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Assessment Of Maximum Power Output of Photovoltaic Modules to Rated Power Currently in Nigeria

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Abstract- This paper evaluates the maximum power output of photovoltaic (PV) modules compared to their rated power as indicated in the Nigerian market, a key consideration for vendors involved in solar installations and standalone solar home systems. Various solar panels from numerous manufacturers are imported into Nigeria, many of which feature power ratings that do not align with their actual performance. The study employed Current-Voltage (I-V) curve analysis, a graphical representation of the relationship between current and voltage in solar panels, to determine the true maximum power output of PV modules. The analysis utilized specialized laboratory equipment, including a sun simulator (Minikla Solar Test Machine) and I-V plotter, to generate data such as Short-Circuit Current (Isc), Open-Circuit Voltage (Voc), Maximum Power Point (MPP), Fill Factor (FF), and Efficiency (Eff). These measurements were conducted under temperature-matched operating conditions (TMOT) specified on the product datasheets. The results were compared with the expected values for each tested solar panel. This study revealed that, while most commercial systems are reported to have achieved average efficiency of 21%, the average efficiency of tested imported solar panels in Nigeria was found to be around 15.91%. Additionally, the actual maximum power output of many imported PV modules was significantly lower than their manufacturer-rated power. However, smaller capacity panels (less than 10 W), commonly used in standalone solar home systems (SHS) for devices like flashlights and small household appliances, exhibited an average efficiency higher than manufacturer rated power efficiency. The findings highlight that using multiple low-efficiency PV panels for major installations, with design calculations based on their rated power output, often results in inefficient systems that fail to meet user expectations and are ultimately unfit for purpose.

Indexed Terms- Short-Circuit Current (Isc), Open-Circuit Voltage (Voc), Maximum, Power Point (MPP)Fill Factor (FF) Efficiency (Eff). at temperature-matched operating conditions (TMOT), Standard Test conditions (STC) Solar Home Stand alone (SHS)

I. INTRODUCTION

Nigeria is a nation endowed with abundant human and natural resources capable of achieving self-sufficiency in energy production. However, the current reality paints a starkly different picture, characterized by severe energy shortages and frequent power outages. These challenges have significantly contributed to an economic crisis, low manufacturing capacity utilization, rising unemployment, corruption, capital flight, and a declining Gross Domestic Product (GDP). Approximately 60–70% of Nigerians experience less than four hours of electricity daily, and only 60.5% of the population has access to electricity [4]

By 2014, many national and regional governments worldwide had adopted renewable energy policies or guidelines, marking nearly a nine-fold increase since 2004. These policies were revised in 2013 in response to evolving market and economic conditions, enabling significant growth in renewable energy markets and investments [3]. Ambitious, clearly defined renewable energy goals have proven essential in driving global adoption, creating employment opportunities, and fostering structural economic change, particularly in industrialized nations.

Nigeria, with its vast energy resources—including hydropower, fossil biogas, biomass, wind, tidal energy, solar power, coal, and nuclear energy—cannot afford to lag behind. As of 2020, Nigeria's energy generation mix consisted of 12–20.8% from hydropower, 1.8% from coal, 0.1% each from solar and bioenergy, and approximately 77% from fossil fuels [2]

Solar energy, a prominent renewable resource, has seen increased importation and installation in Nigeria in recent years. However, its potential remains underutilized, despite the country's year-round sunshine. Annual solar radiation in Nigeria ranges between 12.6 megajoules per square meter (MJ/m²) per day in coastal regions and 25.2 MJ/m² per day in the northern regions [1] This abundant solar resource presents an opportunity to diversify the energy mix and address Nigeria's energy challenges.

Despite this potential, several barriers hinder the effective adoption of solar energy systems. These systems, comprising solar panels, charge controllers, high-quality batteries, and inverters, require minimal maintenance compared to conventional energy sources. However, the widespread importation of substandard solar panels undermines their effectiveness and reliability. Poor-quality solar installations have left many users disillusioned, as their performance falls short of expectations. This issue is compounded by inadequate certification processes from regulatory agencies, weak enforcement of quality standards, and unprofessional practices by vendors. Addressing these challenges is essential for Nigeria to harness the full potential of solar energy and promote sustainable energy solutions [1] [3].

