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Analysis Of Centralized PV Array Solar Power For Street Light Using PVSYST Simulation Software

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***Abstract*— In this paper, the analysis of centralized photovoltaic (PV) array solar power system for street light is presented. In this case, the PV array are installed in one location and the energy they generate is used to power the street light on several poles. The load demand of the street light is determined from the knowledge of the street light route length, the adjacent pole distance, the number of street light poles, the power rating of the street light per pole and the number of operating hours per day. In all, the 3.83 Km route street light has load demand of 76.8 kWh per day. PVSyst software was used to select the appropriate PV system component sizes and also to simulate the PV system. The simulation results show that the yearly energy demand is 28,032 kWh, the energy effectively supplied to the user yearly is 26,872 kWh and the energy produced yearly by the PV array is 28,174 kWh while the yearly solar fraction is 0.959. The results show that the value of operating efficiency based on the total PV module area of 13.25 % as obtained from the PVSyst simulation is approximately the same as the value of 13.31 % obtained from the analytical computation. Similarly, the results show that the value of operating efficiency based on the total PV cell area of 15.19 % obtained from the PVSyst simulation is the same as the value of 15.19 % obtained from the analytical computation. In all, the analysis of the street light solar power system as presented in this paper, provides essential approach for validating some simulation generated parameters of the system using analytical computation approach.**

Keywords* — *Solar Power, Street Light, PVSyst, Simulation Software, Diffused Irradiation, Load Demand, Street Light, Global Irradiation

1. INTRODUCTION

Today, across Nigeria, the rising insecurity challenges has called for measures to tackle the issues [1,2,3,4,5,6,7,8,9,10,11,12]. Accordingly, some States governors are advocating for state police, community policing and other forms of security frameworks to secure their domain [13,14,15,16,17,18,19,20]. In addition, the night-time security is also top on the list; increasingly, some States are installing solar-powered street light in the urban centres and their adjoining communities [21,22,23,2,4,25,26]. This is to facilitate safe night businesses and legitimate activities that do take place at night in the various city centres.

Notably, the use of photovoltaic solar power to run the street light project has been due to the poor power supply from the national grid [27,28,29, 30,31,32, 33,34,35, 36,37,8,39, 40, 41, 42,43, 44,45,46]. Even in the urban centres with relatively fair access to the national grid, there is uncertainty on the availability of power at night times when the street lights are needed most. In such case, the usual alternative had been diesel power generator. However, given the environmental unfriendly nature of such power supply and the relatively long-term cost benefit of the PV power supply, most State in Nigeria have adopted the solar-powered option [47,48,49,50,51,52,53,54,55,56,57,58,59].

Accordingly, in this paper, analysis of centralized PV array solar power system for street light is studied. The centralized PV array is considered because of the high rate of failure of the discrete (per pole) PV module approach. Also, the problem of vandalisation is a setback for the per pole PV module approach. In this study, the analysis was conducted using PVSyst simulation software and the operating efficiency of the PV array was validated using analytical approach.

2 METHODOLOGY

2.1 Determination of the Load demand of the street light

The load demand of the street light is determined from the knowledge of the street light route length, the adjacent pole distance, the number of street light poles, the power rating of the street light per pole and the number of operating hours per day. The street light route length is determined using the Google map distance measurement, as presented in Figure 1. The listed parameters are presented in Table 1 for the case study street light. The street light path (Figure 1) started from Waterline junction along Aba road Port Harcourt at coordinates of 4.817243, 7.009501 to River State University junction long Mile 3 Diobu road at coordinates of 4.806253, 6.987958. A total of 3.83 Km route. The daily load demand is determined using the specifications presented in Table 1 and the hourly distribution of the energy demand is given in Figure 2. The

3.83 Km route street light has load demand of 76.8 kWh per day. The global irradiation, the diffused irradiation, the ambient temperature and the wind speed of the case study site are presented in Figure 3.

