Effect of Change in Design Parameters on the Performance of Photovoltaic Systems in Port Harcourt

Emmanuel Chinweikpe Obuah[1], Tamuno-Omie Joyce Alalibo[2]
[1] Electrical Engineering Department, Rivers State University
Nkpolu-Oroworokwo, Port Harcourt, P.M.B. 5080, Rivers State Nigeria
[2] Computer Engineering Department, Rivers State University
Nkpolu-Oroworokwo, Port Harcourt, P.M.B. 5080, Rivers State Nigeria

Abstract- *Over the years, electricity generation in Nigeria has depended solely on burning of cheap fuels contributing to damage to the environment. Photovoltaic (PV) power system through direct conversion of solar irradiance into electricity can be used as electrical power source for homes to meet its daily energy requirement. The performance of PV modules depends upon the geographical factors (longitude, latitude, and solar intensity), the environmental factors (temperature, wind, humidity, pollution, dust, rain, etc). Design assumption has been a major research and development in PV systems and has usually been concentrated in studies on radiation, availability, efficient operating strategies, design and sizing of these systems. On the other hand, the influence of design parameters such as change in Days of Autonomy on the performance of PV systems has not been given much attention. In this work, electrical performances of two autonomous photovoltaic systems with different number of days of autonomy were studied for domestic application in Port Harcourt, Nigeria. The panels were inclined at a tilt angle of 15˚ facing the northern hemisphere, so that the sun makes an incidence angle of 0º. The system location has latitude of 4.46N and a longitude of 7.01E with typical energy consumption is selected. A total AC load of 2170Wh/day was considered. The selected PV module capacity was 185W and the battery capacity of 160Ah. The solar charge controller of 30A was also selected. Results show the overall performance of the system with the higher number of days of autonomy to be better. The system was carried out using PVSyst 6.4.3; and the system can be used for a location with similar weather condition.*

Keywords- PV, Days of Autonomy, performance ratio, Port Harcourt-Nigeria

1. Introduction

Photovoltaic systems are solar energy supply systems that convert sunlight directly to electricity. The PV system mainly comprises of the panel, battery and battery charge controller, inverter, and a load.

By way of installation, the PV panels are typically mounted on rooftops or in locations with minimal shading/obstruction. PV systems in the Southern Hemisphere generally face north while the reverse is true for systems in the Northern Hemisphere.

The orientation of the PV systems is also highly dependent on the location of the installation. Correct installation design where appropriate panel orientation, exposure, sun-tracers are considered to maximize solar installation, can potentially ensure sustained electricity yield.

However, the output of solar PV system is mainly affected by different environmental factors like panel, tilt, irradiance, shading, etc., because in all the cases, the output power and efficiency are more rather than affected condition because in all the cases, the output power and efficiency are more rather than affected condition. In addition to being dependent on the intensity of solar radiation, the amount of power produced by a given PV system may also be affected by the system efficiency in converting incident irradiance into power or efficiency of the inverter.

Various studies on design of solar power system in different locations have been carried out globally. In [1], the results obtained from simulated performance monitoring of seven different roof-mounted PV systems in Abu Dhabi UAE were presented. Data were analyzed to evaluate the suitability of PV systems for installations in different types of buildings in the UAE. The PV systems consisted of amorphous silicon (a-Si) and polycrystalline silicon (p-Si) PV technologies. Different performance evaluation parameters are presented.

The authors in [2] gave design idea of optimized grid connected solar PV plant proposed at Bhopal. Comparison was made among results obtained after using three technologies available for modules poly crystalline silicon, mono crystalline silicon and a-siH thin film. Actual data for both loads and irradiance were used for simulation of grid connected PV, with the use of computer software package PVSyst 5.53. Analysis of results goes in favor of polycrystalline silicon technology.

