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Performance Evaluation of 10KVA Solar Power System in Semi-Arid Climate Condition: a Case Study of Uromi, Edo State, Nigeria

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Abstract: *This study investigated the performance of a 10KVA stand-alone solar photovoltaic system to determine the cell operating factor and cell efficiency of the system. The stand-alone solar photovoltaic system was made up of 48V inverter, twenty (20) solar panels of 80W, 12V each, eight (8) deep cycle batteries of 150Ah, 12V each, a 60A Tristar solar controller, a digital multimeter for measuring the voltage produced by the solar panels and an analog panel meter for measuring the current produced by the solar panels. The system was operated for four months, from January through April, 2024 and voltage and current readings were taken for all days from 6.00am in the morning to 7.00pm in the evening. Maximum power output, fill factor and efficiency ca were then calculated. The average cell operating factor or fill factor for the twenty solar panels was found to be 0.49 while the average efficiency was obtained to be 9.05%. These values are however lower than the laboratory or theoretical values.*

Keywords: *Photovoltaic, Solar panel efficiency, Fill factor, Performance*

INTRODUCTION

The main objective of photovoltaic (PV) research industry is to develop high efficiency low-cost photovoltaic cells (modules). Photovoltaic technology clearly offers tremendous environmental benefits in that it requires no fuel and produces no emissions or other waste beyond that inherent in the manufacturing process. Moreover, photovoltaic have proven to be deployed for a wide range of applications that have traditionally relied on diesel generators. The use of photovoltaic cell has increased in the last few decades as their manufacturing cost have decreased and as many people have become more concerned about energy use. Unfortunately, solar cell is still far too expensive to produce a significant fraction of the world's energy needs.

The basic requirement of photovoltaic power generation system in any geological location of outdoors depends on operating conditions. The information given by the manufacturers of a PV module is based on standard test condition. Electrical properties of a PV devices comprise of seven parameters which are: open circuit voltage, short circuit current maximum power, maximum voltage, maximum current, conversion of efficiency and fill factor. These parameters measured at standard test condition are supplied by the manufacturer, and the results may not agree with actual local operating condition due to variations of environmental parameters. Consequent upon this, a large number of researches on solar photovoltaic cells exist in literature. The performance comparison of fire different types of solar power PV modules including crystalline silicon (C-Si) module with laser grooved buried contact, polycrystalline silicon (P-Si), triple junction amorphous silicon and copper indium diselenide (CIS) in the climate of Perth for a year was reported and the results showed that this film PV modules have high performance ratio and produce most energy at that site (Ahmed *et al.,* 1997).

The investigation of the performance of monocrystalline and polycrystalline amorphous silicon and copper indium diselenide PV modules for three consecutive days in Malaysia was carried out by (Amin *et al.,* 2009) and it was found that CIS module had performance ratio of 1.09 which is the highest amongst four tested PV module. Experimental investigation also showed that monocrystalline PV module performed best in terms of maximum efficiency and overall energy production at that region (Carr and Pryor, 2004). Others researchers (Gossen and Kersebaever, 1997), investigated the outdoor performance of amorphous silicon and polycrystalline silicon module and concluded that amorphous silicon has high efficiency and output power during summer time and it was opposite for polycrystalline silicon module. In spite of many researches, there has been influx of various types of solar panels from different countries into Nigeria as a result of extensive usage of photovoltaic systems in the country. It has been observed that the theoretical efficiency and operating factors claimed by some manufacturers may not necessarily be the practical ones because of the inefficiency of manufacturing processes and connection of solar cells into modules. It is therefore important to test the performance of these solar panels when they are in operation by determining the cell operating factor and cell efficiency. In this paper, a 10KVA stand-alone solar photovoltaic system cell operating factor and cell efficiency performance was determined for the month of January to April, 2024 in Uromi, Edo State. The data and information generated in this work will guide in evaluating the performance of similar systems and also help the public to be aware, advised and get value for their money when investing in solar panels or photovoltaic system.

MATERIALS AND METHODS

In this study, a 10KVA stand-alone solar photovoltaic system was designed installed and operated for four months. The 10KVA stand-alone solar photovoltaic system was made up of a 48V power inverter, twenty (20) solar panels of 80W 12V each, eight (8) deep cycles batteries of 150AH, 12V each, a 60A tristar solar controller, a metal stand on which the twenty (20) solar panels were mounted, a digital multimeter for measuring or recording the voltage produced by solar panels, an analog panel meter to measure the current produced by the solar panel and wiring system. Table-1 shows the specifications and characteristic parameters of the modules used in this research. Rated values are given by the manufacturer of PV modules as STC and actual values are measured of outdoor conditions.