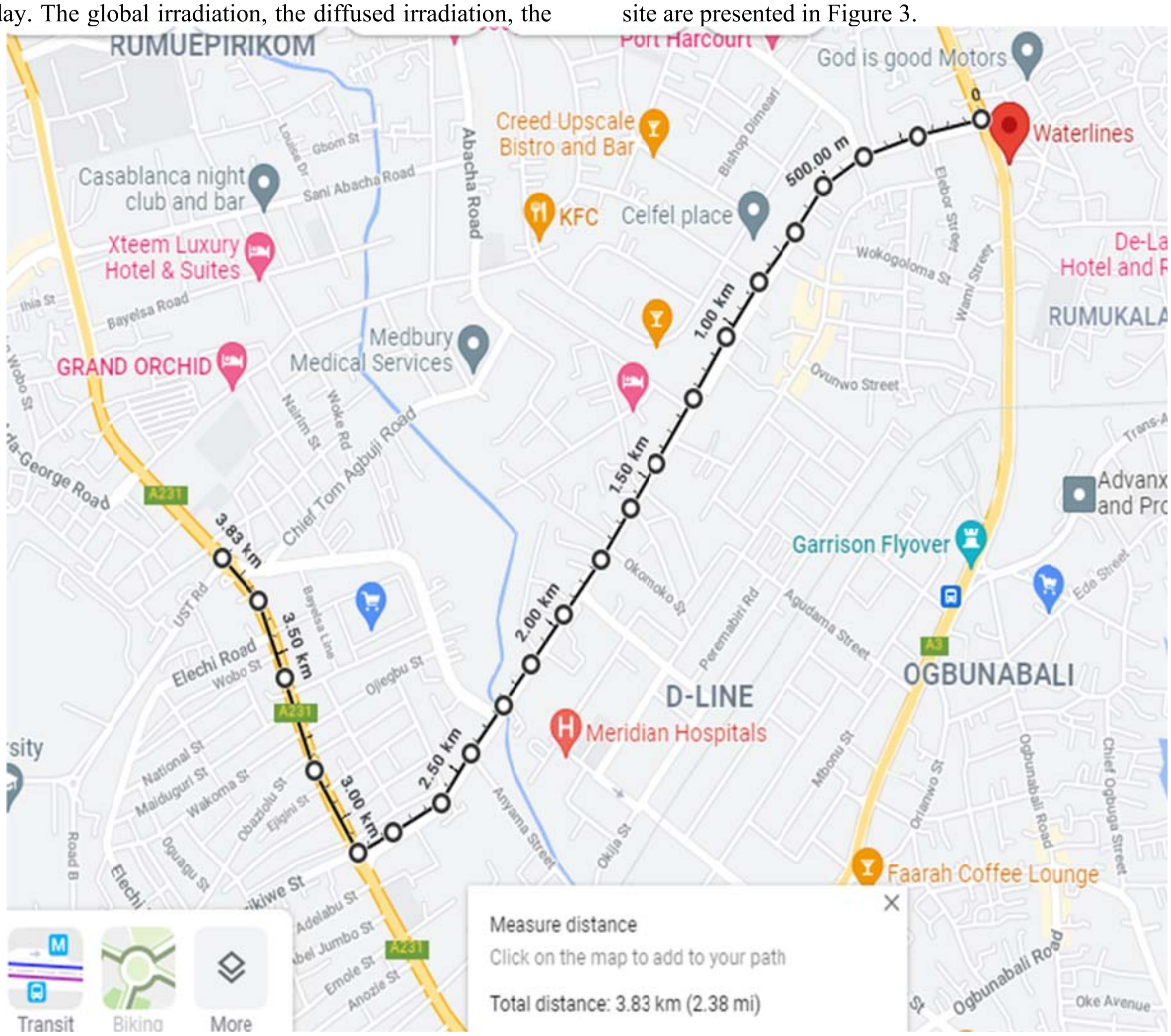


Figure 1 The Google map-Based Distance Measurement for the Street Light Path Length

Table 1 The Daily Load Demand and the parameters used to compute it

S/N	Parameter title and unit	Parameter Value	Comment/Formula
A	Route Length of Street Light (Km)	1.915	Measured value (specified value)
B	Adjacent Poles Distance (m/P)	15	Measured value (specified value)
C	Watts/pole	50	Measured value (specified value)
D	Total no. of poles	128	$\frac{(A)(1000)}{B}$
E	Total watts (Kw)	6.4	$(D)\left(\frac{C}{1000}\right)$
F	No. of hours in operation (hour)	12	Measured value (specified value)
G	Daily Energy Demand (kWh)	76.8	(F)(E)

