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Effect of Dust Deposition on Solar Panel in Solar Power Generation

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The deposition of dust on the surface of a solar panel affects the power generation of the solar panel and even shortens its service life. Thus, it is necessary to evaluate the effect of dust deposition on power generation quantitatively. We designed an automatic dust measurement platform with a micro-weather station that can be installed on the solar panel to evaluate the effect of dust deposition on the solar panel. The platform comprised a glass cover, a programmable logic controller (PLC), light transmittance sensors, and a sliding rail motor, and measured the irradiance and light transmittance every 10 s. We compared the measured values with the generated power of the solar panel. To understand the effect of dust deposition, we installed two solar power generation systems with measurement platforms at the same location. One platform was cleaned daily and maintained a light transmittance of 94%. The other platform was left without cleaning for 3.5 days. Then, measurements were carried out on the two solar power generation systems from 8:00 AM to 5:00 PM on a sunny day and a cloudy and rainy day. On the sunny day, dust deposition decreased the light transmittance from 94 to 87.36% (an average of 25 measuring points), resulting in a 2.14% decrease in daily cumulative power generation. On a cloudy day, the average light transmittance decreased to 51.40%, and the daily cumulative power generation decreased by 10.83%. These results confirmed that the effect of dust deposition on power generation was more significant than that of weather, and that cleaning the dust was beneficial to power generation. It was found that the automatic dust measurement platform could be used effectively to monitor dust deposition on the solar panel. The results of this study can be used as the basis for installing and managing solar panels so as to achieve their effective use.

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1. Introduction

Increasing electricity demands have caused a global energy crisis, while the use of fossil fuels has decreased owing to the concern about the acceleration of global warming.[1] Therefore, renewable energy sources have been exploited and used increasingly. Among them, solar energy is regarded as the ideal green energy source owing to its simple system structure, high reliability, and easy expansion of power generation capacity. Solar power generation is particularly appropriate for remote areas as a major or emergency power source and reduces carbon dioxide emissions. Thus, solar power generation technology has developed rapidly[2] and is being used widely. As a result, the proportion of solar power generation in the total global power production is steadily increasing.

However, solar power generation has several drawbacks. One of the most serious problems is dust deposition on the solar panel. Since the solar panel is placed outdoors, its power generation efficiency varies depending on the amount of dust deposited on the surface. Dust deposition affects the power generation efficiency and the life of the solar panel.[3–5] To reduce dust deposition, the optimal inclination of the solar panel should be determined to maximize the solar radiance while minimizing dust deposition, taking into consideration various meteorological factors.[6–8] This requires collecting and understanding data on the amount of dust deposited on the surface of the solar panel, wind speed, wind direction, and even rainfall. Even with reduced dust deposition, the solar panel needs to be cleaned to maintain the appropriate power generation. Periodic cleaning is conducted in most solar power generation plants about 3 to 4 times a year depending on the condition of the plant. However, it is necessary to decide how often the solar panel should be cleaned, as it requires considerable time and cost. Several plants decide the time for cleaning by comparing the cleaning cost with the total revenue reduction due to reduced solar power generation as a result of dust deposition.[9] Also, more effective cleaning methods are necessary to reduce the frequency of cleaning and recurring costs in order to gain economic benefit.[10] Therefore, we designed an automatic dust measurement platform with a micro-weather station to investigate how dust deposition on the solar panel affects the power generation efficiency and how it is affected by wind speed and direction. The effect of the inclination of the solar panel on dust deposition was also investigated to minimize dust deposition. The platform was also designed to monitor the amount of dust deposited by sector on the panel in real time. The results of this study and the collected data from the platform will become an important reference for the maintenance of the solar power panel, especially for deciding when to clean the panel.

2. Design of Automatic Dust Measurement Platform and Measurement Method

2.1 Automatic dust measurement platform

The automatic dust measurement platform consists of a glass cover, a programmable logic controller (PLC) with a human–machine interface, light transmittance sensors, and a sliding rail motor. The schematic diagram of the platform structure installed on the solar panel is shown in

Fig. 1. The amount of dust deposited was measured on the glass cover. Figure 2 shows the appearance of the automatic dust measurement platform and the micro-weather station.

