Analysis of Measured Irradiance from Experiment of Diffuse Irradiance Shadowing

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Abstract

Photovoltaic technology is constantly evolving and its supply is increasing in various regions. Especially, as installation technology of solar panel is developed and efficiency increases, installation is increasing in a complex area with many shadows. Therefore, it is necessary to study the shadow effect caused by the complex objects in the surroundings such as buildings and trees. An experiment of measuring diffuse irradiance with shadowing blocks is designed in this study. The objectives of this experiment is to quantitatively measure and analyze the change in irradiance by the shadowing blocks. Shadowing blocks are designed to make blocks having an equal area, the angular blocked area in sky dome, from the view of solar radiation meters but different distances. Calibration of the measured data from two solar radiation meter and the preprocessing methods are devised and applied. Tendency and variance of data are analyzed and patterns are derived. The results show a linear pattern of the transmittance according to the distance from shadowing objects in few meters. The proposed transmittance model is expected to increase the accuracy of approximately 10% in diffuse irradiance calculation.

Keywords: Photovoltaic, Irradiance, Diffuse Irradiance, Shadowing

1. Introduction

International agreements have made it important to develop and spread renewable energy. Photovoltaic technology is one of the major renewable energy sources. It constantly evolves and its supply increases in various areas. As installation technology of solar panel is developed and efficiency is increased, installation is increasing in a complex area such as urban cities. Photovoltaic systems on building facades such as BIPV(Building Integrated Photovoltaic) systems have been frequently studied and have been installed in many places. However, these power systems are exposed to many shadows. Solar panels in building façade are easy to be shadowed by other front buildings. Therefore, it is necessary to study the shadow effect caused by the objects in the surroundings such as buildings and trees.

Many previous studies focused on the shadows of nearby buildings. There are many models which can estimate irradiance with shadows such as SAM(NREL), CBDM(Mardaljevic, 2010), PPF(Compagnon, 2004), CAD(Autodesk). Most studies estimate shadows with a simple calculation based on sun position. However, this simple calculation cannot consider shadows of diffuse irradiance. Although diffuse irradiance come from everywhere in the sky, it can be shadowed by nearby buildings. Some studies consider diffuse irradiance shadows by applying the ratio of the covered sky, which is referred as the Sky View Factor (SVF) (Dubayah and Rich, 1995), but there is not enough evidence yet. The effect of shadows by diffuse irradiance should be studied and Quantitative data should be obtained

2. Set up of Experiment

The experiment system comprises of two solar irradiance meters, data logger, battery, two rotatable fixed frames, and shadowing blocks which are shown in Fig. 1. Two irradiance meters satisfy secondary standard and Installed to look horizontally. The data logger can store measurement data per second and can be moved freely without external power via battery. To reduce the effect of surface and the surrounding environment, irradiance meters are installed in 40 cm height and covered by the attachable device. This small semi-cylindrical shape device is designed to block reflected irradiance from surroundings. It is made by the 3D printer and shown in Fig. 2.

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Shadowing blocks are stacked to make 3 different sizes, 40 cm to 120 cm. Rotatable fixed frames are designed to install sensors with different height and direction.

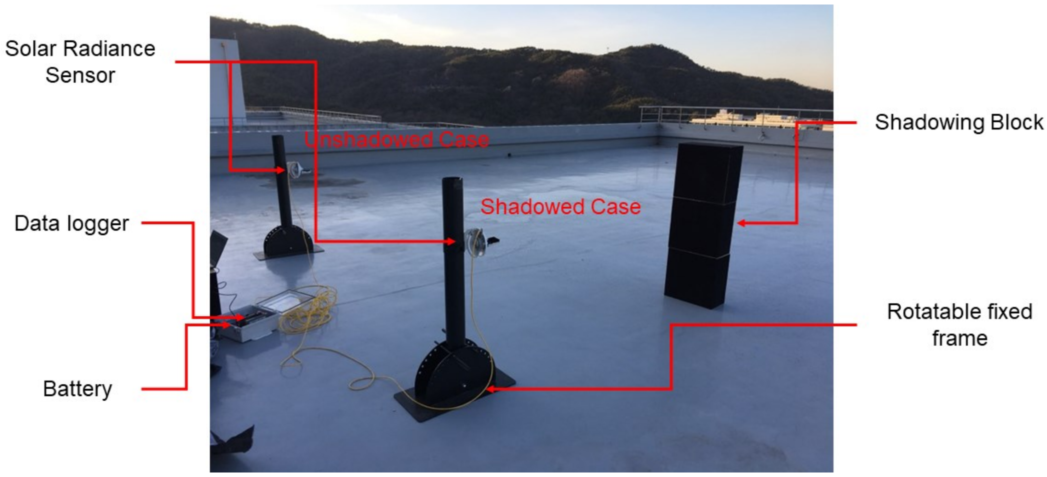

Fig. 1: Picture and configuration of an experimental system for diffuse irradiance shadowing