In [3], calculative accuracy of PV sizing tools such as TRNSYS, Archelios, Polysun, PVSyst, PV* SQL and PVGIS were examined in comparison to the real electrical energy generated by a grid-connected 19.8kWp PV installation. The assessment has been performed by using the climatic data which have been recorded at the site of the real PV Park over the same calendar year.

Ramoliya and his associates also presented the simulation of a grid-connected solar photovoltaic system with the use of the computer software package PVsyst in [4]; and their performance was evaluated. The maximum solar irradiation is achieved at a tilt angle of 22degree (for shapur) which is nearly equal to the latitude of that location (21 degree28minute) and no shading effect is considered. For 1MW Grid connected solar PV system Energy injected to grid is 1416980kWh and the performance ratio is 0.764 and the various power losses are calculated.

In [5], the feasibility of installing a grid-connected photovoltaic (PV) system in a typical residential in Surabaya, Indonesia was examined. The study was conducted to evaluate the technical, economic and environmental aspects of PV system for supplying of household electricity energy needs. A 1kWp grid connected PV system simulation is carried out with PVSyst and RET Screen software. The simulation expected to help in demonstrating the advantages and challenges of installing of a grid-connected PV system for residential in Surabaya.

In [6], sizing the solar power plant in standalone mode of operation was done. Based on the load survey and the utilization factor, the capacity of the plant is determined for battery sizing and PV sizing tools PVSYST, and C programming were used for the sizing of the solar PV power plant presented. The total load is 14 kW. The total energy consumption is 66.196kW-hour. Considering the utilization factor 0.7, the effective load is 9.8kW. In the girls hostel mess the total load is 11kW.

The author in [7] compared different panel arrangement that will minimize the floor area and maximize power generation through tracking the sun. The maximum generation was obtained from a three layer solar PV System with dual axis tracking system. By this arrangement we can reduce the space requirement to 58% to generate maximum energy.

In [8], the simulation of a grid-connected solar photovoltaic system with the use of the computer software package Pvsyst and their performance was evaluated. Result shows for 1MW Grid connected solar PV system, the energy production is maximum in Tuticorin(1523MWh/Year) as compared to other locations such as Madurai (1414 MWh/year), Sivagangai (1335 MWh/year) and Sivakasi (1398 MWh/year.

By other literatures reviewed, it is also clear that study of the effect of environmental factors on different PV arrangements was conducted in India. In [9], the design of stand-alone PV systems with the field losses considerations in Thiruvananthapuram, India was considered. The simulations was done using PVsyst.

Judging from the studies above, the effect of design factors like, tilt angle, number of days of autonomy, loss of load of probability, on different PV system arrangements for standalone system have been given little or no thought, particularly in Port Harcourt region of Nigeria.
The overall purpose of this project is to investigate the performance two PV systems with different number of days of autonomy in Port Harcourt, Nigeria.

The research report is organized as follows: section 2 describes the PVSYST software; section 3 describes system simulation Governing Equations. System Design Procedure is discussed in section 4, while System Application and Description are discussed in section 5. Simulation result and analysis is summarized in section 6, and, finally, section 7 is devoted to conclusion.

2. PVSyst Software

PVsyst is a simulation program able to simulate both stand alone and grid connected PV systems. PVSyst provides the design proposals (Area required, module size, inverter size etc.). PVsyst performs the simulation on the basis of power required or available area. It consists of input radiation meteo files of many locations in itself and can be import from NASA-SSE Worldwide. [10]

3. Governing Equations

The total capacity of PV panel is calculated as:

$$P_{AV} = \frac{D_T}{\eta_b * \eta_c * \eta_i} \quad (1)$$

Where,
η_b is the battery efficiency
η_b is the charge controller efficiency
η_i is the inverter efficiency

Total Wp of PV power required is expressed as:

$$P_T = \frac{P_{AV}}{S_{AV}} \quad (2)$$

Where S_{AV} is the average sun hour of the system site per day

The total DC current of the PV panel is expressed as

$$I_{DC} = \frac{P_T}{V_{DC}} \quad (3)$$

Where V_{DC} is the PV panel voltage.

