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INVESTIGATION OF THE FIELD PERFORMANCE OF MONOCRYSTALLINE AND POLYCRYSTALLINE PHOTOVOLTAIC (PV) MODULES IN ENUGU STATE

by

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ABSTRACT

The field performance data for silicon-based monocrystalline and polycrystalline photovoltaic cell (PV) modules in Enugu State were investigated and collected. The choice of the modules was based on availability, cost and power ratings. The Manufacturers' specifications were taken. The parameters measured and calculated during the experiment were; open circuit voltage (Voc), short circuit current (Isc), relative humidity (R.H), ambient temperature, solar radiance, power, efficiency, fill factor and performance ratio. The results of hourly average values of these parameters were used to plot time series graphs. There was a decrease in Voc of the modules with time, with the Polycrystalline modules clearly showing the Staebler-Wronski effect. The Isc of the modules showed little variation while maximum power of the modules had reduced significantly. The maximum power of most of the modules was found not to match with the manufacturers specifications provided in their data sheet. On inspection of the modules, the polycrystalline modules revealed a defect which was as a result of overheating of the cells. This contributed greatly to its poor performance in comparison with monocrystalline modules. The efficiency of the Monocrystalline modules was found to be above 20%, while that of Polycrystalline was up to 19%. Time series plot for the performance ratio of monocrystalline and polycrystalline PV modules showed that monocrystalline PV modules performed better than polycrystalline PV modules in Enugu state.

Keywords: Monocrystalline, Polycrystalline, Field Performance and Time Series.

1.1 Introduction

The inconsistencies in the supply of conventional power in Nigeria by Power Holden Company and the need to protect our environment from fossil attacks gave room for alternative power supply and this is found in photovoltaic and other environmental friendly technologies. Reliability on solar PV modules became a critical performance measure for the success of the industry (Rongand Govindasammy, 2011). The performance of PV modules has been observed to gradually decrease with operation time (Dunlop and Halton, 2006). Long term performance of PV modules is vital if they have to pay back to the consumer. It is important to investigate the performance parameters of the modules. In order to have maximum sunlight conversion, the tilt and orientation of the modules should be maximized (Akachuku, 2003). According to Duke *et al*., (2010), Nigeria has an active market for photovoltaic (PV) solar home systems (SHSs). Small 80W monocrystalline silicon (c-Si) and polycrystalline (p-Si) modules dominate the Nigerian market. Despite this commercial success, there is substantial concern about the performance of this two PV Modules (Monocrystalline and Polycrystalline) because of the technologies, uneven quality record and the uncertainty introduced by short term degradation which occurs when this type of modules are initially exposed. The field performance parameters of monocrystalline and polycrystalline photovoltaic (PV) modules was investigated at solar moon in Enugu State. Parameters such as short circuit current (Isc), open circuit voltage (Voc), fill factor (FF) and current and voltage at maximum power point of the modules were calculated. The study analysed silicon based solar cell technologies commonly found in the Nigeria market. The findings were used to investigate the degradation rates of the modules, there by determining their stability and reliability. The performance of PV module once in use differs significantly with time from the specifications provided by the manufacturers. This performance degradation of the module greatly affects the output of the modules as well as disappointing the user.

1.2: Study Area

Enugu is located in the southern part of Nigeria. It was created from old Anambra state in 1991 and its capital is Enugu. Its main cities are Nsukka, Enugu, Awgu and Agbani. It shares borders with Imo and Abia to the south, Benue state to the northeast, Kogi state to the northwest, Anambra to the west and Ebonyi to the east. It is on the railroad from Port Harcourt. It is 240 km south-southwest and at the intersection of roads from Onitsha and Abakiliki and Aba. It is about 4 hours' drive from Port Harcourt where coal was shipped; about an hour's drive from Onitsha, one of the biggest commercial cities in Africa and two hours' drive from Aba another very large commercial city. The average temperature runs from 60 degrees Fahrenheit cooler months to 80 degree Fahrenheit in warmer months. It has good soil for agriculture and climatic conditions all year round. It is about 223 metres above sea level, (Wikipedia)

1.2 MATERIALS AND METHODS

In determining the performance test for different PV modules in Enugu State; photovoltaic cells of power rating 10W, 15W and 20W; 12 volts – 100Ah deep cycle solar battery; inverter of 1KVA; Sp-214-4-20mA pyronometer, Hygrometer, Digital meter (Agilent 34401A); K-type thermocouple embedded with multimeters, pulse with modulation solar charge controller and digital clock were used. The initial I-V data of the six silicon based modules; mono crystalline and poly-crystalline of 10 W, 15 W and 20 W respectively from two different manufacturers were measured at an angle of inclination of 15 degrees to determine the initial parameters as shown on figure1.1. The modules were then mounted on a fixed angle rack. Visual inspection of the modules was also done before they were mounted.

Figure 1.1: Experimental set up of solar panels

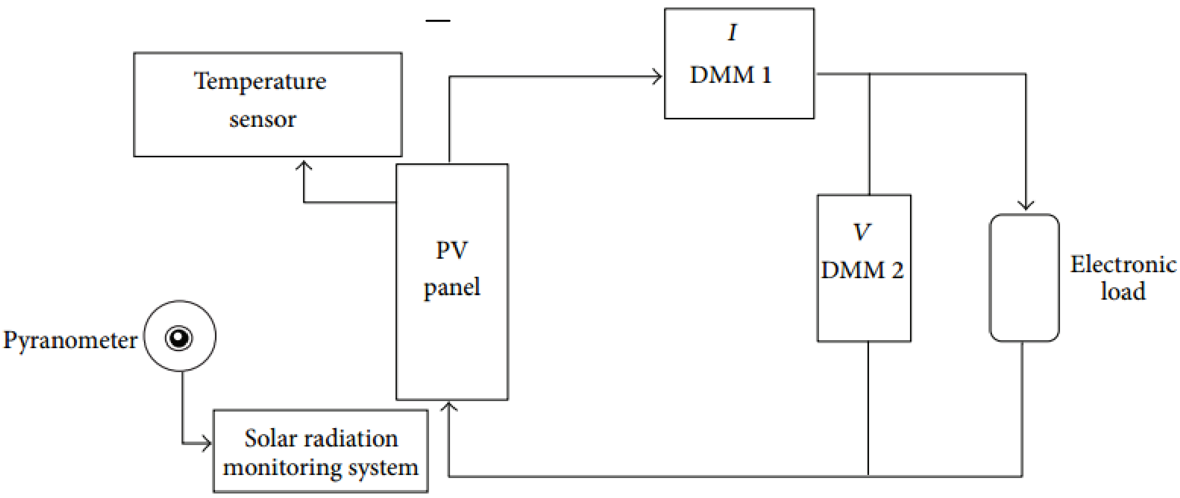

Fig. 1.2: Schematic diagram of experimental setup.