The PLC is used to control the entire operation of the platform. Its human–machine interface displays real-time data and stores it for subsequent analysis. The glass cover is made of the same material as the commercial solar panel. The light transmittance sensor measures the light transmittance of the glass cover and shows the amount of dust deposited on the surface of the glass cover. The micro-weather station measures wind direction and speed, temperature, humidity, irradiance, and rainfall. The flow chart of the control of the platform is shown in Fig. 3. The light transmittance sensor was tested with an artificial light source, and Table 1 shows the technical parameters of the transmittance sensor.

Data from micro-weather stations, light transmittance sensors, and electricity meters were transmitted to the PLC, which displayed the data at the human–machine interface. The PLC communicated with the micro-weather station using the Modbus/remote terminal unit (RTU) communication protocol. Pyranometers (LP PYRA 02, Delta Ohm) were used to measure the irradiance of the sunlight on two solar power generation systems (PV1 and PV2).(11) The PLC obtained the signals from the pyranometers through the 6-channel analog input module. The PLC automatically recorded the time taken for the measurement of dust deposition and controlled the sliding rail motor that moves the glass cover. The hardware and communication scheme of the platform are shown in Fig. 4. Figure 5 shows the motor control screen. Once the measurement point of dust deposition was decided and sent from the PLC, the servo motor was moved to the point.

The solar panel (TYNP62610260) was manufactured by Tynsolar Corporation in Taiwan. The maximum power of a single solar panel was 260 W. Table 2 shows the specifications of the solar panels.

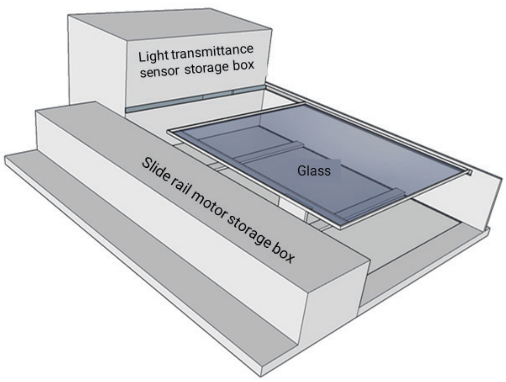

Fig. 1. (Color online) Schematic diagram of automatic dust measurement platform.

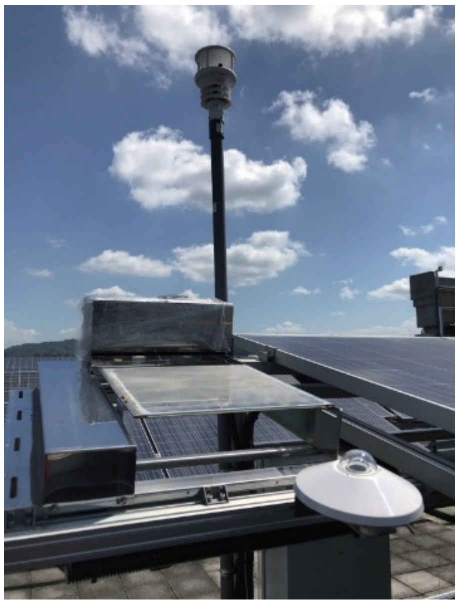

Fig. 2. (Color online) Automatic dust measurement platform and micro–weather station.

