





An Approach to Predicting the Effect of Shadows from Surrounding Buildings on the Performance of Solar Photovoltaic

Sun Yongkuan ^{*}, Na Wei ^{‡**}, Zhang Shanwu ^{*}, Ilhan Garip ^{***}

^{*} Beijing Urban Construction Group Co., Ltd, Beijing, China

^{C**+} Beijing University of Civil Engineering and Architecture, Beijing, China

Faculty of Engineering and Architecture, Beykoz University, Istanbul, Turkey

(Yongkuan@gmail.com, Wei256812@hotmail.com, Shanwuurban@gmail.com, ilhangarip60@gmail.com)

[‡] Corresponding Author; Na Wei, Beijing University of Civil Engineering and Architecture, Beijing, China.

Received: 09.02.2024 Accepted: 27.03.2024

Abstract- For a photovoltaic system in an urban building, building shadow occlusion is an often-encountered problem, photovoltaic array covered area will change with time, resulting in the photovoltaic array output volt-ampere performance curve being also different with time. With the engineering analytical model of silicon solar cells, the series-parallel of electrical circuits theory, and the solar Angle change formula, an approach to predicting the effect of shadows from surrounding buildings on the performance of solar photovoltaics is established. The simulation results show the difference of the PV array's I-V and P-V performance curves with periods. An actual test is carried out for the completed photovoltaic project with building shadow occlusion, and the comparison with Matlab simulation I-V and P-V performance curve proves the predicting model can describe the output performance of the PV array with building shadow occlusion.

Keywords: Building shadow occlusion, photovoltaic array, a predicting approach, simulation analysis, ambient temperature, solar irradiance.

1. Introduction

The PV array system is mainly affected by solar irradiance and ambient temperature, and the actual operation of the PV array often appears part of the PV module in the shadow of the surrounding buildings, shadow occlusion will make part of the photovoltaic module loss of direct solar radiation, so that the solar irradiance of the photovoltaic module is uneven distribution, resulting in the output performance of the photovoltaic array decline.

Literature

The hot-spot effect may even form and damage the photovoltaic module [1]. Partial building shadow occlusion is a kind of occlusion with certain regularity. Analyzing the effect of building shadow occlusion on PV array is of important significance in exploring the output performance of PV array. The partial shading effect on the photovoltaic array has been analyzed and studied in many aspects in China or abroad. Su Jianhui et al. [2] introduced an engineering analytical model of silicon solar cells, and Wu Zhongjun et al. [3] optimized the parameters for this model. Ding Ming, Chen

Changsong et al. [4,5] established a prediction model of PV system output power based on the neural network prediction and simulation method, the direct prediction method of the historical output power of the photovoltaic system. Zhang Zhen, Xue Yang et al. [6,7] analyzed the output and performance curve changes of photovoltaic modules under partial shading conditions through simulation and establishment of photovoltaic module occlusion test based on the equivalent circuit model of the double diode and avalanche breakdown effect of photovoltaic modules. With the current equation of solar cells and the basic theory of circuits, Zhai Zaiteng et al. [8] theoretically deduced that piecemeal functions can be used to accurately describe the I-V output performance of partially blocked series PV modules. Zhu Wenjie, Hu Yihua, Liu Xiaoyan et al. [9~11] studied the PV array output performance under partially shaded conditions through modeling, simulation, and experiments. Zhu Wenjie et al. [9] analyzed the output power of photovoltaic array branches under partially shaded conditions in detail through simulation and experiments based on series-parallel circuits. Hu Yihua et al. [10] used Matlab/Simulink to simulate the output performance of a photovoltaic module in different

shaded conditions and analyzed the variation regulation of the output performance of PV module with the influence of shadow in detail. Liu Xiaoyan et al. [11] established a mathematical model describing the output performance of PV arrays with partially shaded conditions. Based on this, different occlusion situations are simulated and analyzed. Meng Anbo et al. [12] used Matlab/Simulink to establish model simulation and analysis to verify the role of bypass and anti-reverse diodes in photovoltaic arrays and summarized the output performance of photovoltaic arrays under complex shadow conditions. Yang Haoyuan et al. [13] established a dynamic model of PV array with the location, moving speed, and path of the shadow and carried out a simulation analysis. Tingting Pei et al. [14] established a dynamic model of photovoltaic arrays considering the change of light intensity and temperature with time and verified it by case simulation. Dan Yangqing, Tan Jianbin et al. [15,16] did research and analysis on optimal control and output efficiency improvement of PV arrays with partially shaded conditions. Zuo Xiaoyun et al. [17] proposed a dual-mode maximum power point tracking algorithm by studying the output performance of photovoltaic arrays under shadow conditions and verified and compared the MPPT of photovoltaic arrays realized by simulation and traditional perturbation observation method. Although the above literature has carried out a detailed analysis of the PV array affected shadow shading, the effect of surrounding building shadow occlusion on the output performance of photovoltaic array with certain regulation is rarely discussed. With the engineering mathematical model of silicon solar cell and the theory of series and parallel circuits, the mathematical model of PV array output performance under shadow occlusion is established in this paper, which provide an approach on predicting effect of shadows from surrounding buildings on performance of solar photovoltaic. According to the model, the effect of building shadow occlusion on PV array is simulated, and the output power of simulated actual PV power generation system is compared with the actual test value.