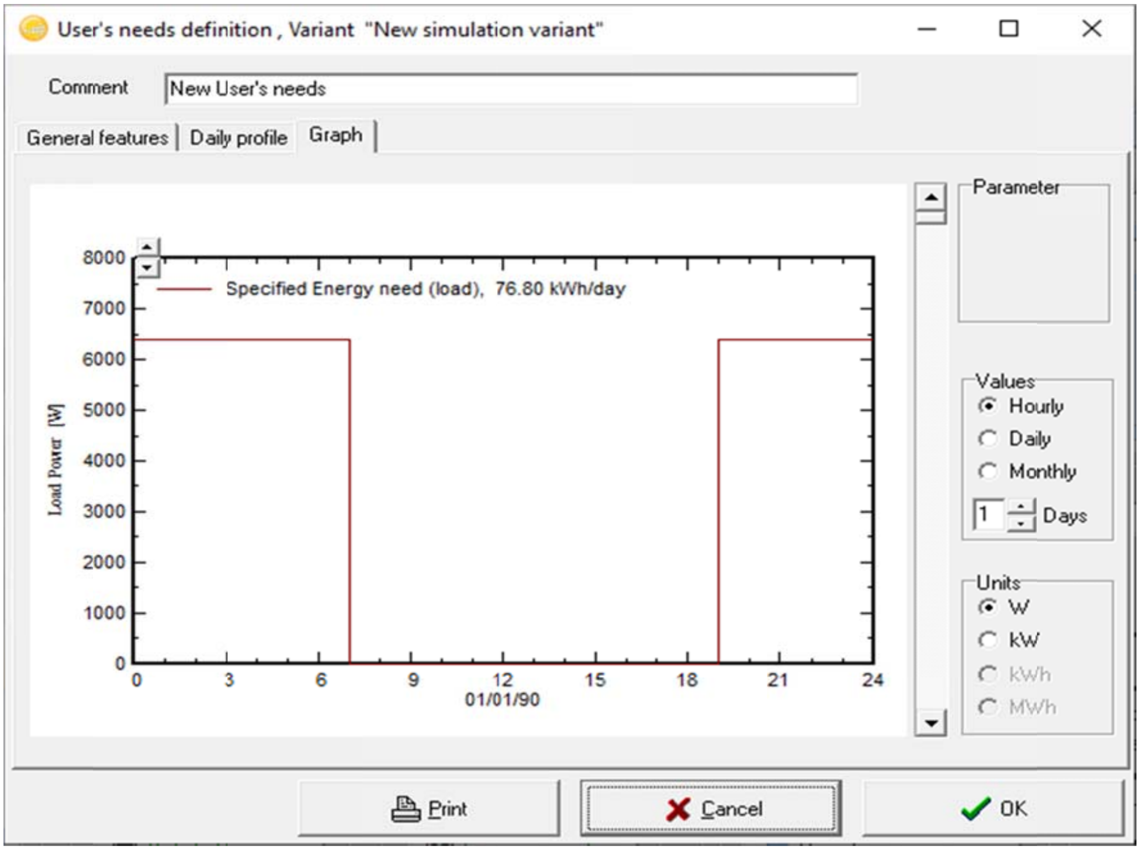
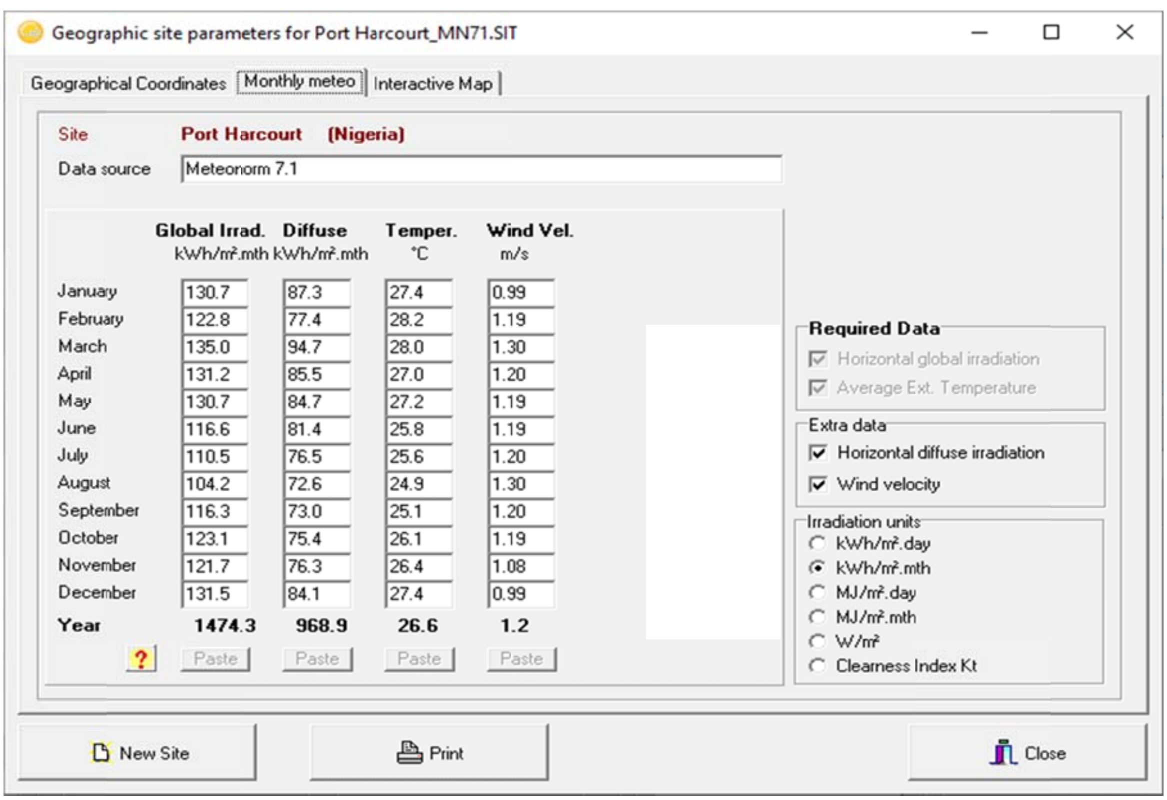