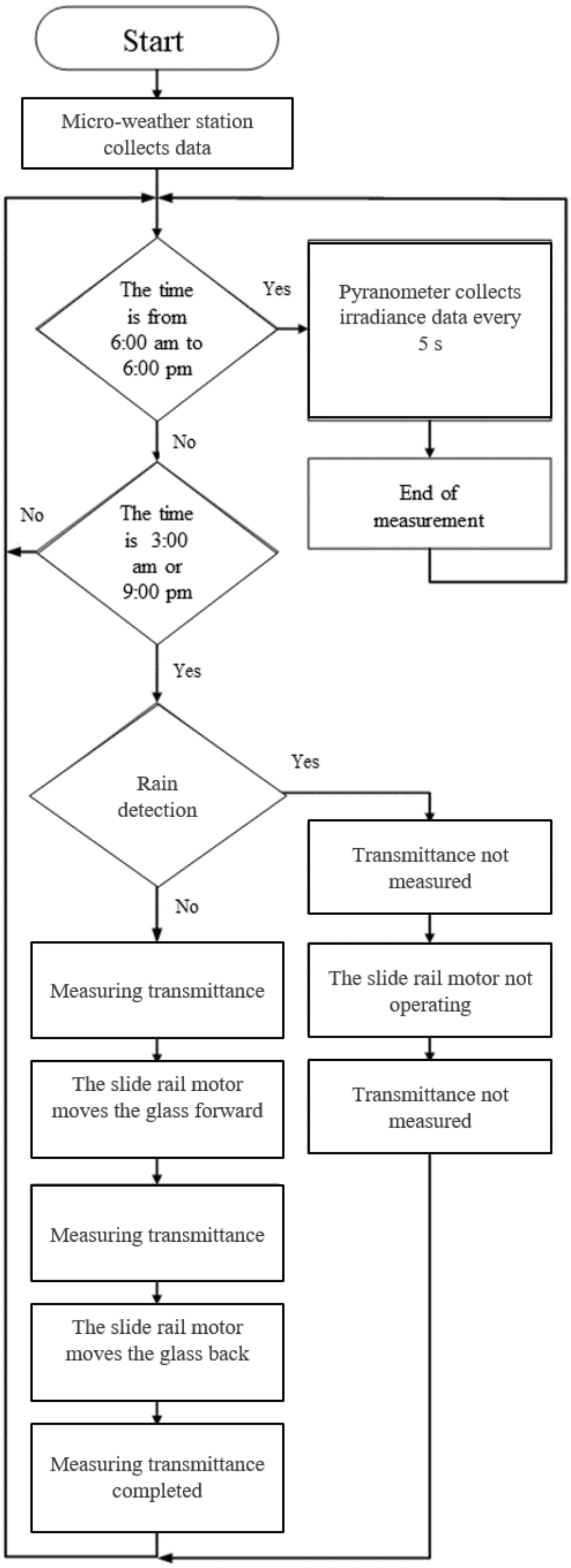

Fig. 3. Flow chart of control of automatic dust measurement platform.

Table 1
Technical parameters of light transmittance sensor.

Wavelength of light source	380–760 nm
Measuring range	0–100%
Resolution	0.1%
Measurement error	≤1%
Measured thickness	≤50 mm

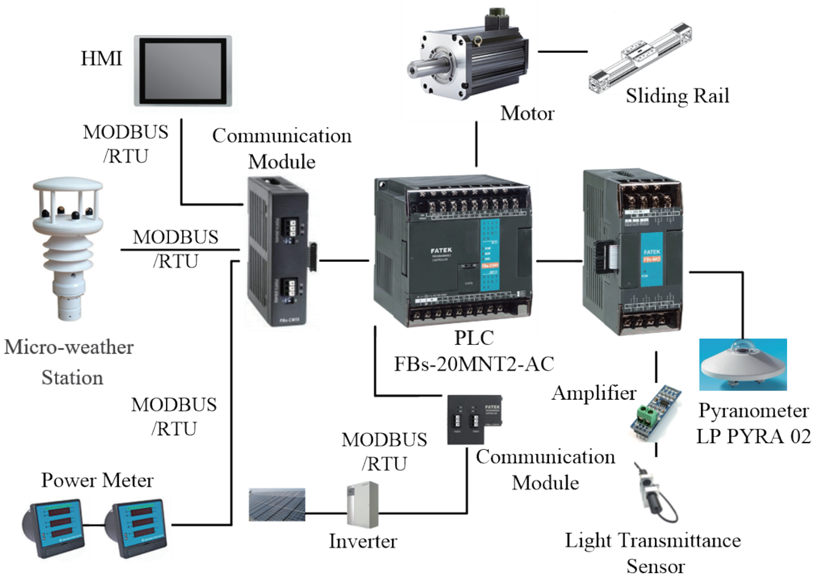

Fig. 4. (Color online) Hardware and communication scheme of proposed automatic dust measurement platform.

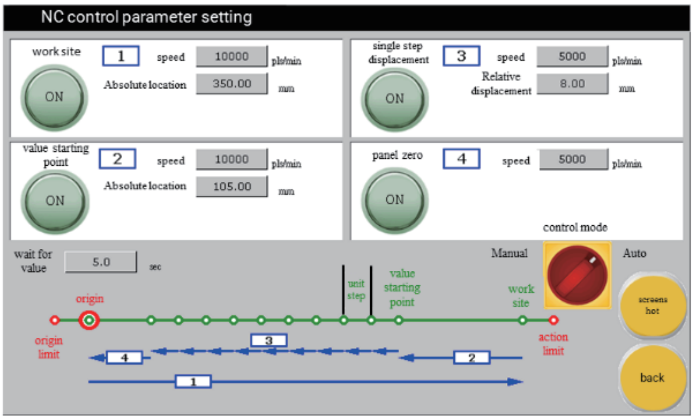

Fig. 5. (Color online) Motor control screen.