From Figure 1.2, photovoltaic cells of power rating of 10W, 15W and 20W monocrystalline and polycrystalline were placed at a fixed tilt angle of 15 degrees. Charge controller was connected to the photovoltaic cell panel to control the charging of the battery in other to keep the electric cell from overcharging and discharging. Inverter (1KVA) used in the system was for conversion of variable direct current (DC) output of a photovoltaic (PV) solar panel into alternating current (AC). The battery in the system was for storing energy produced by the PV arrays during the day and to supply it to electrical loads as needed. Hourly readings for the output of the PV cells were taken for one month. Parameters measured were current

(Dmm1) and voltage (Dmm2) measured with digital multimeter solar irradiance, measured with pyronometer. Ambient temperature measured with thermocouples and relative humidity measured with hygrometer.

1.3 RESULTS AND DISCUSSION

The parameters measured and calculated during the experiment were; open circuit voltage (Voc), short circuit current (Isc), relative humidity (R.H), Ambient temperature, Solar irradiation, Power, Efficiency, Fill Factor and Performance ratio. The hourly average value of this parameters are shown Table 1.1

Table 1.1: The Average Values of the Observed and Estimated Parameters

Parameters	**10W Mono**	**15W Mono**	**20W Mono**	**10W Poly**	**15W Poly**	**20W Poly**
	Mean	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**
$V_{oc}\ (V)$	19.1 ± 0.3	19.1 ± 0.4	19.1 ± 0.6	18.8 ± 0.4	18.8 ± 0.2	18.8 ± 0.4
$I_{sc}\ (A)$	0.6 ± 0.2	0.7 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.6 ± 0.2	0.5 ± 0.2
$AT\ (°C)$	32.7 ± 1.2	34.6 ± 1.3	35.8 ± 1.7	28.5 ± 0.7	27.8 ± 0.8	28.2 ± 0.5
$RH\ (\%)$	46.4 ± 4.1	46.3 ± 4.5	39.1 ± 3.1	82.4 ± 2.9	79.6 ± 2.9	79.1 ± 3.3
$P(W)$	11.2 ± 4.1	13.1 ± 1.9	13.7 ± 2.5	12.9 ± 2.2	11.7 ± 4.6	10.1 ± 3.4
$Eff\ (\%)$	17.8 ± 4.9	22.2 ± 4.1	15.7 ± 3.1	17.8 ± 2.9	17.8 ± 2.1	16.7 ± 1.8
FF	0.5 ± 0.2	0.6 ± 0.1	0.6 ± 0.1	0.6 ± 0.1	0.6 ± 0.2	0.6 ± 0.2
PR	1.1 ± 0.3	1.2 ± 0.2	0.9 ± 0.2	1.1 ± 0.2	0.9 ± 0.1	0.8 ± 0.1
	Median	Median	Median	Median	Median	Median
$V_{oc}\ (V)$	19.1	18.8	18.8	18.9	18.9	18.7
$I_{sc}\ (A)$	0.6	0.7	0.8	0.7	0.6	0.5
$AT\ (°C)$	32.8	35.1	35.8	28.6	28.1	28.3
$RH\ (\%)$	46.1	48.1	38.1	82.1	79.1	78.1
$P(W)$	11.4	13.5	14.5	13.6	12.2	9.1
$Eff\ (\%)$	19.7	22.2	16.2	16.4	17.3	16.3
FF	0.5	0.6	0.7	0.6	0.6	0.5
PR	1.1	1.2	0.9	0.9	0.9	0.8
	Max	Max	Max	Max	Max	Max

$V_{oc}\ (V)$	19.9	20.0	20.3	19.9	19.6	20.0
$I_{sc}\ (A)$	0.9	0.9	1.0	0.9	1.0	1.0
$AT\ (°C)$	34.9	37.0	39.8	29.9	28.9	29.1
$RH\ (\%)$	64.0	54.0	52.0	89.0	93.0	94.0
$P(W)$	17.5	17.3	19.2	16.9	18.2	20.2
$Eff\ (\%)$	28.4	36.0	23.6	26.9	23.9	30.8
FF	0.9	0.8	0.9	0.8	0.9	1.0
PR	1.5	2.0	1.4	1.5	1.3	1.5
	Min	Min	Min	Min	Min	Min
$V_{oc}\ (V)$	18.2	18.1	18.2	18.1	18.1	18.1
$I_{sc}\ (A)$	0.2	0.5	0.3	0.3	0.2	0.3
$AT\ (°C)$	30.0	29.5	28.4	26.5	18.3	27.1
$RH\ (\%)$	40.0	34.0	34.0	73.0	75.0	73.0
$P(W)$	3.4	8.4	5.0	5.4	3.1	4.9
$Eff\ (\%)$	6.4	9.6	6.8	13.2	11.4	12.3
FF	0.2	0.4	0.2	0.3	0.2	0.3
PR	0.3	0.5	0.4	0.8	0.6	0.6

Table 1.1 shows the Average Values (Mean With Associated Error And The Median), Maximum (Max) And Minimum (Min) Values Of The Observed And Estimated Parameters For The 10 W, 15 W And 20 W Mono Crystalline and Poly Crystalline PV.

Table 1.2: The Correlation Values of the Observed and Estimated Parameters for Monocrystaline PV Modules.

	10 W Mono		**15 W Mono**		**20 W Mono**	
Parameter	r	$m \pm n$	r	$m \pm n$	r	$m \pm n$
$SI \propto V^{m\pm n}$	0.16	2.62 ± 0.14	0.25	2.45 ± 0.11	-0.14	-0.72 ± 0.08
$SI \propto I^{m\pm n}$	0.61	0.40 ± 0.11	0.31	0.40 ± 0.11	0.40	0.24 ± 0.07
$SI \propto AT^{m\pm n}$	0.42	2.92 ± 0.13	0.16	0.81 ± 0.11	0.49	1.22 ± 0.07
$SI \propto RH^{m\pm n}$	0.18	0.51 ± 0.14	-0.42	-0.82 ± 0.10	0.15	0.25 ± 0.08
$SI \propto P^{m\pm n}$	0.61	0.39 ± 0.11	0.34	0.45 ± 0.10	0.38	0.23 ± 0.07
$SI \propto E^{m\pm n}$	-0.04	-0.03 ± 0.14	-0.72	-0.70 ± 0.08	-0.22	-0.14 ± 0.08
$SI \propto FF^{m\pm n}$	0.61	0.40 ± 0.11	0.27	0.35 ± 0.11	0.42	0.25 ± 0.07
$SI \propto PR^{m\pm n}$	-0.04	-0.03 ± 0.14	-0.72	-0.70 ± 0.08	-0.22	-0.14 ± 0.08
$V \propto I^{m\pm n}$	0.27	0.01 ± 0.01	-0.05	-0.01 ± 0.01	-0.01	0.00 ± 0.02
$V \propto AT^{m\pm n}$	0.22	0.10 ± 0.01	0.22	0.11 ± 0.01	-0.12	-0.06 ± 0.02
$V \propto RH^{m\pm n}$	0.26	0.05 ± 0.01	0.06	0.01 ± 0.01	0.16	0.05 ± 0.02
$V \propto P^{m\pm n}$	0.31	0.01 ± 0.01	0.09	0.01 ± 0.01	0.11	0.01 ± 0.02
$V \propto E^{m\pm n}$	0.25	0.01 ± 0.01	-0.18	-0.02 ± 0.01	0.21	0.03 ± 0.02
$V \propto FF^{m\pm n}$	0.23	0.01 ± 0.01	-0.18	-0.02 ± 0.01	-0.12	-0.01 ± 0.02
$V \propto PR^{m\pm n}$	0.25	0.01 ± 0.01	-0.18	-0.02 ± 0.01	0.21	0.03 ± 0.02
$I \propto AT^{m\pm n}$	0.27	2.93 ± 0.21	-0.06	-0.24 ± 0.08	0.35	1.48 ± 0.12
$I \propto RH^{m\pm n}$	0.43	1.91 ± 0.20	-0.16	-0.24 ± 0.08	0.16	0.47 ± 0.13

