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DESIGN OF SOLAR PHOTOVOLTAIC POWER SYSTEM FOR DUGURIYEL VILLAGE USING SOLARPRO

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ABSTRACT

The quest for diversification of power generation source in Nigeria is becoming necessary, going by the lingering power shortage experienced. Many rural communities in the country are situated far from grid electricity and are characterised by low population densities (about 165.4 people per sq.km) and disperse settlement, making the construction of electrification infrastructure very challenging, expensive and time-consuming. Although, the country has in abundance renewable and non-renewable energy sources capable of providing the needed power for her growth and development if justly harnessed, yet, the country faces huge power deficit due to gas shortage, vandalism activities and poor infrastructure, which necessitate the study of a better approach for sustainability and energy security. The Government has an expansion strategy of electricity generation from renewable energy with solar photovoltaic to contribute 75 MW by 2020. In this research, an off-grid solar photovoltaic farm was designed for Duguriyel village Bauchi using solarPro. Estimated load demand of the village was found to be 1702.84 kWhr/day and that of solar radiation was 5.2 kW/m^2/yr. Result of solar photovoltaic farm shows that solar facility capacity of 444 kW has to be installed over 2396.2 m^2 to generate an average of 1788.89 kWhr/day of power.

KEYWORDS: Solar irradiance, electricity, cost, load demand.

INTRODUCTION

Many rural communities in Nigeria are situated far from grid electricity and are characterised by low population densities [about 165.4 people per sq. km in 2012.[1] and disperse settlement, making the construction of electrification infrastructure very challenging, expensive and time-consuming.[2] The country's electricity sector suffers serious neglect over the years which resulted in generation deficit, weak transmission and distribution infrastructure, poor utility performance, and a long period of investment and maintenance neglect. As a result, the availability and reliability of electricity supplies have always been a vexing issue with the performance of the sector being below international best practice.[3] Approximately 95 million Nigerians are living without access to electricity, and those that do have access face extensive power outages.[4] The power accessibility of 126 kWh per capita/year obtainable in the country is far below what is obtainable in developed countries despite the abundance renewable and non-renewable energy sources available in the country. For instance, in Europe, an average of 6,491 kWh per capita/year is the obtainable value and 7,517 kWh/capita/year for USA.[5] This research aimed at designing a solar pv power system that can meet the load demand of Duguriyel village, Bauchi. The application of solar PV-based home electrification will offer a quick, economic and reliable answer to the rural households' need for power, especially for those of light-duty appliances''.[6]

1.1.Solar energy potentials in Nigeria

Nigeria is located in the tropics, near the equator line between 3°E and 14°E longitude and 4°N and 14°N latitude north of the equator.[6,7] with a land area of about 924,000 sq km. Extensive studies carried out by various researchers in Nigeria indicate that significant amount of solar radiation is been received daily; although, some variations exist between the various locations in the country, north to south, and depending on the time of the year.[8] It has been estimated that the country receives about 16.7×10^{15} kJ of solar energy each clear day, with the minimum hours of the sunshine amount to 0.1 and maximum hours of 9.9.[6] ''In addition, about 1,500 petajoules (PJ) (about 258 million barrels of oil equivalent) could be available to Nigeria annually from solar energy if solar appliances with 5% conversion efficiency were used over only 1% of the total land area of the country for about six months of the year''.[9] One study shows that the average solar insolation in the country is between 2217 and 6264 Wh/m^2 (Adeoti, et al., 2001), while.[3] indicate a better value between 3.5–7.0 kWh/m^2-day. In another report it has been shown that 'the solar radiation in the country ranges from 4 kWh/m^2 in the south to 7 kWh/m^2 in the north, which is sufficiently above the threshold average value of 2.3 kWh/m^2 required for the operation of simple domestic load especially in rural communities'.[10] Both of these reports show good solar radiation capacity capable of offering an alternative to the existing power generation source in the country thereby cutting carbon emission from fossil fuels which pose a threat to the climate condition. Figure 1 shows the solar map of Nigeria.

