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Analysis of Monocrystalline and Polycrystalline Solar Panels in Small-Scale Power Generation Systems Based On Microcontrollers

***Abstract**. The solar power generation prototype used in this research consists of monocrystalline and polycrystalline solar panels. The solar panels are positioned at coordinates latitude -7.290764 and longitude 112.779205. The panels are oriented towards the West at 08:00, 10:00, 13:00, and 16:00 to enhance the output voltage. After conducting a 10-day testing period, it was found that the average voltage of the monocrystalline solar panel was higher at 16.292 volts compared to the polycrystalline solar panel at 12.700 volts, with average temperatures of 32.012 ℃ and 39.563 ℃, respectively. This can be attributed to the fact that monocrystalline solar panels are made of purer silicon and have a black color. In terms of average current, the polycrystalline solar panel exhibited a higher value of 0.8264 Amperes at a temperature of 39.563 ℃, due to the higher temperature received by the polycrystalline solar panel. Therefore, it can be concluded that the monocrystalline solar panel performs more efficiently than the polycrystalline solar panel under the weather conditions at ITATS campus.*

***Streszczenie.** Prototyp elektrowni słonecznej używany w tej badawczej konstrukcji składa się z paneli słonecznych monokrystalicznych i polikrystalicznych. Panele słoneczne są umieszczone na koordynatach szerokości geograficznej -7.290764 i długości geograficznej 112.779205. Panele są skierowane na zachód o godzinie 08:00, 10:00, 13:00 i 16:00 w celu zwiększenia napięcia wyjściowego. Po przeprowadzeniu 10-dniowego okresu testowego stwierdzono, że średnie napięcie paneli słonecznych monokrystalicznych wynosiło 16,292 woltów, podczas gdy dla paneli słonecznych polikrystalicznych wynosiło 12,700 woltów, przy średnich temperaturach odpowiednio 32,012 ℃ i 39,563 ℃. Wynika to z faktu, że panele słoneczne monokrystaliczne są wykonane z czystszego krzemu i mają czarny kolor. Jeśli chodzi o średni prąd, panel słoneczny polikrystaliczny wykazywał wyższą wartość równą 0,8264 ampera przy temperaturze 39,563 ℃, ze względu na wyższą temperaturę odbieraną przez panel słoneczny polikrystaliczny. Zatem można wywnioskować, że panel słoneczny monokrystaliczny działa bardziej wydajnie niż panel słoneczny polikrystaliczny w warunkach pogodowych na terenie kampusu ITATS. (**Analiza monokrystalicznych i polikrystalicznych paneli słonecznych w małych systemach wytwarzania energii opartych na mikrokontrolerach**)*

Keywords: Monocrystalline, Polycrystalline, Solar Panels, Small-Scale Power Generation Systems, Microcontrollers.
Słowa kluczowe: Monokrystaliczne, polikrystaliczne, panele słoneczne, systemy wytwarzania energii w małej skali, mikrokontrolery.

Introduction

The utilization of renewable energy sources, known as New and Renewable Energy (NRE), in Indonesia has not reached its maximum potential. As of the end of 2018, the operational NRE capacity owned by the company throughout Indonesia reached 7,000 MW or 12%[1]. NRE power generation consists of hydropower, geothermal, solar, wind, biomass, and others. Meanwhile, the national electricity consumption is increasing due to the expanding access to electricity, with an average consumption growth rate of 4.8% from 2014 to 2017 [2]. Therefore, there is a need to add more electricity generation capacity to meet the growing demand. One of the energy sources that can be converted into electricity is solar energy, considering that Indonesia has a solar energy potential of 207,898 MW or approximately 4.80 kWh/m2/day[3].

Solar panels are one of the devices used to convert solar energy into electrical energy. The performance of solar panels is highly dependent on weather and climate conditions. Weather refers to the atmospheric conditions in a specific area that change constantly, while climate is the average weather conditions with a minimum data collection period of 30 years. However, for current purposes in Indonesia, it is based on a minimum of 7 days or a week, according to the information from BMKG[4]. Previous research focused on using the dual-axis method to improve the output voltage of polycrystalline solar panels. The research compared the output voltage of polycrystalline solar panels using the dual-axis method with conventional methods. The optimized output voltage obtained using the dual-axis method was around 5% higher compared to the conventional method [5].