Table 2
Features and specifications of solar panels of PV1 and PV2.

Maximum output power	260 W
I_{sc}	8.64 A
V_{oc}	37.86 V
I_{mp}	8.19 A
V_{mp}	31.86 V

2.2 Measurement method

We installed the proposed automatic dust measurement platform on PV1 and PV2 each with a power generation capacity of 4 kW. PV1 and PV2 were placed at the same location in the Engineering Hall of Qinyi University of Science and Technology, Taichung City, to induce the same conditions (irradiance, ambient temperature, wind speed, and direction). The glass cover on PV1 was cleaned every day, while that on PV2 remained untouched. Then, the voltage, current, and generated power of PV1 and PV2 were measured with light transmittance to investigate the effect of dust on solar power generation. The measurement was conducted twice on June 19 and July 4, 2019, between 8:00 AM and 5:00 PM. The data of the light transmittance, weather, and generated power of PV1 and PV2 were collected and stored every 10 s. PV1 and PV2 showed a light transmittance of 94% initially. We exposed them to the sun for 3.5 days. Dust deposition on the glass cover was measured from the reduction in light transmittance. Light transmittance was measured at 25 measurement points on 25 sectors of the glass cover. The sectors were set by dividing the glass cover into five equal rows and columns.

3. Results and Discussion

The light transmittance on July 19, 2019, after 3.5 days of dust deposition is shown in Fig. 6. The light transmittance was in the range of 86−88%, and the average light transmittance was 87.36% with a standard deviation of 0.83%, implying that the distribution of deposited dust was rather even.

Figure 7 shows the irradiance of PV1 (blue line) and PV2 (orange line), while Fig. 8 displays the generated power of PV1 (yellow line) and PV2 (blue line) through time. The changes in irradiance were consistent with those in generated power; this indicates the appropriate operation

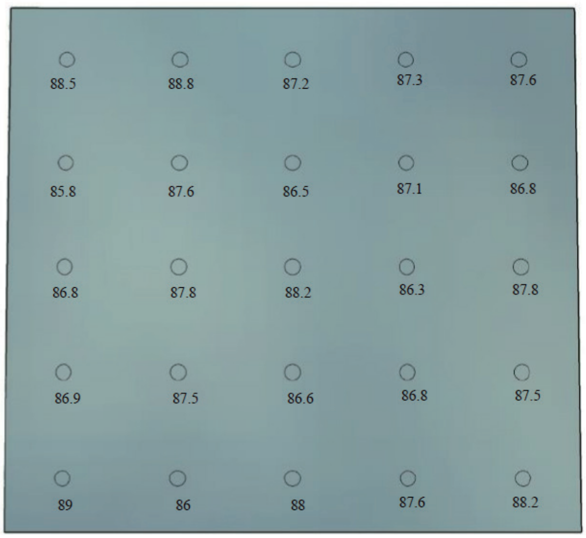

Fig. 6. (Color online) Light transmittance (%) after 3.5 days of dust deposition. The initial light transmittance was 94%.

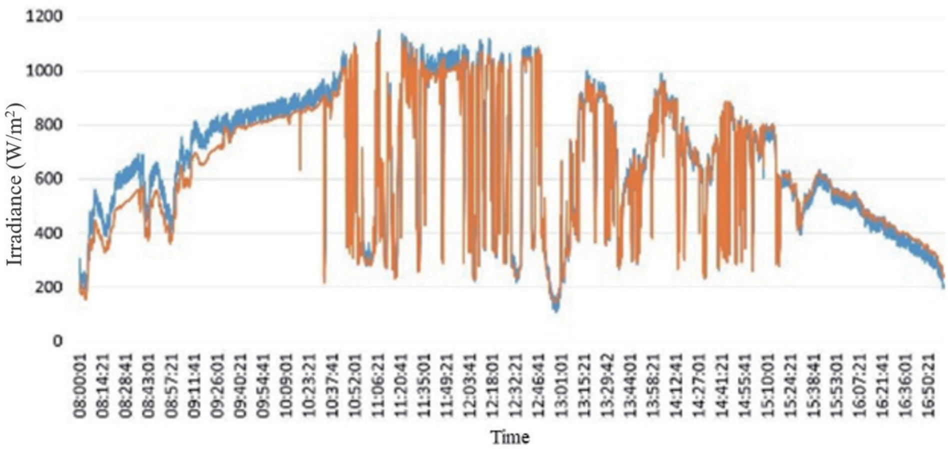

Fig. 7. (Color online) Irradiance of PV1 (blue) and PV2 (orange) between 8:00 AM and 5:00 PM on June 19, 2019.

