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Research Article

**Design and Simulation of an off Grid Solar Photovoltaic System
for a Radio Broadcasting Station in Maiduguri**

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ABSTRACT

The attacks on transmission towers along the Maiduguri-Damaturu and Maiduguri-Dambo routes in Nigeria since 2021 have isolated Maiduguri, the capital city of Borno state, from the national grid, forcing communication and radio stations to rely on diesel generators, which are obviously uneconomical. This study presents a design and simulation of an off-grid solar photovoltaic (PV) system for Al-Ansar Radio and Television Station in Maiduguri. The station's load profile was obtained from the station and used to determine the size of the photovoltaic system. The results of the system sizing were used to simulate system performance in BlueSol. Based on a 36 kW load profile and daily operation of 8-12 hours, the system's energy demand is estimated at 224 kWh/day. The proposed PV system comprised a 54 kW PV array, 134 PV modules, a 13,566 Ah battery bank, and a 75 kVA inverter. Simulations using BlueSol software indicate that the system can meet the station's energy needs, producing 101,932.73 kWh annually, with a minimum of 6896.95kWh in August, presumably due to cloudy weather, and a maximum of 9900.82kWh in March, with clear skies and high solar irradiance. While load profiles may vary across stations, this approach is easily adaptable, enabling accurate performance forecasting before implementation and making it a viable model for other radio, television, and ICT centres seeking sustainable energy solutions..

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1.0 INTRODUCTION

Maiduguri, the capital city of Borno State, Nigeria, has faced significant challenges related to power outages as a result of insurgent attacks on the 330kV and 132KV transmission towers connecting the city to the national grid. This has forced residents and critical sectors of the

society including government institutions, radio and television stations, internet service providers and markets to rely on diesel and petrol generators to meet their power needs. This significantly increased the costs of energy and environmental pollution by the conventional generators. In response to these challenges, the

design of off-grid solar photovoltaic (PV) systems provides a viable solution to ensuring stable power supply for the residents and other critical sectors of the economy.

A study by Hussain in 2021 examined the environmental and economic impacts of renewable energy resources in Pakistan. The study focused on hybrid (solar-wind) systems comparing it with the conventional energy systems like diesel generators. His findings showed that operating with a hybrid solar energy system instead of diesel generators of average generated power of 5kW and 3kW, carbon dioxide (CO₂) emissions can be reduced up to 8,446.6 kg and 6,131.725 kg of CO₂, respectively over the system life span of 25 years. Comparison of costs indicated that renewable energy has a comparatively low cost per electric unit. It can pay back its total installation cost in just 8 years and can save a sum of \$4,936.4375. Although the system considered is for residential applications, its findings are highly relevant for larger-scale applications.

Akwukwaegbu *et. al.*, 2021 designed a standalone PV system to provide an uninterrupted power supply for Heartland FM in eastern Nigeria. The study carried out a detailed design and analysis of a 327.89kW standalone PV system to provide constant power supply for the radio station. The system was simulated using BlueSol software and the findings suggested an estimated annual production energy of 510,976.79 kWh and producibility of 1,558.39 kWh/kWp by the proposed system, from a total annual global irradiance of 1536.65 kWh/m². The proposed model met the energy demand of the radio station.

Kut & Nowak, 2019 emphasized the role of simulation software in optimizing PV system installations for maximum efficiency. The study showcased how tools like BlueSol Design software can aid in selecting ideal parameters for photovoltaic setups. The study analysed a single-family building located in Poland. In the analysed case, the annual energy production in the first year of use was 2111.89 kWh and an Annual productivity of 1005.66 kWh/kWp with Annual CO₂ reduction of 1267.13 kg by an installation consisting of seven 300 W monocrystalline panels connected in series with

a total power of 2.1 kW. The designed installation was not equipped with batteries, but with a bi-directional electric meter, enabling the transmission of energy in both directions.

While their study focused on a residential PV system, their methodology of using simulations to optimize the system design can be adopted to larger-scale installations as well.

