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Performance Analysis of Polycrystalline and Monocrystalline Solar Module in Dhaka, Bangladesh

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***Abstract*—**Achieving national climate goals requires transforming the energy system and increasing the use of renewable energy in Bangladesh as renewable energy offers an environmentally friendly energy supply. In view of this, Bangladesh has set a goal of 100% renewable power generation by 2050. Among all the renewable energy, solar is the most effective and popular source of renewable energy in Bangladesh. In order to build up on-grid and off-grid solar systems to increase energy transformation, monocrystalline type (highly efficient) solar module, and the polycrystalline type (low-efficient) solar module are commonly used. Due to their low price and availability, polycrystalline-type solar modules dominated the local market in the past years. However, in recent times the use of monocrystalline types modules has increased considerably owing to the significant decrease in price difference that existed between these two modules. Despite the deployment of both mono- and poly-crystalline modules in the market, the proliferation of low-quality solar panels are dominating the market resulting in reduced generation of solar electricity than expected. This situation is further aggravated by insufficient information regarding the effect of solar irradiation on solar module performance in relation to the quality of the materials used for the production of the module. This research aims to evaluate the efficiency of monocrystalline and polycrystalline solar modules that are available in Bangladesh by considering seasonal variations. Both types of solar modules have been tested for three different capacities 45W, 60W, and 100W in Dhaka regions to evaluate their power generation capability under Standard Test Conditions (STC). Module testing data were recorded twelve months in a full year from January to December. Data for solar irradiation were collected using HT304N while HT I-V400 multifunction instrument was used for testing voltage and current of photovoltaic (PV) systems and complete power quality analyzer. Results obtained in this study indicated differences between the efficiencies of polycrystalline and monocrystalline solar modules under the country's solar irradiation. The average efficiencies of 45W, 60W, and 100W monocrystalline solar panels were recorded as 11.73%, 13.41%, and 15.37% respectively while for polycrystalline panels were 8.66%, 9.37%, and 12.34%. Monocrystalline solar panels, which offer greater working output than polycrystalline ones, are also represented by the Pearson Correlation value. The output of polycrystalline solar panels fluctuated highly with the changes in irradiation and temperature whereas monocrystalline panels were much stable.

***Keywords*—**Solar energy, solar irradiation, efficiency, polycrystalline solar module, monocrystalline solar module, SPSS analysis.

I. Introduction

DIFFERENT primary energy resources have been used in Bangladesh to meet up the primary energy and electricity demand. The two major categories of energy for electricity generation are fossil fuels (natural gas, coal, and oil) and renewable energy sources (solar, hydro, and biomass). Of all the renewable energy sources in Bangladesh, solar energy is the most efficient and popular form of renewable energy in the country. However, low-quality polycrystalline solar panels still dominate the market, resulting in less than expected solar electricity production. Now maintaining standard and efficient solar appliances along with infrastructure development for medium and large-scale projects are needed for the overall energy sector development of the country. Thus, two types of solar modules – polycrystalline and monocrystalline were tested with three different capacities of 45W, 60W, and 100W to evaluate their power generation capacity according to STC aligning with solar irradiation. This study found that polycrystalline solar modules fluctuate greatly due to changes in weather and temperature, while monocrystalline solar panels are much more stable and produce more solar energy.

A. Objectives

- To investigate the technical performance of solar modules under solar irradiation
- To evaluate the efficiency of monocrystalline and polycrystalline solar modules under typical weather conditions in Dhaka, Bangladesh

II. Literature Review

In Bangladesh, electricity generation capacity has increased from about 5 gigawatts (GW) in 2009 to around 25.5 GW in 2022. But still the reliability and quality of electricity remain major issues. About 61.5% of the total population in rural and off-grid areas depend on solar energy [1].

The fuel mix of power plants in Bangladesh relies heavily on natural gas which contributes to about 44.10% indigenous source of energy for electricity generation. Liquid fuel (such as heavy fuel oil, and diesel) is the second largest energy source for electricity generation which is about 29.27%. The share of renewable energy in the energy mix is 4.61% where solar energy has the highest share about 80.5% in power generation. Currently, Bangladesh generates 26024 megawatt (MW) of

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electricity that including captive power and renewable energy (RE) with the renewable-based total generation of 1200.86 MW including 230 MW hydropower capacity which is shown in Fig. 1 [2].

