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The impact of cloudy weather on the energy production of a solar power plant

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Abstract: This paper examines the impact of cloud cover on the efficiency of solar panels. Cloudiness significantly reduces the amount of solar radiation reaching the surface of the panels, directly affecting their electricity generation. The study analyzes different types of clouds, their density, altitude, and duration, as well as seasonal cloud patterns in various climatic conditions. Special attention is paid to the dynamic changes in cloud cover throughout the day, as sudden fluctuations in sunlight can cause instability in photovoltaic systems. Methods for accounting for cloudiness in solar power generation modeling are discussed, including the use of satellite monitoring data and local meteorological stations. The paper also explores the application of intelligent forecasting systems based on artificial intelligence and machine learning, which can improve the accuracy of solar potential assessments under variable cloud conditions. The findings of this study can be useful for the design and operation of solar power plants in regions with frequent or unpredictable cloud cover.Using the Solarmeter device, we measured solar insolation in the city of Almalyk under light and dense cloud cover. The obtained values were used in the Matlab Simulink program to model the station and determine the possible power output.

Keywords: Sun, light clouds, solar power plant, measurement, power, sunlight, shadow, insolation, cloud cover, efficiency, renewable energy, solar panels, cloud density, solar radiation, tilt angles, diffuse lighting, energy performance.

Introduction:

Relevance and demand for the topic. Today, worldwide attention is focused on expanding the use of renewable energy sources, primarily solar and wind energy, which serves as a driver for the development of green energy. The development of green energy is particularly relevant because it primarily contributes to saving the country's primary energy resources, reducing CO_2 emissions, mitigating the effects of climate change, ensuring energy security and independence, and improving the standard and quality of life of the population.

In addition, the large-scale introduction of practical applications of renewable energy helps improve the social conditions of the population by providing guaranteed and uninterrupted access to affordable, reliable, sustainable, and modern energy sources for all.

One of the pressing issues is achieving high power output by optimizing the orientation and installation angles of solar panels, which requires new approaches to enhance the efficiency of solar energy use on an industrial scale in the country.

According to Resolution No. PP-4477 dated October 4, 2019, "On approval of the strategy for the transition of the Republic of Uzbekistan to a green economy for the period 2019-2030," as well as other regulatory documents in this area, the relevance of this research topic is further confirmed.

In this context, a particular priority is given to the assessment and forecasting of resource, technical, economic, and environmental indicators of energy systems based on renewable energy sources, taking into account the characteristics of the specific network and the climatic conditions of the given region to ensure their safe integration into the power grid.

The purpose of the research is to study the potential power generation of a solar power plant under conditions of light and dense cloud cover.

Research objectives:

Measurement of solar insolation under cloudy weather conditions.

Investigation of the maximum power generation of a solar power plant under these insolation conditions.

Clouds can also shade solar panels, but in this case, insolation does not disappear completely — it simply decreases. This is because clouds, unlike solid objects such as buildings or trees, do not create complete shading. Instead, they scatter solar radiation, which reduces the intensity of sunlight but does not eliminate it entirely.

Clouds, especially mid-level and high-level clouds, do not fully block sunlight. Instead, they scatter light, creating diffuse illumination. This means that sunlight can still penetrate through the clouds, although with reduced intensity.

Type of clouds: Light clouds (such as cirrus clouds) only slightly reduce insolation, allowing most of the sunlight to pass through.

Figure 1. Light cloud cover.

Thick clouds (such as stratiform or cumulus clouds) can significantly reduce insolation, but even in this case, sunlight is not completely blocked.

Figure 2. Thick cloud cover.

Diffuse Lighting: Clouds create a diffuse lighting effect, where solar rays are scattered in different directions, and part of this light still reaches the solar panel. Even in cloudy weather, solar panels can register insolation, although significantly lower than on a clear day.

Clouds do not cast sharp shadows but instead create soft, diffused lighting. This allows solar panels to receive some amount of energy even when the sky is overcast. Clouds can reduce insolation throughout the day, but this effect is especially noticeable in the morning and evening hours when the sun's rays are more inclined. Clouds enhance this effect, and the light can be scattered even when the sun is not very high in the sky.