Table-1 Module specification and characteristic parameter

Dimensions	(P-si)
Module dimension(mmxmmxmm)	935x670x35
Weight (kg)	7.5
Maximum series fuse rating	600VDC
Maximum system voltage suitable for the panel	12VDC
Maximum power P_{max}(W)	80
Open circuit voltage V_{oc}(V)	21.6
Voltage of P_{max} (V_{mp}), v_{se}(V)	17.2
Short-circuit current I_{sc} (A)	5.5
Current at P_{max} (I_{mp}), I_{max}(A)	4.65
Normal operating cell temp (°C)	48$\pm$2
Technical standard conditions:	
Air mass, AM	1.5
Solar irradiance (W/m$^{2)}$	100
Temperature condition (°C)	25

2.1 Experimental Setup and Approach

In order to carry out the performance evaluation of a 10KVA stand-alone solar power system, the experiments, were performed outdoors at the Electrical Engineering Department of NICTM, Edo State, Nigeria. The place of the solar module was chosen such that a shadow would not be cast into solar module of any time during the evaluation period. Measurements were taken hourly from 6am to 7pm. The solar power under study was mounted on the south facing rack at fixed tilt angle of 45°with horizontal (at a nearly optimum tilt at this site during the months of experimentation). The plane of array (POA) global solar irradiance was measured using a pyranometer TBQ-2 (sensitivity 11.346V/Wm^2. The solar power was connected to digital multimeter (Fluke 179, true RM, accuracy $\pm$1% for DC current and +0.09% for DC volt) for the measurement of current and voltage. A high power multiturn variable resistance (100W) was connected in series in the circuit to vary the output of module from zero to maximum. A standard resistance of thermometer dector (RTD-PT100) was used to monitor the surrounding ambient temperature to guarantee high accuracy for critical temperature. The maximum power, fill factor, module conversion efficiency and performance ratio are calculated to understand the behaviour of the solar module. Using the following Equations 1 to 10.

Maximum power (P_{max}) = V_{max} x I_{max} (1)

Fill factor (FF) $$\frac{(P_{max}(output)}{V_{oc} \times I_{sc}} \quad (2)$$

Module efficiency (R_m) = $$\frac{P_{max}(output)}{E \times A_c} \times \frac{100}{1} \quad (3)$$

Performance ratio (PR) = $$\frac{P_{max}(output)}{P_{max}(STC \times E \times 100)} \quad (4)$$

Direct solar irradiance (E_D) = $$\frac{E_H}{Cos(\sigma)} \quad (5)$$

To determine quantitatively the effect of temperature on different electrical parameters, the following equations were used to determine the effects of working temperature (T_w) on these parameters with reference to their values at STC

$$(V_{oc}) = (V_{oe})\ STC + \alpha\left(T_w - 25^{oc}\right) \quad (6)$$

$$(I_{se}) = (I_{se})\ STC + \beta\left(T_w - 25^{oc}\right) \quad (7)$$

$$(P_{max}) = (P_{max})STC\ \gamma\left(T_w - 25^{oc}\right) \quad (8)$$

$$\left(\ell_m\right) = \left(\ell_m\right)STC + \delta\left(T_w - 25^{oc}\right) \quad (9)$$

$$(FF) = (FF)STC + \in\left(T_w - 25^{oc}\right) \quad (10)$$

where,

T_w = working temperature

$$\alpha = \frac{dV_{oc}}{dT}\left(V\,^{o}C^{-1}\right)$$

$$\beta = \frac{dI_{sc}}{dT}\left(A^{o}C^{-1}\right)$$

$$\alpha = \frac{dp_{max}}{dT}\left(W\,^{o}C^{-1}\right)$$

$$\delta = \frac{dT}{dT}\left(\%C^{-1}\right)$$

$$\in = \frac{dFF}{dT}\left(OC^{-1}\right)$$

Maximum power output, current at maximum output, maximum power output, operating factor and efficiency change on the 10KVA PV Panel performance for the technology. In this phase, the panels were pointed to the sun and records were taken.

RESULTS AND DISCUSSION

During the research, the calculation of the solar cells operating factor (fill factor) and the cells efficiencies for the months of January, 2024 to April, 2024 are shown in Table-2 to 5.