Monocrystalline and polycrystalline solar panels are commonly used solar panels with different characteristics and efficiencies. The efficiency of a solar panel is influenced by climate conditions, cell type, and other factors. The average efficiency of monocrystalline and polycrystalline solar panels is 6.65% and 5.38% respectively [6]–[8]. A research conducted in Bangladesh to investigate the availability of silicon in polycrystalline and monocrystalline modules under different temperature and light intensity revealed that monocrystalline silicon modules perform better in terms of series resistance, saturation current, and fill factor. The current and power generated by monocrystalline silicon modules are significantly lower compared to polycrystalline silicon modules. The lower current in monocrystalline silicon modules is attributed to high recombination in the thick silicon layer due to lower crystal quality in monocrystalline silicon modules. These findings suggest the need for better regulation in the quality control of commercially available solar panel modules[9]."

The use of a 20 WP monocrystalline solar panel results in better energy output compared to a 20 WP polycrystalline solar panel, with an average efficiency difference of 0.5%. Monocrystalline solar panels are capable of converting sunlight intensity entering the panel more effectively compared to polycrystalline solar panels[10]. Monocrystalline solar panels outperform polycrystalline panels by 229 WH, even when observed under varying intensity and air temperature. The investment cost in Indonesian Rupiah per WH for monocrystalline solar panels is lower than that of polycrystalline solar panels. Therefore, monocrystalline solar panels are the appropriate choice for weather conditions in Banda Aceh [11].

Microcontrollers have been widely developed to meet various data processing needs, including in the fields of monitoring systems[12]–[14], control[15]–[18]. In this research, microcontrollers are used to process data from several sensors, such as current, voltage, and temperature sensors. This study aims to compare the performance of monocrystalline and polycrystalline solar panels under varying weather conditions on the ITATS campus. Testing is conducted under changing sunlight intensity, air temperature, and wind speed. Both types of solar panels are placed in the same field, positioned parallel to each other, and tested simultaneously. The voltage is stored using a battery and used to power a 100 Watt DC load. By making this comparison, it is hoped to provide recommendations for the most effective type of solar panel based on the weather conditions on the ITATS campus."

Metode

This research was conducted at the Adhi Tama Institute of Technology Surabaya campus. To ensure that the power generation system functions according to the design, the following components are required to assist the system can se at fig 1.

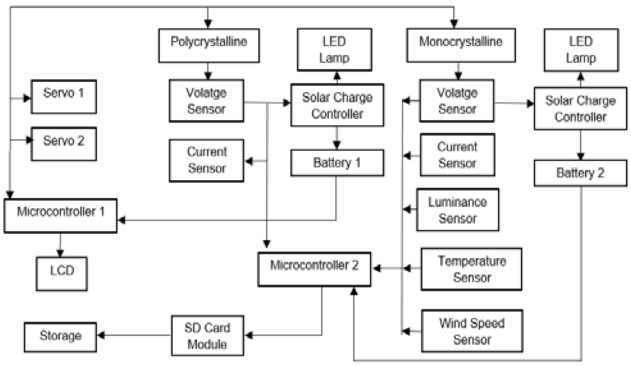

Fig.1. Block Desing System

Monocrystalline and polycrystalline solar panels convert solar energy into DC voltage, which is connected to a solar charge controller. Monocrystalline and polycrystalline solar panels are connected to current and voltage sensors to monitor the output current and voltage of the solar panels. The solar charge controller is connected to the battery and regulates the charging voltage. Battery 1 stores the DC voltage from the polycrystalline solar panel. Battery 2 stores the DC voltage from the monocrystalline solar panel. The polycrystalline solar charge controller supplies power to the LED lights at night. The polycrystalline solar charge controller is connected to Battery 1. Battery 1 supplies power to Arduino 1 through the polycrystalline solar charge controller.

Arduino 1 is connected to a gyroscope sensor and motor driver. The motor driver is connected to servo motor 1 and servo motor 2. Servo motor 1 moves the solar panel towards the North and South directions, while servo motor 2 moves the solar panel towards the West and East directions. The gyroscope sensor reads the predetermined angles. The tilt angle of the solar panel can be adjusted using a potentiometer and displayed on an LCD. The monocrystalline solar charge controller is connected to Battery 2. Battery 2 supplies power to Arduino 2 through the monocrystalline solar charge controller. Arduino 2 reads the polycrystalline voltage sensor, monocrystalline voltage sensor, polycrystalline current sensor, monocrystalline current sensor, polycrystalline temperature sensor, monocrystalline temperature sensor, wind speed sensor, and light intensity sensor. The SD card module transfers the sensor data readings from Arduino 2 to the storage memory. Mechnaics design can see at fig 2.