The PV module in series was obtained as:

$$N_{MS} = \frac{V_{DC}}{V_{MPP}} \quad (4)$$

Where V_{MPP} is the Maximum Power Point Voltage of the PV panel.

The PV panel in parallel was obtained as:

$$N_{MP} = \frac{I_{DC}}{I_{MPP}} \quad (5)$$

Where
I_{MPP} is the Maximum Power Point Current of the PV panel

I_{DC} is the PV panel current

Estimated battery energy is expressed as:

$$B_E = D_T * N \qquad (6)$$

Where N is the Number of autonomy

The Safe energy storage is expressed as:

$$B_{ES} = \frac{B_E}{B_{DOD}} \qquad (7)$$

B_{DOD} is the battery depth of charge

The total capacity of battery bank is expressed as:

$$N_{BC} = \frac{B_{ESB}}{V_B} \qquad (8)$$

Where V_B is the voltage of the selected battery measured in Volt.

The total number of battery required in bank is expressed as

$$N_{BB} = \frac{B_{CB}}{B_C} \qquad (9)$$

Where B_C is the capacity of the selected battery measured in Ah.

Number of battery in series is expressed as:

$$N_{BS} = \frac{V_{DC}}{V_B} \qquad (10)$$

Total charge controller current is expressed as:

$$I_{TCC} = I_{SC} * N_{MP} * 1.25 \qquad (11)$$

Where 1.25 is a safe factor as recommended by IEC
I_{SC} is the short circuit current of the PV panel

Number of charge controller need is calculated as:

$$N_{CC} = \frac{I_{TCC}}{I_{BC}} \qquad (12)$$

Where B_{SC} is the current rating of the selected battery controller.

Normally, the required solar inverter power is sized by scaling the sum of the power in Watt with a safe factor of 125%. But if there are high current inductive loads, a scale of 3 times inductive loads is added. These loads should be sorted and calculated. The only high current inductive load in this work is the refrigerator, which consumes a power of 500Wh/day.

The total inverter power needed can thus be calculated as:

$$P_{IT} = 1.25(P + 3Q) \qquad (13)$$

Where
P is the power of all is loads running simultaneously
Q is the power of all inductive loads with large surge currents

4. Design Procedure

The method to be used in this work relies on the Optimization Principle. With this approach, indices such as low of operating cost, improve electricity supply will be used to measure the optimal system. The basic requirement for the design of any solar based conversion system is the knowledge of the optimal orientation and tilt angle surface at which peak solar energy can be collected. We defined the meteonorm for the calculation of annual total yield for every moth of the year. To receive more solar energy to meet the user's need and to reduce the investment cost, the tilt angle was selected to North East 15^o, and the azimuth angle of 0^o was considered as well. During the raining season, the transposition factor (FT) is 1.04 while loss by respect to optimum is -0.3%. The Global on collector plane is 802Wh/mm^2. On the other hand, during the dry season, the FT is 0.94 while loss by respect to optimum is -6.4%. The Global on collector plane is 674Wh/mm^2. For yearly irradiation, FT is 0.99 and the loss by respect of optimum is 0.8%, The Global on collector plane is 1477Wh/mm^2

5. System Description and Application

One of the requirements for execution of any solar PV project is to have the knowledge of the system location, weather data, solar irradiance measured in (W/d), and solar irradiation measured in kWh/d. The PV system in this work is a stand-alone type. The location for the project is Port Harcourt. Port Harcourt is 5.4 latitude and 4.4 longitudes. The latitude specifies location on the earth's surface. It is an important variable in solar systems' calculations, including the radiation incident on a titled surface. The system location and solar monthly data can be found in a suitable sizing software or NASA. There are three seasons in this region: the winter, which is normally called the raining season, the summer, which is called the dry season; and the moderately warm season, which can be called the spring. The lowest mean temperature in the region is about 23.3^{o}C and the highest is about 33.4^{o}C. For the dry season, the total average daily load used per hour is 2300Wh/d. This of course means daily use of fans and fridge is high since it is dry season. On the other hand for the rainy season, the user needs less use of fan and fridge since the season is characterized with rains and cool breeze, thus the average daily power used per day is 2006Wh/d. For the season that is moderately warm and cold, the loads are moderately defined. The average daily load per day is 2200Wh/d.