$I \propto P^{m\pm n}$	1.00	0.99 ± 0.01	0.99	$0.99 \pm .01$	0.99	0.99 ± 0.02
$I \propto E^{m\pm n}$	0.77	0.96 ± 0.14	0.43	0.32 ± 0.08	0.80	0.84 ± 0.08
$I \propto FF^{m\pm n}$	1.00	1.01 ± 0.01	0.99	0.98 ± 0.01	0.99	0.99 ± 0.02
$I \propto PR^{m\pm n}$	0.77	0.96 ± 0.14	0.43	$0.32 \pm .08$	0.80	0.84 ± 0.08
$AT \propto RH^{m\pm n}$	0.07	0.03 ± 0.02	−0.34	-0.13 ± 0.02	0.21	0.15 ± 0.03
$AT \propto P^{m\pm n}$	0.28	0.03 ± 0.02	−0.03	-0.01 ± 0.02	0.34	0.08 ± 0.03
$AT \propto E^{m\pm n}$	0.01	0.00 ± 0.02	−0.18	-0.04 ± 0.02	0.05	0.01 ± 0.03
$AT \propto FF^{m\pm n}$	0.26	0.02 ± 0.02	−0.09	-0.02 ± 0.02	0.36	0.09 ± 0.03
$AT \propto PR^{m\pm n}$	0.01	0.00 ± 0.02	−0.18	-0.04 ± 0.02	0.05	0.01 ± 0.03
$RH \propto P^{m\pm n}$	0.44	0.10 ± 0.04	−0.15	-0.10 ± 0.06	0.18	0.06 ± 0.04
$RH \propto E^{m\pm n}$	0.41	0.12 ± 0.04	0.29	0.14 ± 0.05	0.10	0.04 ± 0.05
$RH \propto FF^{m\pm n}$	0.43	0.10 ± 0.04	−0.17	-0.11 ± 0.06	0.14	0.05 ± 0.04
$RH \propto PR^{m\pm n}$	0.41	0.12 ± 0.04	0.29	0.14 ± 0.05	0.10	0.04 ± 0.05
$P \propto E^{m\pm n}$	0.77	0.97 ± 0.14	0.41	0.30 ± 0.08	0.82	0.86 ± 0.08
$P \propto FF^{m\pm n}$	1.00	1.02 ± 0.02	0.96	0.95 ± 0.02	0.97	0.97 ± 0.03
$P \propto PR^{m\pm n}$	0.77	0.97 ± 0.14	0.41	0.30 ± 0.08	0.82	0.86 ± 0.08
$E \propto FF^{m\pm n}$	0.76	0.62 ± 0.11	0.45	0.60 ± 0.10	0.77	0.73 ± 0.08
$E \propto PR^{m\pm n}$	1.00	1.00 ± 0.00	1.00	1.00 ± 0.01	1.00	1.00 ± 0.01
$FF \propto PR^{m\pm n}$	0.76	0.94 ± 0.14	0.45	0.34 ± 0.08	0.77	0.81 ± 0.09

Table 1.3: The correlation values of the observed and estimated parameters for Polycrystalline PV modules.

	10 W Poly		15 W Poly		20 W Poly	
Parameter	r	$m \pm n$	r	$m \pm n$	r	$m \pm n$
$SI \propto V^{m\pm n}$	0.02	0.28 ± 0.14	0.08	2.06 ± 0.21	0.39	5.61 ± 0.17
$SI \propto I^{m\pm n}$	0.80	1.02 ± 0.08	0.96	0.84 ± 0.06	0.93	1.03 ± 0.07
$SI \propto AT^{m\pm n}$	−0.36	-4.07 ± 0.13	−0.12	-0.72 ± 0.21	−0.40	-8.63 ± 0.17
$SI \propto RH^{m\pm n}$	0.21	1.47 ± 0.14	0.23	2.27 ± 0.20	0.39	3.17 ± 0.17
$SI \propto P^{m\pm n}$	0.78	0.98 ± 0.09	0.96	0.84 ± 0.06	0.93	0.99 ± 0.07
$SI \propto E^{m\pm n}$	−0.60	-0.96 ± 0.11	0.30	0.92 ± 0.20	−0.36	-0.96 ± 0.18
$SI \propto FF^{m\pm n}$	0.80	1.04 ± 0.08	0.96	0.84 ± 0.06	0.93	1.06 ± 0.07
$SI \propto PR^{m\pm n}$	−0.60	-0.96 ± 0.11	0.30	0.92 ± 0.20	−0.40	-1.53 ± 0.17
$V \propto I^{m\pm n}$	0.15	0.02 ± 0.01	0.06	0.01 ± 0.01	0.43	0.03 ± 0.01
$V \propto AT^{m\pm n}$	−0.19	-0.18 ± 0.01	−0.03	-0.01 ± 0.01	−0.34	-0.50 ± 0.01
$V \propto RH^{m\pm n}$	0.31	0.19 ± 0.01	−0.02	-0.01 ± 0.01	0.02	0.01 ± 0.01
$V \propto P^{m\pm n}$	0.26	0.03 ± 0.01	0.09	0.01 ± 0.01	0.49	0.04 ± 0.01
□ ∝ □^(□±□)	*0.29*	*0.04 ± 0.01*	*0.08*	*0.01 ± 0.01*	*0.18*	*0.03 ± 0.01*
□ ∝ □□^(□±□)	*0.04*	*0.01 ± 0.01*	*0.02*	*0.01 ± 0.01*	*0.36*	*0.03 ± 0.01*
□ ∝ □□^(□±□)	*0.29*	*0.04 ± 0.01*	*0.08*	*0.01 ± 0.01*	*−0.10*	*−0.03 ± 0.01*
□ ∝ □□^(□±□)	*−0.30*	*−2.66 ± 0.10*	*−0.10*	*−0.67 ± 0.23*	*−0.43*	*−8.22 ± 0.15*
□ ∝ □□^(□±□)	*0.23*	*1.25 ± 0.11*	*0.26*	*2.92 ± 0.23*	*0.33*	*2.43 ± 0.16*
□ ∝ □^(□±□)	*0.99*	*0.97 ± 0.01*	*1.00*	*1.00 ± 0.01*	*1.00*	*0.96 ± 0.01*