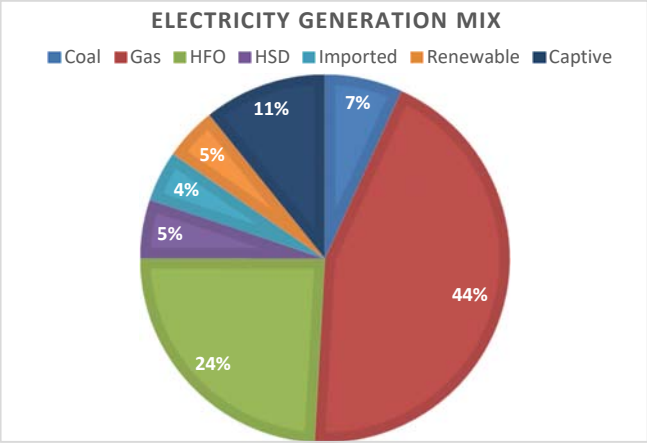

Fig. 1 Fuel type contribution on electricity generation in Bangladesh

According to the Bangladesh Power Development Board (BPDB), as of July 2021, 92% of the population had access to electricity. The percentage has increased significantly about 99.5% that included captive and RE where per capita energy generation is 560 kWh. In comparison, the country's projected energy consumption increased from 9000 MW to 56000 MW between 2015 and 2041 [3].

The Bangladesh government plans to reduce its dependency on national natural gas and has taken action to increase its use of imported liquified natural gas (LNG). By 2021, the Ministry of Power, Energy, and Mineral Resources is considering plans to shift Bangladesh's fuel mix to coal, including generating up to 50% of all total electricity from coal-fired power plants by 2030. The government's goal has been well executed and it has even managed to attain a greater degree of economic growth.

To achieve the national goal, solar PV energy system has been considered one of the most promising RE technologies in the country. Currently, the share of solar electricity is relatively low, accounting for 4.61% of the total electricity generation although there is a significant number of on-grid and off-grid solar systems in Bangladesh [2]. More detailed information on the share of on-grid and off-grid energy from renewable sources is given in Table I.

TABLE I
SHARE OF DIFFERENT CATEGORIES OF RE IN BANGLADESH

Technology	Off-grid	On-grid	Total
Solar	366.72	600.06	966.79
Wind	2	0.9	2.9
Hydro	0	230	230
Biogas to Electricity	0.69	0	0.69
Biomass to Electricity	0.4	0	0.4
Total	369.81	830.96	1200.78

Among all RE technologies, solar PV has experienced a remarkable growth trend in Bangladesh. The daily solar intensity in the country varies from 4.7 to 6.5 units of energy for every square meter (m^2) of area which is very good for solar electricity generation. It plays an important role in energy supply mainly to rural, hilly, and coastal areas in Bangladesh. Fig. 2 represents the country's solar PV growth trend between 2011 and 2020.

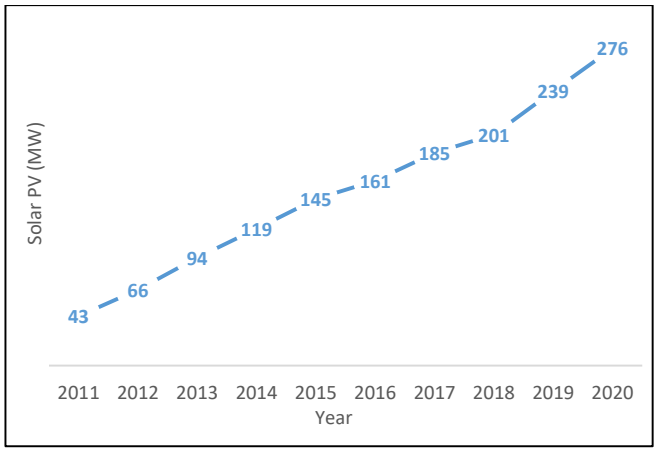

Fig. 2 Solar PV growth trend in Bangladesh

Stakeholders are contributing to the small-scale solar home system (SHS), medium -scale (solar mini-grid) and large-scale (solar park) projects. In 2003, the first RE project was initiated through SHS by targeting off-grid people. Up to December 2020, 5.8 million SHSs have been installed across the country and 1.8 million people are benefiting from solar home systems [5]. The country's first-ever successful 100 KWp capacity solar mini-grid project was commissioned in 2010. Now 27 off-grid solar mini-grid systems are supplying electricity. Until June 2020, 30 large-scale solar projects have been taken up by GOB with a capacity of 1695 MW [6]. Currently, 7 grid-connected solar PV parks with capacity of 200 MWp are in operation. Among other types of solar PV projects are solar charging stations, roof-top solar, solar irrigation pumps, solar nano-grid etc. are notable. As shown in the solar energy statistics are presented in Table II [2], [3].