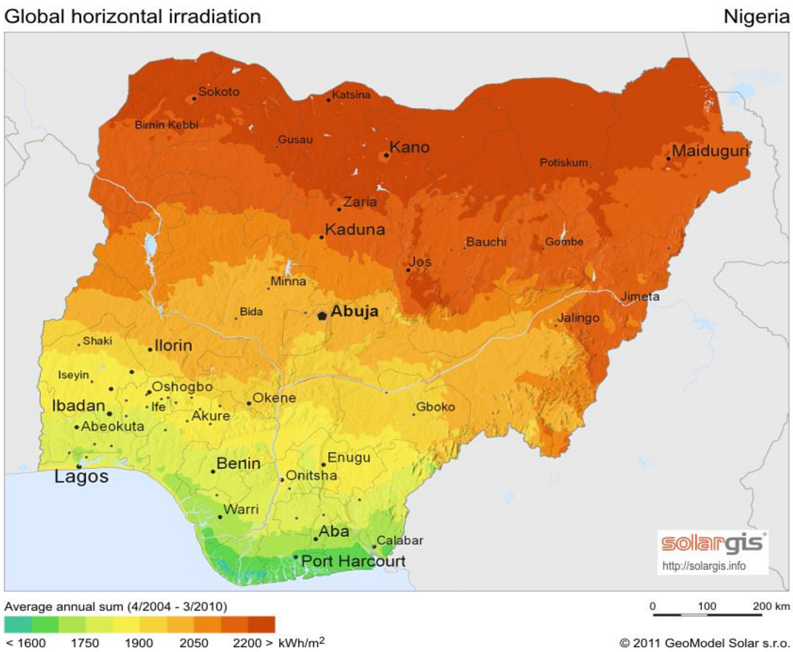


Figure 1: Solar Map of Nigeria,[11] from Solargis.

1.2.Duguriyel solar potential

Bauchi state is one of the areas with average annual sun of between 2050 to 2200 kWh/m^2 as depicted in Figure 1. Duguriyel is a village about 50 km away from Bauchi city, having solar radiation suitable for solar PV applications based on Nigeria's solar map. The village is located 9.9°N 9.76°E with its view shown in Figure 2.

Figure 2: Map of Duguriyel.[12]

The solar radiation data was obtained from National Aeronautics and Space Administration (NASA) surface meteorology and solar energy station.[13] The data are in form of horizontal, tilt, direct, and diffuse radiation. It has been observed that the time of sunshine ranges from 11 to 12 hours. Its availability forms the basis of solar systems development in any specific area, because it serves as the fuel. As such, thorough analysis is required to ascertain how much energy may be harnessed.

2.0 Solar PV farm design

2.1.steps for PV design

'It is important to properly size the solar power plant. If the system is too large, it will be too expensive and un-economical and if it is too low, it will not be able to meet the load requirement of the village,[14,15] outlined three basic steps in the design of a PV system, which are:

a. Estimation of load and load profile;
b. Estimation of available solar radiation; and
c. Design of PV system, including area of PV panels, selection of other components, etc.

2.2.Load demand profile

The estimation of load demand was carried out by categorising the buildings in the village into residential, school, place of worship, healthcare centre and business enterprises. The load demand at any particular time was calculated by considering the power consumption of the appliances at that time,[16] i.e.

$$\text{Load } (L_i) = \text{appliance power (1)} + \text{appliance power (2)} + \ldots + \text{appliance power (n)} \qquad \ldots (1)$$

Where i = 1, 2, 3… 24 representing hourly time and n = number of appliances working at a specified time.

The total load demand Figure 3, was determined by combining the loads demand from each of the categories.