For applications where the load varies significantly on a daily or monthly basis, the average daily load for each day or month has to be determined. A yearly consumption definition was used in this work. For yearly estimate of the three seasons, the mean daily use and power consumption of the appliances was calculated and obtained as 2170Wh/d. Table 1 shows the load profile construction for the yearly load consumption.

Table 1: System Load Profile Construction

Appliances	Quantity	Power (W/Appliance)	Average Daily Use (h/d)	Daily Consumption (Wh/d)
32'' Color TV	1	120	3	360
Fan	3	10	7	210
Fridge	1	100	5	500
Florescence Lamp	6	8	5	240
Laptop Computer	1	120	3	360
Iron	1	1000	0.5	500

6. Simulation Results

An estimated load of 2.2Wh/d was gotten to take care of for losses. Choosing 4 days of autonomy and 5% of lost-of-load of probability, the estimated battery energy of 427Ah of was recommended and 802Wp nominal PV panel power. The high estimated battery energy implies less charging time as shown in figure 1. 185Wp modules was chosen, of which 4 string of the panel can be connected to meet the users need of 2.2kWh/d. The PV panel Maximum Power Point Voltage (MPPV) is 30.3V at temperature of 60^{O}C while the open circuit voltage is 51V at -10^{O}C temperature. Other operating parameters of the PV are shown in table 2. The capacity of the selected batteries is 160Ah. The battery voltage is 12V and the battery stored energy is 1.5kWh at 80 percent depth of discharge (DOD). Number of batteries in series and parallel is 1 and 6 respectively. The voltage of the Maximum Power Point Tracker (MPPT) converter is 12V with maximum discharging and discharging current of 23A and 8A respectively, for the system with 4 days of number of autonomy.

For the system with 2 days of autonomy, and same loss- of load of probability, 860Wp of PV panel was recommended. This is higher than the recommended capacity for the system with 4 days of autonomy. The high number of panel also implies high cost of purchase, compared to the system with 4 days of autonomy. The operating parameter of the system can also be found in table 2. However, the estimated battery capacity is 213Ah, lower than that of the system with 4 days of number of autonomy. This shows that little battery energy storage is needed. Again, because the storage capacity is low, this requires more charging time as illustrated in figure 2. The battery voltage is 24V and the battery stored energy is 3.1kWh at 80 percent depth of discharge (DOD). 1 battery can be connected in parallel while 2 batteries are connected in series.

The voltage of the Maximum Power Point Tracker (MPPT) converter is the same for the system with 2 days of number of autonomy.

Table 2: Operating parameters of the studied systems

System Type	System with 4 Days of autonomy	System with 4 Days of autonomy
Model Type	AE QM 5/72 185	AE QM 5/72 185
Peak Power	185Wp	185Wp
Maximum Power Point Voltage(V_{mpp})	30V	30V
Maximum Power Point Current(I_{mpp})	20.1A	25.3A
Open Circuit Voltage(V_{OC})	51V	51V
Short Circuit Current(I_{SC})	21.6A	27A
Maximum System Voltage	38V	38V
Normal Operating Cell Temperature	60^{O}C	60^{O}C
Area	5mm^2	6mm^2