□ ∝ □ □±□	*0.01*	*0.01 ± 0.11*	*0.55*	*1.91 ± 0.20*	*0.00*	*0.01 ± 0.17*
□ ∝ □□ □±□	*0.99*	*1.00 ± 0.01*	*1.00*	*1.00 ± 0.01*	*1.00*	*1.03 ± 0.01*
□ ∝ □□ □±□	*0.01*	*0.01 ± 0.11*	*0.55*	*1.91 ± 0.20*	*−0.15*	*−0.50 ± 0.17*
□□ ∝ □□ □±□	*−0.03*	*−0.02 ± 0.01*	*−0.05*	*−0.08 ± 0.03*	*−0.62*	*−0.24 ± 0.01*
□□ ∝ □ □±□	*−0.31*	*−0.03 ± 0.01*	*−0.10*	*−0.01 ± 0.03*	*−0.44*	*−0.02 ± 0.01*
□□ ∝ □ □±□	*0.17*	*0.02 ± 0.01*	*0.02*	*0.01 ± 0.03*	*−0.01*	*0.00 ± 0.01*
□□ ∝ □□ □±□	*−0.28*	*−0.03 ± 0.01*	*−0.10*	*−0.01 ± 0.03*	*−0.41*	*−0.02 ± 0.01*
□□ ∝ □□ □±□	*0.20*	*0.02 ± 0.01*	*0.02*	*0.01 ± 0.03*	*−0.16*	*−0.03 ± 0.01*
□□ ∝ □ □±□	*0.26*	*0.05 ± 0.02*	*0.25*	*0.02 ± 0.02*	*0.32*	*0.04 ± 0.02*
□□ ∝ □ □±□	*−0.01*	*0.01 ± 0.02*	*0.19*	*0.06 ± 0.02*	*−0.23*	*−0.08 ± 0.02*
□□ ∝ □□ □±□	*0.20*	*0.04 ± 0.02*	*0.26*	*0.02 ± 0.02*	*0.34*	*0.05*v*0.02*
□□ ∝ □□ □±□	*−0.01*	*0.01 ± 0.02*	*0.19*	*0.06 ± 0.02*	*−0.20*	*−0.09 ± 0.02*
□ ∝ □ □±□	*0.03*	*0.04 ± 0.11*	*0.55*	*1.92 ± 0.20*	*0.02*	*0.04 ± 0.18*
□ ∝ □□ □±□	*0.98*	*1.01 ± 0.02*	*1.00*	*1.00 ± 0.02*	*0.99*	*1.06 ± 0.02*
□ ∝ □□ □±□	*0.03*	*0.04 ± 0.11*	*0.55*	*1.92 ± 0.20*	*−0.15*	*−0.53 ± 0.17*
□ ∝ □□ □±□	*−0.04*	*−0.03 ± 0.09*	*0.55*	*0.16*v*0.06*	*−0.01*	*0.01 ± 0.07*
□ ∝ □□ □±□	*1.00*	*1.00 ± 0.01*	*1.00*	*1.00 ± 0.01*	*1.00*	*1.00 ± 0.01*
□□ ∝ □□ □±□	*−0.04*	*−0.04 ± 0.11*	*0.55*	*1.90 ± 0.20*	*−0.14*	*−0.48 ± 0.16*

Table 1.1 shows one month average values of daily measurements of the voltage Voc, (V), current Isc (A), Temperature on the panel, T (^{0}C), Relative Humidity, RH (%), Power P (W), Efficiency, Eff (%), Fill factor FF, and performance Ratio PR, for 10W, 15W and 20W monocrystalline and polycrystalline PV modules. From the table, it was observed that there is a relationship between the parameters. Tables 1.2 and 1.3 show the correlation values of the observed and estimated parameters (with associated errors) of 10W, 15W and 20W monocrystalline and polycrystalline PV modules.

1.3a Monocrystaline PV modules of 10 W, 15 W and 20 W.

From table 1.1, open circuit voltage (Voc) for monocrystalline PV modules was 19.1 for the three modules. This means that the maximum voltage that the monocrystalline provides when the terminals are not connected to any load is 19.I V for the three modules. For short circuit current I_{sc} (A), the values of 15W and 20W was 0.7 while 10 W was 0.6. This means that the maximum amount provided by the monocrystalline when the connectors are short circuited was 0.7 A for 15 W and 20 W while that of 10W was 0.6 A. The power (W) values for 15 W and 20 W were as well the same 13.1 and 13.7 respectively while 10 W power (W) value was 11.2. This means that, the power supplied by 15 W and 20 W is higher than power supplied by 10 W. For efficiency (%); 15W monocrstalline PV module showed higher efficiency of 22.2% which was higher than the other two monocrystalline modules (10 W and 20 W). This means that the ratio between maximum electrical power that 15 W monocrystalline PV module can give to the load and the power of the solar radiation incident on the panel is higher than other modules. Fill factors; the fill factor values for 15 W and 20 W was 0.6 while that of 10 W was 0.5. That is, the relation between the maximum power that 15 W and 20 W monocrystalline PV modules can actually provide and the product of their short circuit current I_{sc} and open circuit voltage $V_{oc}$is 0.6. This gives an idea of the quality of the solar cell. The closer fill factor is to 1.0, the more power a panel can provide.

For performance ratio, the value of 15 W monocrystalline was higher than 10 W and 20 W monocrystalline PV modules. 15W value was 1.2 while 10 W and 20 W was 1.1 and 0.9 respectively. This is a measure of increase in energy production.

1.3b Polycrystalline PV modules of 10 W, 15 W and 20 W.

From the same table 1.1, open circuit voltage v_{oc} (v) values for polycrystalline PV modules was 18.8 for the three polycrystalline PV modules. Comparing the values with that of monocrystalline modules, the mean voltage monocrystalline PV modules provided was 19.I V which was higher than polycrystalline PV modules with a value of 18.8 V.

For short circuit current I_{sc}(A), 20 W polycrystalline PV module showed least value while that of 10W and 15W was 0.7A and 0.6A respectively, The average mean value of monocrystalline PV modules for Isc which was 0.67 A is higher than average mean value of polycrystalline PV modules with a value of 0.6A. For Power (W), 10 W and 15 W Polycrystalline PV modules values are 12.9 and 11.7 respectively, which was higher than 20 W polycrystalline PV module with a value of 10.1. The power (W) supplied by monocrystalline PV modules were higher than Polycrystalline PV modules. The average mean value of monocrystalline PV modules was 12.7 W while that of polycrystalline was 11.6 W. The efficiency (%) of 10 W and 15 W Polycrystalline PV modules is the same 17.8% while efficiency of 20 W polycrystalline PV module was 16.7%. There was a degradation observed and considering the average mean values of both monocrystalline and polycrystalline PV modules which were 18.6% and 17.4% respectively. From this values, it was clearly shown that monocrystalline PV modules has better efficiency than polycrystalline PV modules. The three polycrystalline PV modules have the same value of 0.6.