The previous researcher used a sufficiently strong support structure to hold the solar panels. Therefore, in this study, the author did not create a new support structure but utilized the solar panel support structure from the previous researcher. The support structure design used in this study is shown in Figure 1, the solar panels are set to move at changing angles at 08:00, 10:00, 13:00, and 16:00. This is done to enhance solar energy absorption, resulting in higher voltage and current output for each solar panel compared to panels in static conditions. For measurement flowchart can see at the figure3.

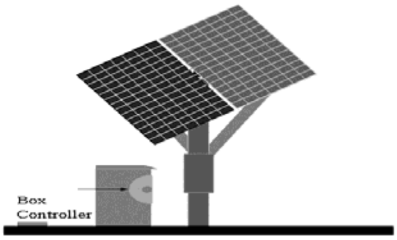

Fig.2. Mechanics Design System

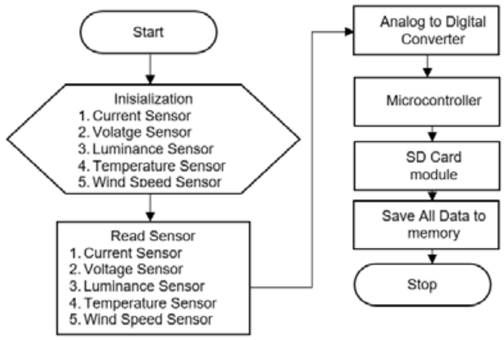

Fig.3. Flowchart System

Measurements are conducted using several sensors to obtain real-time data and save measurement time. The sensors used include voltage sensor, current sensor, light intensity sensor, temperature sensor, and wind speed sensor. The voltage sensor is used to measure the voltage generated by monocrystalline and polycrystalline solar panels. The measured voltage is then forwarded to the Arduino and stored in the memory. The current sensor is used to measure the current generated by monocrystalline and polycrystalline solar panels. The measured current is then forwarded to the Arduino and stored in the memory.

The light intensity sensor is used to measure the intensity of sunlight. The measured light intensity is then forwarded to the Arduino and stored in the memory. The temperature sensor is used to measure the temperature of monocrystalline and polycrystalline solar panels. The measured temperature is then forwarded to the Arduino and stored in the memory. The wind speed sensor is used to measure the wind speed around the prototype. The measured wind speed is then forwarded to the Arduino and stored in the memory.

Result and Discussions

Comparison of Monocrystalline and Polycrystalline Solar Panels

To assess the performance of the developed prototype, which consists of monocrystalline and polycrystalline solar panels, both panels are positioned side by side as shown in Figure 3. The prototype moves at specific times, namely 08:00, 10:00, 13:00, and 16:00, in order to enhance solar energy absorption, resulting in higher voltage and current output for each solar panel compared to panels in static conditions. Mechnaics result can see at fig 4.

The designed measurement system functions to measure voltage, current, temperature, light intensity, and wind speed. Some sensors have an error percentage of up to 5.022% and 12.47%, namely the light intensity sensor and wind speed sensor, respectively. Therefore, measurements are conducted using an anemometer and a lux meter to overcome these errors.

Fig.4. Prototype of Monocrystalline and Polycrystalline Solar Panels

Testing Results of Monocrystalline and Polycrystalline Solar Panels conducted at ITATS Campus from 08:00 AM to 05:00 PM.
On February 29.

The measurement results of voltage on the first day for monocrystalline and polycrystalline solar panels are presented in fig 5.