The objective of this study is to establishes a mathematical model to predict the effect of surrounding building shadow occlusion on the performance of solar photovoltaic (PV) arrays. While previous research has extensively analyzed the impact of partial shading on PV arrays, there has been limited discussion on the specific effects of surrounding building shadows with certain regularity. Utilizing an engineering mathematical model of silicon solar cells and theories of series and parallel circuits, this paper fills this gap by providing a method to predict the performance of PV arrays under such shadow occlusion.

Methodology

The height of building and the sun height angle determine the length of shadow, the orientation of the building and the azimuth of the sun determine the direction of the shadow [18]. Therefore, to calculate the building shadows, it need have the height angle and the azimuth angle of the sun first. The formula to calculate the building shadows [19]:

$$\sin h_s = \sin \varphi \cdot \sin \delta + \cos \varphi \cdot \cos \delta \cdot \cos \Omega \quad (1)$$

$$\cos A_s = (\sin \delta \cdot \cos \varphi - \cos \delta \cdot \cos \varphi \cdot \cos \Omega) / \sin h_s \quad (2)$$

Where

- hs - solar altitude,
- φ - observer's latitude,
- δ - the solar declination,
- Ω - hour angle.
- As - azimuth angle

φ is the local latitude (reserve one decimal place); δ is the declination of the sun; Ω is the solar hour Angle, $\Omega = (TT - 12) \times 15^\circ$, TT is the true solar time, $TT = C_T + L_c + E_Q$, C_T is the Beijing time, L_c is the longitude correction (4min/ degree), if the local meridian is in the east of the Beijing meridian, L_c is positive, and vice versa, E_Q is the time difference. We know that the sun's altitude angle is a function of time.

Under the shadow of the building, the number of photovoltaic modules covered by the building shadow will constantly change at a certain moment. For a single cell element, when the shadow area is above 60%, the maximum power point of the PV module begins to change and shift to the left, and the photogenerated current of the battery element is less than the output current of the PV module when it runs at the maximum power point[20]. A large number of photovoltaic cells constitute photovoltaic modules that can provide a certain capacity of direct current energy through series and parallel. In this paper, the model of PV array under the surrounding building shadow occlusion use the photovoltaic modules as the analysis unit[21-23]. When the photovoltaic modules are covered by building shadow, a row or a column is covered at the same time, as shown in Figure 1. Therefore, the output performance of PV modules under shadow conditions can be analyzed according to the output performance of battery cells under shadow conditions. That is, when the shielding ratio of a module in the photovoltaic array exceeds 60%, it can be considered that the photovoltaic module is under the shadow shielding [2].

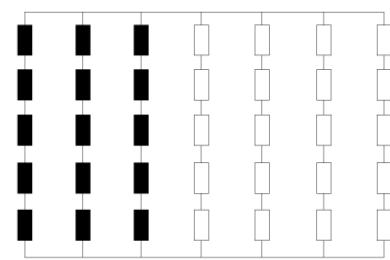


Fig. 1. (a). Longitudinal occlusion model of PV array.

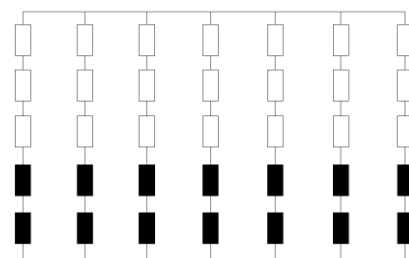


Fig. 1. (b). Lateral occlusion model of PV array.

