Optimization Study and Evaluation of Small Photovoltaic Power Generation System based on Specific Geographical Location

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Abstract

Background: Solar energy, as one of the important new energy sources, has been widely used all over the world and different kinds of solar systems are used for different fields. The superiority of the photovoltaic system is more and more obvious and small photovoltaic power generation system has a wider range of applications in the field of power generation.

Methods: This paper carries out the research of a small photovoltaic power generation system for different areas. Four typical geographical locations are selected after confirming the photovoltaic model system and the PVsyst is applied to the simulation study. Besides, one of the cities, Changchun, is selected as the experimental area to carry out experimental research and to verify the conclusion of simulation study.

Results: The simulation results show that the annual power output is 4829kWh, 3444kWh, 4455kWh and 2766kWh for the four selected cities respectively. The results show that the difference in power generation is attributable to the radiation conditions, optimum tilt angle, minimum spacing and the different geographical location. V-I characteristic curve and power output curve show that no defect, hot spot, partial shading and damage for this photovoltaic system. Moreover, the experimental results of the total power output in Changchun is 4119 kWh per year.

Conclusions: It could be seen that the simulation results agree with the experimental results in this research. Hence, the application of small photovoltaic system needs to fully consider the region condition in order to obtain better power generation efficiency.

Keywords: Photovoltaic system; Minimum spacing; Optimum tilt angle; Power generation

Background

New energy is one of the inevitable choices to solve the problems of environmental pollution, ozone layer destruction, greenhouse gas emissions, energy demand shortage, etc. The new energy includes solar energy, wind energy, biomass energy, etc. In recent years, with the continuous development of new energy industry, solar energy has been more and more recognized and applied by humans because of its advantages of rich, clean, safe and sustainable utilization. It has a broad application prospect to provide energy for people and bring convenience to life at the same time. The lack of power supply and low-cost power demand in the world is driving the development of photovoltaic power generation. Photovoltaic power generation is more convenient and could provide power for medical treatment, education, communication, lighting, water conservancy and agriculture in remote rural areas. With the continuous development of science, technology and economy, the photovoltaic industry is also constantly upgrading and optimizing. The traditional mainstream large-scale photovoltaic power plants have limited installed capacity and low power generation efficiency due to the phenomenon of light abandonment. The photovoltaic system with small capacity and special purpose is more and more popular. Many researchers are carrying out relative research in the field of solar energy.