Figure 2 The hourly distribution of the energy demand per day



	Global Irrad. kWh/m².mth	Diffuse kWh/m².mth	Temper. °C	Wind Vel. m/s
January	130.7	87.3	27.4	0.99
February	122.8	77.4	28.2	1.19
March	135.0	94.7	28.0	1.30
April	131.2	85.5	27.0	1.20
May	130.7	84.7	27.2	1.19
June	116.6	81.4	25.8	1.19
July	110.5	76.5	25.6	1.20
August	104.2	72.6	24.9	1.30
September	116.3	73.0	25.1	1.20
October	123.1	75.4	26.1	1.19
November	121.7	76.3	26.4	1.08
December	131.5	84.1	27.4	0.99
Year	**1474.3**	**968.9**	**26.6**	**1.2**

Figure 3 The global irradiation, the diffused irradiation, the ambient temperature and the wind speed of the case study site

2.2 Determination of the Daily and Yearly Energy Output Of PV Module

The energy that can be generated per day ($E_{PVDaily)}$) by the PV array can be determined using the irradiation data, the ambient temperature and the PV module parameters. Notably, the PVSyst generates the hourly solar irradiance and ambient temperature data. With the hourly data the PVSyst simulates the daily and yearly energy output of the PV system. The mathematical relationship for estimating the daily energy production ($E_{PVDaily)}$ based on the hourly solar irradiance ($\mathrm{G_t}$) at time t can be calculated as follows;

$$E_{PVDaily} = \sum_{t=0}^{t=24}\left(P_{PVarray(stc)}\left(\frac{(G_t)(t)}{1000}\right)\left\{1+\left(\frac{\%\gamma_{pv}}{100}\right)\left(T_{c(t)}-25\right)\right\}\left\{\left(f_{(dirt)}\right)\left(f_{(mm)}\right)\left(f_{(cable)}\right)\left(f_{(inv)}\right)\right\}\right) \quad (1)$$

Where $P_{array(stc)}$, $P_{PVarray(stc)}$ denotes Standard Test Condition (STC) total array power rating (kWp), $G_{t(STC)}$ denotes STC peak solar radiation which is 1000 w/m^2, $T_{(t)}$ denotes cell temperature of the PV PV module at time t, $T_{c(STC)}$ = 25°C, $f_{(dirt)}$ denotes dirt de-rate factor (typical value is 0.97), $f_{(mm)}$ denotes mismatch factor of the PV module, $f_{(cable)}$ loss factor due to cable inefficiency (typical value 0.95 to 0.99) , $f_{(inv)}$ denotes inverter efficiency and $\%\gamma_{(pmp)}$ denotes PV module temperature coefficient in %/°C.

Hence, the annual energy production ($E_{PVYEAR)}$is defined as;

$$E_{PVYEAR)} = \sum_{i=0}^{i=365}\left(E_{PVDaily(i)}\right) \quad (2)$$

The key performance parameters are determined using the PVSyst simulation software. The operating efficiency of the system is also computed and compared with the one generated from the PVSyst simulation. The PV system configuration used in the simulation is shown in Figure 4.