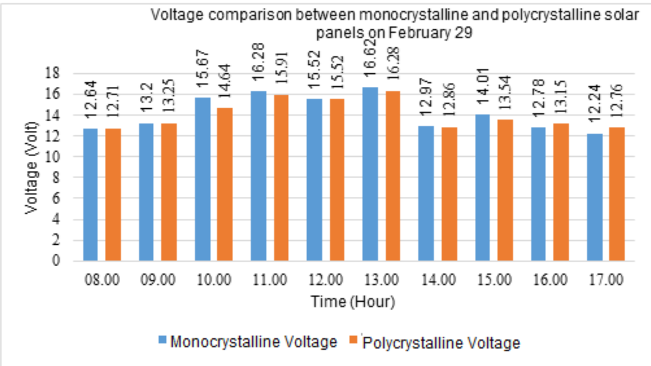

Fig.5. Voltage Comparison Monocrystalline and Polycrystalline

Based on Figure 5, the highest output voltage of the monocrystalline solar panel occurs at 13:00, measuring 16.62 V. This is attributed to an increase in temperature from 43.12 ℃ to 45.12 ℃ under cloudy weather conditions. The highest output voltage of the polycrystalline solar panel also occurs at 13:00, measuring 16.28 V, which is a result of a temperature increase from 42.68 ℃ to 45.06 ℃. On the other hand, the lowest output voltage of the monocrystalline solar panel occurs at 17:00, measuring 12.24 V. This is due to a decrease in temperature from 32.06 ℃ to 29.8 ℃ during rainy weather. The lowest output voltage of the polycrystalline solar panel occurs at 08:00, measuring 12.71 V. This can be attributed to the longer time required for the polycrystalline material to reach optimal performance, despite the temperature reaching 46.37 ℃. And the measurement results on February 29, the output current of monocrystalline and polycrystalline solar panels can be seen in fig 6.

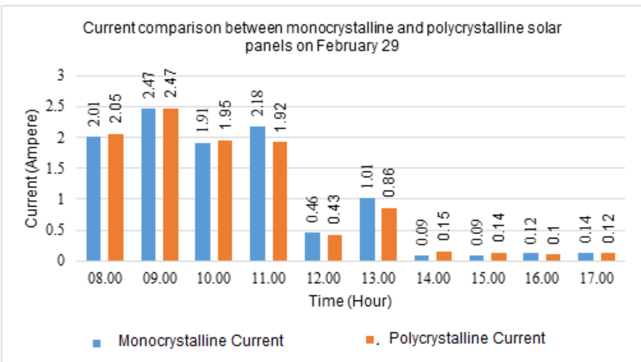

Fig.6. Current Comparison Monocrystalline and Polycrystalline

Based on Figure 5, the highest current in the monocrystalline solar panel occurred at 09:00, reaching 2.47 A. This can be attributed to the increase in temperature from 49.75 ℃ to 54.68 ℃ under sunny weather conditions. Similarly, the highest current in the polycrystalline solar panel also occurred at 09:00, measuring 2.47 A. This increase was due to the temperature rising from 46.37 ℃ to 51.75 ℃. On the other hand, the lowest current in the monocrystalline solar panel was recorded at 14:00 and 15:00, with a value of 0.09 A. This decrease in current can be attributed to the temperature increase from 45.12 ℃ to 52.43 ℃ under sunny weather conditions. The lowest current in the polycrystalline solar panel was observed at 16:00, measuring 0.1 A. This decrease was caused by a temperature drop from 40.68 ℃ to 30.81 ℃. The temperature measurements of the monocrystalline and polycrystalline solar panels on February 29th are presented in Figure 7.

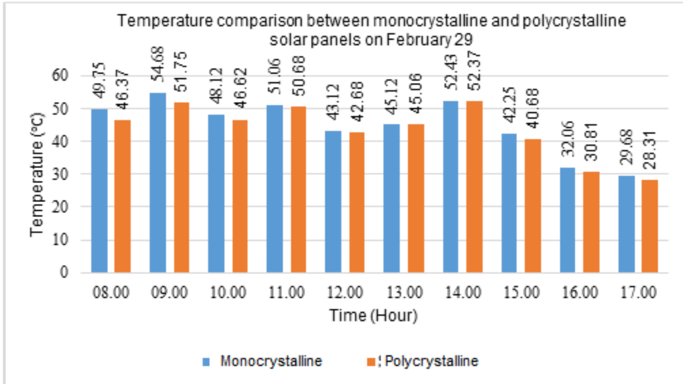

Fig.7. Temperature Comparison Monocrystalline and Polycrystalline

Based on Figure 7, the highest temperature recorded in the monocrystalline solar panel occurred at 09:00, reaching 54.68 ℃. This can be attributed to the fact that monocrystalline solar panels, which are black in color, have a higher heat absorption capacity. On the other hand, the polycrystalline solar panel reached its highest temperature at 14:00, measuring 52.37 ℃. This can be attributed to the fact that polycrystalline solar panels, which are blue in color, require more time to absorb heat. And then result luminance and wind speed at February 29 can see at fig 8..