Computer software is very helpful in the photovoltaic installation design, economic analysis and preliminary analysis of the profitability of investment. It enables to predict at the design stage the electricity generation based on meteorological data for a given location from previous years. (Paweł Kut, 2019) Ishaq, 2013, also explored the design of an off-grid PV system for Government Technical College (GTC) in Wudil, Kano. In that study, the electrical appliances (loads) available at the college were itemized with their power ratings and time of operation during the day to obtain the total energy demand by the college in Watt-hour per day. The total load stood at 11.87 kW and was estimated to need a total of 48.787 kWh of energy daily. The energy can be supplied from a 13 kW PV array that comprised of 72 PV modules, a 6377 Ah battery bank (20 batteries), a voltage regulator, and a 15 kVA inverter. The findings suggested that the initial cost of the PV system was relatively higher than that of diesel generators, but the payback period of 2.8 years was much shorter than the 30-year lifespan of the PV modules.

The study highlights the potential for off-grid PV systems to address energy needs in educational institutions and provides a valuable framework for other institutions considering similar solutions.

Musa *et al.*, 2024, designed an off-grid PV system developed for the department of mechanical Engineering at the Federal Polytechnic Monguno, Nigeria, to meet the school's daily energy demand of 218.83 kWh. The system presented comprised of a 42.5 kW PV array with 164 solar panels, 48.1 kWh battery bank made from 241 batteries, 34 charge controllers, and a 4.9 kW inverter. The total cost of the system estimated at N60, 125,000.

This project serves as a model for sustainable energy solutions in regions with abundant sunlight, contributing to energy independence

and environmental conservation (A.B. Musa, 2024)

The above literatures demonstrate the growing interest in off grid solar PV systems and its feasibility for various sectors in Nigeria, ranging from residential to educational applications. However, a research gap exists in the application of these systems to radio communication infrastructure in northern Nigeria.

While (Akwukwaegbu 2021) is the only available study that focused on radio communication infrastructure in, the study conducted in Imo State, south eastern Nigeria — geographically far from Maiduguri and the northeast—the difference in weather data (between Oweri and Maiduguri) and the nature of power challenges in Maiduguri, and high reliance on diesel and petrol generators, calls for further research.

This paper aims to design and simulate a stand-alone solar PV system to meet the energy demand of a radio broadcasting station in Maiduguri. As a case study, Al ansar radio and television station is chosen.

By employing solar PV systems, broadcasting stations can reduce their dependence on diesel generators for power generation. It also tackles the environmental impact, and lowers operational costs thus addressing the long-term sustainability of radio communication services, reducing carbon emission and supporting broader environmental goals.

2.0 METHODOLOGY

This section presents the standards set by the designer in the design process. Covers the methods used in the load estimation of the station, factors that affects the system, design, sizing and simulation of the PV system. The required data will be outlined and the method used in the system sizing is presented.

2.1 Selection of site

The output power generated by a PV system varies significantly depending on the time and location of the site. It is therefore important to make appropriate selection of the site for the PV system to be installed.

While selecting the site, the following factors were carefully considered.

Shading: the site selected should be free of shading from trees and other structures that may interrupt the solar radiation falling on the pv modules

Space: the surface area available at the site should be enough to accommodate the estimated number of modules required to generate the output power for the station.

Strength of supporting structure: in the case of roof mounted modules, the roof should be strong enough to carry the overall weight of the modules and should also give the modules the appropriate tilt angle needed to generate the output power.

2.2 Power consumption of the station

The most important step in designing a PV system is to determine the power consumption (energy demand) of the available loads at the station. The daily average energy demand of each load in the station will be calculated as:

$$E = P \times t \text{ (kWh/day)} \quad 3.1$$

Where E is the daily average demand in kilowatt hour/day

P is the power rating of the load in kilowatt

t is the average time of operation of the load in hours/day.

2.3 Solar energy assessment of the site

The solar energy assessment of the site is extremely significant. The solar insolation can be obtained in two ways

1. Using a pyrometer
2. From a meteorological station nearest to the site.

The solar insolation can be presented in two ways,

- i. In terms of the quantity of power in kilowatt falling on a square meter per day. That is kilowatt-hour per meter square (kWh/m²)
- ii. In terms of the number of hours in a day during which solar irradiance averages 1kW/m².

2.4 Selection of system voltage

The system voltage is selected based on the capacity of the system. The system voltage increases with increase in the load available on the system. Generally, inverters over 2000 W are actually 24 V DC and inverters over 5000 W are often 48 V or above as shown in fig 1. (Mohanty, 2015).