A mobile photovoltaic hybrid system for remote areas had been designed by Krisada Prompinit et al [1]. This unit built in an easy way to move container unit. A series of experiments results showed that the system could worked normally because of the design and stability of power supply. Mehmed Eroglu et al.
[2] tested a mobile, renewable home with a photovoltaic/wind/fuel cell hybrid system. As an independent power system in remote areas, mobile houses generated enough power to meet the peak load in specific situations such as natural disasters. Photovoltaic and wind power were used for the main power supply in the mobile residential system. The optimum tilt angle of photovoltaic systems had been studied by Yong Sheng Khoo et al [3]. The results found that an oriental oriented module provided the largest tilt exposure to Singapore’s climate conditions in each year. Rehman S and El-Amin I [4] designed different wind, photovoltaic and diesel hybrid systems for a village in the northeast and optimized the hybrid Saudi Arabian administrative zoning system based on local average wind speed per hour, total solar radiation per hour and hourly load data. Jinyong song and yosoon Choi [5] analyzed the potential of a floating photovoltaic system on a mine Lake in South Korea. The layout design of the floating photovoltaic system took into account the optimal tilt angle and array spacing of photovoltaic panels. Amrita Raghoebarsing and Anand Kalpoe [6] calculated the key performance index (KPI) of grid connected photovoltaic system under the weather conditions in Suriname and compared it with the expected value through using PVsyst. In view of the application of photovoltaic array in ships, the application characteristics of photovoltaic array and its components in ships were analyzed by Liang Chen et al. [7] on the basis of the introduction of the principle and method of photovoltaic array utilization. This study discussed and summarized the important characteristics of marine power grid on the basis of photovoltaic array which provided a reference for future system design and application. Taking large ocean-going ships as the research object, the application of distributed photovoltaic power generation in ship power generation system had been studied by Jie Yang et al. [8] and the corresponding model was established. The theoretical calculation and experimental results of the variation characteristics of the surface irradiance of silicon photovoltaic array were compared by V. V. Kuvshinov et al. [9]. V. V. Kuvshinov et al. [10] discussed the application of solar power plants in the Crimean region by developing and designing a combined solar power plant. Smart photovoltaic technology was applied to combine photovoltaic modules with roof coating was launched by Wisdom Opare et al. [11] for an institutional hall in Ghana. The performance of the photovoltaic module deployed on the rooftop which was evaluated as well. A method for the MPPT of the PV module with some shading was proposed by Andrés Tobón et al. [12] and the simulation and experimental research were conducted to demonstrate this method. The results showed that the proper MPPT with IPSM algorithm had a faster response. An optimized DE algorithm by researching the output characteristics of PV module under partial shading conditions was carried out by Peng Zhang and Huibin Sui [13]. The results showed that the proposed algorithm had a higher convergence speed and less steady-state oscillation loss by the simulation research. The Gompertz model which involved three parameters and the sigmoid equation was applied to photovoltaic power forecasting model by Alba Vilanova et al. [14] in South Korea. The results showed that coefficient C of Gompertz model had a good correlation with the capacity factor. Mehreen Gul et al. [15] reviewed the photovoltaic technology from the perspective of photovoltaic material efficiency and global leading countries comprehensively. With regard to a serial research direction, this work inherits some previous research foundation.

A mobile photovoltaic hybrid system was proposed by authors [16] from the aspects of structure, control system, electrical flow and heat flow. The experimental results showed that the system generated 691 kWh of electric energy and 3047.8 kWh of heat energy every year under normal conditions. The authors [17] analyzed a floor radiant heating system based on photovoltaic and solar thermal technology. The calculation method of this system and this heating system were applied to the actual heating system. The authors [18] also proposed a solar dedicated ventilation system based on ADRC. Through the experimental research, higher control accuracy and energy saving potential were obtained compared with the conventional system. The authors also had some works in the field of the photovoltaic system and got some achievements. This is the basic condition for the smooth development of this study.

According to the analysis of the above studies, this study finds that the current photovoltaic system often has the characteristics of mobility, small capacity, specific needs. It also has very strict requirements
for the mutual position between the sunlight and the photovoltaic system, the area where the system is located and the specific installation mode of the system. Therefore, the main work of this study will establish a small capacity photovoltaic model system, then use the PVsyst to simulate specific needs and different geographical locations for photovoltaic system and build the experimental system and measure the data according to the simulation model at last. A general conclusion of this study will provide the basis for the installation of the small photovoltaic power generation system.

Methods

Model System

Model System and Parameter

A model system has been established in the first step of this study. The main model parameters involve the size of the module, the optimum tilt angle according to the location, the sun altitude angle and the minimum spacing between photovoltaic modules will be considered for the photovoltaic system. The optimal inclination, minimum spacing and main parameters of PV module which are applied to the model system are shown in figure 1. These parameters have different values in different geographical locations to achieve the optimal power generation. The size of the standard photovoltaic module is constant, but the solar altitude angle and the optimum tilt angle will vary according to the regional location. The minimum spacing between photovoltaic modules could be calculated by the equation 1 to 6:

\[
D = \cos \beta \cdot L 
\]

\[
L = H \div \tan \alpha 
\]

\[
\sin \beta = \cos \delta \cdot \sin \omega \div \cos \alpha 
\]

\[
\sin \alpha = \sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega 
\]

\[
\alpha = \arcsin(\sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega) 
\]

\[
\sin \delta = 0.39795 \cdot \cos[0.98563(n - 173)] 
\]

where:

- \(H\): Height of PV module, m;
- \(\alpha\): Solar altitude angle, °;
- \(D\): Minimum spacing, m;
- \(L\): Projection of solar rays on the ground, m;
- \(\beta\): Sun azimuth, °;
- \(\delta\): Solar declination angle, °;
- \(\phi\): Local latitude, °;
- \(\omega\): Hour angle, take 0° at noon, 180° at midnight, 90° at 6:00 and 18:00, 45° at 9:00 and 15:00;
- \(n\): Days, calculated from January 1.

The optimum tilt angle \((Z)\) of photovoltaic modules is generally related to the latitude and longitude of the location of photovoltaic modules. In general, the total solar irradiation on the inclined plane of photovoltaic modules could be represented by the scattering irradiation, ground reflection irradiation and direct irradiation which is obtained on the inclined plane. Thus, the hourly total solar irradiation on the inclined plane for the photovoltaic modules could be obtained by follow equations:

\[
G_n(i) = G_{st}(i) + G_{d}(i) + G_r(i) 
\]

where:
$G_{ri}(i)$: Total solar irradiation on the inclined plane of photovoltaic module at $i$ time, $W/(m^2 \cdot h)$;
$G_{di}(i)$: Direct solar irradiation on the inclined plane of photovoltaic module at $i$ time, $W/(m^2 \cdot h)$;
$G_{si}(i)$: Scattering irradiation of solar radiation on the inclined plane of photovoltaic module at $i$ time, $W/(m^2 \cdot h)$;
$G_{ri}(i)$: Reflection of solar irradiation on the inclined surface of photovoltaic module at $i$ time, $W/(m^2 \cdot h)$.

For a certain azimuth, the optimum tilt angle could be obtained by the following equation:

$$
\frac{d}{dZ} \left[ \sum_{i=1}^{m} G_{ri}(i) \right] \bigg|_{Z_{opt}} = 0
$$

(8)

where:

$m$: The total number of hours in the calculation process, take 8760 for the whole year, 2160 for a quarter and 720 for a month.

The direct sunlight on the inclined surface of photovoltaic module $G_{bi}$ could be expressed as:

$$
G_{bi} = G_{bh} \cdot \frac{\cos \theta}{\cos \theta_z} = G_{bh} \cdot R_h
$$

(9)

where:

$G_{bh}$: Direct solar irradiation available on the horizontal plane, $W/(m^2 \cdot h)$;

$\theta$: Incidence angle, the direction angle between the direct irradiation incident on a surface and the normal of the surface, °;

$\theta_z$: Incident angle of horizontal plane, also known as the zenith angle of the sun, °;

$R_h$: Shape factor.

The following equation could be used for determine the incident angle:

$$
\cos \theta = \sin \delta \sin \phi \cos Z - \sin \delta \cos \phi \sin Z \cos \gamma + \cos \delta \cos \phi \cos Z \cos \omega
$$

$$
+ \cos \delta \sin \phi \sin Z \cos \gamma \cos \omega + \cos \delta \sin Z \sin \gamma \sin \omega
$$

$$
\cos \theta_z = \cos \delta \cos \phi \cos \omega + \sin \delta \sin \phi
$$

(10)

(11)

where:

$\delta$: The tilt angle of the sun, $-23.45^\circ \leq \delta \leq 23.45^\circ$, °;

$\phi$: Local latitude, °;

$\gamma$: Azimuth of photovoltaic module, take 0 for the south, negative for the East and positive for the West, $-180^\circ \leq \gamma \leq 180^\circ$, °;

$\omega$: Hour angle, take negative in the morning and positive in the afternoon.