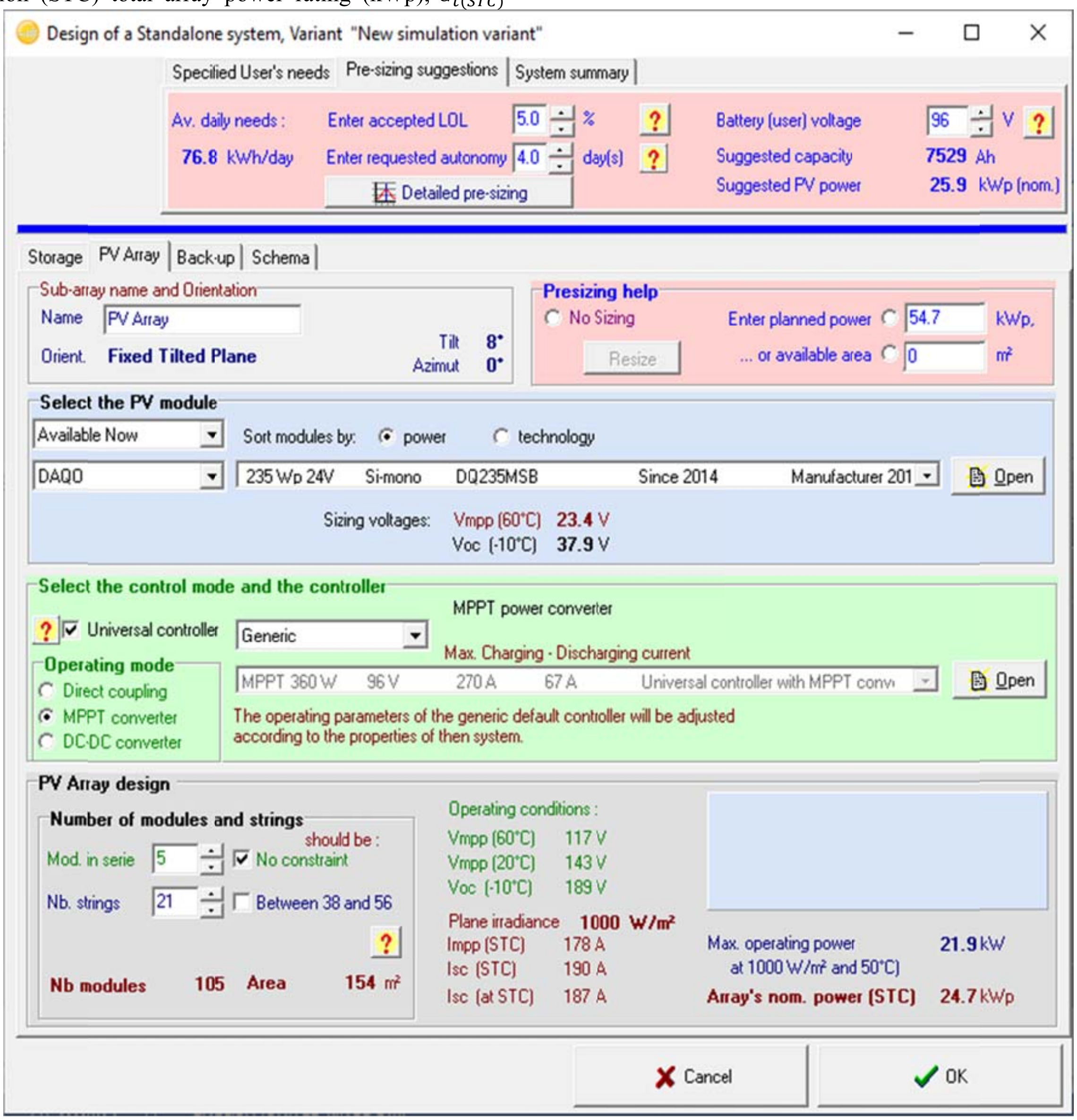


Figure 4 The PV system configuration used in the simulation

3 RESULTS AND DISCUSSION

The simulation results showing the monthly and annual available output energy, the load demand energy, the energy supplied to the user as well as the solar fraction are shown in Figure 5 while Figure 6 shows the bar chart of the monthly available output energy, the load demand energy and the energy supplied to the user. The results in Figure 5 and Figure 6 show that in the months of July, August and September, there are not enough generated energy to meet the load demand for the street light. In that case, in those three months there will be some nights that the street light will not last throughout the night. The yearly energy demand is 28,032 kWh, the energy effectively supplied to the user yearly is 26,872 kWh and the energy produced yearly by the PV array is 28,174 kWh and the yearly solar fraction of 0.959.

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail kWh	EUnused kWh	E Miss kWh	E User kWh	E Load kWh	SolFrac
January	130.7	130.9	2577	0.15	0.0	2381	2381	1.000
February	122.8	121.4	2362	0.00	0.0	2150	2150	1.000
March	135.0	130.6	2570	66.52	0.0	2381	2381	1.000
April	131.2	124.2	2449	0.15	0.0	2304	2304	1.000
May	130.7	121.5	2407	0.15	0.0	2381	2381	1.000
June	116.6	107.4	2166	0.00	0.0	2304	2304	1.000
July	110.5	102.2	2061	0.15	384.5	1996	2381	0.839
August	104.2	97.8	1972	0.00	510.6	1870	2381	0.786
September	116.3	111.5	2219	0.00	264.6	2039	2304	0.885
October	123.1	120.7	2373	0.30	0.0	2381	2381	1.000
November	121.7	121.7	2405	0.00	0.0	2304	2304	1.000
December	131.5	132.7	2615	0.15	0.0	2381	2381	1.000
Year	1474.4	1422.6	28174	67.56	1159.7	26872	28032	0.959

Figure 5 The simulation results showing the monthly and annual available output energy, the load demand energy, the energy supplied to the user