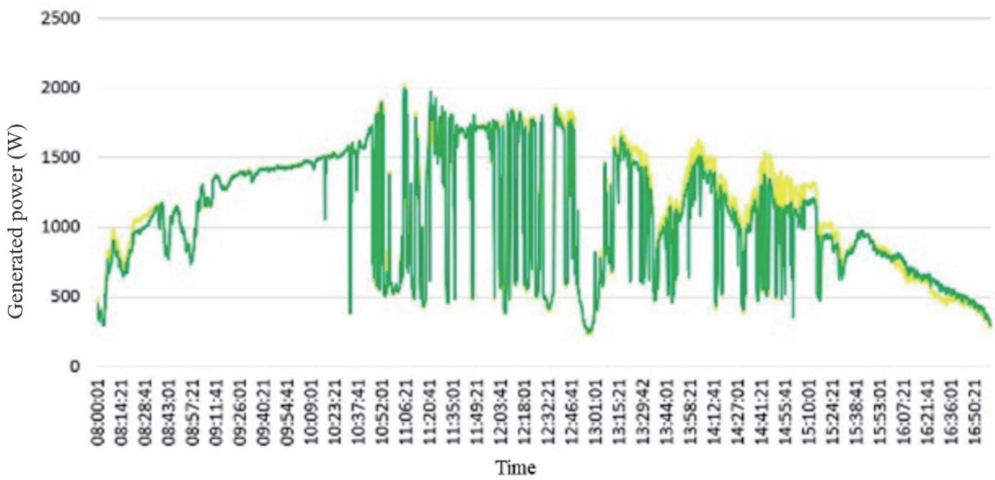

Fig. 8. (Color online) Generated power curve of PV1 (yellow) and PV2 (green) on June 19, 2019.

of PV1 and PV2. The irradiance and generated power of PV1 were higher than those of PV2. The dust deposition for 3.5 days led to such differences as the light transmittance of PV1 remained near 94% and the average light transmittance of PV2 became 87.36%.

The daily cumulative power generation of PV1 reached 9900 Wh, while that of PV2 was 9680 Wh (Fig. 9). A difference in generated power began to occur after 1:00 PM on July 19, 2019. Thus, a 6.64% difference in light transmittance produced a difference of 2.22% in daily cumulative power generation. Thus, if the solar panels are not appropriately cleaned for a long time, there might be a considerable loss of the total generated power.

On July 4, 2019, occasional rainfalls were observed from 12:54 PM to 1:33 PM (Table 3). The average light transmittance was 51.4% in the morning. Figures 10 and 11 show the irradiance and generated power of PV1 and PV2, respectively. The irradiance curve was again consistent with the generated power curve. Before the rainfall, dust deposition on July 4 was more severe

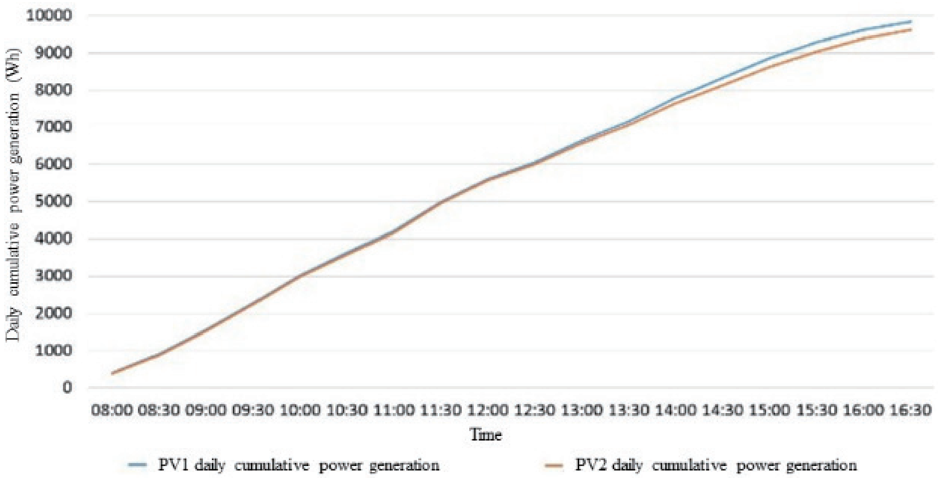

Fig. 9. (Color online) Daily cumulative power generation through time on June 19, 2019.