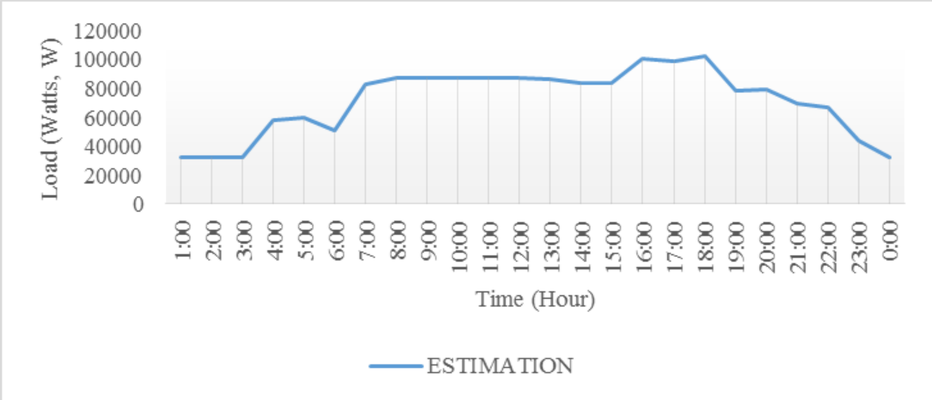


Figure 3: Total load demand profile.

2.3.Solar Radiation for Duguriyel

Solar radiation is mostly measured on a horizontal surface which can be broken down into direct normal (beam) and diffuse components,[15] as earlier discussed. Figure 4 shows the monthly average amount of the total solar radiation incident on a surface tilted relative to the horizontal and pointed toward the equator for a given month.[17] This can be considered a long-term data which is the most favorable data for solar design. Comparing the values obtained with researches conducted by,[3,6] and,[10] on the average solar radiation in Nigeria shows that the village has good potentials for solar PV.

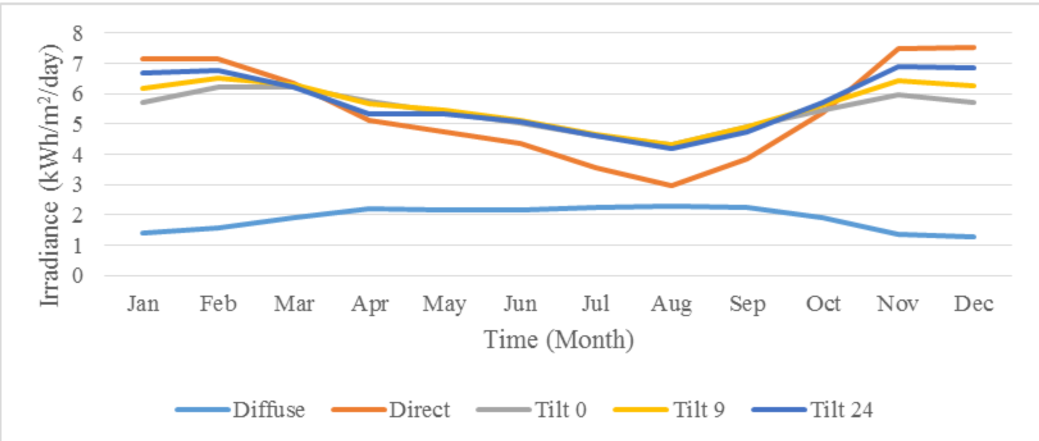


Figure 4: Monthly Averaged Radiation Incident on an Equator-Pointed Tilted Surface.

2.4.Simulation package

Equations 2, 3, and 4 were used by the simulation package (SolarPro) to calculate the global horizontal irradiance, direct normal irradiance and diffuse horizontal irradiance respectively.[18]

$$I = 0.42\sin H + \frac{2.92-\sin H_o}{2\sin H_o}\sin^2 H - \frac{2.92-\sin H_o}{4\sin^2 H_o}\sin^3 H \qquad \ldots (2)$$

$$I_{DN} = \frac{1.323I}{\sin H} - 0.5466 \quad \dots (3)$$

$$I_{SH} = I - I_{DN} \sin H \quad \dots (4)$$

Where: I [kW/m^2]: Global Horizontal Irradiance; I_{DN} [kW/m^2]: Direct Normal Irradiance; I_{SH} [kW/m^2]: Diffuse Horizontal Irradiance; H : Solar Altitude, H >0, If $H \leqq 0$, all irradiance equal to 0; and H_0 : Culminating Solar Altitude