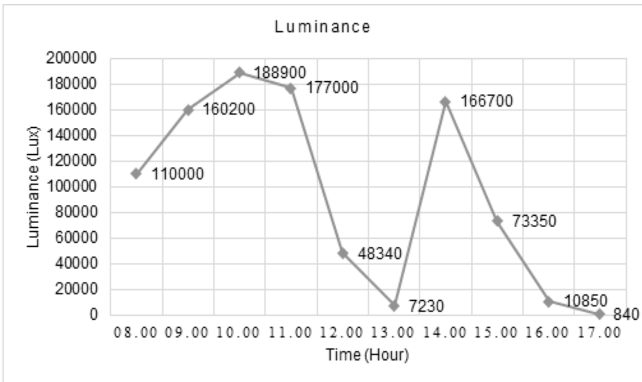

Fig.8. Luminance value on February 29

Based on Figure 8, the highest light intensity was recorded at 11:00, measuring 188,900 lux. This can be attributed to clear weather conditions that allowed for a strong influx of sunlight. Conversely, the lowest light intensity occurred at 17:00, measuring 840 lux, which can be attributed to rainy weather conditions that resulted in reduced sunlight penetration. The result can se at fig 9.

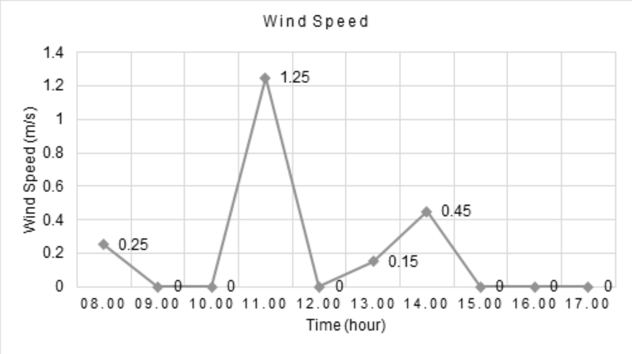

Fig.9. Wind Speed value on February 29

Based on Figure 9, the wind speed remained relatively low, averaging around 0 m/s throughout the day. However, the highest wind speed was recorded at 11:00, measuring 1.25 m/s, during clear weather conditions. It is worth noting that this wind speed had minimal impact on the temperature of the respective monocrystalline and polycrystalline solar panels. Data collection like this was carried out continuously for 10 consecutive days.

Comparison of Monocrystalline and Polycrystalline Solar Panels at 10 day collecting data

The average measurement results of voltage on monocrystalline and polycrystalline solar panels over a period of ten days were calculated show at table 1.

Table 1. The average voltage measurement on monocrystalline and polycrystalline solar panels was calculated.

Day	Voltage Monocrystalline (Volt)	Volatge Polycrystalline (Volt)
1	14,193	14,062
2	11,539	12,973
3	11,201	13,032
4	16,671	12,149
5	17,804	11,956
6	16,293	11,993
7	19,055	13,007
8	16,312	12,302
9	19,794	12,792
10	20,059	12,735
Average	16,2921	12,7001

Based on Table 1, the highest average voltage of the monocrystalline solar panel occurred on March 9, at 20.059 V. This is due to the varying weather conditions of sunny, cloudy, and rainy, which resulted in cooling of the solar panel temperature and increased voltage output. The highest average voltage of the polycrystalline solar panel occurred on February 29, at 14.062 V. This is attributed to predominantly sunny weather conditions, where the voltage generated experienced minor fluctuations.

The lowest average voltage of the monocrystalline solar panel occurred on day 4, at 11.539 V. This is due to changing weather conditions from sunny to cloudy, resulting in a significant decrease in temperature and affecting the voltage output. The lowest average voltage of the polycrystalline solar panel occurred on day 4, at 12.149 V. This is because of predominantly cloudy weather conditions. Monocrystalline solar panels have relatively higher voltage compared to polycrystalline solar panels under varying weather conditions. The total average voltage of the monocrystalline solar panel is 16.2921 volts, while the total average voltage of the polycrystalline solar panel is 12.7001 volts. The monocrystalline solar panel experiences larger fluctuations in voltage compared to the polycrystalline solar panel, which exhibits relatively smaller changes in voltage. Then caomparison between current at 10 day, can see at table 2.