Figure 1 Plane model of photovoltaic modules obscured by longitudinal and transverse shadows

The building shadow occlusion model as shown in Figure 2 is established, and the following assumptions are made in the built model:

- (1) In the photovoltaic array, the serial PV modules number is N_s and the parallel PV modules number is N_p , then the total photovoltaic modules $N_t=N_s \times N_p$;
- (2) The minimum distance between the photovoltaic module and the shielding building is l_1 ;
- (3) The height of the shielding building is H ;
- (4) Here is to analyze the performance of the photovoltaic array under the building shading occlusion. In order to calculate, it is assumed that the photovoltaic array is arranged according to the projection direction of the building, without considering the effect of the solar azimuth Angle on the shading area change;
- (5) The length of the photovoltaic module in the projection direction is l_0 ;

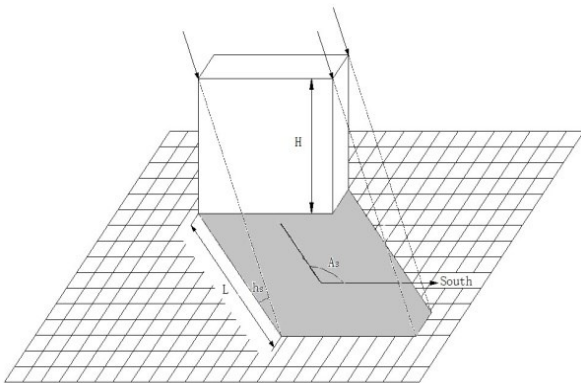


Fig. 2. (a). Schematic diagram of the sun's altitude angle and azimuth angle.

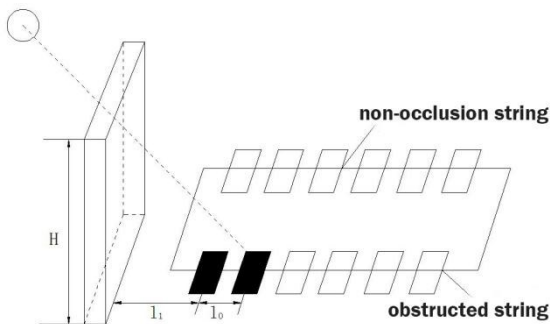


Fig. 2. (b). Schematic diagram of the photovoltaic array under the surrounding building shadow.

According to the position of the sun, the height of the surrounding building, and the position of the photovoltaic array, the total number of photovoltaic modules N in the system can be confirmed. To analyze a single array, perform the following steps:

According to the constructed model, the projected length of the building can be denoted as:

$$L=H/\tan h_s \tag{3}$$

The number of blocked photovoltaic modules N_{s2} is calculated as follows:

$$N = \begin{cases} \text{INT} \left(\frac{L-l_1}{l_0} \right), & \frac{H/L-l_1}{l_0} - \text{INT} \left(\frac{L-l_1}{l_0} \right) \leq 0.6 \\ \text{INT} \left(\frac{L-l_1}{l_0} \right) + 1, & \frac{H/L-l_1}{l_0} - \text{INT} \left(\frac{L-l_1}{l_0} \right) > 0.6 \end{cases} \tag{4}$$

In engineering applications, the reference data of solar cell modules is usually only a current-voltage curve under standard test conditions (STC), including maximum power point voltage, maximum power point current, open circuit voltage, and short-circuit current value. This paper use the solar cell engineering mathematical model as follows[2] :

$$I=I_{SC} [1 - C_1 (e^{V/C_2 V_{OC}} - 1)] \tag{5}$$

$$C_1 = (1 - I_m/I_{SC}) \exp[-V_m/(C_2 V_{OC})] \tag{6}$$

$$C_2 = (V_m/V_{OC} - 1) [\ln(1 - I_m/I_{SC})]^{-1} \tag{7}$$

In the application of this model, when the solar irradiance does not exceed 2 solar constants, the deviation is small [2].

The photo-generated current generated by each photovoltaic cell inside the array is different when the solar irradiance is different, and the current generated by the shielded solar cell $ISC1$ is smaller than $ISC2$ that generated by the unshielded solar cell [24]. At this time, under the conditions of temperature, illumination and array pattern determination, the working current of the photovoltaic array is determined by the load. For a single series array, when the load impedance is very small, its working current of the array is the output current of the unshaded solar cell module $ISC2$. With the increase of the load impedance, the working current of the array continuously decreases to less than or equal to the photo-generated current of the shielded solar cell module IPH , and the working current of the single series array is the output current of the shielded PV module $ISC1$, and the photovoltaic module under surround building shadow occlusion operates at the maximum power point.

For a single string of photovoltaic arrays, if the total number of PV modules in series is NS , the number of unshaded PV modules is $NS1$, and the number of shielded photovoltaic modules is $NS2$. According to the engineering suitable mathematical model of solar cell, the current equation of single string array under shadow condition and the mathematical model of a PV array under arbitrary shadow occlusion condition can be derived:

The current equation of a single series array is:

$$I = \begin{cases} I_{SC1} \left\{ 1 - C_1 \left[\exp \left(\frac{V/N_{S1}}{C_2 V_{OC}} \right) - 1 \right] \right\}, & I_{SC2} \leq I \leq I_{SC1} \\ I_{SC2} \left\{ 1 - C_1 \left[\exp \left(\frac{V/N_{S2}}{C_2 V_{OC}} \right) - 1 \right] \right\}, & 0 \leq I \leq I_{SC2} \end{cases} \tag{8}$$

The array mathematical model under arbitrary shadow occlusion is:

$$\begin{cases} I_a = \sum_{x=1}^{N_p} I_x \\ V_a = \max\{V_x\} \end{cases} \tag{9}$$

In summary, formula (1), (2), (3), (4), (6), (7), and (8) constitute a mathematical model of the output performance of a single array under building shadow occlusion. Formula (1), (2), (3), (4), (6), (7) and (9) constitute the output performance mathematical model of any scale PV array under the building shadow occlusion.