The plane of array (POA) Irradiance was calculated using the Hay transposition model and is the total irradiance that is incident upon (or normal to) the surface of the array.[18]

$$I_{\beta\gamma} = I_{b\beta\gamma} + I_{s\beta\gamma} + I_{r\beta\gamma} \quad \dots (5)$$

$$I_{b\beta\gamma} = I_{DN} \cos\theta \quad \dots (6)$$

$$I_{s\beta\gamma} = I_{SH}\left[\frac{I - I_{SH}}{I_{oH}} \times \frac{\cos\theta}{H} + \left(1 - \frac{I - I_{SH}}{I_{oH}}\right) \times \frac{1+\cos\beta}{2}\right] \quad \dots (7)$$

$$I_{oH} = I_{SC}\{1 + 0.033\cos(n-2) \cdot \frac{2\pi}{365}\} \cdot \sin H \quad \dots (8)$$

$$I_{r\beta\gamma} = \rho I \frac{(1-\cos\beta)}{2} \quad \dots (9)$$

Where: $I_{\beta\gamma}$: Total (Solar) Irradiance; $I_{b\beta\gamma}$: Direct Component; $I_{s\beta\gamma}$: Diffuse Component; $I_{r\beta\gamma}$: Reflected Component; I_{SC} : Solar Constant (=1.382[kW/m^2]); I_{oH} : Extraterrestrial Solar Irradiance; ρ : Albedo (Ground Reflectivity); β: Tilt Angle of PV Module; and γ : Azimuth Angle of PV Module

2.5.Design Parameters

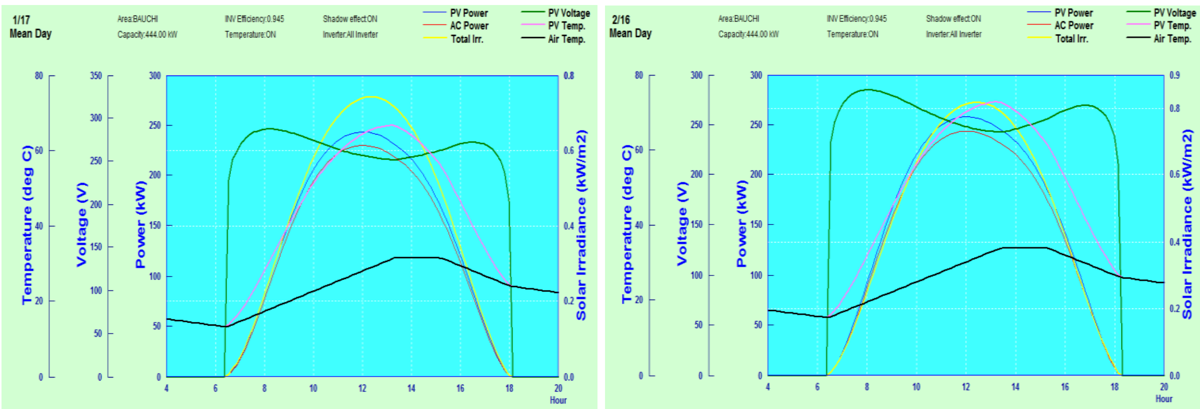
The technical parameters considered in the design are as shown in Table 1.

Table 1: Solar PV design parameters.