The tilt angle of the sun could be expressed as:

$$
\delta = 23.45 \sin(360 \times \frac{284 + n}{365})
$$

(12)
where:

$n$: Day, Day of the whole year, value: 1-365.

The reflected part of the ground on the inclined plane of the photovoltaic module could be expressed as follows:

$$G_r = \frac{\rho_d}{2} \cdot G_{th} \cdot (1 - \cos Z)$$

(13)

where:

$G_{th}$: Total solar irradiation on the horizontal plane, $W/(m^2 \cdot h)$;

$\rho_d$: Ground reflection coefficient. The reflection coefficient of snow surface could be set as 0.6, and the reflection coefficient of snow free ground could be determined as 0.2.

The solar scattering on the inclined plane of photovoltaic module could be calculated by Reindl model:

$$G_{ds} = G_{dh} \cdot \cos^2\left(\frac{Z}{2}\right) \cdot (1 - A_i) \left[1 + f \cdot \sin^3\left(\frac{Z}{2}\right)\right] + G_{dh} \cdot A_i \cdot R_b$$

(14)

where:

$G_{ds}$: Scattering irradiation on the horizontal plane, $W/(m^2 \cdot h)$;

$$A_i = \frac{G_{bm}}{G_m} = \frac{G_{bh}}{G_0} \cdot \frac{\cos \theta_z}{\cos \theta}$$. (15)

$$f = \sqrt{\frac{G_{bh}}{G_{th}}}$$

(16)

where:

$G_0$: The solar irradiation that could be obtained on the horizontal plane of the outer atmosphere and it could be expressed:

$$G_0 = G_{sc} \left[1 + 0.033 \cos\left(\frac{360n}{365}\right)\right] \left(\cos \delta \cos \phi \cos \omega + \sin \delta \sin \phi\right)$$

where:

$G_{sc}$: constant, around $1353 \, W/m^2$.

$n$: Days, calculated from January 1.

The optimum tilt angle and the minimum spacing could be calculated according to the above mathematical formula.
**Figure 1**: Schematic diagram of optimal inclination, minimum spacing and main parameters of PV module for model system

**Calculation and Analysis**

This study selects four representative geographical locations in the world after determining the photovoltaic model system. Optimum tilt angle and minimum spacing of four representative regions could be calculated by the equation 1-16. The results are shown in Table 1.

| No. | City         | Latitude (°) | Longitude (°) | D(m) | Optimum tilt angle (°) |
|-----|--------------|--------------|---------------|------|------------------------|
| 1   | Mexico City  | 19.4         | -99.2         | 2.6  | 14.3                   |
| 2   | Xinyang      | 32.2         | 115.7         | 4    | 29.2                   |
| 3   | Changchun    | 43.9         | 125.2         | 7.3  | 46.3                   |
| 4   | London       | 51.5         | -0.1          | 15.5 | 59.6                   |

The results show that the four typical cities have a significant for the following study. The latitude changes from 20 ° to 52 ° and optimum tilt angle ranges from 15 ° to 60 °. These scopes of latitude and optimum tilt angle are suitable for photovoltaic system and have a higher power generation efficiency.
The minimum spacing between photovoltaic modules in different regions are calculated on the basis of equation 1-6 at the same time. The above data information provides the basic basis for the follow-up simulation and experimental research of this study.

PVsyst is used for simulation to evaluate the power generation situation and power differences caused by different geographical locations in Chapter 3. The proposed system is tested according to the simulation results subsequently. The actual power generation is measured and calculated under the optimum tilt angle and minimum spacing.

**Simulation Based on PVsyst**

The PVsyst is a popular software which has been used for the simulation and design of the photovoltaic system all over the world. The PVsyst is an auxiliary software for the design of photovoltaic system and could be used for the simulation calculation of power generation for photovoltaic system. The PVsyst could complete the research, design and data analysis for photovoltaic system. The PVsyst involves the following functions:

a. Set the type of photovoltaic system: on-grid, off-grid, photovoltaic pump and so on;

b. Set the layout parameters of photovoltaic modules: fixed mode, PV array tilt angle, line spacing, azimuth and so on;

c. Evaluate the influence of buildings on the shading for photovoltaic system and calculate the shading time and proportion;

d. Simulate the power generation capacity and efficiency for different types of photovoltaic systems;

e. Study the environmental parameters of photovoltaic system.