TABLE II
ONGOING SOLAR PROJECTS IN BANGLADESH

SL	Projects	Quantity	Total MW
1.	Solar park (BPDB)	7	200.02
2.	Solar park (IPP)	23	1227.77
2.	Rooftop solar (except NEM)	116	41.766
3.	NEM rooftop solar	1067	16.429
4.	Solar Irrigation	1855	42.904
5.	Solar home systems	5804422	251.64
6.	Solar mini-grid	27	5.656
7.	Solar nano grid	2	0.001
8.	Solar charging station	14	0.278
9.	Solar Street Light	202017	10.59
10.	Solar-powered telecom BTS	1933	8.06
11.	Solar water system	82	0.095
	Total		415.82 MW

III. Materials and Methods

A. Study Area

This experiment to determine the efficiencies of monocrystalline and polycrystalline solar panels were conducted in Dhanmondi, Dhaka, Bangladesh, shown in Fig. 3. Dhaka is situated at 23°42′ North latitude and 90°24′ East longitude meaning 12-13 hours'/day sunshine is available on average which is quite good for solar electricity generation [7]. In total, six direct-current (DC) stand-alone PV systems with peak capacities of 45Wp, 60Wp, and 100Wp off-grid solar PV systems were selected for performance testing. These systems were installed on the roof of a building in Dhaka city which is circled by red color in Fig. 3.

B. Research Process: Apparatus and Experimental Set-up for Solar Module

The power generated by the polycrystalline and monocrystalline solar PV modules was measured with a multifunction solar analyzer HT I-V400 that enabled real-time power data display and storage, whereas solar irradiation data were captured by the radiation sensor HT304N mounted on the analyzer. All quantitative data; voltage, current, and solar irradiation were recorded daily under Standard Test Condition (STC) and processed with Microsoft Excel sheet.

C. Qualitative Research Approach

Quantitative analysis determines relationships between dependent and independent variables, hypothesis tests, predictions, provides statistical explanations, and produces facts [8]. Considering the research aim, a quantitative technique was used to obtain valid results by examining the relationship between sun irradiance and solar panel efficiency. In this study, sun irradiance is considered the independent variable while panel efficiency served as the dependent variable.

D. Calculation of Solar Module Efficiency

The amount of solar power generation by the panels was calculated by measuring the voltage and output current of the panel which is expressed in (1):

$$P_{output} = V \times I \tag{1}$$

where P_{output} = Output power from the solar panels (Watt); V = Voltage produced by panel (V); I = Current (Amp).

To calculate the efficiency (η) of the panels in conformity with sun irradiation, (2) was used:

$$\eta = \frac{\text{Poutput}}{\text{Solar Irradiance} \times \text{Panel Area}} \text{ x } 100 \tag{2}$$

where η = Efficiency of solar panel (%); P_{out} = Maximum power; (Solar irradiance x Panel area) or P_{in} = Power enters into solar panel.

E. Statistical Analysis by SPSS Tools

Collated data for daily and monthly average solar irradiation (kWh/m^2/month) for Dhaka city were processed using Microsoft Excel. Statistical analysis to build correlation among different parameters such as sun irradiance, panel efficiency, and Bivariate analysis was performed via the use of Statistical Package for the Social Science (SPSS).

The decision rule for accessing if the test is significant (α = 0.01):

- If $p \leq 0.01$, the test is significant (there is a significant relationship between irradiation and panel efficiency).
- If $p \geq 0.01$, the test is not significant (there is no significant relationship between irradiation and panel efficiency).

IV. Results

Table III shows the results of the first experiment comparing the efficiencies of monocrystalline and polycrystalline solar panels. Results of the second experiment to determine the Pearson Correlation are shown in Figs. 5 and 6. The round-year results revealed the differences between the efficiencies of polycrystalline and monocrystalline solar modules under the country's solar irradiation. The average efficiencies of 45W, 60W, and 100W monocrystalline solar panels were recorded as 11.73%, 13.41% and 15.37% respectively, while the average efficiencies for polycrystalline panels were 8.66%, 9.37% and 12.34%.

A. Efficiency

The power outputs of 45W, 60W, 100W for both monocrystalline and polycrystalline solar panels were measured and recorded. Using the solar analyzer data obtained, the efficiency of both monocrystalline and polycrystalline solar panels was documented as shown in Table III.

From Table III, three pi-charts have been shown by using the conclusive data and efficiency differences in Fig. 4 and Table IV.

From Fig. 4 and Table IV, it is indicated that the monocrystalline solar panel is more efficient than the polycrystalline for any capacity of power output.