S/No.	Conditions	Values
1.	Location	Duguriyel Bauchi
2.	Power requirement	51085260.0 Wh/month (51,085.26 kWh/month)
3.	Solar panel manufacturer	Solar world
4.	Modules to connect	2440
5.	Facility capacity	440.00 kW
6.	Model orientation	Landscape
7.	Panel rated capacity	185 W
8.	Efficiency	16%
9.	Area	2396.2 m^2
10.	PV installation mode	Free standing
11.	Tilt angle	10
12.	Azimuth angle	170

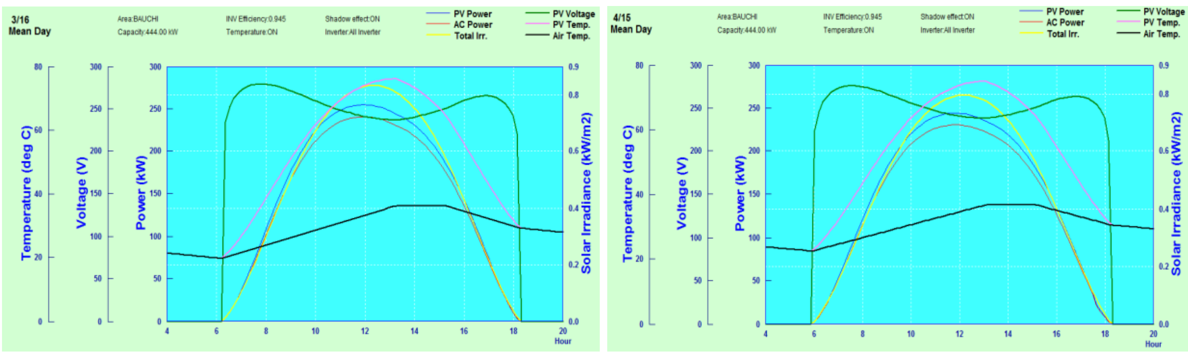
3.0. Solar Photovoltaic Farm Simulation Result

The solar power system was modelled and simulated using Solar Pro. Figure 5 through Figure 10 show the monthly average solar power output of a year. The PV power, AC power, PV voltage, total solar irradiance on a tilt surface, PV temperature as well as air temperature are plotted in the said Figures. The PV power represent the amount of power produced by the solar panels as direct current; and the AC power was obtained as the output from the inverter based on 0.945 inverter efficiency. The right axis shows the solar irradiance in kW/m^2. It can be seen from the axis that the maximum value is 0.9 kW/m^2, while the maximum solar radiation in the area is more than 5 kW/m^2. This is because the axis only represents the incoming solar irradiance to the PV based on the solar panel conversion efficiency. For instance, if at a given time the solar radiation falling on the solar panel is 4.5 kW/m^2, then with conversion efficiency of 12 % the solar irradiance will be 0.48 kW/m^2. The PV temperature depicts the decrease in PV voltage when there is rise in PV temperature during daytime.[19]