Consequently, the PVsyst will be chosen for the simulation in this study. The layout parameters of photovoltaic modules and the power generation of the proposed photovoltaic system will be simulated by this software.

**Model Setting**

The PVsyst is applied to simulate and analyze the photovoltaic systems of four typical cities in this study and the simulated site conditions of four regions are chosen for the simulation study. The weather information map of four different regions could be gained and the array mode of photovoltaic modules is set in each region according to the selected cities. The rated power of the photovoltaic system is 3kW and the optimum tilt angle of the four regions are set at 15 °, 30 °, 45 ° and 60 ° respectively.

The photovoltaic array model is carried out in this study. The width of the module is set to 1 m and the vertical height is set to 0.5 m. The minimum spacing of photovoltaic modules for four regions are set to 2.6, 4.0, 7.3, and 15.5 respectively according to the calculation results in Table 1. The setting interface and modeling effect are shown in figure 2.
Figure 2: The setting interface and modeling effect of Photovoltaic array

Because of the different angles of inclination in different regions, the shading loss in each region are 0.5%, 1.7%, 2.2%, 2.4% respectively in this study. The energy loss caused by shading and its influence on the solar horizon line are shown in figure 3. According to the data analysis of shading loss in each region and the overall analysis of shadow map, it could be seen that the shading loss in the lower latitude and higher latitude is smaller and the shading loss in the middle latitude is relatively higher. Therefore, it could be found that the energy loss caused by the accurate setting of photovoltaic model system in four regions is less after reasonable parameter setting. It basically covers all periods of solar radiation on the horizon line which shows that the setting of tilt angle and array mode is reasonable at the same time.
Figure 3: Schematic diagram of shading loss and sun shadow area of different areas

The detailed setting of the model: the standard module is adopted for the PV module, the polycrystalline silicon cell is selected for the solar panel, the flat roof is selected for the installation position and the ventilation is free. The setting method is the same for different regions and the specific setting method is shown in figure 4.
Results and Analysis for simulation

The results involve the solar radiation conditions in different regions and the power generation of photovoltaic system which are simulated by the PVsyst after the detailed setup. The average daily irradiation per unit area of each month and the whole year on the horizontal plane, the average daily irradiation per unit area of each month and the whole year on the corresponding tilted plane and the average daily irradiation per unit area of each month and the whole year after considering the shading loss for each region are shown in figure 5. It could be found that the average daily irradiation per unit area of the whole year after considering the shading loss is higher than the average daily irradiation per unit area of the whole year on the horizontal plane. The simulation results show that the optimal layout of photovoltaic array enables the PV module to obtain more effective solar radiation.

(a) Mexico City  (b) Xinyang
Figure 5: The average daily irradiation per unit area of each month and the whole year on the horizontal plane, the average daily irradiation per unit area of each month and the whole year on the corresponding tilted plane and the average daily irradiation per unit area of each month and the whole year after considering the shading loss of each region.

The monthly and annual average daily power outputs of different regions are shown in figure 6. The annual power outputs are 4829kWh, 3444kWh, 4455kWh and 2766kWh respectively. The radiation conditions and simulation output results of the four regions are summarized in Table 2. Based on these data, it could be found that:

a. The performance of photovoltaic system is mainly affected by radiation conditions;
b. The difference of simulation results is obvious for different regions, but it is not completely related to optimum tilt angle and minimum spacing;
c. The solar radiation is different due to the different geographical location which also affects the power generation in different areas;
d. The proposed model and simulation results are consistent with the differences of power generation in different regions.