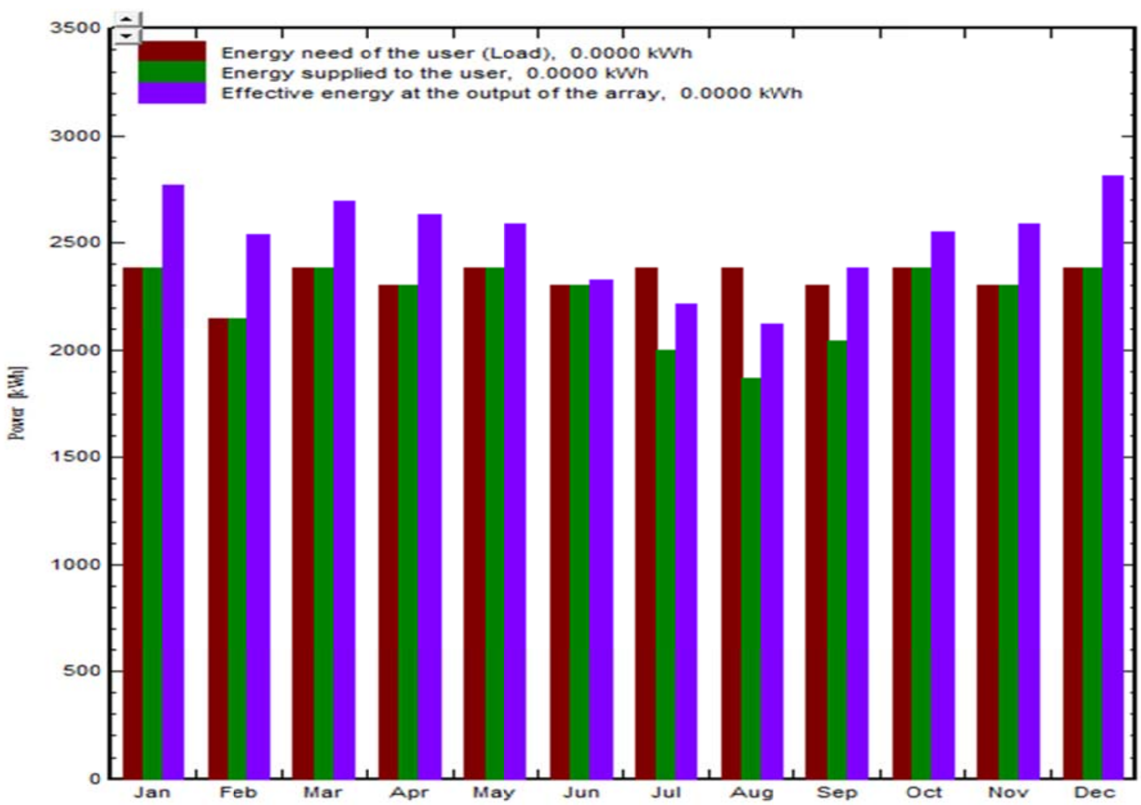


Figure 6 The bar chart of the monthly available output energy, the load demand energy and the energy supplied to the user.

The simulation results showing some key simulation parameters of the PV array is shown in Figure 7. According to the results in Figure 7, the total module area of the PV array is 154 m^2 and the total cell area for the PV array is 135 m^2. Again the daily input and output graph plot if shown in Figure 8. A point at input irradiance on the plane of the PV module of 4 kWh/m^2 $per\ day$ is selected on the daily input and output graph of Figure 8 and that point corresponds to a daily output energy of 82 kWh $per\ day$. The set of information from Figure 7 and Figure 8 are used to determine the actual operating efficiency of the PV array when computed with respect to the total PV module area and when computed with respect to the total PV cell area. The computation is performed as follows;

From Figure 7 we have;

- Total Module Area = 154 m^2
- Total Cell Area = = 135 m^2

From Figure 8 we have;

- Selected Input Irradiance on the plane of the PV module = 4 kWh/m^2 $per\ day$
- The effective energy at the output of the array for the selected Input Irradiance of 4 kWh/m^2 $per\ day$ irradiation = 82 kWh $per\ day$

Operating Efficiency Based on Total Module Area

$$=\left[\frac{82\text{ kWh } per\ day}{(4\text{ kWh}/m^2\ per\ day)(Module\ Area)}\right]100\ \%$$

Operating Efficiency Based on Total Module Area

$$=\left[\frac{82\text{ kWh } per\ day}{(4\text{ kWh}/m^2\ per\ day)(154\ m^2)}\right]100\ \% = 13.31\%$$

Similarly,

Operating Efficiency Based on Total Cell Area

$$=\left[\frac{82\text{ kWh } per\ day}{(4\text{ kWh}/m^2\ per\ day)(\text{Total Cell Area})}\right]100\ \%$$

Operating Efficiency Based on Total Cell Area

$$=\left[\frac{82\text{ kWh } per\ day}{(4\text{ kWh}/m^2\ per\ day)(135\ m^2)}\right]100\ \% = 15.19\%$$

The PVSyst simulated values for operating efficiency based on total PV module area (EffArrR) and operating efficiency based on total PV cell area (EffArrC) are shown in Figure 9. The results show that EffArrR = 13.25 % obtained from the PVSyst simulation is approximately the same as the value of 13.31 % obtained from the analytical computation. Similarly, the results show that EffArrC = 15.19 % obtained from the PVSyst simulation is the same as the value of 15.19 % obtained from the analytical computation.