An experiment which measures diffuse irradiance with shadowing blocks is designed in this study. The objective of this experiment is to quantitatively measure the difference of diffuse irradiance by the shadowing blocks. Two same solar irradiance sensors are installed on the same site. One measures diffuse irradiance without any shadows. The other measures diffuse irradiance with shadowing blocks. These blocks can be stacked to create blocks of different sizes. It is possible to make blocks having an equal area from the view of irradiance meter but different distances. Fig. 2 shows the diagram of experiments for diffuse irradiance shadowing. As the sensors face north, the beam irradiance is not measured by sensors.

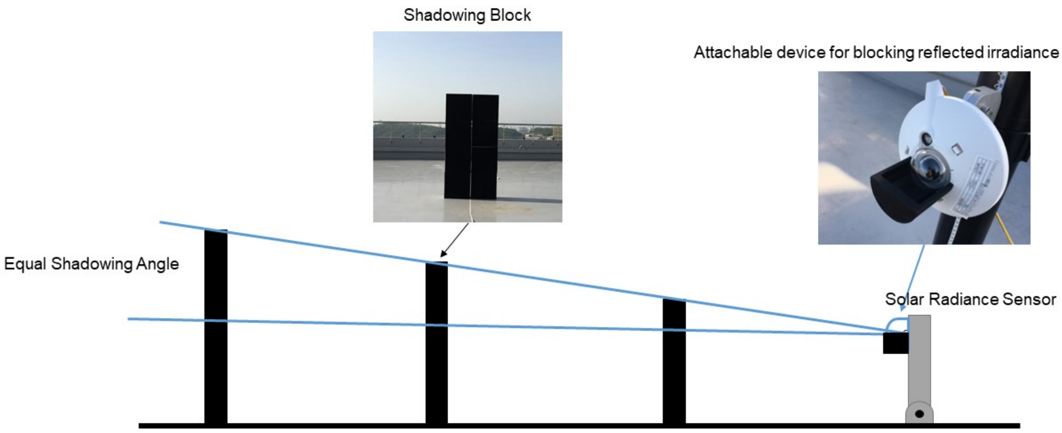

Fig. 2: Diagram of experiments for diffuse irradiance shadowing and a picture of the attachable blocking device

The experiment was conducted on the roof of a five-story building on the campus of Seoul National University in Seoul, Korea. It was conducted in 2018 and early 2019 but the data of the year 2018 were not used because the experimental design was changed to reduce the error. In addition, several data have been lost or excluded because of data logger errors and abnormal values. Therefore, total used measurements were made for approximately 5 days with three measurements cycle per day. Calibration data with no shadowing and measurement with three different distances were acquired in each cycle.

3. Data Analysis

Since the measurement experiments are very error-prone, the preprocessing and analysis of error was conducted. Diffuse irradiance by respect to three different distances and irradiance without blocks to calibrate are measured in each specific time by vertically installed sensors. In each cycle, data of each distance are measured for a few minutes. They are calibrated by data without shadows and averaged in minutes to remove errors. The difference between the averaged values of the two sensors is calculated and compared to original values. The ratio of this difference is shadowing ratio and it is expected to be higher the closer the distance is. Boxplot, mean value and the standard deviation is calculated to analyze error of experiments.

To estimate calculation model for diffuse irradiance shadowing, the measured data are compared to meteorological data. The estimated irradiance with no diffuse shadowing is calculated with three irradiance indices, GHI(Global Horizontal Irradiance), DNI(Direct Normal Irradiance), and DHI(Diffuse Horizontal Irradiance). As these indices are measured in seconds at a nearby station, diffuse irradiance from the sky can be calculated in each second. The distribution of the diffuse irradiance is calculated by the Perez model. Measured data and calculated data are analyzed and a new formula for estimate diffuse irradiance by distances are devised. Flowchart of this study is shown in Fig. 3.