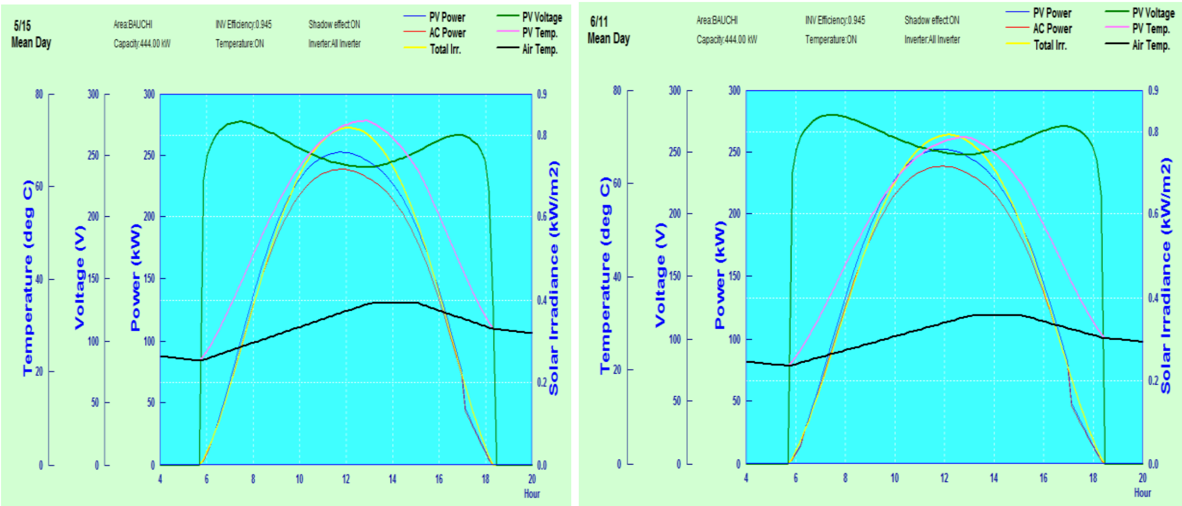
(a) **(b)**

Figure 5: Estimated Power and Solar Irradiance for (a) January (b) February.



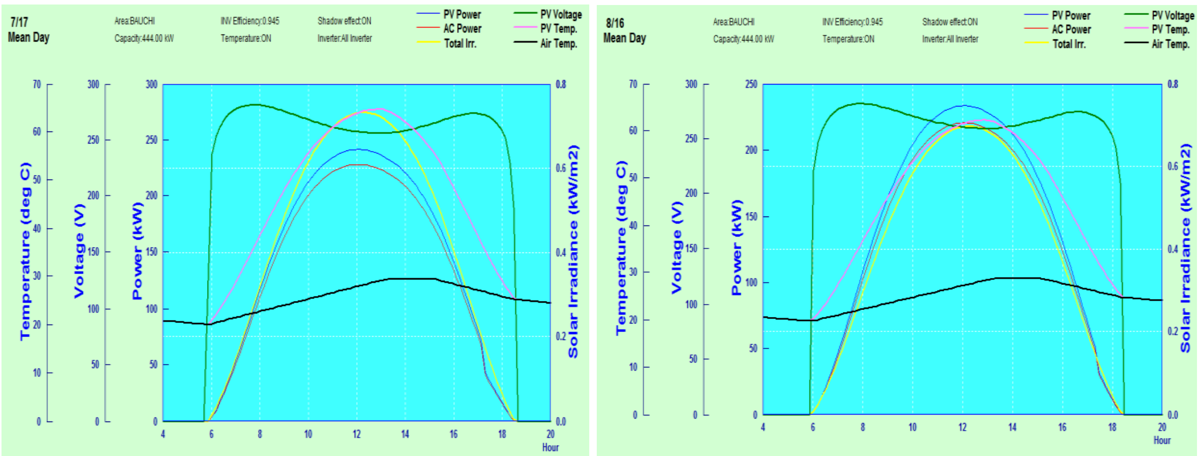
(a) **(b)**

Figure 6: Estimated Power and Solar Irradiance for (a) March (b) April.