For performance Ratio, 10 W polycrystalline PV module showed a better performance ratio, with a value of 1.1 followed by 15W with a value of 0.9 and 20W with a value of 0.8. Comparing performance ratio of monocrystalline and polycrystalline PV modules, the average mean value of monocrystalline PV modules for performance ratio was 1.1 while that of polycrystalline was 0.9. This means the performance ratio of monocrystalline is better than polycrystalline PV module. For ambient temperature (^{0}C), the average mean value for monocrystalline was 34.4 while polycrystalline was 28.2 but for relative humidity, the average mean value for polycrystalline is higher than monocrystalline PV modules.

Table 1.4: Manufacture's specification for monocrystalline

Module Type	Manufacturer	I_{sc} (A)	Voc (V)	P(W)	Efficiency	Fill factor

10W	Sunshine solar Germany	0.63	22.05	9.98	14	0.72
15W	Euro solar	0.95	21.8	14.96	18.7	0.72
20W	Euro sola	1.28	21.8	19.95	13.5	0.72

Table 1.5: Field Performance result for Monocrystalline

Module Type	Manufacturer	I_{sc} (A)	Voc (V)	P(W)	Efficiency	Fill factor
10W	Sunshine solar Germany	0.6	19.1	11.2	17.8	0.5
15W	Euro solar	0.7	19.1	13.1	22.2	0.6
20W	Euro sola	0.7	19.1	13.7	15.7.	0.6

Table 1.6: Manufacture's specification for Polycrystalline

Module Type	Manufacturer	I_{sc} (A)	Voc (V)	P(W)	Efficiency	Fill factor
10W	Sunshine solar Germany	0.65	21.6	9.98	12	0.71
15W	Euro solar	0.95	22.05	14.86	15	0.71
20W	Euro sola	1.27	22.05	19.95	15.3	0.71

Table 1.7: Field Performance result for polycrystalline

Module Type	Manufacturer	I_{sc} (A)	Voc (V)	P(W)	Efficiency	Fill factor
10W	Sunshine solar Germany	0.7	18.8	12.9	17.8	0.6
15W	Euro solar	0.6	18.8	11.7	17.8	0.6
20W	Euro sola	0.5	18.8	10.1	16.7	0.6

From Tables 1.2 and 1.3, the correlation analysis showed that most parameters ofmonocrystalline PV modules have positive correlational values than parameters of polycrystalline modules which means that there were perfect relation among the parameters. The small 'r' is the correlation values, 'm' is the strength of the relation while 'n' shows the level of scatter or error in the relation.

1.3c. Measured Open Circuit Voltage (V_{oc})

The open circuit voltage (V_{oc}) of a cell is the voltage of the cell when the current is zero. From the obtained results, the V_{oc} was found to have undergone degradation within few days of exposure. The polycrystalline module type registered a higher degradation of V_{oc} compared with the monocrystalline module types. This was attributed to a large layer of dust that covered the module.

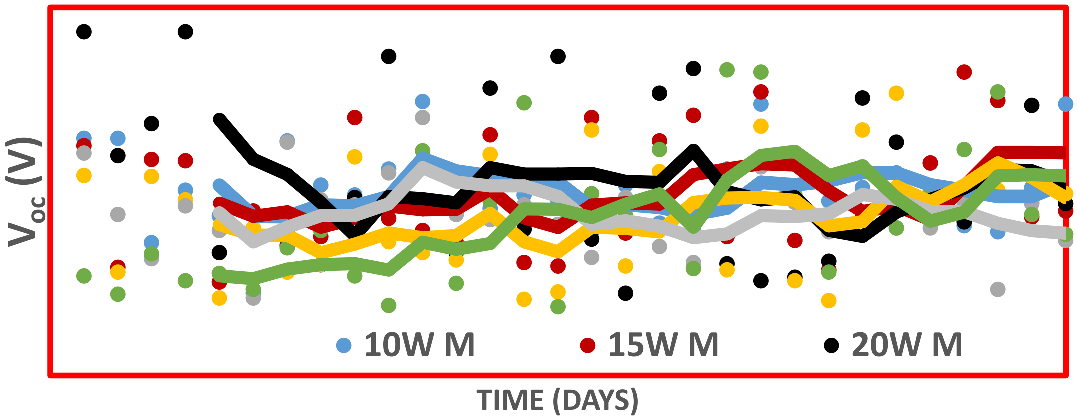

Figure 1.3: Time series plot of the variation of V_{oc} (V) With the fitted weekly average (Blue – 10 W Mono; Red – 15 W mono; Black – 20 W Mono; Yellow – 10 W Poly; Ash – 15 W Poly; Green – 20 W Poly)

Figure 1:3 shows the average hourly variation of Voc for monocrystalline and polycrystalline PV modules for one month solar exposure. From the graph, a gradual drop in Voc was observed. The 10 W monocrystalline was found to degrade faster as compared to 15 W and 20 W modules. The normalized graphs of Voc against time for polycrystalline modules shows that there was general drop in Voc for all the modules. 10 W polycrystalline modules has a higher drop.

1.3d. Measured Short Circuit Current (I_{sc})

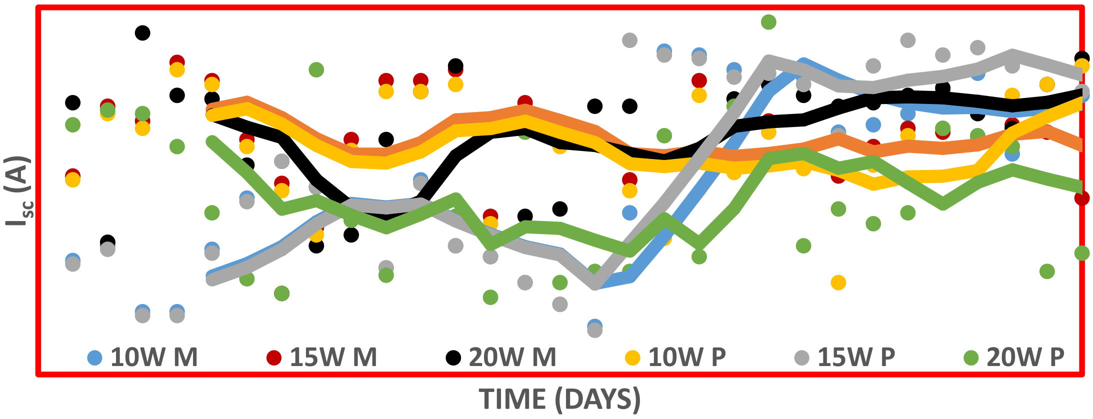

Figure 1.4: The Time series plot of the variation of I_{sc} (A) with the fitted weekly average (Blue – 10 W Mono; Red – 15 W mono; Black – 20 W Mono; Yellow – 10 W Poly; Ash – 15 W Poly; Green – 20 W Poly)

Figure 1.4 is a graph of Isc against number of days for the monocrystalline and polycrystalline modules. From the graphs it was noted that there is negligible change in Isc for the three monocrystalline module, while for the polycrystalline modules, it can be seen that there is very little change in Isc with the number of days for the polycrystalline modules.