Table-2 Solar panels operating factors and efficiencies for January

Day	V_{mp}(V)	I_{mp}(A)	P_{max}(W)	FF	R_m
1	51.90	18.00	936.00	0.39	7.34
2	68.00	15.00	1020.00	0.43	8.00
3	53.70	18.00	972.00	0.41	7.63
4	63.10	17.50	1102.50	0.46	8.65
5	59.20	18.00	1062.00	0.45	8.33
6	54.80	18.00	990.00	0.42	7.76
7	56.30	17.50	980.00	0.41	7.69
8	53.90	19.00	1026.00	0.43	8.05
9	54.50	17.50	953.80	0.40	7.48
10	60.40	18.00	1080.00	0.45	8.47

11	54.10	18.00	972.00	0.41	7.63
12	53.30	18.00	954.00	0.40	7.49
13	51.90	18.00	972.00	0.41	7.63
14	57.80	18.00	936.00	0.39	7.34
15	58.10	17.00	986.00	0.40	7.73
16	58.10	19.00	1102.00	0.46	8.65
17	59.20	18.00	1062.00	0.45	8.33
18	54.10	19.00	1102.00	0.46	8.65
19	58.40	17.00	918.00	0.39	7.20
20	55.10	18.50	1073.00	0.45	8.42
21	57.90	17.00	935.00	0.40	7.34
22	53.20	18.00	1040.00	0.44	8.19
23	56.20	18.00	990.00	0.42	7.77
24	61.00	18.00	954.00	0.40	7.49
25	56.30	19.00	1064.00	0.45	8.33
26	61.20	16.00	976.00	0.41	8.67
27	59.00	18.00	1062.00	0.45	7.41
28	65.20	17.00	1105.00	0.47	8.67
29	59.20	16.50	944.00	0.40	7.41
30	62.00	18.00	1116.00	0.47	8.76
31	58.20	18.00	1044.00	0.44	8.19
				13.23	246.63

Table-3 Solar panels operating factors and efficiencies for February

Day	V_{mp} (V)	I_{mp}(A)	P_{max}(W)	FF	R_m
1	80.90	20.00	1618.00	0.68	12.70
2	80.20	19.00	1523.00	0.64	11.96
3	69.50	19.00	132050	0.56	10.36
4	68.90	20.00	1378.00	0.60	10.81
5	67.80	14.00	949.20	0.40	7.45
6	54.80	20.00	1096.00	0.46	8.60
7	67.00	14.00	938.00	0.46	7.36
8	69.30	15.00	1039.50	0.39	8.16
9	78.30	12.00	943.20	0.44	7.40
10	67.50	18.00	1215.00	0.40	9.53
11	69.40	18.00	1249.20	0.51	9.80
12	76.80	12.00	883.50	0.53	7.23
13	58.90	15.00	986.40	0.39	6.93
14	54.80	18.00	1033.50	0.37	7.74
15	68.90	15.00	1372.00	0.42	8.11
16	68.60	20.00	1132.40	0.43	10.77
17	59.60	19.00	392.00	0.48	8.89
18	78.40	15.00	1192.00	0.16	3.08
19	59.60	20.00	1132.40	0.50	9.35
20	59.60	19.00	1208.40	0.48	8.89
21	63.60	19.00	1210.00	0.51	9.48
22	60.50	20.00	1316.70	0.51	9.49
23	69.30	19.00	990.10	0.55	10.33
24	58.30	17.00	833.30	0.42	7.78

25	64.10	13.00	639.00	0.35	6.54
26	63.90	10.00	1206.00	0.27	5.01
27	60.30	20.00	1206.00	0.51	9.46
28	64.30	12.00	768.00	0.32	6.03
29	56.30	9.00	506.70	0.21	3.98
30	60.60	18.00	1090.80	0.46	8.56
				13.53	251.78

Table-4 Solar panels operating factors and efficiencies for March

Day	V_{mp}(V)	I_{mp}(A)	P_{max}(W)	FF	R_m
1	53.00	18.00	954.00	0.40	7.49
2	63.00	17.00	1071.00	0.45	8.40
3	68.10	18.00	1225.80	0.52	9.62
4	68.00	18.00	1224.00	0.52	9.60
5	68.10	19.00	1293.90	0.54	10.15
6	68.90	19.00	1307.10	0.55	10.27
7	62.80	18.50	1161.80	0.49	9.11
8	59.20	18.50	1095.20	0.46	8.59
9	59.00	18.00	1062.00	0.45	8.33
10	65.00	18.00	1170.00	0.49	9.18
11	69.00	19.00	1311.00	0.55	10.29
12	65.30	20.00	1306.00	0.55	10.25
13	78.30	19.00	1487.70	0.63	11.67
14	78.50	18.00	1413.00	0.59	11.09
15	68.40	18.00	1231.20	0.54	9.66
16	64.00	18.00	1152.00	0.47	9.04
17	58.90	19.00	1119.10	0.47	8.78
18	73.20	20.00	1464.00	062	11.49
19	64.50	18.00	1116.10	0.48	9.11
20	68.10	19.00	1293.90	0.54	10.15
21	58.50	19.00	1111.50	0.46	8.72
22	76.00	18.00	1368.00	0.58	10.73
23	66.10	18.00	1189.80	0.56	9.34
24	65.90	20.00	1318.00	0.55	10.34
25	59.90	20.00	1198.00	0.50	9.40
26	75.60	19.00	1436.40	0.50	11.27
27	65.60	19.00	1246.40	0.52	9.78
28	68.20	19.00	1295.80	0.55	10.17
				14.57	261.95