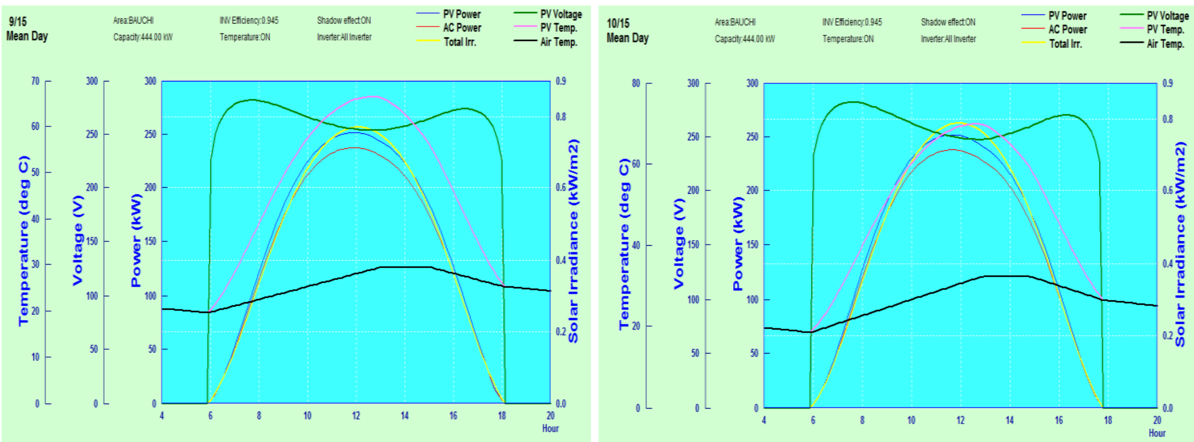
(a) **(b)**

Figure 7: Estimated Power and Solar Irradiance for (a) May (b) June.



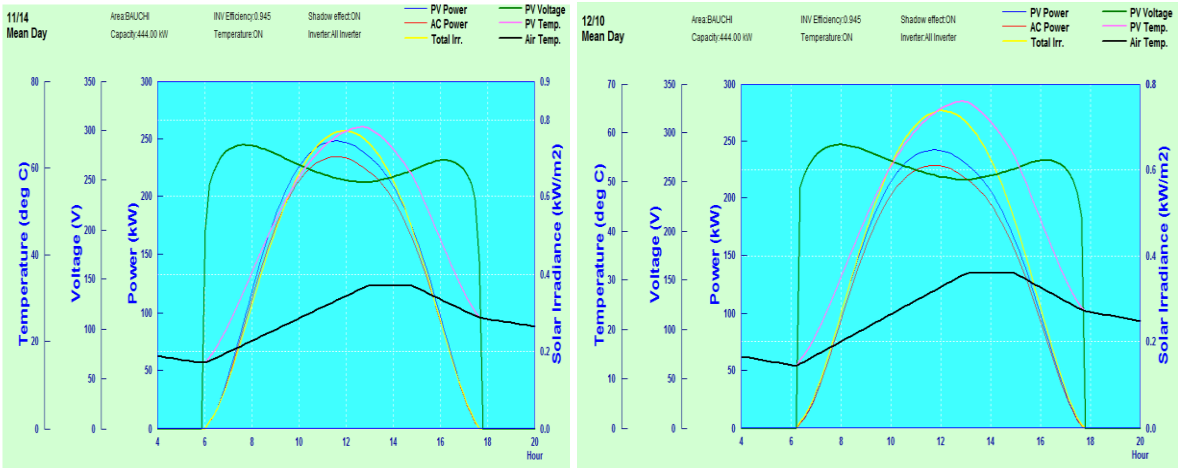
(a) **(b)**

Figure 8: Estimated Power and Solar Irradiance for (a) July (b) August.



(a) **(b)**

Figure 9: Estimated Power and Solar Irradiance for (a) September (b) October.



(a) **(b)**

Figure 10: Estimated Power and Solar Irradiance for (a) November (b) December.

Figure 11 gives the total power output for each month of the year from the solar PV farm. It can be seen that the power generation (the AC power output) is enough to meet the estimated electricity requirement of the village.