1.3e. Obtained Ambient Temperature

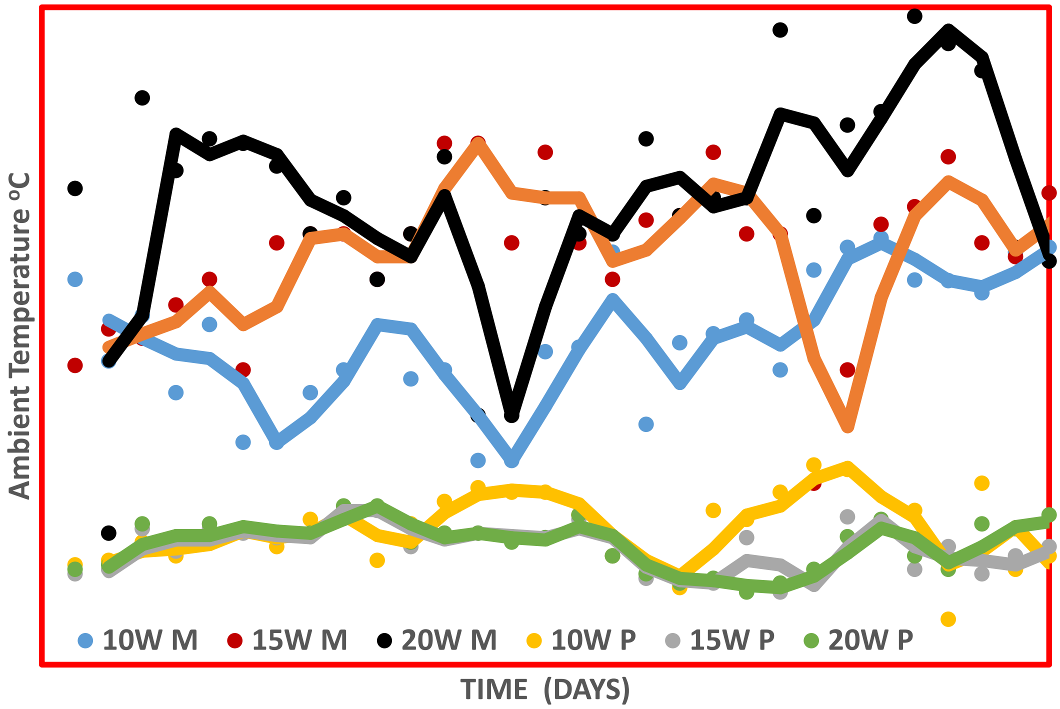

Figure 1.5: Time series plot of the variation of Ambient Temperature (T_a) of the PV with the fitted weekly average (Blue – 10 W Mono; Red – 15 W mono; Black – 20 W Mono; Yellow – 10 W Poly; Ash – 15 W Poly; Green – 20 W Poly)

In figure 1.5, there was little variation and the maximum value was observed at 38 ^{0}C by 20W modules, while the minimum value was observed at 28.4^{0}C. The temperature of all the three monocrystalline PV module used in this study stayed above the ambient temperature, unless near the evening and increased with increase in irradiance. For polycrystalline module, the maximum value was at 29.5°C by 10W modules while minimum value was observed at 27°C by 20W modules.

1.3f. Measured Relative Humidity

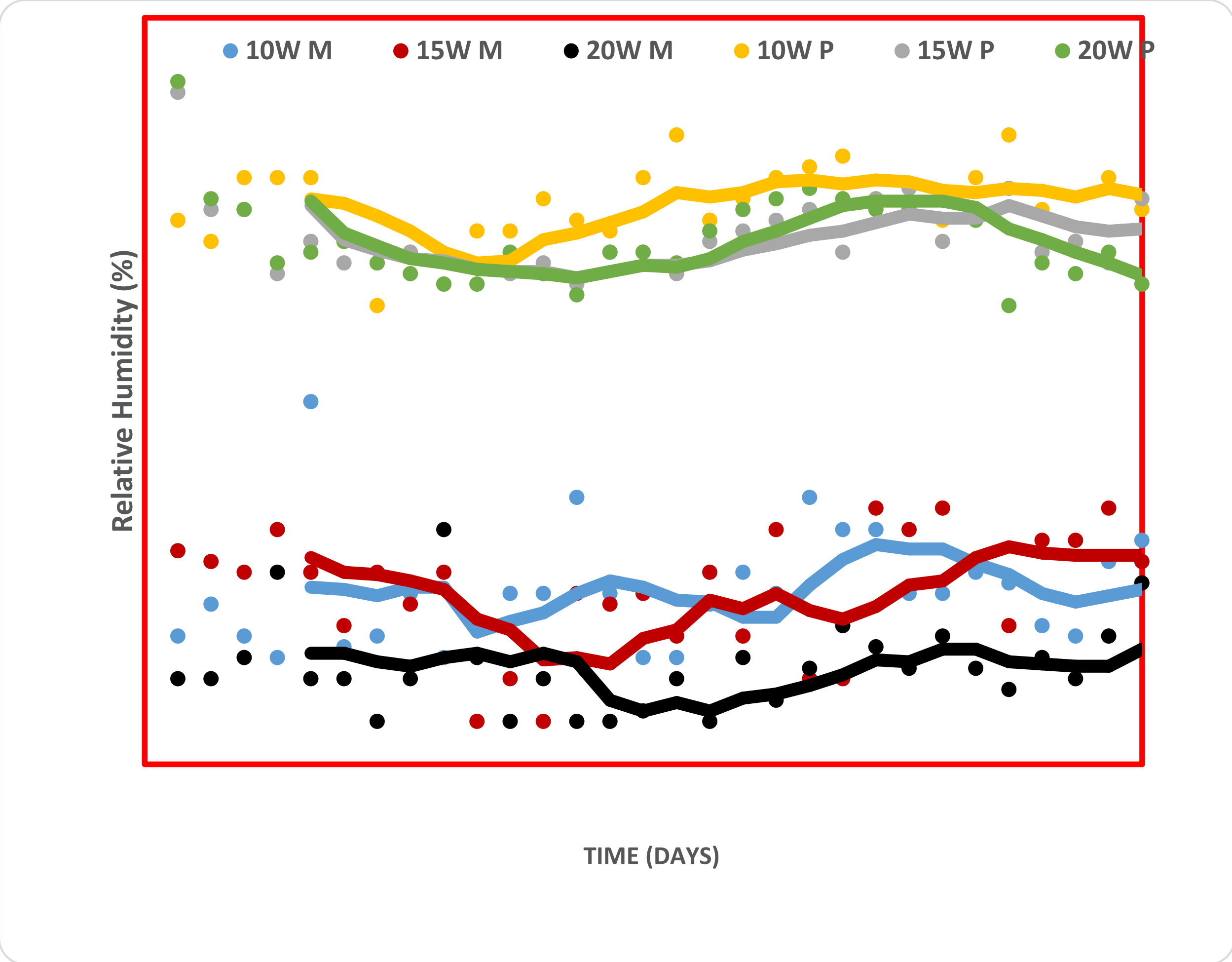

Figure 1.6: The Time series plot of the variation of Relative Humidity (%) of the PV with the fitted weekly average (Blue – 10 W Mono; Red – 15 W mono; Black – 20 W Mono; Yellow – 10 W Poly; Ash – 15 W Poly; Green – 20 W Poly)

Figure 1.6 shows variation of relative humidity with number of days for monocrystalline and polycrystalline PV modules. It was observed that the 10w module degraded more, when compared to the 15W and 20W modules for both PV modules. It was also observed that the 15W and 20W modules varied simultaneously.