Table 3
Rainfall data on July 4, 2019.

Time	Accumulated precipitation (mm)	Time	Accumulated precipitation (mm)
12:55	0.1	13:15	0.8
13:04	0.2	13:17	0.9
13:08	0.3	13:19	1.0
13:11	0.4	13:21	1.1
13:12	0.5	13:27	1.2
13:13	0.6	13:33	1.3
13:14	0.7		

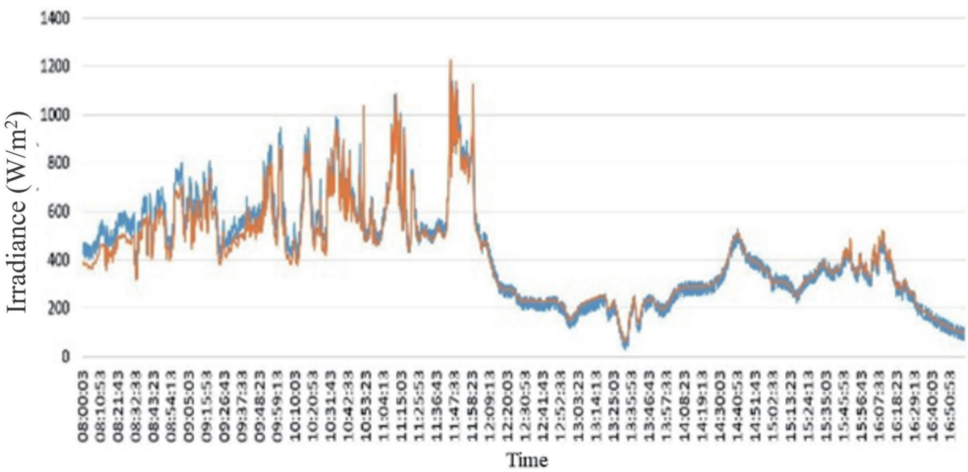

Fig. 10. (Color online) Irradiance of PV1 (in blue) and PV2 (in orange) between 8:00 AM and 5:00 PM on July 4, 2019.

than that on July 19, and irradiance and generated power were significantly lower than those on July 19. PV1 showed higher irradiance and generated power than PV2 in the morning before the rainfall. This also showed the effect of dust deposition on the power generation of the solar

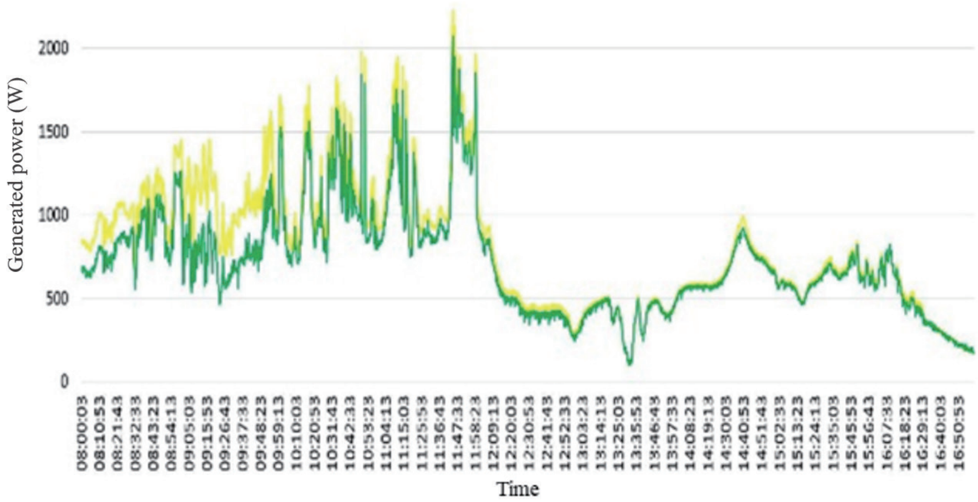

Fig. 11. (Color online) Power generation curve of PV1 (yellow) and PV2 (green) on July 4, 2019.