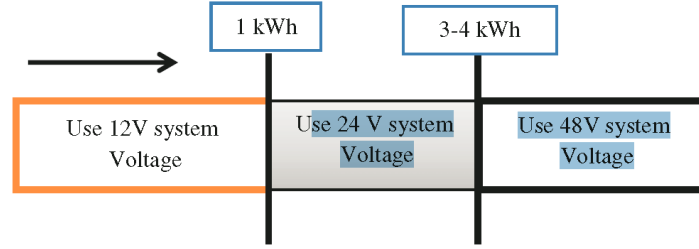


Figure 1: Variation of system voltage with load. (Mohanty, 2015).

2.5 Module sizing

The size of the PV module refers to the output power of the PV array. This can be calculated by the equation (Ahmad, 2002)

$$P_{pv\ array} = \frac{E}{\eta_{bo} \times K \times I} \times PSI \quad 3.2$$

Where E= daily load energy consumption,
 I= average solar radiation per day,
 PSI = peak solar intensity at the earth surface,
 η_{bo} = efficiency of balance of the system which is the product of inverter and wire losses and
 K = loss factor.

The typical values for inverter, wiring and K losses are 15%, 10% and 90% respectively.

2.6 Battery bank sizing (battery bank capacity (BBC))

The size of the battery bank required to store the energy capable of meeting the energy demand of the station will be computed using equation 3.5

$$BBC = \frac{E \times N_{aut.}}{DOD \times \eta_{out} \times V} \quad 3.5$$

Where $N_{aut.}$ Is the days of autonomy, DOD is the depth of discharge, η_{out} is the battery loss and V is the system voltage.

The days of autonomy refers to the number of days the system will operate without receiving energy from the sun. Such as cloudy or rainy days.

$$\eta_{out} = 0.85 \quad (\text{Leonics, 2009})$$

In a PV system design, the minimum number of autonomy is 2 days. In this paper, the days of autonomy will be taken as 2days.

The depth of discharge is normally specified by the manufacturer; however, the maximum depth of discharge is 75%.

More so, the total number of batteries (N_B) needed to meet the required battery bank capacity will be calculated using equation 3.6

$$N_B = \frac{BBC}{C_B} \quad 3.6$$

Where C_B . is the rated capacity of one battery in ampere hour (Ah)

2.6.1 Number of batteries in series and parallel.

The number of batteries in series will be obtained by the equation

$$N_{Bseries} = \frac{V_{dc}}{V_B} \quad 3.7$$

Where V_B . is the rated voltage of each battery

The number of batteries in parallel given as

$$N_{Bparallel} = \frac{N_B}{N_{Bseries}} \quad 3.8$$

The total number of batteries required in the battery bank is the product $N_{Bseries}$ and $N_{Bparallel}$.

2.7 Inverter sizing

When sizing the inverter, the actual power drawn by the appliances that will run at the same time must be determined as a first step.

Secondly, the starting current of large motors or related devices must be taken into account by multiplying its power by a factor of 1.3. (Ishaq M., 2013).

Furthermore, to avoid under sizing, the rating of the inverter will be at a value 30% higher than the total watts of the appliances. The inverter will therefore be sized as

$$P_{inv} = (P_T + P_{LSC}) \times 1.3 \quad 3.9$$

Where P_{inv} is the power of the inverter, P_T is the power of equipment running simultaneously and P_{LSC} is power of large surge current.

2.8 System simulation and optimization

The stand-alone PV system will consist of solar energy as the source, PV modules for energy conversion from solar to electrical, battery bank for energy storage and an inverter for DC to AC conversion. The proposed system will be implemented in BlueSol simulation tool. Different sizes of PV arrays will be considered for a given inverter.

For the optimization, BlueSol mixes and matches these components to find what

combinations satisfies the load requirements at the lowest net present cost.

3.0 RESULTS AND DISCUSSION

This section presents the results obtained using the load profile of the station. The solar energy assessment of the selected site, the sizing and simulation of the system will be presented and the result will be discussed.

3.1 Selection of site

The station selected in this study is al-ansar radio and television broadcasting station located in Maiduguri.

Maiduguri is located on lat. 11.85°N, long 13.16°E.