B. Pearson Correlation

Pearson's r changes between +1 and -1, where +1 could be a perfect positive correlation, and -1 may be a culminate negative correlation. The sign of the correlation coefficient demonstrates the direction of the correlation. The value 0 implies there is no linear correlation at all. A positive correlation shows that as one variable increments, so does the other variable whereas a negative correlation indicates that as one variable increases, the other variable will decrease.

The 45W monocrystalline panel's r-value is -.995 indicating a very strong negative correlation. It means that with increasing solar irradiation, the efficiency of solar panels decreases. The efficiency of solar panels is affected by the average monthly sun irradiation. The assessment of the correlation between the variables is done to determine its statistical significance. A 2-tailed significance test has also been done where the significance value found in this case is .000. Since the p-value is 0.01, the correlation result is highly significant. For the 60W monocrystalline panel, the Pearson correlation has a strong negative correlation -.989 between solar irradiation and panel efficiency. The best results were observed for 100W

monocrystalline solar panels which is represented by the straight line. A perfect negative Pearson correlation means the value is almost -1. Undoubtedly, the panel quality is very high, enabling it to generate a substantial amount of solar power.

Fig. 3 Map of Dhaka City

TABLE III
EFFICIENCY COMPARISON AMONG 45W, 60W AND 100W SOLAR PANELS

Month	Efficiency 45W Mono (%)	Efficiency of 45W Poly (%)	Efficiency of 60W Mono (%)	Efficiency of 60W Poly (%)	Efficiency of 100W Mono (%)	Efficiency of 100W Poly (%)
Jan	12.27	8.84	13.96	9.77	16.48	13.12
Feb	11.99	8.64	13.8	9.63	15.9	12.85
Mar	11.18	8.42	12.79	8.62	14.16	11.9
Apr	10.93	8.17	12.36	8.77	13.72	11.67
May	11.02	8.35	12.43	8.75	13.85	11.56
Jun	11.82	8.71	13.56	9.45	15.53	12.09
Jul	12.27	8.87	13.97	10.08	16.43	13.05
Aug	11.83	8.79	13.54	9.41	15.47	12.05
Sep	11.99	9.21	13.81	9.62	15.86	12.87
Oct	11.43	8.49	13.1	9.08	15.03	11.66
Nov	11.76	8.63	13.6	9.46	15.59	12.12
Dec	12.28	8.86	13.98	9.78	16.51	13.16
Average	11.73	8.66	13.41	9.37	15.37	12.34

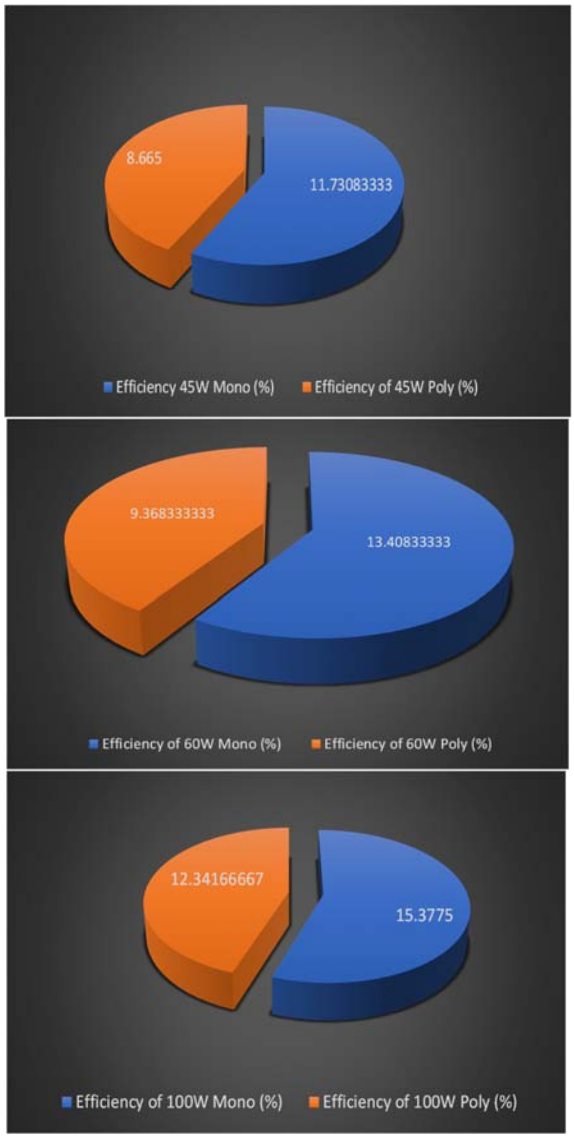

Fig. 4 Graphical representation of solar panels' average efficiencies

TABLE IV
DIFFERENCES IN AVERAGE EFFICIENCIES BETWEEN MONOCRYSTALLINE AND POLYCRYSTALLINE SOLAR PANELS

Solar Panel	Power (W)	Average Efficiency (%)
Monocrystalline	45	11.73
	60	13.41
	100	15.37
Polycrystalline	45	8.665
	60	9.37
	100	12.34