Output performance analysis of photovoltaic array under building shadow occlusion

For an actual photovoltaic project, the solar irradiance and battery temperature are not standard value, and the following formulas are commonly used in engineering to calculate the four electrical parameters corresponding to different environmental conditions, namely maximum power point voltage V'_m , maximum power point current I'_m , open circuit voltage V'_{oc} , and short-circuit current I'_{sc} .

$$T = T_{air} + K \times S \tag{10}$$

$$\Delta T = T - T_{ref} \tag{11}$$

$$\Delta S = S / S_{ref} - 1 \tag{12}$$

$$I'_{sc} = I_{sc} \times S / S_{ref} (1 + a \Delta T) \tag{13}$$

$$I'_m = I_m \times S / S_{ref} (1 + a \Delta T) \tag{14}$$

$$V'_{oc} = V_{oc} (1 - c \Delta T) (1 + b \Delta S) \tag{15}$$

$$V'_m = V_m (1 - c \Delta T) (1 + b \Delta S) \tag{16}$$

In the formula, S_{ref} is the reference solar irradiance, 1000 W/m^2 ; T_{ref} is the reference battery temperature, 25°C ; T_{air} is the ambient temperature, K ; K is the temperature coefficient of the solar cell when the solar irradiance changes, the typical value is $0.03^\circ\text{C} \cdot \text{m}^2/\text{W}$; ΔT is the difference between the actual battery temperature and the reference battery temperature, K ; S is the solar irradiance, W/m^2 ; ΔS is the difference between the actual solar irradiance and the reference solar irradiance, W/m^2 ; The short-circuit current corresponding to S and T is I'_{sc} , the open circuit voltage is V'_{oc} , the maximum power point current is I'_m and the maximum power point voltage is V'_m . a , b and c are constants, and the recommended values are $a=0.0025/^\circ\text{C}$, $b=0.5/^\circ\text{C}$, and $c=0.00288/^\circ\text{C}$.

3. Result and Analysis

A total of 3 photovoltaic modules with type Yingli YL250p-29b were selected in series for simulation analysis, the shielding building height $H=3.2\text{m}$, and the location was Beijing, the true solar time was Beijing time. The electrical performance parameters of the PV array under standard test conditions (battery temperature 25°C , irradiance 1000 W/m^2) are $P_m=250\text{W}$, $I_{sc}=8.92\text{A}$, $I_m=8.39\text{A}$, $V_{oc}=37.6\text{V}$, $V_m=29.8\text{V}$. The solar irradiance is 880 W/m^2 under the unshielded condition, the solar irradiance is 140 W/m^2 under the shielded condition, and the ambient temperature is 30°C .

According to formula (10) ~ (16), four electrical parameters under the corresponding solar irradiance can be calculated:

To avoid the occurrence of a hot-spot effect in this simulation, it is assumed that each photovoltaic module is

connected with a bypass diode. According to the above mathematical model and corresponding electrical parameters, the relationship diagram between the number of photovoltaic modules and time, the I-V performance curve, and P-V performance curve of photovoltaic arrays in different periods are obtained, as in Fig. 3, Fig. 4 and Fig. 5.

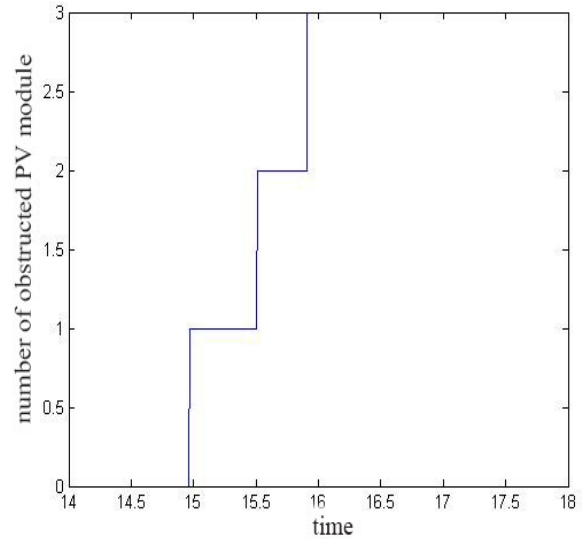


Fig. 3. Shielded single array changes over time.