The PV modules will be roof mounted. The available area of the rooftop is approximately 2000m².

There are no tall structures such as storey buildings close to the site, hence there is minimal shading for most hours of the day on the site as such shading analysis would not be performed.

3.2 Solar Energy Assessment of the Site

Fig 1 shows the monthly average values of global solar radiation over Maiduguri. The table reveals that Maiduguri has much months with high radiation. The average global solar irradiance for Maiduguri (lat. 11.85°N, long 13.16°E) is approximately 5.6kwh/m²/day.

Month	H_{est} ($MJm^{-2}day^{-1}$)	H_{meas} ($MJm^{-2}day^{-1}$)
JAN	14.22	11.10
FEB	15.43	12.60
MAR	17.04	15.50
APR	17.91	16.70
MAY	16.59	15.40
JUN	14.66	13.30
JUL	13.27	10.70
AUG	12.08	10.80
SEP	14.82	12.80
OCT	15.62	13.20
NOV	14.87	12.70
DEC	13.22	10.30

Figure 2: values of estimated GSR and measured GSR in Maiduguri. (N.O. Adeniji, 2020)

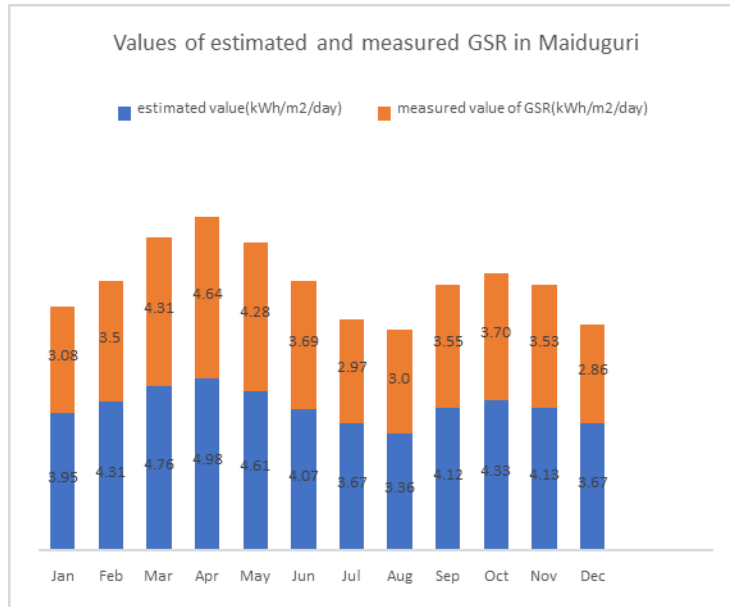


Figure 3: Values of estimated GSR and measured GSR in Maiduguri

3.3 Load profile of the station

The daily energy demand of the each load at the station is calculated using eqn.3.1

$$E = P \times t \text{ (kWh/day)}$$

Table 1 shows the load profile of the station. The data was obtained from the radio station.

Table 1: load profile of the radio station

LOAD	QUANTITY	ENEgy(kWh/day)
Light(cylinder)	12	2.95
Air conditioner	11	135
TV		2.7
Desktop	6	2.72
Mixer	1	0.25
Speaker	4	2.65
Light(normal)	39	2.8
transmitter	1	60
AVR	1	3.6
dispenser	3	5.5
Printer	5	2
Fan	2	0.6
freezer	1	0.5
microphones	1	0.02
decoder	3	2.75
total energy demand		224.04

3.4 Energy demand of the station

The daily energy demand of each load at the station is shown in table 1.

The energy demand of each load is obtained using eqn. 1.

The data was obtained directly from the station. From the tables, the total energy demand of the station is the summation of the total energy demand from each section. This gives 224kWhr/day.

E= 224kWhr/day

The total power of the load is 36kW.

Maximum power (P_{max})	400W
Output tolerance	5%
Current at maximum power (I_{mp})	11.35A
Short circuit current (I_{sc})	11.83A
Open circuit voltage (V_{oc})	42.45V
Voltage at maximum power (V_{mp})	35.50V
Maximum system voltage	1000V
Maximum series fuse	20A

3.5 Selection of system voltage

The total power of the load at the station is 36kW. This according to fig 1 will require a system voltage of 48v. Therefore, the system voltage selected for this PV system is 48v.