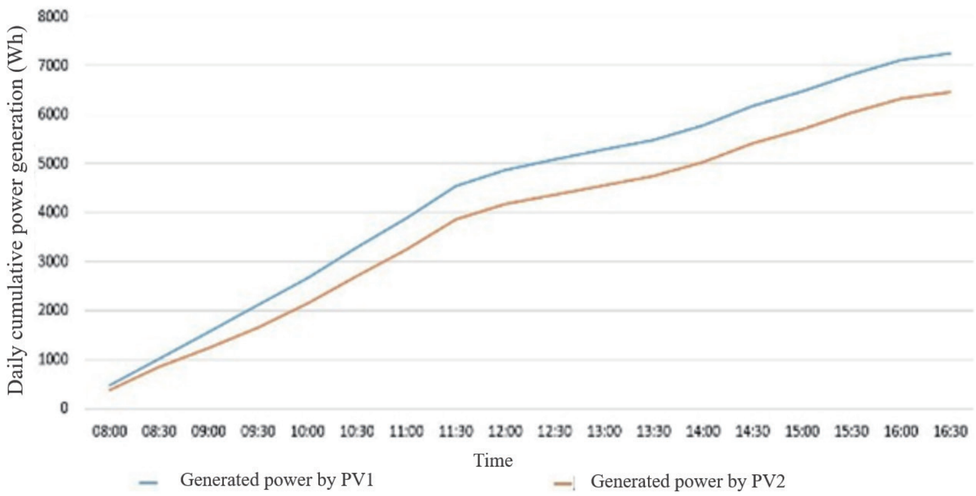

Fig. 12. (Color online) Cumulative power generation on July 4, 2019.

panel. During the rainfall, the differences in irradiance and power generation between PV1 and PV2 decreased significantly. Even though the low light transmittance due to cloud and rainy weather lowered the efficiency of power generation of both PV1 and PV2, the dust removal effect of rainfall might play a more significant role in the reduction in the difference in power generation between PV1 and PV2. This could be confirmed from the observation that the differences in irradiance and power generation occurred again from 2:30 PM.

The daily cumulative power generation of PV1 was 7340 Wh, while that of PV2 was 6545 Wh. Because of additional dust deposition, a difference in power generation occurred from 8:00 AM, and PV1 had an 11% higher daily cumulative power generation than PV2 (Fig. 12). Thus, it

Table 4
Results of solar power generation of PV1 and PV2 on June 19 and July 4, 2019.

	June 19	July 4
Average light transmittance (%)	87.36	51.40
Daily cumulative power generation (Wh) of PV1	9.90	7.34
Daily cumulative power generation (Wh) of PV2	9.68	6.55
Difference in daily cumulative power generation between PV1 and PV2 (%)	2.14	10.83

was assumed that dust deposition on the solar panel would have a more significant effect in cloudy weather than in clear weather. Table 4 shows the results of the measurements on June 19 and July 4, 2019.

4. Conclusions

We designed an automatic dust measurement platform with a micro-weather station to evaluate the effect of dust deposition on the solar panel. The platform contained a glass cover, a PLC with an HMI, light transmittance sensors, and a sliding rail motor. The platform installed on the solar panel measured irradiance and light transmittance along with wind direction and speed every 10 s. Measured values were compared with the generated power of the solar panel to investigate the effect of dust deposition on the efficiency of solar power generation. We installed two solar power generation systems (PV1 and PV2) with the platform at the same location. To understand the effect of dust deposition, we cleaned the surface of the glass cover of the platform on PV1 every day to maintain the light transmittance of 94%. PV2 was left without cleaning for 3.5 days before the measurements from 8:00 AM to 5:00 PM on June 19 and July 4, 2019. It was sunny the whole day on June 19, while it was cloudy and rainy in the afternoon for 2 h on July 4. On June 19, the light transmittance decreased from 94 to 87.36% (an average of 25 measuring points on the glass cover during the measurement hours) owing to the dust deposition, resulting in a 2.14% decrease in daily cumulative power generation. On July 4, the average light transmittance was 51.40%, and the daily cumulative power generation decreased by 10.83%. The trends in the irradiation and power generation of PV1 and PV2 on the measurement day showed that dust deposition affected the efficiency of power generation more significantly than cloud cover, and the dust cleaning effect of rainfall also affected the power generation. The results of this study confirmed the appropriate operation of the automatic dust measurement platform and the effect of dust deposition on the solar panel. The measurement data provide basic information for the installment and management of solar panels so as to achieve effective power generation.

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