Furthermore, the results on the monthly and annual performance ratio and solar fraction is shown in Figure 10. The performance ratio of 0.737 or 73.7 % means that about 26.3 % of the energy generated was lost due to several factors.

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Stand Alone System: Simulation parameters

Project :	**STREET LIGHT**			
Geographical Site	**Port Harcourt**		Country	**Nigeria**
Situation	Latitude	4.77° N	Longitude	7.02° E
Time defined as	Legal Time	Time zone UT+1	Altitude	16 m
	Albedo	0.20		
Meteo data:	**Port Harcourt**	Meteonorm 7.1 - Synthetic		
Simulation variant :	**New simulation variant**			
	Simulation date	28/03/22 15h29		
Simulation parameters	System type	**Stand-alone system**		
Collector Plane Orientation	Tilt	8°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
PV Array Characteristics				
PV module Si-mono	Model	**DQ235MSB**		
Original PVsyst database	Manufacturer	DAQO		
Number of PV modules	In series	5 modules	In parallel	21 strings
Total number of PV modules	Nb. modules	105	Unit Nom. Power	235 Wp
Array global power	Nominal (STC)	**24.68 kWp**	At operating cond.	21.94 kWp (50°C)
Array operating characteristics (50°C)	U mpp	124 V	I mpp	178 A
Total area	Module area	**154 m²**	Cell area	135 m²

Figure 7 The simulation results showing some key simulation parameters of the PV array