1.3g. Measured Maximum Power (P_{max})

The measured P_{max} as found to be below that specified by the manufacturers in most of the modules other than the 10W mono crystalline which was giving 10.7W and 10W polycrystalline with 11.4W. The 10W polycrystalline module indicated a higher rate of degradation as compared to the 15W and 20W polycrystalline modules. The daily inspection of the modules revealed cells that are damaged as a result of overheating as seen in figure 1.7.

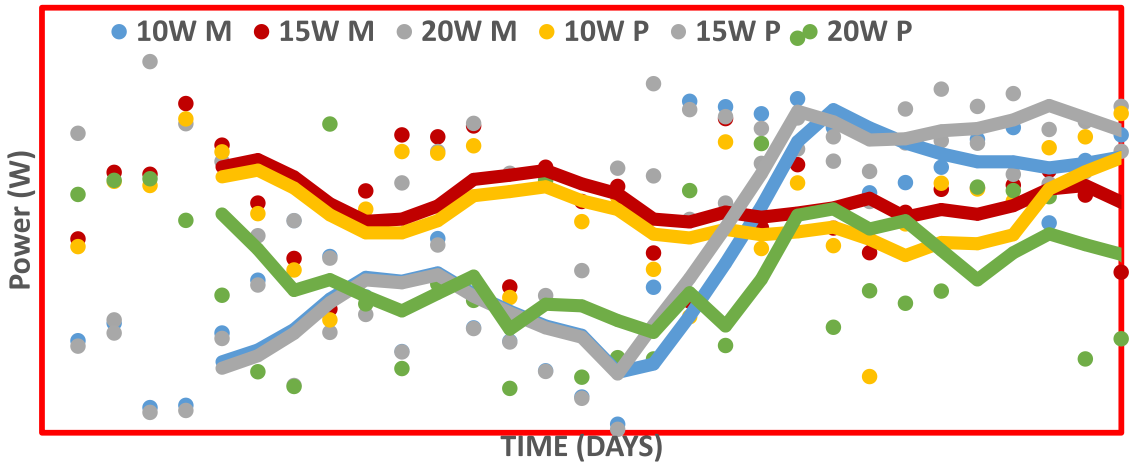

Figure 1.7: Time series plot of the variation of Power (W) of the PV with the fitted weekly average (Blue – 10 W Mono; Red – 15 W mono; Black – 20 W Mono; Yellow – 10 W Poly; Ash – 15 W Poly; Green – 20 W Poly)

Figure 1.7 is a graph of maximum power against the number of days for the monocrystalline and polycrystalline modules. From the graphs, the 10Wmonocrystalline modules registered a higher rate of degradation while the 20W monocrystalline had the least. The 10W polycrystalline modules degraded more while the 15W module had the least rate of degradation.

1.3h. Module Efficiency

The efficiency of the modules was found to have degraded within the few days of exposure. The 20W monocrystalline module had the lowest efficiency compared with the other monocrystalline modules. This was attributed to defects which may have gone unnoticed during the time of manufacture. The 10W polycrystalline module had the highest rate of degradation compared with the other polycrystalline modules.

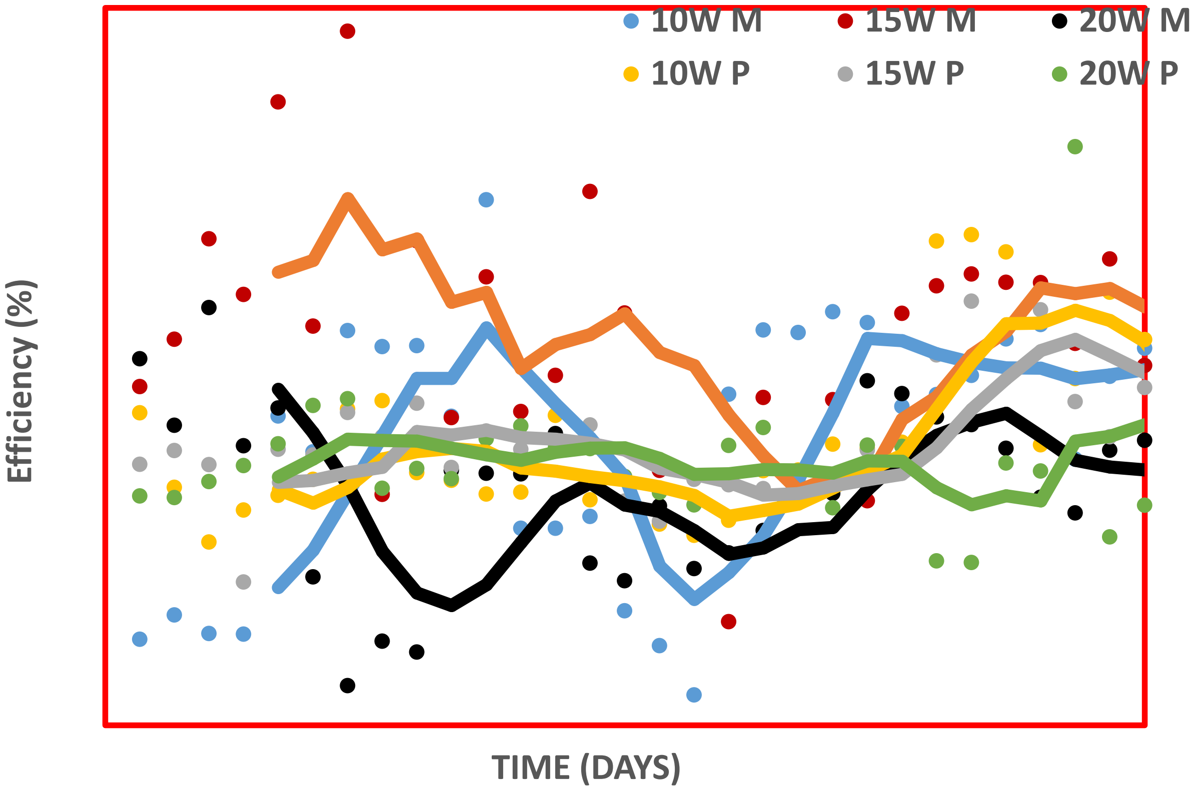

Figure 1.8: Time series plot of the variation of Efficiency (%) of the PV with the fitted weekly average (Blue – 10 W Mono; Red – 15 W mono; Black – 20 W Mono; Yellow – 10 W Poly; Ash – 15 W Poly; Green – 20 W Poly)

Figure 1.8 is a graph of efficiency against number of days for the monocrystalline and polycrystalline PV modules. It was noted the 10W monocrystalline module had a higher rate of degradation compared with the other two modules. The 20 W modules had the least efficiency while the 15 W modules had the highest efficiency. But for the polycrystalline modules, rapid drop in efficiency was observed for 15 W modules. The 10 W polycrystalline

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modules had been found to degrade faster as compared to the 15 W and 20 W modules. The variation of the module efficiency as shown is negligible.