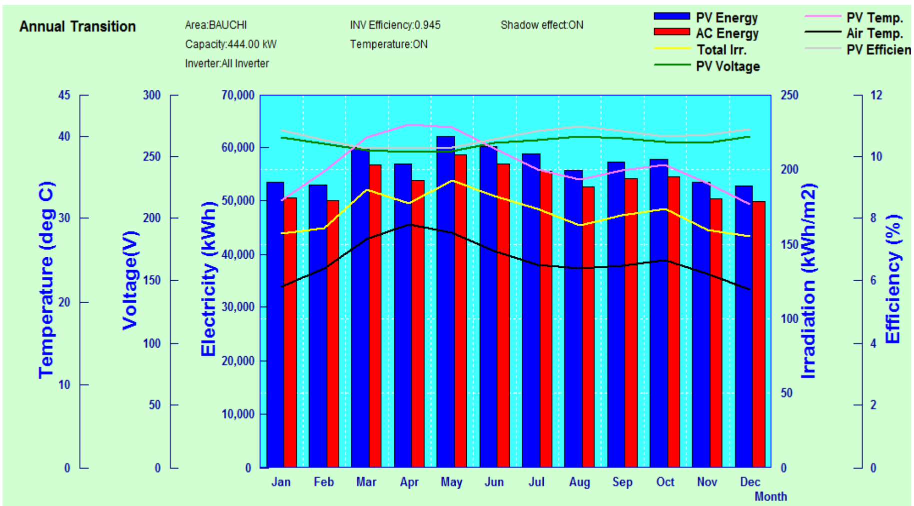


Figure 11: Total Yearly Average Estimated Power and Solar Irradiance.

The power produced by solar cell in Watts along the current-voltage (I-V) curve was calculated by the equation P=IV.[20] Figure 12 shows the graph of the total I-V curve as well as P_{max}, I_{pm}, and V_{pm}.

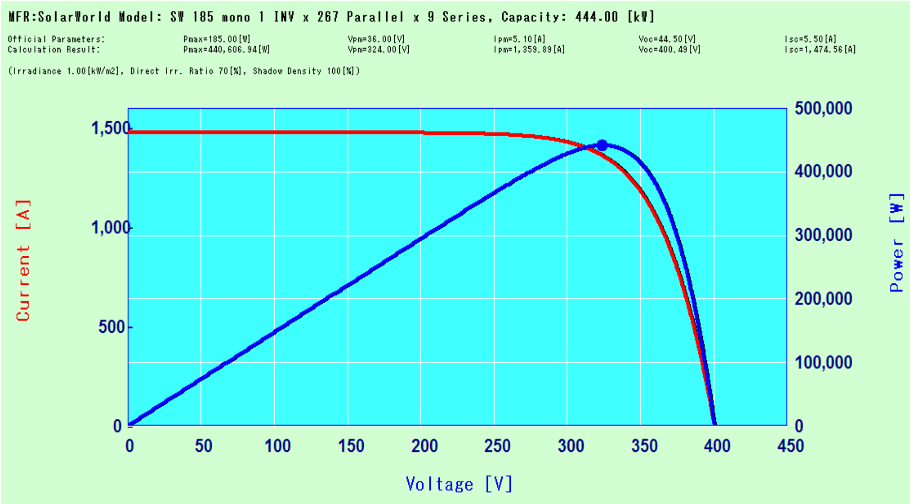


Figure 12: I-V characteristics of the Solar PV arrays.

Figure 13 depicts the arrays of the solar PV farm designed.

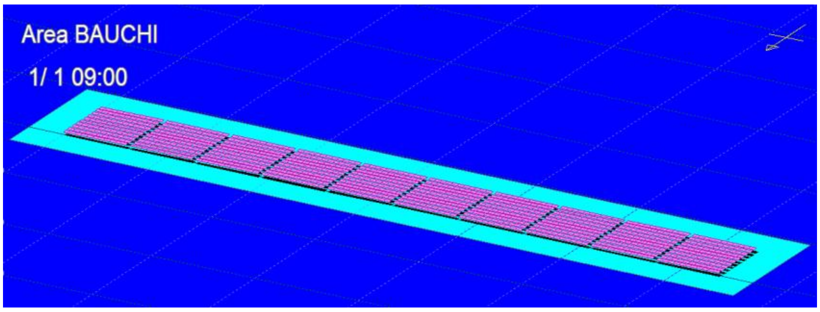


Figure 13: View of Proposed PV Arrays.

4.0. CONCLUSION

The average radiation for each month was determined and simulated using SolarPro. The solar power system was designed as a standalone that meet the power requirement of the village. Facility capacity of 444 kW using solar PV of 16% conversion efficiency was considered. The expected power from the facility for each month was determined.

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