1. Measuring solar insolation in cloudy weather.

To assess the performance of a solar power plant in cloudy weather, it is necessary to determine the level of solar insolation. Accurate insolation values can only be obtained through direct measurement.

Various instruments and devices are used to measure solar insolation (the amount of solar energy falling on a surface over a specific period). The main instruments include:

Pyrheliometer

Pyranometer

Heliograph

Solar Power Meter

Our main measurements were carried out using the Solar Power Meter, which, according to its technical specifications, is capable of measuring solar insolation up to 2000 W/m², with a measurement error of ±10 W/m².

Figure 3. Device for measuring solar insolation (Solar Power Meter).

In clear weather, solar insolation reaches 1000 W/m². Together with our academic supervisors, we conducted precise measurements under conditions of light cloud cover and thick cloud cover in the city of Almalyk.

b)

Figure 4.
a) Measured solar insolation under light cloud cover,
b) Measured solar insolation under thick cloud cover.

Observations showed that light cloud cover can persist for a certain period — from several hours to half a day. The density of the clouds is also variable, which directly affects the level of solar insolation.

Thick cloud cover, on the other hand, can last for days and is most often observed before and after rainfall. In such cases, the cloud layers allow almost no sunlight to pass through, and solar insolation remains at extremely low levels. The density of the clouds is almost constant, which correspondingly affects solar insolation values, changing them by only 1-2 W/m².

The importance of solar insolation on cloudy days. W/m².

The importance of solar insolation on cloudy days. W/m².			
Day	Light cloud	Day	Thick cloud
22 November	525	20 November	60
	669		61
	710		62
25 November	306	29 November	98
	352		100
	482		102

Table 1. Solar insolation values on cloudy days in the city of Almalyk.

2. Potential power generation of a solar power plant in cloudy weather.

Based on the measured values presented in the table, a 100 kW solar power plant is modeled in MATLAB Simulink to study how such weather conditions can affect the performance of the solar power plant.

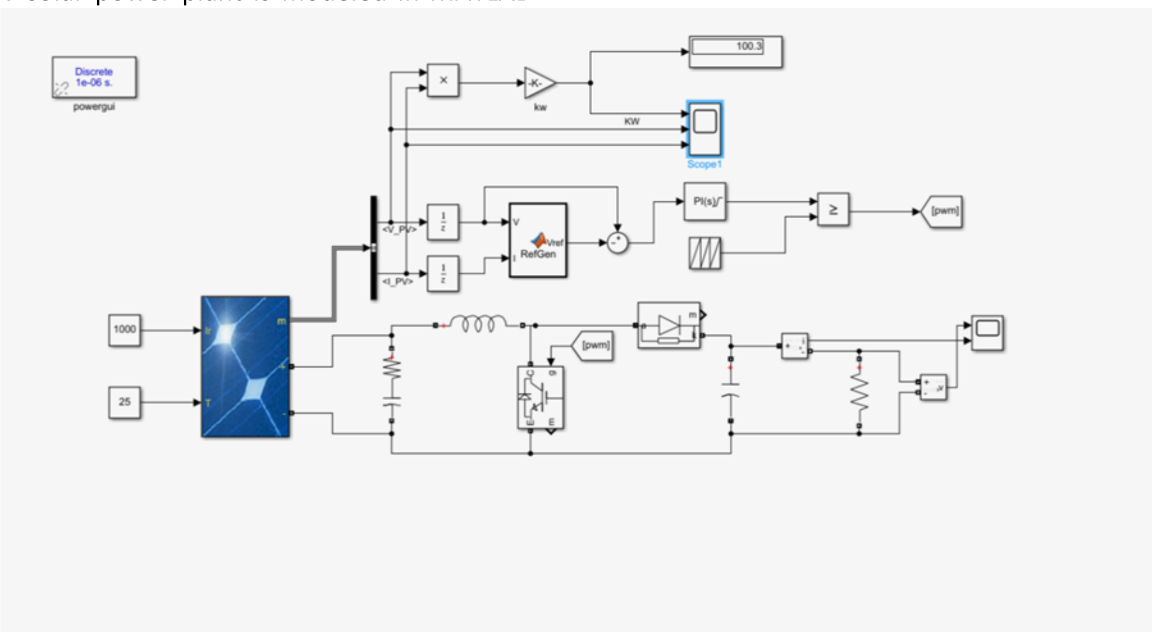


Figure 5. Simulation model of a 100 kW solar power plant.