Solar irradiance (W/m^2)	Ambient temperature ($^\circ\text{C}$)	I'_{sc} (A)	I'_m (A)	V'_{oc} (A)	V'_m (A)
880	30	8.55	8.04	31.46	24.94
140	30	1.28	1.20	20.86	16.54

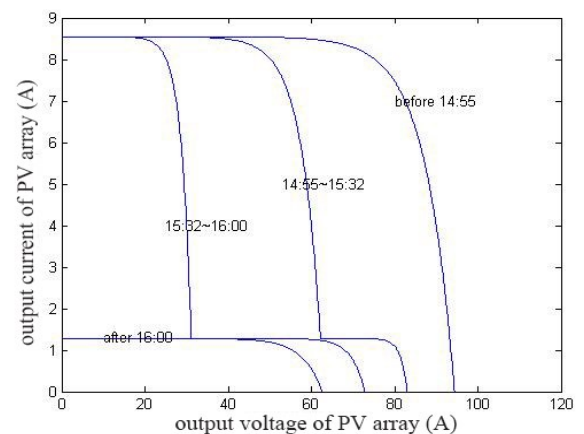


Fig. 4. I-V curves of single array over the time periods.

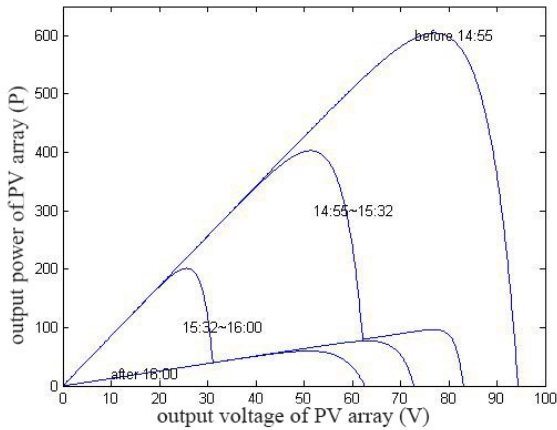


Fig. 5. P-V curve of single series array over the time periods

Fig. 3 shows the variation of the blocked single array over time, Fig. 4 shows the I-V curve of the single array in different time periods, and Fig. 5 shows the P-V curve of the single array over the time periods. From Fig. 3, 4, and 5, shows the output performance of PV arrays under the buildings shadow occlusion:

- 1) According to the simulation conditions, the building shadow occlusion starts to affect the photovoltaic array at 14:55, and the occlusion rate of the shadow on the photovoltaic module is different with time: the earlier the time, the slower the occlusion rate; The later the time, the faster the occlusion rate;
- 2) When part of the photovoltaic module is blocked, the shielded single-series array changes over time in a stepped shape, the array I-V curve is knee shape, and the array P-V curve is multi-peak type;
- 3) The occlusion rate of the photovoltaic module for the single array used in this simulation varies with time during time period 14:55~15:32, time period 15:32~16:00 and after 16:00: the earlier the time, the slower the occlusion rate; The later the time, the faster the occlusion rate;

The above analysis results show that the power generation of photovoltaic arrays under the buildings shadow needs to be analyzed in different time periods to obtain more accurate power generation. The maximum power point of the array also changes over time. At this time, using the traditional MPPT method may make the PV array work near the small peak, and it is impossible to track the real maximum power point.

4. Discussion

In this paper, a photovoltaic project in Fangshan District of Beijing is selected for practical test to verify the mathematical model and analys its practicability. The test contents include: total solar radiation, solar scattered radiation, ambient temperature, photovoltaic array voltage and current. The total installed capacity of this project is 112kw, 440 Yingli polycrystalline components YL250p-29b components and 5 Huawei SUN2000-20 inverters are used. Among them, 22 pieces are formed in a series, and 4 series are connected to one inverter in parallel. In order to prevent the generation of reverse current when running in parallel, each branch is connected with at least one blocking diode in series.

The electrical parameters of the components have been mentioned above. In this paper, three strings of photovoltaic modules are selected as test objects, and two strings of photovoltaic modules are affected by the buildings shadow occlusion. As shown in Figure 6, when the photovoltaic modules that may be obscured by the shadow are completely in shadow, there are 8 photovoltaic modules in each string under the shadow occlusion, and both photovoltaic modules change with the shadow length. The other series is unobstructed, three series in parallel and connected to the same inverter.



Fig. 6. Photovoltaic power generation project case site.

As shown in Figure 6, a total of 16 photovoltaic modules are likely to be shielded by building shadows. The test data on September 9 were selected for analysis, the solar declination $\delta = 5.55^\circ$ and the latitude of the project location is $\varphi = 39.72^\circ$, and $E_Q = 16.083\text{min}$. According to formula (6), (8) and (9), the change regulation of the shielded photovoltaic modules number over time is obtained, as Figure 7.