However, a 48v battery is not easily obtainable in the market. This problem can be addressed by connecting 6v or 12v batteries in series to get an equivalent voltage of 48v, which is the system voltage.

3.6 Module sizing

The module selected is sunshine solar MS-M400-30. The specifications of then module are as follows:

The power required from the PV modules is calculated using eqn.3.2

$$P_{array} = \frac{E}{\eta \times K \times I}$$

The total energy demand of the station E is 224kWhr/day

$$\eta = \eta_{inverter} \times \eta_{wire}$$

$$= 0.95 \times 0.9 = 0.85$$

$$K_{loss} = 0.85$$

$$I = 5.6 \text{ kWhr/m}^2$$

With the above parameters selected, the power required from the PV array is

$$P_{array} = \frac{224}{0.855 \times 0.85 \times 5.6}$$

$$P_{array} = 54.6 \text{ kW}$$

3.7 Battery bank capacity (BBC)

The capacity of the battery bank for the storage of energy is calculated from eqn 3.5

$$BBC = \frac{E \times N_{out}}{DOD \times \eta_{out} \times V_{sys}} = \frac{224000 \times 2}{0.8 \times 0.85 \times 48}$$

$$BBC = 13566 \text{ Ah}$$

The battery selected for this project is 250Ah, 12V.

The total number of batteries required to obtain the desired BBC is given by

$$N_{bat} = \frac{BBC}{C_B} = \frac{13566}{250}$$

$$N_{bat} = 54$$

The number of batteries to be connected in series is determined from eqn 3.7

$$N_{bseries} = \frac{V_{sys}}{V_B} = \frac{48}{12}$$

$$N_{bseries} = 4$$

The number of batteries in parallel is

$$N_{Bparallel} = \frac{N_B}{N_{Bseries}} = \frac{54}{4}$$

$$N_{Bparallel} = 13.5$$

As 13.5 battery is not possible, the designer decides to round up the figure. Thus the number of batteries in parallel is approximately equal to 14.

$$N_{Bparallel} = 14$$

The total number of batteries required to get the estimated battery bank capacity is the product of $N_{Bparallel}$ and $N_{Bseries}$.

3.8 Inverter sizing

When sizing the inverter, the actual power drawn by the load at the station that will run at the same time is determined at first. This power is assumed to be equal to the power of the load at the station P_T .

The starting current of large motors is neglected because there are no motors or devices with a large starting current.

The inverter is therefore sized using eqn.2.9

$$P_{inv.} = (P_T + P_{LSC}) \times 1.3$$

$$P_{LSC} = 0$$

$$P_{inv.} = 55 \times 1.3$$

$$P_{inv.} = 83.3 \text{ kW}$$

Since inverters are rated in kVA, the power in kW is converted to kVA as

$$P(\text{kW}) = \frac{\text{kVA}}{\text{p.f.}}; \quad \text{p.f} = 0.85$$

$$\text{kVA} = 83.3 \times 0.85$$

$$\text{kVA} = 70.81 \text{kVA}$$

Therefore the size of the inverter is 75 kVA because 71kVA is not commercially available. Hybrid inverter with built in MPPT assumed.

$$P_{\text{inv}} = 75 \text{kVA}$$

A hybrid inverter integrates a Maximum power point tracking (MPPT) charge controller, a battery charging unit. voltage regulation is handled internally by the inverter

Table 2: proposed system description

S/No.	Components	Description	Result/quantity
1	Load estimation	Total energy demand	224kWhr/day
2	PV array	Power required from PV array	55kW
3	Battery bank	Tubula, 12V, 250Ah	54
4	Inverter	Pure sine wave	75kva

3.9 simulation of the proposed system using BlueSol

The proposed system was implemented in BlueSol simulation tool. The average data for global solar irradiance in Borno (Maiduguri) will be used as the solar energy resources. Softwares like HomerPro, SAM and PVSyt are suitable for a stand-alone PV system simulation, BlueSol provides structured approach to components sizing and energy production estimate. The software is available to the author

without the need to acquire and learn new tool, saving time and resources.

3.9.1 Weather Resource

The average global solar irradiance of Maiduguri is 5.9kwhr/m² as shown in fig 3.3.