According to laboratory experiments, solar panels achieve maximum efficiency at an insolation level of 1000 W/m² and a panel temperature of 25°C.

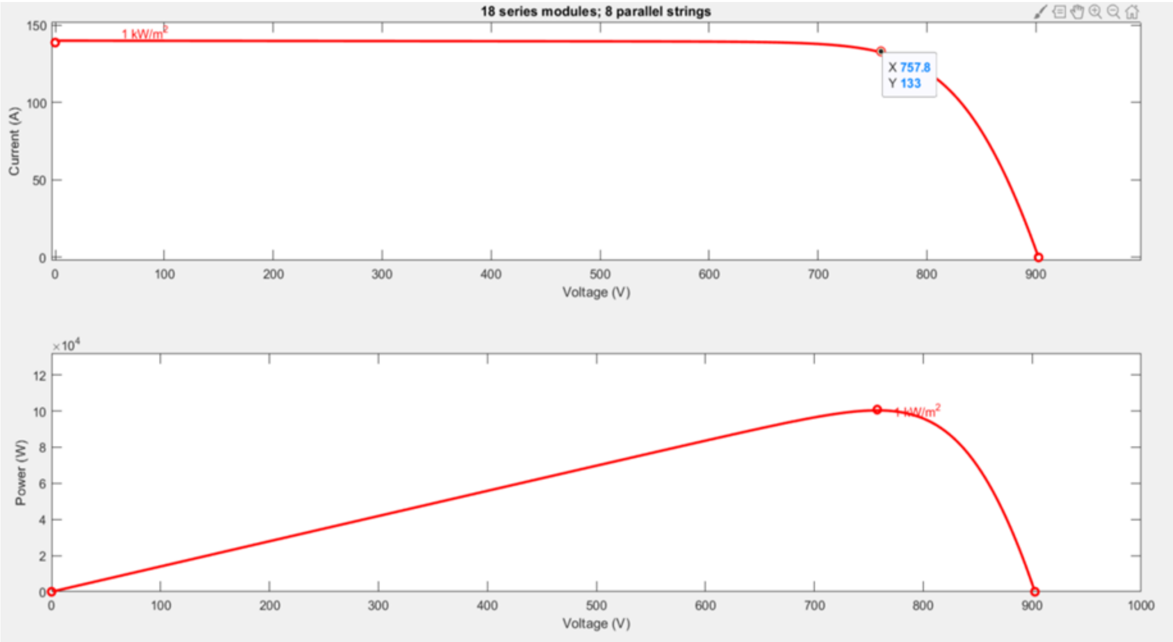


Figure 6. Model values under clear weather conditions

In this case, with solar insolation of 1000 W/m² under clear weather conditions, the obtained values are:

Power — 100 kW

Voltage — 757.8 V

Current — 133 A.