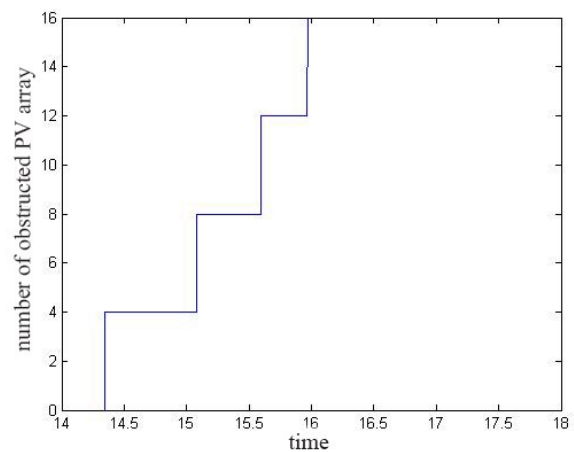


Fig. 7. the number of shaded photovoltaic modules change regulation over time.

From Figure 7, the PV array was obscured by building shadows starts from 14:20, and all modules that may be shielded are under shadow occlusion by 16:03. During this time period, the number of photovoltaic modules shielded at different times is also different. Therefore, the solar irradiance and ambient temperature in the middle of each time period are selected as the simulation conditions. According to the

monitoring data, the selected solar irradiance without occlusion, solar irradiance with occlusion, and ambient temperature are shown in Table 2.

Table 2. Weather monitoring information of a photovoltaic project in Fangshan, Beijing

period	Before 14:20	14:20~15:06	15:06~15:40	15:40~16:03	After 16:03
solar irradiance without occlusion (W/m ²)	850	730	600	460	300
solar irradiance with occlusion (W/m ²)	140	140	140	140	140
Ambient temperature (°C)	30	28	25	24	22

According to the weather conditions shown in Table 2 and formula (10) ~ (16), four electrical parameters of photovoltaic modules with and without shadow occlusion in different periods can be calculated, as shown in Table 3.

Table 3. PV module's electrical parameters over the periods

period	Electrical parameter	Before 14:20	14:20~15:06	15:06~15:40	15:40~16:03	After 16:03
without shadow occlusion	I _{sc} ' (A)	8.16	6.92	5.59	4.23	2.72
	I _m ' (A)	7.68	6.51	5.26	3.98	2.55
	V _{oc} ' (V)	31.72	30.19	28.52	26.44	24.02
	V _m ' (V)	25.14	23.93	22.61	20.95	19.04
with shadow occlusion	I _{sc} ' (A)	1.28	1.27	1.26	1.26	1.25
	I _m ' (A)	1.20	1.20	1.19	1.18	1.18
	V _{oc} ' (V)	20.86	20.99	21.17	21.23	21.36
	V _m ' (V)	16.54	16.63	16.78	16.83	16.93

According to the data in Table 3 and formula (1), (2), (3), (4), (6), (7) and (9), the simulation analysis was carried out and compared with the monitoring data. The results were shown in Figures (8) and (9)

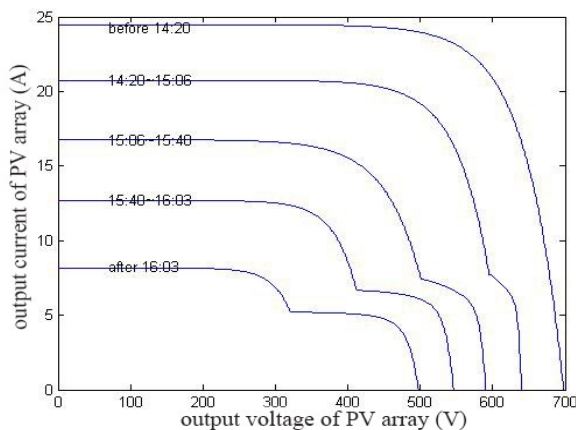


Fig. 8. I-V performance of the PV array over the time periods.

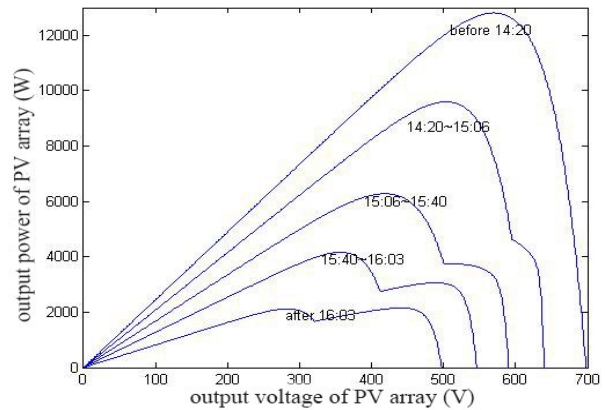


Fig. 9. P-V performance of the PV array over the periods.