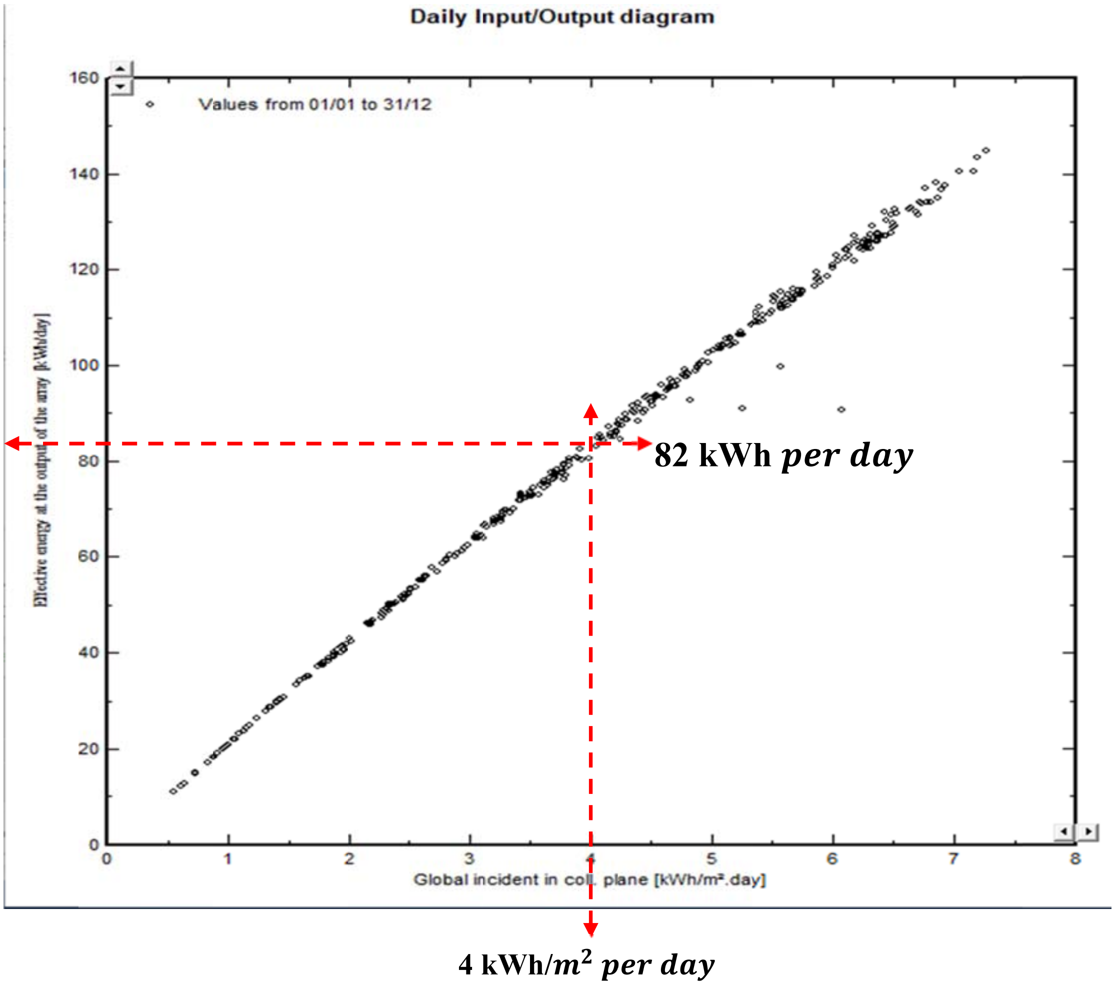

Figure 8. the daily input and output graph plot

	EffArrR %	EffArrC %
January	13.21	15.16
February	13.08	15.01
March	12.86	14.75
April	13.22	15.16
May	13.26	15.20
June	13.46	15.43
July	13.47	15.45
August	13.49	15.48
September	13.34	15.30
October	13.21	15.15
November	13.26	15.21
December	13.23	15.18
Year	13.25	15.19

Figure 9 The PVSyst simulated values for operating efficiency based on total PV module area (EffArrR) and operating efficiency based on total PV cell area (EffArrC)

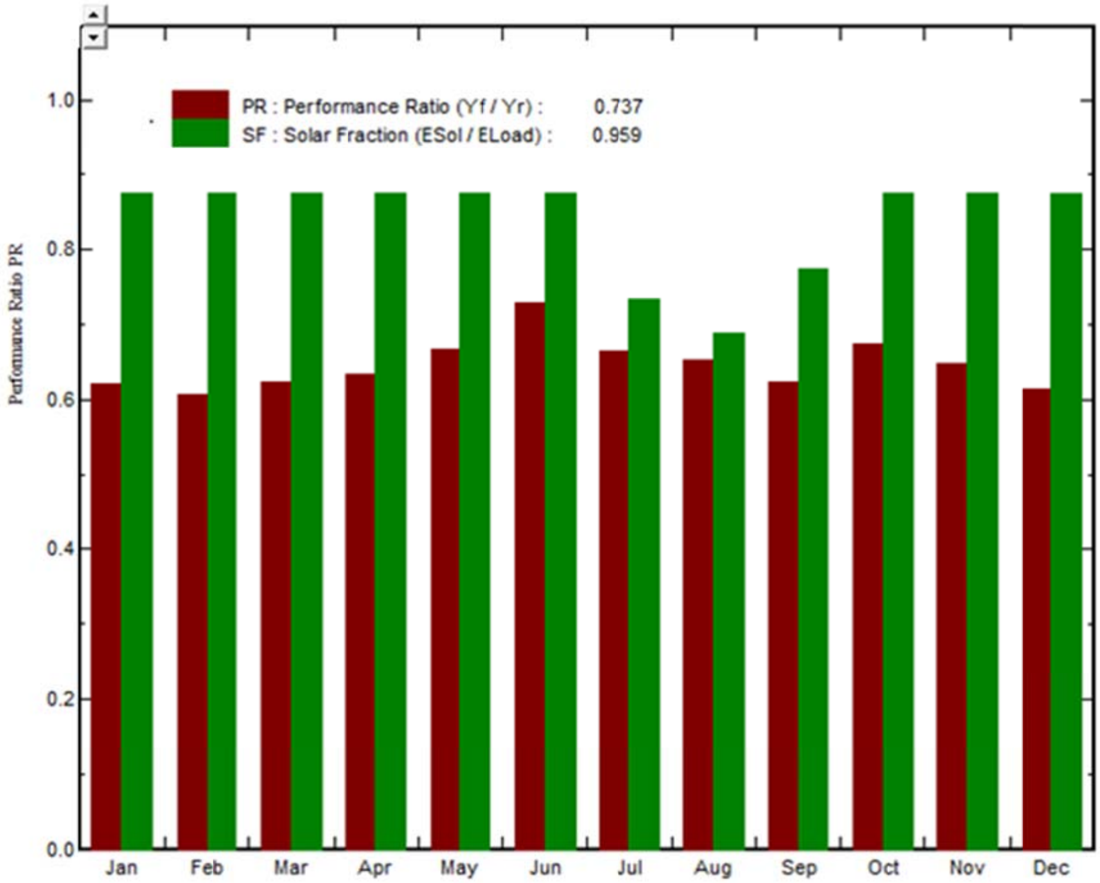

Figure 10 The monthly and annual performance ratio and solar fraction

4 CONCLUSION

The analysis of the solar system for powering street light is presented. The daily energy demand of the street light was determine and the mathematical expression for computation of the daily energy yield of PV array that can meet the daily energy demand were also presented. The PVSyst software was used to select the appropriate PV system component sizes and also to simulate the PV system. The results was further analytically evaluated to determine the operating PV efficiency and to compare the two results. In all, the analytically computed operating efficiency of the PV array is the same as the result generated from the PVSyst simulation.

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