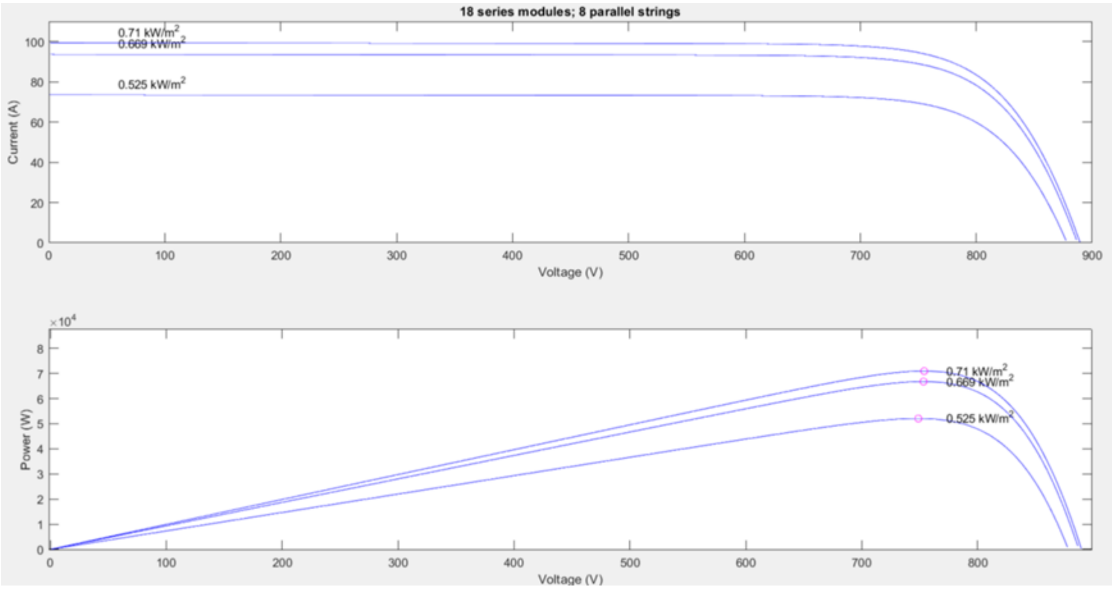


Figure 7. Model values under light cloud cover on November 22.

Based on the measured solar insolation values under light cloud cover on November 22, the power, current, and voltage indicators can be observed.

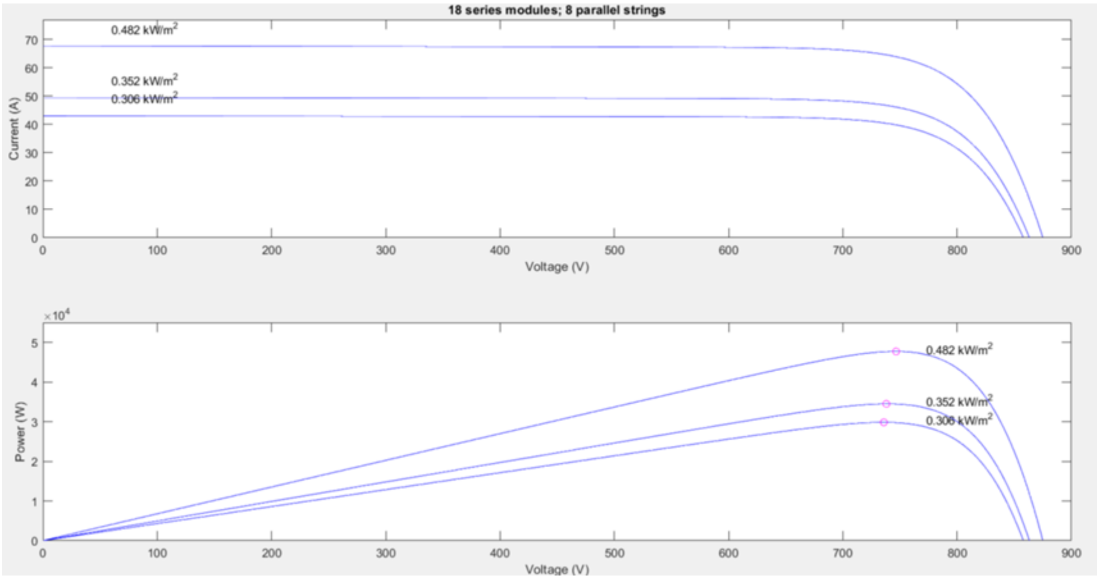


Figure 8. Model values under light cloud cover on November 25.

Based on the measured solar insolation values under light cloud cover on November 25, the power, current, and voltage values can be observed.