Figure 8 shows the I-V curves of photovoltaic arrays over the periods, and Figure 9 shows the P-V performance curves of PV arrays over the periods. It can be seen from Fig. 7 and Fig. 8 that: the influence of building shadow occlusion on the output performance of PV arrays; The fewer the number of shielded modules, the less obvious the knee performance of the I-V curve of the photovoltaic array, and the less obvious the P-V curve multi-peak performance. Therefore, if the number of photovoltaic modules shielded by building shadows just a small proportion, the traditional MPPT method will not be significantly affected; If the number of photovoltaic modules blocked by building shadows have a large proportion, the traditional MPPT method is not suitable.

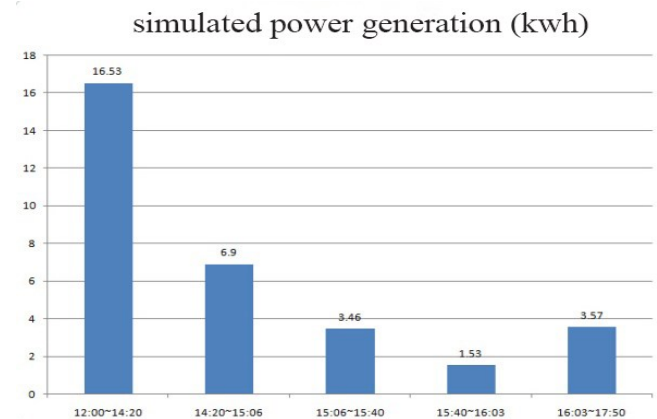


Fig. 10. (a). Histogram of simulated power generation.

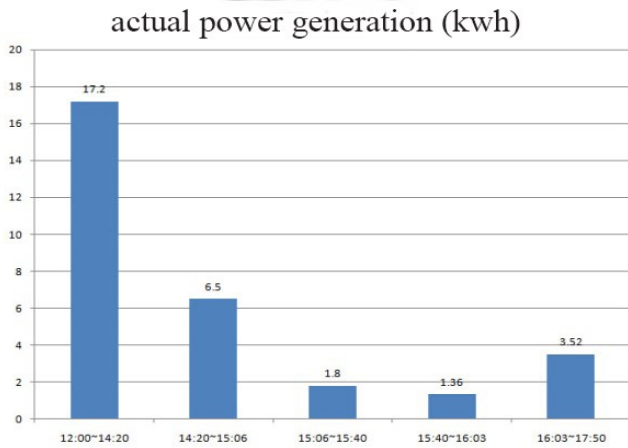


Fig. 10. (b). Histogram of actual power generation.

Fig. 10. Comparison of simulated and actual values

Figure 10(a) and 10(b) respectively show the simulated power generation data and the actual monitored values of the PV array in different time periods during the operation of the maximum power point between 13:00 and 17:50. It can be seen that except for time period 15:06~15:40, there is only a little difference in power generation in other periods, and in period 15:06~15:40, the simulated power generation is near twice the actual values. The reasons may be as follows: 1) the light intensity selected by the simulation cannot accurately represent the average light intensity in the period; 2) The maximum power point tracked by the MPPT of the PV array is the smaller extreme point. But in general, the mathematical model shown in this article can accurately analyze of PV array output performance under the shadow of buildings and can be used to simulate the actual project power generation.

5. Conclusion

This paper provides an approach on predicting PV array output performance in the partially shaded by surrounding buildings conditions. Four electrical parameters of the photovoltaic module, solar irradiance (monitored by solar radiometer), and ambient temperature (monitored by temperature recorder) are taken as input values. It can be used to analyze the PV array output performance partially shaded by surrounding buildings and to simulate the daily and monthly power generation of similar situations in different regions.

References

[1] S. Silvestre, and A. Chouder, "Effects of shadowing on photovoltaic module performance," *Progress in photovoltaics: Research and Applications*, <https://doi.org/10.1002/pip.780>. vol.16, pp.141-149, 2008.

[2] S. Jian-Hui, Y. Shi-Jie, and Z. Wei, "Investigation on engineering analytical model of silicon solar cells," *Acta Energetica Solaris Sinica*, vol.22, pp.409-412, 2001.

[3] W. Zhong-jun, L. Guo-Hai, and L. Zhi-ling, "Optimization design of engineering analytical model for

silicon solar cell," *Chinese Journal of Power Sources*, Corpus ID: 114124459 vol.31, pp.897—901, 2007.