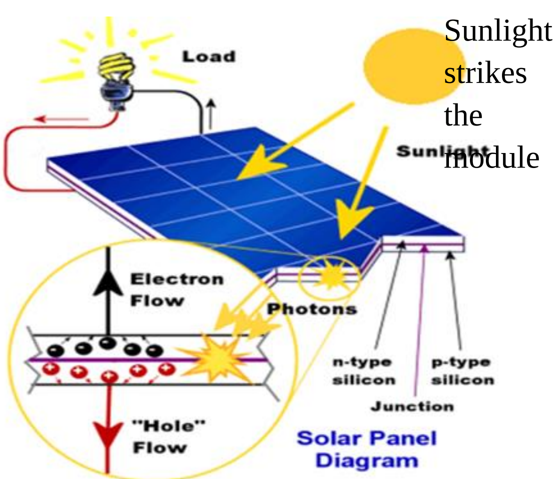


Figure 1: Principle of Photovoltaic Panel

II. METHOD AND MATERIALS

The effectiveness of solar energy systems in Nigeria is significantly limited, with an average lifespan of only five years, contrary to vendor claims of lasting 20 to 25 years. To investigate the causes of this shortfall, the study evaluated the compliance of photovoltaic (PV) module manufacturers' rated maximum power outputs with their actual performance. Both national and international standards were used as benchmarks for the assessment.

The research utilized laboratory analysis and data collection methods. Samples were obtained from various sources, including ports of entry, randomly selected products for registration, and items examined during enforcement and compliance activities. These activities were conducted in alignment with national regulations, such as SONCAP, MANCAP, NPR, and PAM, as well as certification inspections.

I-V curves were generated using various facilities, including an I-V curve tracer, which applies a voltage sweep to the module and measures the resulting current, and a sun simulator (Minikla Solar Test Machine) for both outdoor and indoor testing, depending on the module's capacity. Figures 1 through 4 illustrate these processes.

The I-V curve test is typically conducted under Standard Test Conditions (STC) and serves the following purposes:

i. Determining the maximum power output (Pmax) of the PV module.
ii. Calculating the fill factor (FF), which indicates the module's efficiency.
iii. Identifying defects or irregularities in the module's performance.
iv. Comparing the module's performance to its rated specifications.

The tested parameters for photovoltaic (PV) modules include:

i. Efficiency: The efficiency of the PV module is measured by its ability to convert incoming solar energy into usable electrical power.
ii. Open Circuit Voltage (Voc): This is the maximum voltage available when no current is drawn from the module.

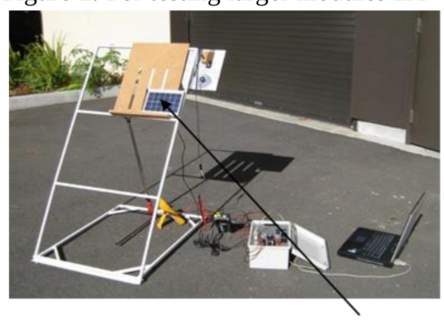
iii. Short Circuit Current (Isc): This refers to the maximum current output of the module under normal conditions with zero resistance.
iv. Maximum Power Point (MPP): The maximum power output of the PV module, calculated as the product of the maximum voltage and the maximum current.
v. Effect of Sunlight Intensity: The current output of the PV module, which is proportional to the intensity of solar radiation.
vi. PV Module Cell Temperature: The temperature of the module's cells, which often rises above the standard operating temperature of 77°F (25°C). Higher temperatures reduce voltage and lower the module's efficiency.