Figure 1: State of Charge of battery PV system with 4 days of autonomy

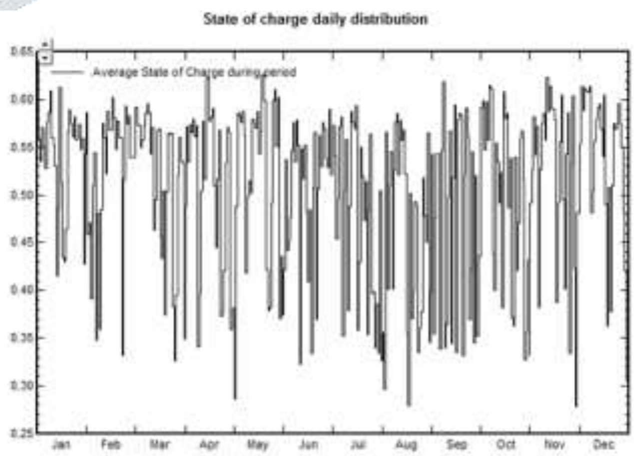

Figure 2: State of Charge of battery PV system with 2 days of autonomy

Figure 3 and 4 shows the graph for the system performance ratio. As seen in figure 3, the performance ratio for the system with 4 days of autonomy is 0.6, while that of the system with 2 days of autonomy is 0.50 which is 60% and 50% performance respectively. The performance of the system with 4 days of autonomy seems to be improved due to less charging and discharging of the battery. However, in the two cases, the month of January and December gave the highest yield while the month of August gave the lowest yield. This is due to the amount of solar radiance in the systems location during these periods.

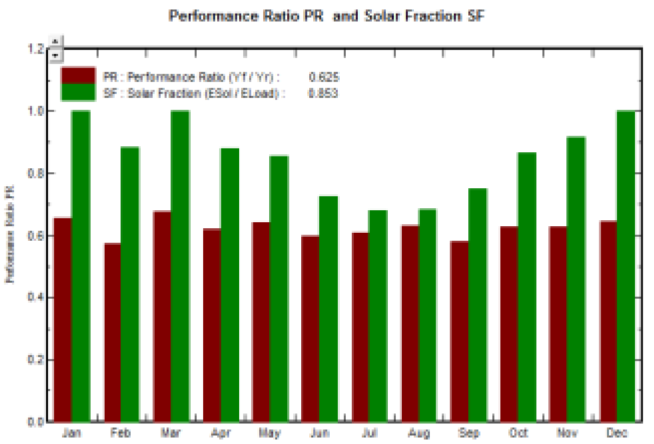

Figure 3: Performance Ratio of system with 4 days of autonomy

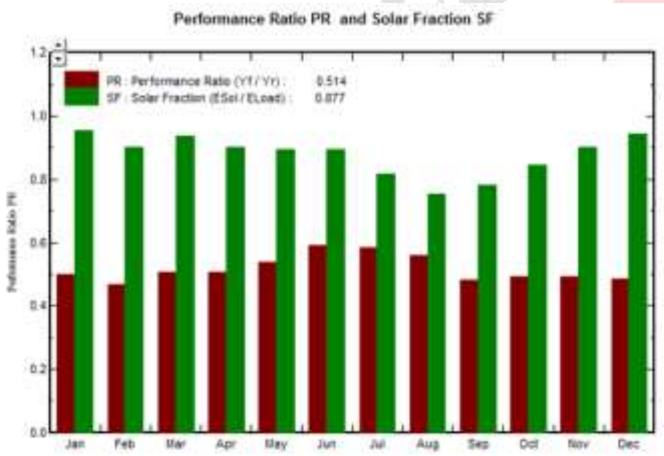

Figure 4: Performance Ratio of system with 2 days of autonomy

7. Conclusion

Design performance evaluation of a PV system situated in Rivers State University, Port Harcourt have been carried out in this research. The study was done using PVSyst 6.4.3 software to simulate and acquire the system required parameters. The variances in design parameters of a solar PV system can cause huge difference in the performance of the system. If the days of autonomy are low more PV panel capacity will be required. From the results section, it can be observed that the location of the system plays a great part in sizing. It is vital that accurate information on solar radiation is obtained to avoid over sizing or under sizing of the system.

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