The direct normal irradiance is the difference between the global horizontal irradiance and the diffuse irradiance. It ranges from a minimum of 2.8kWhr/m²/day in August to a maximum of 5kWhr/ m²/day in March.

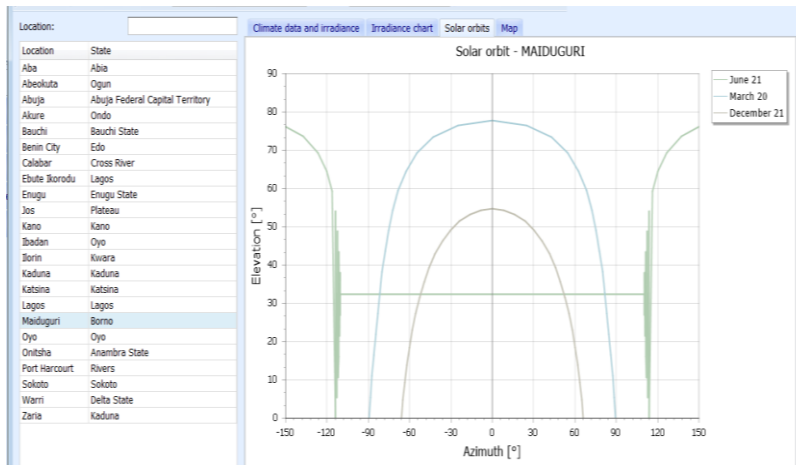


Figure 4: Maiduguri solar orbit

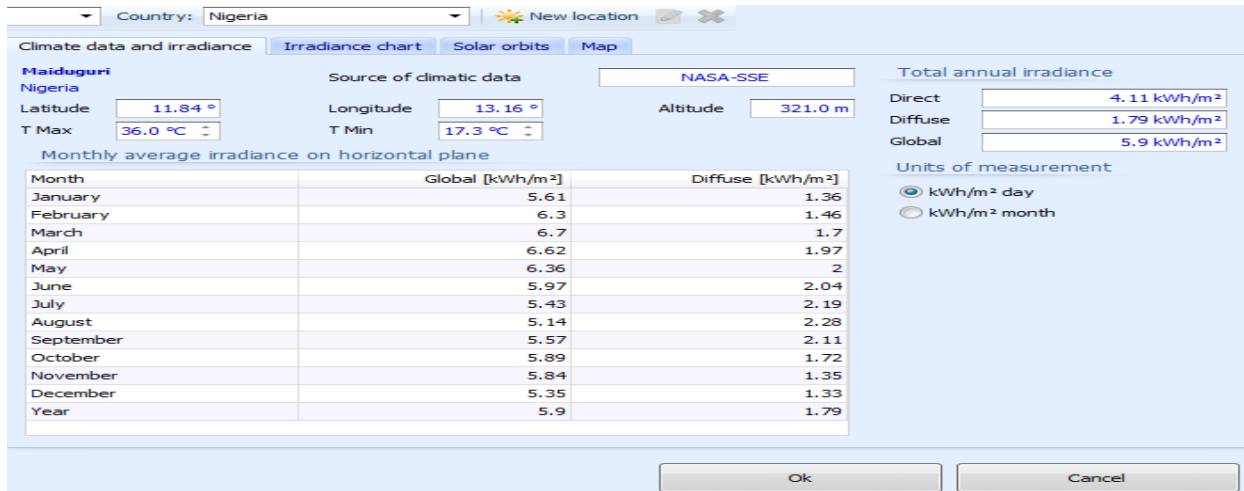


Figure 4: climate and irradiance data

3.9.2 Modules Orientation

The optimum orientation of the PV modules was obtained by BlueSol. The result is shown in figure 5. The optimum tilt angle is 13.1 degrees and an azimuth of 0 degrees. This was optimized for the months of January to December