[4] D. Ming, W. Lei, and B. Rui, "A short-term prediction model to forecast output power of photovoltaic system based on improved bp neural network," *Power System Protection and Control*, vol.40, pp.93—99, 2012.

[5] C. Chang-Song, D. Shan-Xu, and Y. Jin-Jun, "Design of photovoltaic array power forecasting model based on neural network," *Transactions of China Electrotechnical Society*, vol.24, pp.153—158, 2009.

[6] Z. Zhen, S. Hui, and L. Da, "Experimental study on performance of partial shaded solar module," *Acta Energetica Solaris Sinica*, vol.33, pp.05—12, 2012.

[7] X. Yang, and Z. Jia-Dong, "Simulation modeling and analysis of photovoltaic array under partial shading," *East China Electric Power*, vol.39, pp.0949-0952, 2011.

[8] Z. Zai-Teng, C. Xiao-Fang, and D. Jin-Lei, "Performance of partially shadowed serial photovoltaic module output," *Journal of University of Science and Technology of China*, 39, pp.398—402, 2009.

[9] E. Modaresi, and Y. Kheradmand, "New idea for controlling rainfall in urban and suburban regions," *Alkhas*, DOI:10.29252/alkhas.2.2.1 vol.2, pp.01-10, 2020.

[10] H. Yi-Hua, C. Hao, and X. Rui-Dong, "Photovoltaic module performance effected by shadow problem," *Transactions of China Electrotechnical Society*, pp.26, pp.123—128, 2021.

[11] J. V. Mobaraki, "Stability analysis of mineral structures using FLAC software," *SJIS*, vol.3 pp.01-08, 2021.

[12] M. An-Bo, Y. Zhi-Jian, and X. Hai-Bo, "Modeling and simulation analysis of photovoltaic array under complex shadow condition," *Electrotechnical Application*, vol.22, pp.28-32, 2014.

[13] P. Ting-Ting and H. Xiao-Hong, "Dynamic modeling of photovoltaic array under partial shading condition," *Acta Energetica Solaris Sinica*, vol.41, pp.268-274, 2021.

[14] D. Yang-Qing, L. Wen-Ying, and Z. Yan-Wei, "MATLAB Simulation of photovoltaic array and analysis of output efficiency under partial shading," *Acta Energetica Solaris Sinica*, vol.34, pp.997-1001, 2013.

[15] A. Adimi, and A. R. Khaloo, "Behavior of concrete slabs reinforced with frp bars, design and analysis," *SJFST*, DOI: 10.47176/sjfst.4.4.1 vol.4, pp.01-12, 2022

[16] Z. Xiao-Yun, L. Zhen-Zhen, and L Hong-Yi, "A dual mode photovoltaic maximum power point tracking algorithm based on partial shading detection," *Hunan Electric Power*, vol.43, pp.43-48, 2023.

[17] X. Wen-Han, and Z. Guo-Qing, "Occlusion and shadow detection of large-scale true orthophoto in urban area," *Acta Geodaetica et Cartographica Sinica*, vol.01, pp.52-58, 2010.

- [18] W. Guo-An, M. Hong-Tao, D. Tian-Yu, "Calculation of the change range of the sun high angel and the azimuth of sunrise and sunset in one year," *Meteorological and Environmental Sciences*, <https://doi.org/10.1142/9789814539722> vol.S1, pp.161-164, 2007.
- [19] L. Bang-Yin, D. Shan-Xu, K. Yong, "Modeling and analysis of performance of photovoltaic module with partial shading," *Acta Energiae Solaris Sinica*, vol.29, pp.188-192, 2008.
- [20] H. Merabet, T. Bahi, A. Boukadoum, and D. Drici, "Study and analysis of the operation of a Cuk converter for precise voltage regulation," *ijSmartGrid*, vol 7, pp. 148-153, 2023.
- [21] L. Amira, B. Tahar, and I. Yousra, "Performance of meta-heuristic algorithm for a photovoltaic system under partial shade," *ijSmartGrid*, vol. 7, pp. 160-167, 2023.
- [22] P. K. Polamarasetty, S. S. N.Ramakrishna, V. Muddala, and M. V. Kumar, "A Review on the estimate solar pv cell variables for efficient photovoltaic systems," *ijSmartGrid*, vol 7, pp. 154-159,2023.
- [23] M. Kamruzzaman, Md. Anwarul, and Md. A. Abedin, "Optimization of solar cells with various shaped surficial nanostructures," *ijSmartGrid*, vol 7, pp.113-118, 2023.
- [24] A. T. Sofyan, D. Nael, and A. M. Anas, "Detection of xylene as a detrimental chemical compound by employing a photonic crystal based on porous silicon," *ijSmartGrid*, vol.7, pp.38-45, 2023.