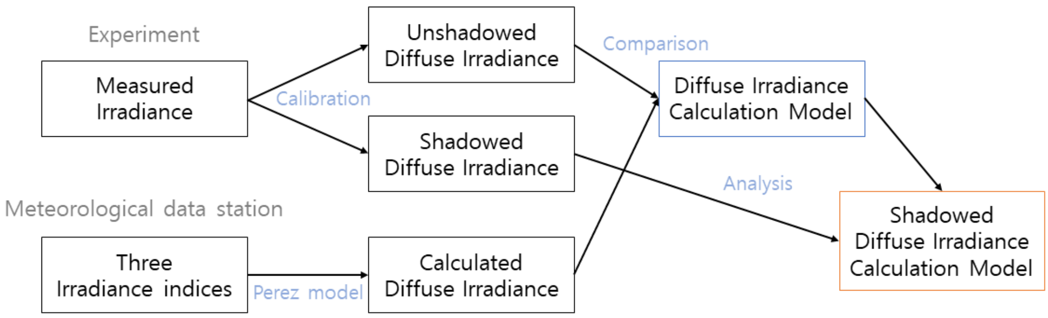

Fig. 3: Flowchart of the data preprocessing and analysis

4. Results

Total of 269 data were measured and analyzed. The difference between two unshadowed sensors was less than 2% for approximately 75% of data, but there were cases that difference exceeds 10%. The shadowing ratio is calculated from calibrated irradiance and basic statistics of all measured data are shown in Tab. 1. The average shadowing ratio decreases as the distance from the sensor increases. However, the error is significant as the maximum values are approximately twice the average and minimum values are marginally negative. As seen as the boxplot in Fig. 4, the error rate of the data is very high, apart from the average or median trend. The reason for this error is that the measured data is basically very small compared to the standard solar radiation, which is 1000 W/m^2, and therefore sensitive to small changes in the surroundings.

Tab. 1: The statistics of the measured data

	Distance (m)	1	2	3
Sensor1 (W/m^2)	Average	39.91	38.18	39.97
	Standard Deviation	16.98	17.91	19.27
	Max	79.57	70.42	78.80
	Min	15.69	11.32	13.07
Sensor2 (W/m^2)	Average	43.15	41.18	42.93
	Standard Deviation	18.75	19.60	21.08
	Max	85.88	76.25	85.65
	Min	17.70	12.36	14.63
Sensor1, 2 Ratio	Average	100.05	99.93	99.91
Shadowing Ratio (%)	Average	7.82	7.26	6.75
	Standard Deviation	4.53	4.29	4.31
	Max	14.09	14.67	14.08

	Min	-0.38	-0.49	-0.12

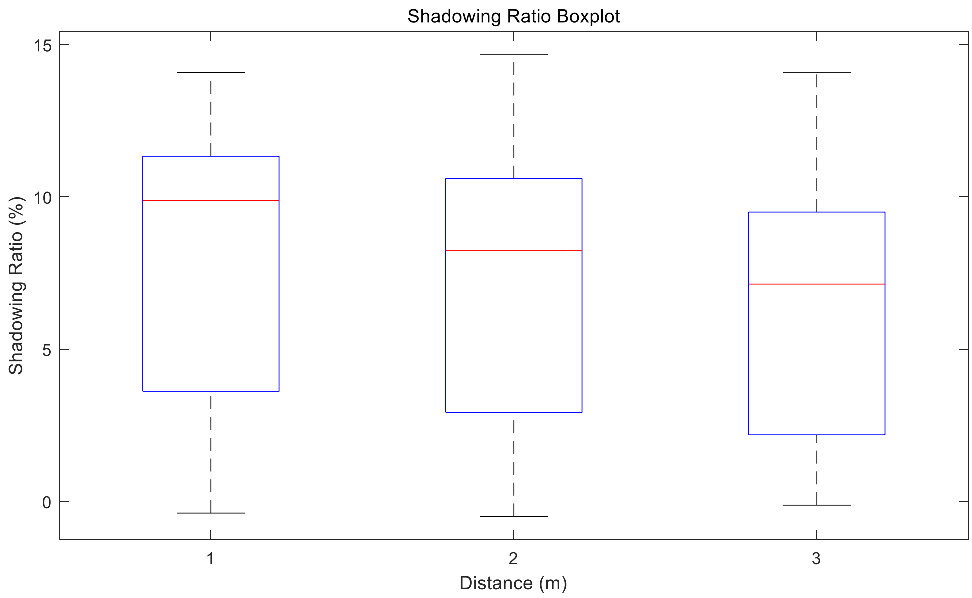

Fig. 4: Boxplot of shadowing ratio according to the distance from shadowing block

The trend of the shadowing ratio is linear as shown in Fig. 5 (a). The distance from the sensor is simplified in Fig. 4, but averaged three-dimensional distances are calculated and used in extracting equation. These distances are calculated to be slightly more than the experiment distance as the vertical distance is considered. From trend line function, the value of 8.35% is estimated as a total of the irradiance from the shadowing block area. Transmittance shown in Fig. 5 (b) are calculated based on this value, which linearly increases as the distance increases. It is about 6% at a distance of 1m and it is estimated to approach 100% at a distance of about 16m or more by calculation. However, the linear pattern is expected to change to a log pattern because it converges to 100%.

