table 1 presents the five-year (2011-2015) solar radiation data for Anyigba.

Table 1: Solar Irradiance (kWh/m^2/day) of Anyigba for Five (5) years (2011-2015)

	Irradiance (kWh/m^2/day)				
Month	**2011**	**2012**	**2013**	**2014**	**2015**
January	8.4	8.2	8.6	8.6	7.9
February	8.4	9.2	9.5	9.6	8.6
March	11.1	11.4	11.3	11.4	11.3
April	10.1	11.6	11.0	10.5	10.4
May	10.1	10.5	10.3	9.5	9.5
June	9.1	10.0	10.2	10.2	10.1
July	8.7	7.9	7.9	7.8	7.8
August	6.8	7.2	9.2	9.1	8.7
September	8.4	8.1	8.6	8.6	8.6
October	9.4	9.1	9.7	9.1	8.9
November	9.9	8.7	8.8	8.9	8.7
December	9.3	8.8	8.9	8.8	8.8
Average	9.1	9.2	9.5	9.3	9.2

From Table 1, similar values were recorded against January and February of the year 2011. The peak value for year 2011was recorded in March, subsequently, the values continue to drop slightly till August. It was observed that there was a gradual rise after august till November before it finally dropped in December.

For 2012, the solar variation for this year follow the same pattern of the previous year considered but it rises to April before gradual drop of the value. The value drastically dropped to about (7.5 kwh/m^2/day). This is similar to the pattern of 2011 where the values dropped in the same month of August.

However, 2013 shows the solar variation as. Just as was observed for the two previous years, the solar variation peak was also in the March but dropped in July unlike for the year 2011 and 2012. The solar variation value dropped earlier than that of 2011 and 2012 during this period. It was shown in 2014 that the peak of the solar variation also occurred in March and dropped in July. The peak value of the solar variation lies between (11.4 kwh/m^2/day and 10.5 kwh/m^2/day).

This shows that it takes a while for the atmosphere to react to heating from the sun. The temperature for 2012 is also slightly higher than 2011. This can be attributed to the solar radiation. The amount of solar radiation for 2011 also lags behind that of 2012 in summer solstice. However, the 2011 solar radiation peaked earlier than that 2012 during this period. This drop in solar radiation can be attributed to the tilting of the earth about its axis relative to the sun during this period. The period of solar irradiation in this season is slightly longer than that of 2013 and 2014as compare to 2011 and 2012 in 2015 it maintained the same pattern.

4.2 HOMER results

After the analysis of solar resources in Anyigba, the estimation of the total energy requirement and power rating of the Laboratory arrived at were inputted into the HOMER software. The screen capture of the Ozone monitor laboratory is presented in Figure 4 below.

Figure 4: Screen Capture of the Ozone Monitor Laboratory Software

The load profile was determined by itemizing and summing up the power rating and hour of use of all the appliances in the Laboratory to obtain the total average energy requirement in watt-hours. This was determined based on the hours of usage per day. The load profile of the proposed laboratory is presented in Figure 5 with the peak power as 1kW, this is due to the fact that at the hour of 10 in the morning the printer is expected to be on for haft an hour thereby making it consume more power thereafter when the printer is off the load drop to 0.3 kW up to the hour of 16000hr, the load shoot up at 1700hr when the mobile phone in the laboratory is plugged for a period of five hours. At 2300hr the load drops back to the normal working load of the monitors in the laboratory.

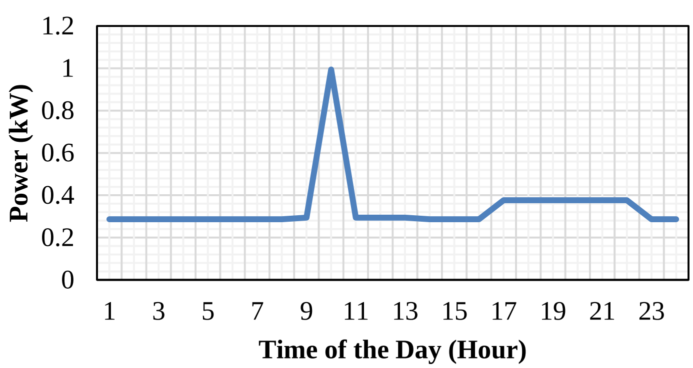

Figure 5: Load Profile Diagram of the Proposed Ozone Monitor Laboratory

HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed-generation (DG) applications. As mentioned before the system consists of; PV modules, batteries, charge controller, inverter, and the necessary wiring and safety devices. The system feasibility analysis was performed using the HOMER software. During the optimization 300 solution were simulated, 176 were feasible while 124 were not feasible and the optimal solution is presented. The most feasible result obtained from the homer software simulation is presented in Table 2.

Table 2: Summary of the PV System and Cost Estimation (Net Present Costs)

Component	Capital Cost (₦)	Replacement Cost(₦)	O&M Cost (₦)	Fuel Cost (₦)	Salvage Cost (₦)	Total Cost (₦)
Generic flat plate PV	2 400 000	0	144 000	0	0	2 544 000
Generic 1kWh Lead Acid	1 536 000	1 048 280	334 400	0	-149 760	2 769 920
Converter	96 000	53 760	0	0	-9 920	139 840
Total	**4 032 000**	**1 103 040**	**478 400**	**0**	**-159 680**	**5 453 760**

It can be clearly seen from Table 2 that the various components of the system were selected as generic and the total system cost is ₦ 5,453 760.00. The cost of the PV was ₦ 2,400 000.00 with the operation and maintenance cost of ₦ 144, 000.00, this gives the total cost as ₦ 2,544 000.00. For the Battery it has the total cost of ₦ 2,769 920.00. The converter has the total cost ₦ 139,840.00. In all both the operating and maintenance cost, replacement cost and salvage cost were taking into consideration by the software.

PV was 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 Anyigba to obtain the peak power. The peak power is then divided by the selected system dc voltage to obtain the total dc current. Finally, the number of series and parallel modules can then be determined to give the array size.

In order to computes the battery bank size, energy storage requirement should be determined. For inverter total input energy needed is 14.2kW or 14200W from battery. The inverter input Voltage is 24V. So Battery voltage should be near about 24V. Days of autonomy are also vital information to determine the size of the battery bank. The summary of the battery sizing is given in Table 5. The battery chosen is the 6FM200D series. It has a nominal voltage of 12 Volts and nominal capacity of 200Ah (2.4 kWh).

The inverter and the rectifier efficiencies were assumed to be 90% and 85% respectively for all the sizes considered. The sizes considered varied from 0.1 kW to 1.5kW. Table 6 shows the inverter specification which includes the capacitor factor of both the inverter and the rectifier as 12 and 17 %, the hours of operation as specified by the load requirement of the Laboratory as 4,938 hrs per year. It also shows the energy in and energy out per year as 1,592 kW/yr and 1,433kW/yr with the rectifier energy as shown above and losses of 159kW per year at the inverter while 351 kW per year at the rectifier . The detailed specifications of the PV system, inverter, charge controllers and batteries can be seen in [11].

H. CONCLUSIONS

The in-situ measurements of weather parameter (solar radiation), in Anyigba have been achieved for the purpose of evaluating it for electricity generation. This system is generally envisaged for use in an area where constant power supply is needed and in rural remote areas where the national grid system is not rechargeable or available. Though the initial investment of PV system is quite high ₦ 5,453,760.00 ($17,500), however, it is good enough to provide the energy requirement of the Laboratory; it's beneficial and suitable for a long term investment as the payback period is less than 10 years while the life expectancy of the system period is above 25years.

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