Table 2. The average current measurement on monocrystalline and polycrystalline solar panels was calculated.

Day	Current Monocrystalline (Ampere)	Current Polycrystalline (Ampere)
1	1,048	1,019
2	0,118	0,166
3	0,578	0,767
4	0,711	0,721
5	0,637	0,652
6	0,897	0,924
7	1,165	1,233
8	0,788	0,818
9	0,789	0,811
10	1,116	1,153
Average	0,7847	0,8264

Based on Table 2, the highest average current of the monocrystalline solar panel occurred day 7. This is due to predominantly sunny weather conditions. Similarly, the highest average current of the polycrystalline solar panel also occurred on day 7, as a result of the sunny weather conditions. The lowest average current of the monocrystalline solar panel occurred on day 2, at 0.118 A. This is attributed to a decrease in temperature despite the predominantly sunny weather conditions. The lowest average current of the polycrystalline solar panel also occurred on day 2, at 0.166 A, again due to a decrease in temperature despite the sunny weather conditions. The total average current of the polycrystalline solar panel is higher than that of the monocrystalline solar panel, amounting to 0.8264 A. Then caomparison between Temperatures at 10 day, can see at table 3.

Table 3. The average temperature measurement on monocrystalline and polycrystalline solar panels was calculated.

Day	Temperature Monocrystalline (℃)	Temperature Polycrystalline (℃)
1	44,827	43,533
2	38,939	37,778
3	42,723	42,941
4	38,701	38,227
5	36,447	35,753
6	38,464	37,628
7	41,155	41,315
8	36,684	36,991
9	39,345	40,077
10	40,671	41,389
Average	32,0117	39,5632

Table 4. The average luminance and wind speed measurement on monocrystalline and polycrystalline solar panels was calculated.

Day	Luminance (Lux)	Wind Speed (m/s)
1	94341	0,21
2	48058,6	0,08
3	53991,5	0,246
4	48789,2	0,1
5	48416,7	0,12
6	40081,2	0,11
7	65415,4	0,13
8	46508,2	0,14
9	54719,7	0,1
10	66303,7	0,1
Average	56662,52	0,1336

Based on table 3, the highest average temperature of the monocrystalline solar panel occurred on February 29, 2020, at 44.827 ℃. This can be attributed to predominantly sunny weather conditions and the black color of the solar panel, which enhances heat absorption. Similarly, the highest average temperature of the polycrystalline solar panel occurred on February 29, 2020, at 43.533 ℃, also due to predominantly sunny weather conditions. The total average temperature received by the polycrystalline solar panel is higher than that of the monocrystalline solar panel, amounting to 39.5632 ℃. Then caomparison luminance and wind speed at 10 day, can see at table 4.

Based on Table 4, the highest average light intensity occurred on February 29, 2020, at 94,341 lux, attributed to predominantly sunny weather conditions. On the other hand, the lowest average light intensity occurred on March 5, 2020, at 40,081.2 lux, despite relatively sunny weather conditions and a moderate temperature. Referring to table 4, the highest average wind speed recorded was 0.246 m/s on March 2, 2020. Conversely, the lowest average wind speed observed was 0.1 m/s.

Conclusions

From the testing of monocrystalline solar panels and polycrystalline solar panels conducted over a period of ten days, the following conclusions can be drawn. The average voltage generated by the monocrystalline solar panels is 16.2921 V, while the polycrystalline solar panels produce an average voltage of 12.7001 V at an average temperature of 32.012 ℃ and 39.563 ℃, respectively. The output voltage of each solar panel is influenced by the weather conditions. The average current value of the polycrystalline solar panels is higher than that of the monocrystalline solar panels, measuring 0.8264 Amperes at a temperature of 39.563 ℃. This is due to the higher temperature received by the polycrystalline solar panels. These findings indicate that monocrystalline solar panels are more efficient than polycrystalline solar panels under the weather conditions at ITATS campus.

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