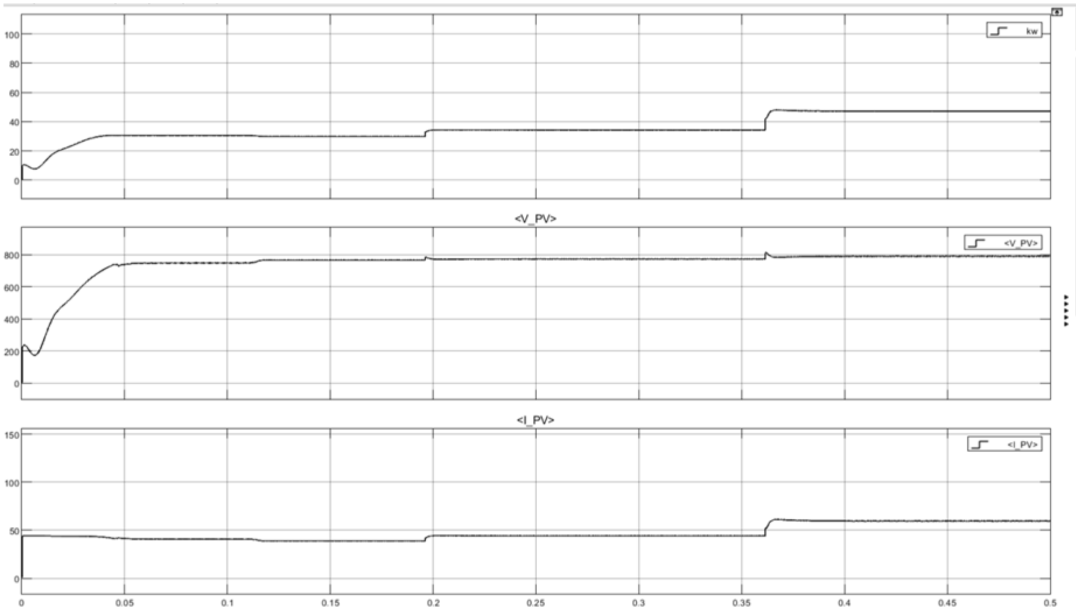
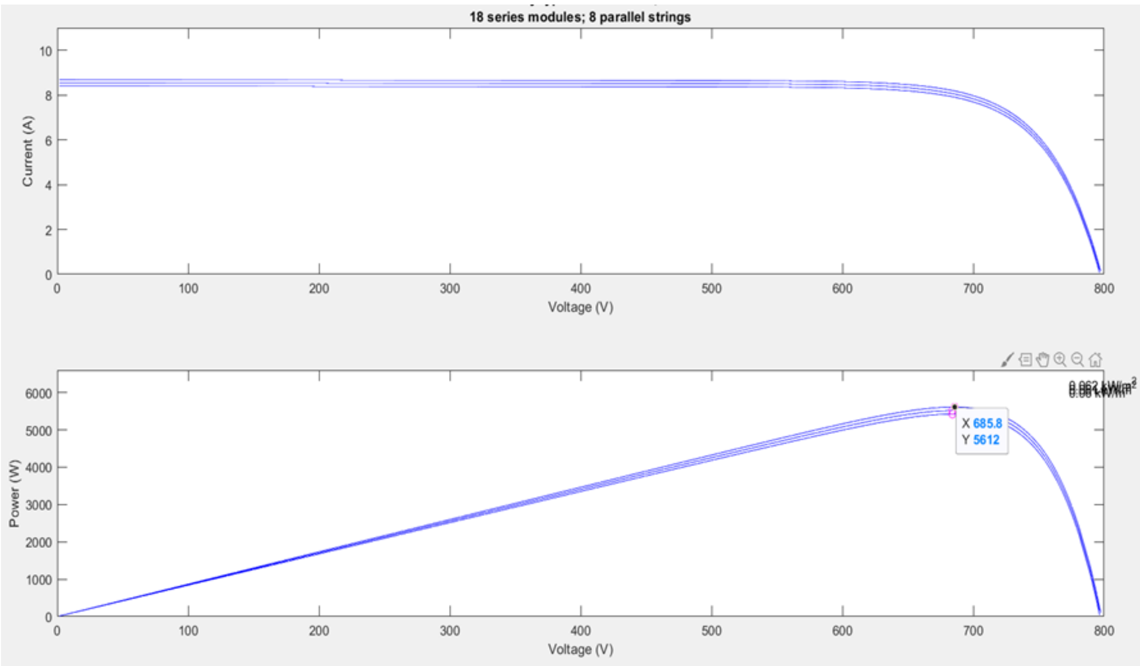