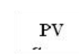
The output characteristics of a PV module are typically represented by an I-V curve (Figure 6). The curve demonstrates the relationship between current and voltage for specific modules under standard operating conditions, which are defined as 1000 watts per square meter of solar irradiance and a cell temperature of 77°F (25°C). Data derived from the I-V curve can be used to assess module performance and determine the appropriate size of a PV system array.
To ensure accurate test results, measured data are converted to Standard Test Conditions (STC) and Temperature-Matched Operating Conditions (TMOT) using Equations 1 to 3. These adjustments account for variations in real-world testing conditions and standardize the reported values.

$$I_{stc}=I_2\left(\frac{G_{stc}}{G_2}\right)\quad (1)$$
$$V_{stc}=\left(1+T_{c,soc}\left(T_{stc}-T_2\right)\right)\quad (2)$$
$$P_{stc}=I_{stc}V_{stc}\quad (3)$$

Outdoor IV Curve Testers

Figure 2: For testing larger modules 2A < $I_{sc} \leq$ 16A





Sample
Figure 3 Custom-built by SERC IVCT For testing smaller modules $I_{sc} \leq$ 2A

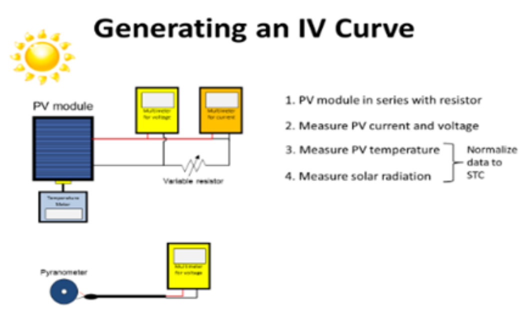


Figure 4. Sun simulator

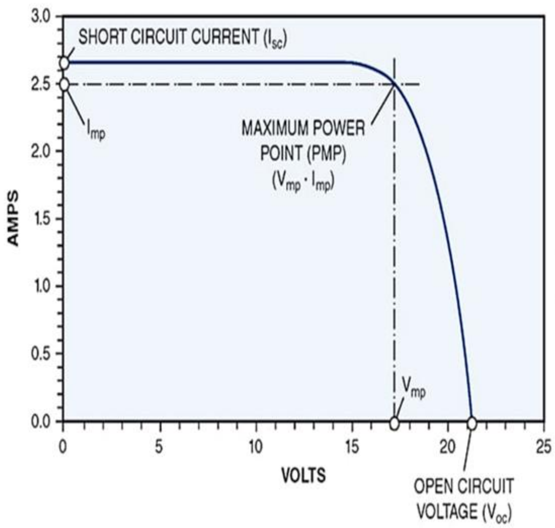


Figure 5: An I-V curve for a common PV module size.

Table 1: Sample Data Obtained

Parameters	Sample1	Sample 2	Sample 3	Sample 4	Sample 5	Sample6	Sample 7
V_{pmR} [V]	36.96	38.1	31.45	6.000	52.1	18.33	34.20
V_{pmm} [V]	38.19	40.235	34.653	6.385	32.772	18.296	34.813
I_{mpR}[A]	8.56	10.5	12.72	4.16	9.05	6.55	8.77
I_{pmm}[A]	8.70	8.515	10.339	3.866	8.630	6.349	7.473
P_{Rat} [W]	325	400	480	25	290	120	300
P_{mpp} [W]	326.91	342.601	358.277	24.683	282.807	116.167	260.164
VocR [V]	45.83	45.5	37.31	7.2	39.3	22.75	41.04
Vocm [V]		40.235	40.771	7.594	39.515	22.937	1.560
IscR [A]	9.87	11.55	13.61	4.57	9.67	7.09	9.30
Iscm [A]		9.137	10.766	3.964	9.033	6.795	8.220
G [W/m²]	905	1000.65	1000.82	1000.75	1003.15	1003.21	1001.61
T [°C]	46	26.4	27.4	26.0	25.6	27.6	24.8
FF [%]	75.1	76.446	81.619	82.068	79.228	74.531	76.155
Eff. [%]	25.67	23.449	24.516	1.689	19.307	7.930	17.789