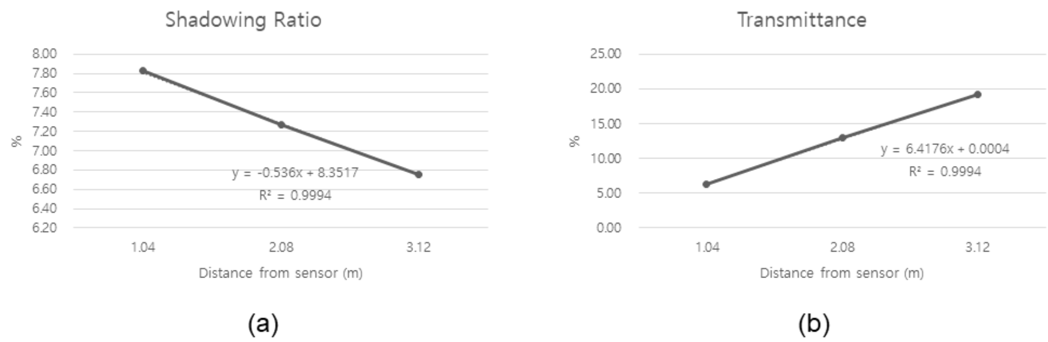

Fig. 5: Boxplot of shadowing ratio according to the distance from shadowing block

Diffuse irradiance distributions can be calculated each time. They are calculated in equal-area skygrid (Oh and Park, 2018) with Perez model. One of the distribution samples is shown in Fig. 6 (a). It shows the distribution of irradiance which is normal to ground. Fig. 6 (b) shows the diffuse irradiance that is normal to measurement sensors. As sensors are installed in the vertical axis, the irradiance on the horizontal plane becomes relatively strong. The shape of the shadowing block is also shown. Theoretically, the diffuse irradiance shown in the block shape will penetrate the block with the transmittance.

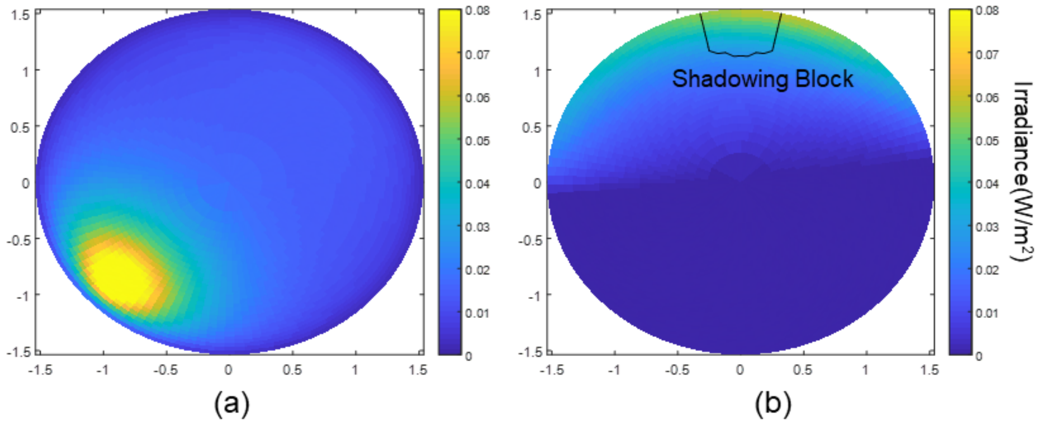

Fig. 6: (a) Distribution of diffuse irradiance and (b) distribution of diffuse irradiance which is normal to sensors with shadowing block area

The average relative RMSE (Root Mean Squared Error) of this calculation shows approximately 8% without transmittance model. It decreases by 13% when transmittance model is applied. Although this calculation is validated in only a day, it shows higher accuracy when the new model was applied. The accuracy improvement is expected to be more noticeable when the distance from shadowing objects is a few meters. The RMSE with the distance 1m is below 2% in this case, but the RMSE with the distance over 2m is over 9%. However, as accuracy in this study is calculated from the diffuse irradiance, it can change when the direct irradiance is considered.

5. Conclusion

The systems for the experiment are constructed and installed. Measured data are acquired and analyzed with comparison and computational calculation. As the acquired data show high variance and unstable results, more measurement and analysis are required. Nevertheless, the data shows meaningful patterns and the results expected to increase calculation accuracy. The results of this study are expected to aid the estimation of solar energy potential and the installation of solar power systems.

6. Acknowledgment

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