Figure 8. Model representation of the effect of changing thickness and density of light cloud cover on November 22.

As solar insolation increases, the power output of the solar power plant also increases. Accordingly, the current rises as well. The voltage, however, changes only slightly.



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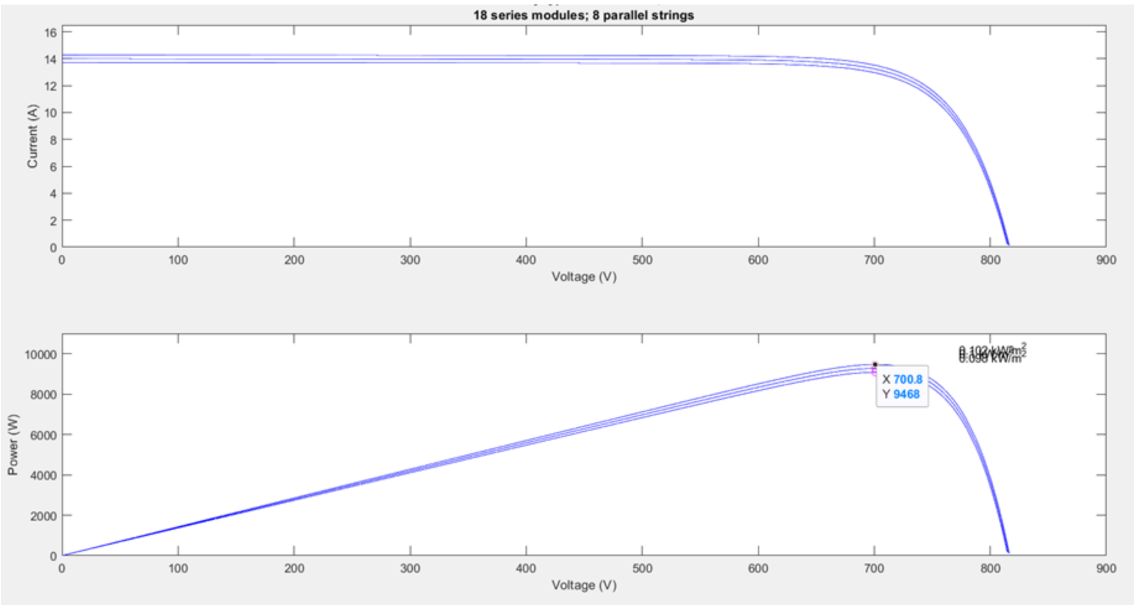

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Figure 9.
a) Model values under thick cloud cover on November 20
b) Model values under thick cloud cover on November 29

Based on the measured solar insolation values on days with thick cloud cover (November 20 and November 29), the power output from the solar power plant remains at an extremely low level. This power reduction persists throughout the day.

CONCLUSION

In cloudy weather, the efficiency of the solar power plant decreases due to reduced solar radiation. Based on the results of measurements and simulations, it can be concluded that under light cloud cover, the solar power plant loses an average of 30% to 70% of its power output, depending on the density of the cloud layer. Under thick cloud cover, power losses reach 90% to 95%. In such weather conditions, to maintain efficiency under the given insolation, attention should be paid to: The cleanliness of solar panels, The tilt angle of the panels, Proper orientation and spacing between panel rows. This will help maintain the maximum possible performance of the solar power plant.

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