1.3i. Fill Factor of the Modules

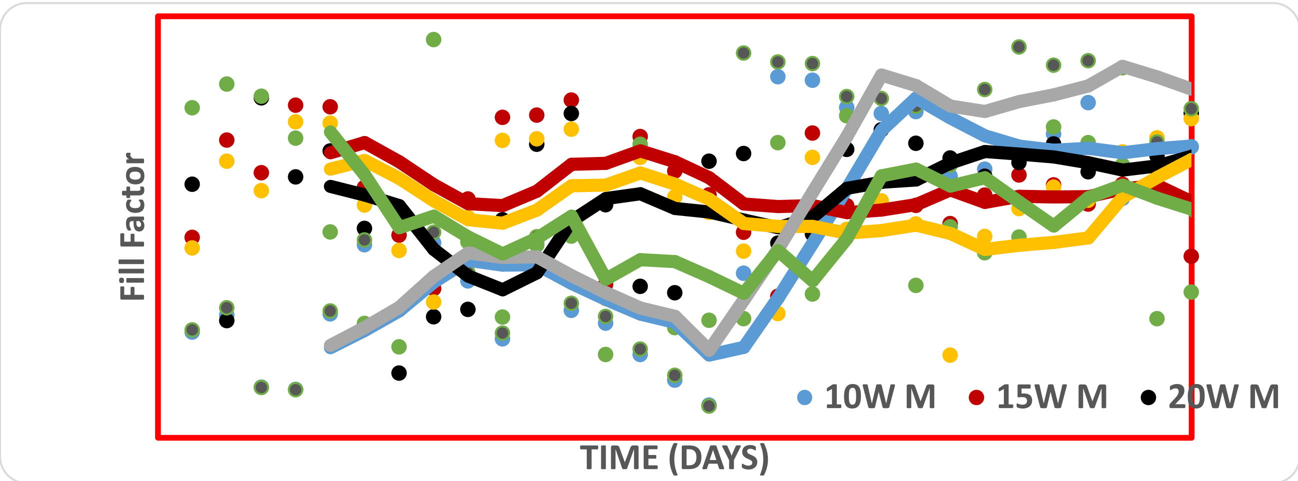

Figure 1.9: Time series plot of the variation of Fill Factor of the PV With the fitted weekly average (Blue – 10 W Mono; Red – 15 W mono; Black – 20 W Mono; Yellow – 10 W Poly; Ash – 15 W Poly; Green – 20 W Poly)

Figure 1.9 shows variation of fill factor with number of days for monocrystalline and polycrystalline PV module. From the graph, all the monocrystalline modules showed similar degradation level. While for polycrystalline PV modules, the 15 W modules showed a higher degradation than 10 W and 20 W modules respectively

1.3j. Performance Ratio of the Modules

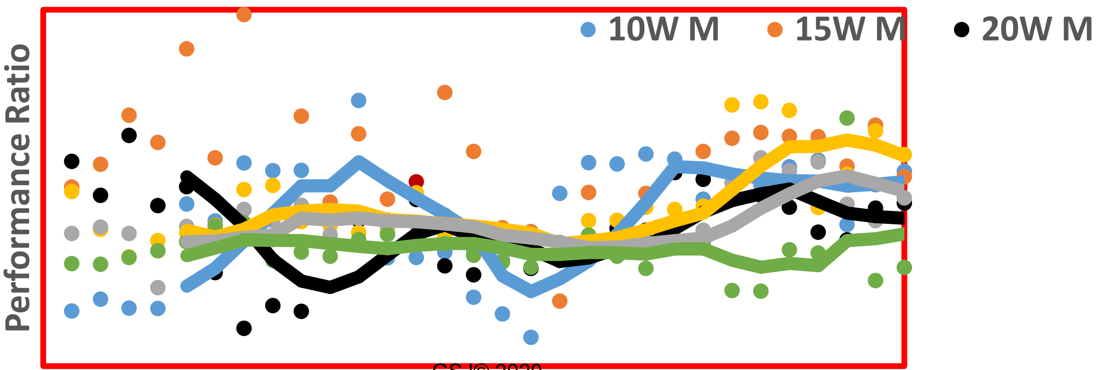

Figure 1.10: Time series plot of the variation of Performance Ratio of the PV with the fitted weekly average (Blue – 10 W Mono; Red – 15 W mono; Black – 20 W Mono; Yellow – 10 W Poly; Ash – 15 W Poly; Green – 20 W Poly

Figure 1.10 shows that monocrystalline PV module always performed higher than polycrystalline modules. Therefore it suffices to say that that is a condition in the Enugu, Eastern Nigeria.

1.4 Conclusion

The modules indicated a decrease in *Voc* with time. The *Voc* of the Polycrystalline modules indicated a higher rate of degradation compared to that of mono crystalline modules. Within the thirty days of exposure, the polycrystalline modules clearly showed the Staebler -Wronki degradation effect. The short circuit current (*Isc*) of the two technologies indicated a very small change with the number of days of exposure. This is not unusual since *Isc*unlike the *Voc*indicated a very minimal change with time of exposure.The average mean value efficiency for polycrystalline modules was found to be 17.4 which was low compared to that of monocrystalline modules whose efficiency was 18.7. The maximum power (*Pmax*) of all the modules indicated a degradation trend. It was also noted that the *Pmax* quoted by manufacturers in most of the modules could not match the measured *Pmax.* The output power of PV modules increased with module temperature but has shown a decrement from linear trend at high module temperature. This effect is due to decrease in modules open circuit voltage. The daily inspection on the modules revealed a defect in the polycrystalline module and that has highly contributed to its low performance.The efficiency of the modules used in this study increased with increase in solar irradiance. The monocrystalline module showed higher power output efficiency compared to polycrystalline module at high level of average solar Irradiance, while in low average solar radiation per day, the power output for poly-crystalline were at low level compared to the monocrystalline photovoltaic module. At low ambient temperature, PV module showed high performance ratio which decreased with increase in temperature.

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