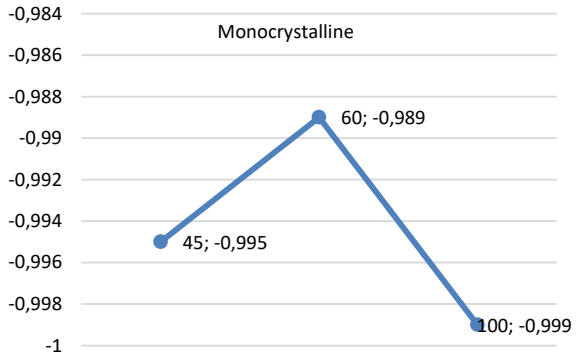

Fig. 5 Pearson's correlation for monocrystalline solar panels

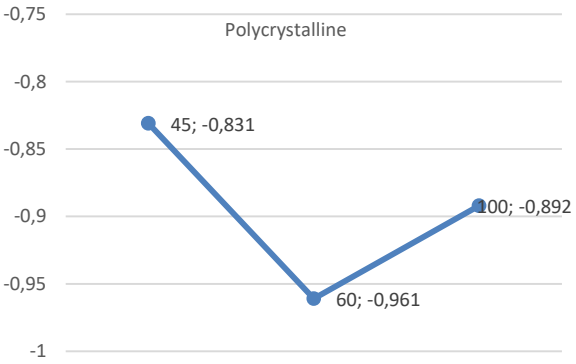

Fig. 6 Pearson's correlation for polycrystalline solar panels

From Fig. 6, it is clear that the correlation is not as strong as monocrystalline panels. If we see the Pearson value, it is -0.831

much lower than -1. So, this panel cannot be recommended for installation if someone wants to have good solar power generation. Results from the 60W capacity polycrystalline panel seem comparatively better than 45W. In Fig. 6, the Pearson value is also higher at -0.961. Thus, this panel can be recommended for cost-effective solar system that requires a satisfactory level of solar power. The worst results were observed from the results of the 100W polycrystalline panels. Though not conclusive, such poor performance may have been attributed to the quality of the panel. The Pearson's r value for this panel is also much lower in comparison to the other polycrystalline panels. In general, the 100W capacity monocrystalline panels produced the best results and should be recommended for high power generation. This is expected to consequently lower the cost of generating solar electricity.

V. Conclusion

There are various arguments for the choice of either monocrystalline and polycrystalline solar panels and several factors are considered when deciding their use for solar project installations. In this paper, we attempt to give an ending to this debate. By conducting various experiments, we arrive at the following conclusion: For power output, monocrystalline solar panels are more efficient than polycrystalline solar panels. Polycrystalline solar cell modules fluctuate highly due to changes in solar irradiation, weather, and temperature. According to the Pearson Correlation value, the working output of a monocrystalline solar panel is better than a polycrystalline solar panel. From the results, it is obvious that the monocrystalline solar panel offers better efficiency than the polycrystalline solar panel. Considering Table V, the difference between these two types of solar panels with regards to their outputs indicates remarked differences with the monocrystalline panel presenting better outcomes.

TABLE V
EFFICIENCY DIFFERENCES AMONG THREE CAPACITIES OF SOLAR PANELS

Panel capacity (W)	Efficiency differences (%)
45	3.06
60	4.04
100	3.04

So, the monocrystalline solar panel provides a significantly higher efficiency than the polycrystalline solar panel. Furthermore, results from the monthly table show that the efficiency of polycrystalline is relatively low in some specific months as the solar panel is highly affected by the outside temperature, weather, and air pressure [9]. On the other hand, the monocrystalline solar is less distressed by the fluctuations in seasonal weather conditions. Results obtained from the Pearson Correlation value, indicated a value that is close to 1 for monocrystalline solar panels while the polycrystalline solar panel represents the reverse curve. This implies that the monocrystalline solar panel offers greater working output than the polycrystalline solar panels. So, the monocrystalline solar panel is giving the best result in both of these two experiments.

Thus, it may be concluded that of the two types of solar panels, the use of monocrystalline is preferable in Bangladesh. It will provide a greater advantage for use in the production of solar electricity over polycrystalline solar panels.

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