III. RESULTS

Parameters	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12	Sample 13
V_{pmR} [V]	9	17.8	18.92	20.04	18.93	8
V_{pmm} [V]	9.374	18.656	19.172	26.883	21.086	9.054
I_{mpR}[A]	0.67	2.77	2.12	1.06	4.22	1
I_{pmm}[A]	0.777	2.735	1.963	1.023	2.963	0.921
P_{Rat} [W]	6	50	40	27.6	80	8
P_{mpp} [W]	7.286	51.019	37.627	27.512	62.478	8.341
VocR [V]	10.8	21.36	22.3	31.47	22.3	9.6
Vocm [V]	11.464	23.011	22.312	32.467	24.499	11.623
IscR [A]	0.83	3.04	2.32	1.08	1.65	1.1
Iscm [A]	0.812	28.68	2.122	1.064	3.10	0.971
G [W/m²]	100.958	100.903	100.735	100.961	100.956	100.701
T [°C]	27.3	27.4	27.1	27.2	27.1	27.3
FF [%]	78.266	77.299	79.475	79.642	82.266	73.3
Eff. [%]	0.494	3.463	2.568	1.866	4.238	73.893
						0.567

RATED VALUE

ACTUAL VALUE

Table 2. Sorted data

Sample No	P_{Rat} [W]	P_{mpp} [W]	FF [%]	Eff. [%]
sample 1	6	7.286	78.266	0.494
sample 2	8	8.341	73.300	73.893
sample 3	25	24.683	82.068	1.689
sample 4	27.6	27.512	79.642	1.866
sample 5	40	37.627	79.475	2.568
sample 6	50	51.019	77.299	3.463
sample 7	80	62.478	82.266	4.238
sample 8	120	116.167	74.531	7.93
sample 9	290	282.807	79.228	19.307
sample 10	300	260.164	76.155	17.789
sample 11	325	326.91	75.100	25.67
sample 12	400	342.601	76.446	23.449
sample 13	480	358.277	81.619	24.516
sample 14	Average			15.9132

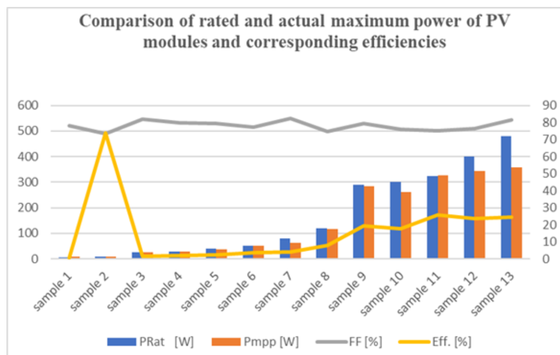


Figure 6: Graphical Representation of Manufacturers' Rated Power, Actual Maximum Power and Efficiencies of Tested PV Modules

IV. DISCUSSION

The analysis revealed that only 21.42% of the tested PV samples conformed to the manufacturers' stated power ratings, while the majority failed to meet the specified standards. Furthermore, highlighting notable performance issues among the imported PV panels, the average efficiency of the tested samples was 15.91%, which is significantly lower compared to the average efficiency of solar PV available today which is 21%. [6]. However, PV modules with efficiencies close to 40% have been developed by some researchers [7]. In 2024, the world highest record of PV efficiency was 47.6%, which was set in 2022 by Fraunhofer ISE [8]

Additionally, as observed in Figure 6, the rated capacities of the PV panels, except for those with capacities less than or equal to 10W were consistently lower than the actual maximum power output measured. An exception was observed with Sample 11, which exhibited a slightly higher maximum power output than its rated capacity.

CONCLUSION

It has been observed that most photovoltaic (PV) panels imported into Nigeria deliver lower power outputs than their manufacturers' rated specifications. The implication of this discrepancy is significant, particularly for installations comprising dozens or even hundreds of panels, as the cumulative power output will be substantially lower than anticipated. Additionally, with an average efficiency of 15.91% and an annual degradation rate of 0.5%–0.8% [5], the effective lifespan and performance of these PV panels will fall short of expectations, leading to reduced operational years and diminished returns on investment.

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