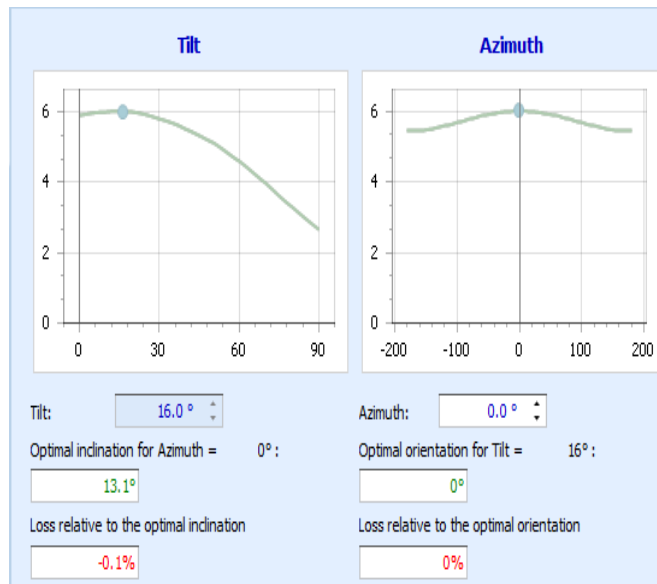


Figure 5: Graphical: optimum orientation of modules

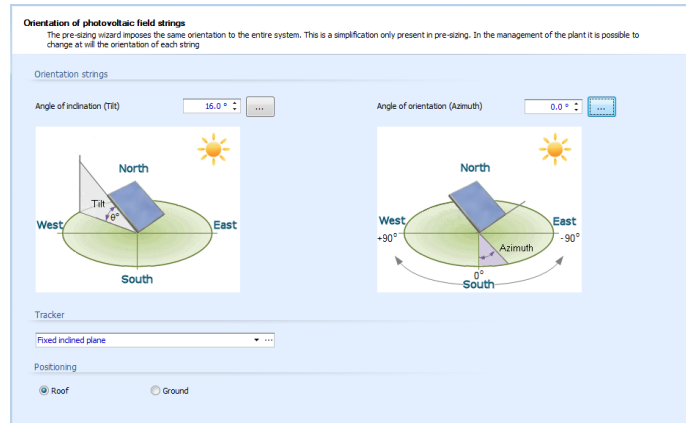


Figure 6: Pictorial: optimum orientation of modules

3.9.3 Simulation Result

The proposed system was simulated in BlueSol software based on the above information of weather resources and module orientation. The result can be seen in figure 6 bellow.

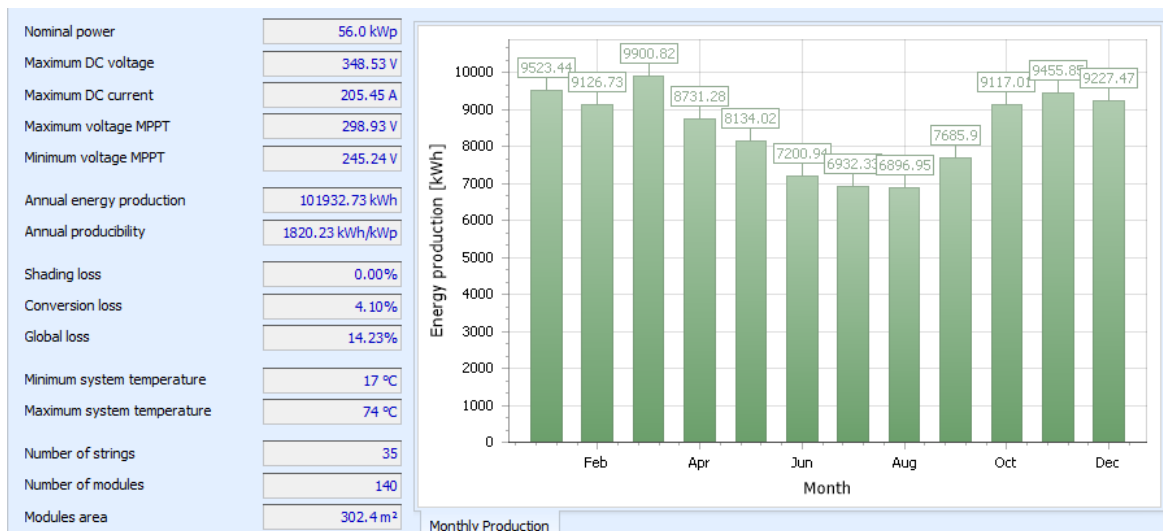


Figure 7: energy production of the system.