Subsequently, Changchun is chosen as the experimental area on the basis of the simulation results.
Figure 6: Monthly and annual average daily power generation and total power generation of different regions

Table 2: Solar radiation conditions and simulation results of different regions

| No. | City          | Global horizontal (kWh/m².day) | Collector plane (kWh/m².day) | Shed shading (kWh/m².day) | System output (kWh/day) | System output (kWh) |
|-----|---------------|---------------------------------|------------------------------|---------------------------|-------------------------|---------------------|
| 1   | Mexico City   | 4.93                            | 5.22                         | 5.19                      | 13.23                   | 4829                |
| 2   | Xinyang       | 3.59                            | 3.81                         | 3.70                      | 9.44                    | 3444                |
| 3   | Changchun     | 3.84                            | 4.88                         | 4.79                      | 12.21                   | 4455                |
| 4   | London        | 2.67                            | 3.04                         | 2.97                      | 7.58                    | 2766                |

**Experiment and Analysis**

**Experimental System**

The experimental system involves photovoltaic module, combiner box, touch screen, current collector, voltage collector, relay, inverter, controller, acquisition board, air switch, diode, emergency power supply and testing instrument.

The combiner box is designed with an anti-reverse diode and varistor which could protect against the lightning. At the same time, the combiner box is installed in the outdoor and near the photovoltaic array.

The photovoltaic array of the experimental system consists of 12 standard polysilicon photovoltaic modules in series which is 3 kW capacity and similar size based on the simulation study. The optimal working voltage is 31.5V and the generating power is 250W for each photovoltaic module. 12 photovoltaic modules are placed in two rows and 6 photovoltaic modules are in one row. Changchun is chosen as the experimental area in this study according to the simulation results and the details of parameters could be found in table 1. The specific placement of photovoltaic array is determined by geographical location of Changchun.

Fuse, air switch, relay, inverter, current collector, voltage collector, controller, acquisition board and other electrical components are used for the experimental test which are shown in figure 7. The main function of the system control cabinet is applied to complete the data acquisition, power supply control and electrical equipment protection for the whole experimental system. The system control cabinet is equipped with controller, monitoring touch screen, inverter, collector and actuator. The system control
cabinet is the "brain" to ensure the normal operation of the whole experimental system which is shown in
The DC generated by the photovoltaic array enters the inverter through air switch and contactor. The inverter converts the DC into AC 220V and controls the power supply through circuit breaker and AC contactor. The Voltage Collector for DC monitors the output voltage of the photovoltaic array, the current collector for DC monitors the output current of the photovoltaic array, the electric meter detects the power of the system and the fuse carries out over-current protection.

The collected signal is transmitted to the controller and communicated with the touch screen to realize the calculation and analysis. The experimental test and data acquisition are shown in figure 7 and 8.

**Figure 7**: Schematic diagram of experimental test
Note: The inverter could be used for inverter, voltage transformation, charging and filtering of emergency power supply in this experimental system.

**Figure 8:** Experimental test and data acquisition

**Results and Analysis for experimental**

The current collector obtains the current value of photovoltaic power generation and the voltage collector gains the voltage value of photovoltaic array in this experiment. The data is collected and fed back on the touch screen which could be used for display and adjust the power supply status. I-V400 professional photovoltaic (solar) module I-V characteristic analyzer is applied to test the V-I characteristic output of the photovoltaic system in this study. The results are shown in figure 9.

The curve is the relatively reasonable V-I characteristic curve (black line) and power output curve (blue line) of the photovoltaic system are more reasonable in figure 9. The results show that the overall
performance of photovoltaic system is good and there are no defect, hot spot, partial shading and damage. Therefore, this photovoltaic system could be put into real-time monitoring operation and data collection.