Solar panels operating factor for March, FF_{feb}=0.52 cells efficiency for March, $\gamma_{Mar} = 9.4\%$

Table-5 Solar panels operating factors and efficiencies for April

Day	V_{mp}(V)	I_{mp}(A)	P_{max}(W)	FF	R_m
1	68.50	18.00	1233.00	0.51	9.67
2	68.90	18.00	1240.00	0.52	9.63
3	65.50	18.00	1179.00	0.50	9.25
4	68.90	18.00	1240.20	0.52	9.63
5	65.60	18.00	1180.80	0.50	9.27
6	68.60	20.00	1372.00	0.58	10.76
7	76.40	18.00	137.50	0.58	10.79

8	75.30	18.00	1355.40	0.57	10.64
9	69.50	19.00	1320.50	0.56	10.36
10	68.30	20.00	1366.00	0.57	10.72
11	74.60	18.00	1342.80	0.57	10.54
12	75.00	19.00	1425.00	0.60	11.18
13	70.20	18.00	1263.60	0.53	9.91
14	71.40	18.00	1288.20	0.54	10.08
15	72.2	19.00	1371.80	0.58	10.76
16	68.90	20.00	1378.00	0.60	10.21
17	73.30	20.00	1466.00	0.62	11.50
18	72.80	19.00	1383.20	0.58	10.85
19	78.30	20.00	1566.00	0.66	12.29
20	79.90	20.00	1598.00	0.67	12.54
21	75.10	20.00	1502.00	0.63	11.79
22	79.90	19.00	1518.80	0.64	11.91
23	60.00	20.00	1200.00	0.51	9.41
24	52.70	19.00	1001.30	0.42	7.86
25	70.80	20.00	1416.00	0.61	11.11
26	72.50	20.00	1450.00	0.40	11.38
27	59.20	16.00	947.20	0.52	7.43
28	64.90	19.00	1233.10	0.61	9.68
29	72.90	20.00	1458.00	0.48	11.4
30	60.00	19.00	1140.00	0.47	8.95
31	79.00	14.00	1106.00	0.47	8.68
				17.25	320.82

Solar panels operating factor for April, 2024, FF_{march} = 0.56 cells efficiency for April, 2024.

$\gamma_{Apr} = 40.4\%$

The cells operating factor or fill factor for the twenty solar panels was found to vary between 0.43 and 0.56 for the four months in Uromi of Nigeria, with an average of 0.49 while the cells efficiency varies between 8.0% and 10.4% with an average of 9.05%. This shows that the cell operating factor and cells efficiency are proportional to the power output from the solar panels and varies daily because of the earth's rotation and seasonally due to the change in the sun's declination. The values obtained for the operating factor (between 0.43 and 0.56) are satisfactory because cells operating factors varies between 0.40 to 0.70 depending on the type of semiconductor used to fabricate the cells, the physical state in which the cells are prepared, the process of extraction and purification of raw materials, the surface preparation, dopants diffusion, anti-reflection coating, electrical contacts, connection of cells into modules, as well as insulation of the area (Sheng, 2007). Also, the values obtained for cells efficiency (between 8.0% and 10.4%) are satisfactory because at present, efficiency of commercial solar cells ranges from 20% to 58%. It should be noted that some of the factors that affect the efficiency of solar cell are the type and area of the material (Semiconductor) used to fabricate the solar cell: panel orientation, shading, temperature and accumulation of dirt on the PV module (Kotheri *et al.,* 2011). The study revealed that the practical cell operating factor and cell efficiency are lower than theoretical or laboratory values. One of the reasons for this, is that solar panel, are usually tested under standard test condition. These conditions are not always practical because insulation varies daily and seasonally and from one location to another. Also, the of efficiency depends on the type of semiconductor used in fabricate the cells manufacturing techniques and method of connection of cells into module.

CONCLUSION

A 10KVA commercially available module has been tested at outdoor conditions in Uromi, Edo State during the month of January to April, 2024. A custom made set up was used to determine the characteristic parameters of the PV under study and the results revealed that the power output of module varies linearly with operating factor and cell efficiency. Due to the capability of better in low light condition and having high fill factor (FF) and efficiency, 10KVA is found to suitable solar energy system in Uromi and its surrounding regions.

CONFLICT OF INTEREST

There is no conflict of interest for this research work.

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