The system comprises 140 modules, grouped into 35 strings, connected to an inverter.

The system's annual energy production is 101932.73kWh, and its annual producibility is 1820.23kWh/kWp.

The monthly energy production of the system shows that the highest energy yield is in March, with 9,900.82kWh. Conversely, the lowest energy produced is in August, having a value of 6896.95kWh.

3.10 DISCUSSION

The proposed photovoltaic (PV) system demonstrated satisfactory performance with an annual energy production of 101,932.73 kWh, equivalent to an average monthly output of approximately 8,577.7 kWh. The station's estimated energy demand is 224 kWh/day, corresponding to about 6,720 kWh/month based on 12 hours of daily operation. The results indicate that the designed system can meet the station's energy requirements throughout the

year. The system consists of a 54 kW PV array comprising 140 PV modules arranged into 35 strings, connected to a 75 kVA inverter.

However, 35 strings implies 4 modules per string resulting in a string voltage of about 170V based on a module voltage of V_{mp} 42.45V. Based on the MPPT operating range of 245 to 298V, a practical implementation of the system will require a configuration with fewer strings for the 144 pv modules. This ensures that the string operating voltage remains within the acceptable range of the inverter MPPT.

The system's annual energy producibility was 1820.23 kWh/kWp, indicating efficient conversion of solar energy into electrical power. Energy producibility is the amount of electrical energy generated per installed kilowatt-peak (kWp) capacity in a year. Reported values for PV systems typically range from 1000 to over 2000 kWh/kWp, depending on climatic and environmental conditions (Zhang, 2017). The obtained value, therefore, indicates good system performance under the climatic conditions in Maiduguri.

Seasonal variations in energy production were observed across the year. The highest monthly energy output was recorded in March with 9,900.82 kWh, likely due to higher solar radiation, clearer skies, and longer sunshine hours. In contrast, the lowest energy production occurred in August with 6,896.95 kWh, mainly due to increased cloud cover and rainfall during the rainy season. Despite this reduction, the minimum monthly energy generated still exceeded the station's estimated monthly demand of 6,720 kWh. These findings highlight the importance of accounting for seasonal weather conditions in PV system design and energy planning.

This study contributes to the growing application of standalone PV systems for communication infrastructure in northeastern Nigeria. Previous studies, such as that of Akwukwaegbu, focused on south-eastern Nigeria, which has different climatic conditions

from Maiduguri. The 327.89 kW PV system reported in that study achieved an annual productivity of 1,558.39 kWh/kWp, whereas the present study achieved 1820.23 kWh/kWp. The higher productivity obtained in this study suggests favourable solar energy potential in Maiduguri and improved system performance under local environmental conditions.

The findings demonstrate that a standalone solar PV system can provide a reliable and sustainable energy solution for radio and television stations in Maiduguri, where unstable grid electricity and dependence on fuel-powered generators remain major challenges. The proposed system also has the potential to support other ICT facilities and communication centres in similar regions with comparable environmental conditions.

4.0 CONCLUSION

The load demand of Al Ansar Radio and Television Station was estimated at 36 kW, with an average daily energy demand of 224 kWh/day. To meet this demand, the designed standalone solar PV system requires a 54 kW PV array, a 75 kVA inverter, and two 60 A, 24 V charge controllers. The system requires a battery bank capacity of 13,566 Ah, which can be achieved with 54 batteries rated at 12 V and 250 Ah each.

The system is capable of producing 101,932.73 kWh annually, exceeding the estimated annual energy demand of 81,760 kWh for the study site. The monthly energy analysis showed that the highest energy production occurs in March, at 9,900.82 kWh, while the lowest occurs in August, at 6,896.95 kWh. These seasonal variations highlight the importance of considering local weather conditions during PV system design.

The results show that implementing a standalone solar PV system for radio and television stations in Maiduguri and the wider Northeastern region of Nigeria is technically feasible, environmentally friendly, and economically beneficial. The high annual energy production of

1820.23 kWh/kWp further indicates efficient system performance. This study also provides a sustainable energy solution that can be applied to similar broadcasting stations and related facilities in comparable environments.

Further studies may focus on detailed economic evaluation and advanced system modelling to improve long-term planning and optimisation.

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