Figure 9: V-I characteristic curve and power output curve of the system corrected by the I-V400

The touch screen is applied to monitor the operation of the whole experimental system. Current and voltage value of photovoltaic array, the instantaneous power generation and cumulative power generation of photovoltaic system could be acquired from the touch screen which could also control the working state of charging and discharging. The system parameters could be set and adjusted in time on the basis of the data displayed on the touch screen in this experimental test. Equation of cumulative power generation could be expressed:

$$E_j = \int_{0}^{j} u_j \cdot i_j \, dj$$

(17)

where:
- $E_j$: Annual power generation of photovoltaic system, kWh;
- $u_j$: Instantaneous voltage of photovoltaic system, V;
- $i_j$: Instantaneous current of photovoltaic system, A;
- $j$: Total operation time of photovoltaic system, s.

According to the experimental results, equation 17 is applied to calculate the total power generation of this photovoltaic. Finally, the total power generation of photovoltaic system is 4119 kWh per year. There are some inevitably errors between the experimental results and the simulation results.

The relative error between simulation results and experimental results is 7.5% through calculation and analysis. The reasons for the relative errors in this study are as follows:
- a. Errors caused by measurement in the process of experimental test;
- b. Errors due to the accuracy of the test instruments;
- c. Optimum tilt angle is 45 ° for the simulation study based on the PVsyst and 46 ° for the experimental study on the basis of local conditions.

These results confirmed that the simulation study could accurately predict the power generation for the proposed photovoltaic system in this study and the experimental study verifies the conclusion of the
simulation study.

**Conclusions**

In order to carry out the optimization research and system evaluation of small-scale photovoltaic power system, the simulation research and experimental research are launched for different geographical location systems.

Four typical geographical locations are selected after confirming the photovoltaic model system and the PVsyst is applied to the simulation study. The rated power of the photovoltaic system is 3kW, the optimum tilt angle of the four regions are set at 15°, 30°, 45° and 60° respectively, the width of the module is set to 1 m, the vertical height is set to 0.5 m and the minimum spacing of photovoltaic modules for four regions are set to 2.6, 4.0, 7.3, and 15.5 respectively in the simulation part. The simulation results show that the annual power generation are 4829kWh, 3444kWh, 4455kWh and 2766kWh for Mexico City, Xinyang, Changchun and London respectively. The difference of power generation is attributable to the radiation conditions, optimum tilt angle, minimum spacing, different geographical location.

To demonstrate the simulation results, the experimental study is carried out subsequently. According to the conclusion of the simulation study, Changchun is chosen as the experimental area in this experiment. The rated power of the photovoltaic system, the width of the module, the vertical height of the module and the minimum spacing of photovoltaic modules are the same as the simulation study. The optimum tilt angle is set to 46° which is similar to the simulation study. The experimental test and data acquisition are carried out after the establishment of the experimental system. V-I characteristic curve and power output curve show that no defect, hot spot, partial shading and damage for this photovoltaic system. The total power generation of photovoltaic system is 4119 kWh per year. The relative error between simulation results and experimental results is 7.5% which is reasonable in this research. The experimental results confirm the validity of the simulation results.

This study verifies that the application of small-scale PV systems should have a fully consideration for the geographical location and installation mode.

**Acknowledgements**

This study was supported by the Lancang-Mekong Vocational Education Training Center and Cambodia Luban Workshop.

**Authors’ contributions**

L.Z. determined the structure and thinking of this study. H.Z. designed the simulation system and carried out calculation based on the PVsyst. L.Z., Z.C. and Z.M. wrote the article and finished the system design and experimental research. Z.C. collected and analyzed the experimental data. All the authors made great contributions to this study.

**Funding**

This research was supported by Tianjin Technical Expert Project under grant 19JCTPJC42700.

**Availability of data and materials**

Not applicable

**Ethics approval and consent to participate**

Not applicable

**Consent for publication**

All the authors consented for publication of this article.
Competing interests
All authors declare no conflict of interest.

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