Research and design of low-power grid-connected PV power generation system based on automatic solar tracking

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ABSTRACT
A low-power grid-connected photovoltaic (PV) power generation system based on automatic solar tracking is designed in this paper. In order to increase the level of accuracy of automatic solar tracking, the part of automatic solar tracking adopts the method of hybrid tracking and uses pin-cushion two-dimensional position sensitive detector plus four silicon PV cells as the photosensitive element. An adaptive topological structure of the main circuit based on a cascaded Boost converter circuit and the H6-type inverter topology are designed for the system to obtain a better working condition. Then an MPPT algorithm combined modified constant voltage algorithm with modified variable step-size increment conductance algorithm is proposed in order to improve the efficiency of PV power generation. The experimental results showed the effectiveness of the control system. Finally, the hardware and software of the system are also designed. Moreover, a graphic interface made with the LabVIEW software allows the user to monitor and save the data in a file.

1. Introduction
A new challenge of power production is the reduction of fossil fuel in the next half-century. Nowadays the issue of renewable energy has attracted more and more attention. Solar energy is an important renewable energy owing to its advantages of non-pollution and wide geographical distribution (Kannan & Vakeesan, 2016; Racharla & Rajan, 2016; Sonkar, Edla, & Gupta, 2013). The photovoltaic (PV) power generation is a technology that the light energy is directly converted into electrical energy by utilizing the PV effect of the semiconductor interface. The traditional PV power generation mostly adopts small and medium off-grid power generation system, but now it is gradually moving towards the use of grid-connected generation system.

Due to the rotation of the earth, the solar light’s illumination angle is constantly changing relative to a fixed-site solar PV power generation system, which ensures that the solar panels can face the sun at all times effectively, and the power generation efficiency may reach an optimal value. The solar power generation system that instantly can allow the photosensitive surface of the solar battery pack remain perpendicular to the solar ray is called the solar automatic tracking system. Currently, most PV power plants at home and abroad adopt the mode of traditional fixed installation. However, this type of installation is no longer a mainstream trend (Li, 2016). To obtain more output power of PV cells, the automatic solar tracking is a better choice. By tracking the rays of the sun, solar panels can automatically adjust as the position of the sun changes, which enables the PV module to receive more solar radiation and increase the system’s output, thereby reducing the cost of the entire PV system. A lot of literature has proposed detailed design scheme. For instance, Haryanti, Halim, and Yusuf (2014) used photo-diodes as photoelectric sensors to track the solar rays. However, there were quite large errors in the measurement, which reduced the level of accuracy seriously. Yuan (2016) used the quadrant photoelectric sensor to realize the tracking of the sun, but there were certain requirements of the size and shape of the incident light spot during the process of measurement, and there were certain blind areas. Zheng and Zhang (2012) utilized a charged coupled device (CCD) to track the sunlight accurately. However, it has the disadvantages of high cost and low measurement speed. Inspired by relevant literature, we designed a low-power grid-connected PV power generation system based on automatic solar tracking, in which a pin-cushion two-dimensional position sensitive detector (PSD) was used as the photosensitive element. Compared with...
photo-diode, quadrant detector and CCD, the device has higher sensitivity, no blind area, higher response speed and higher performance-price ratio. Compared with the tetra-lateral PSD, the pin-cushion two-dimensional PSD has better linearity and the edge signal distortion is also reduced greatly. To obtain more output power of PV module, combined the improved constant voltage algorithm with the modified variable step-size incremental conductance algorithm, an improved MPPT algorithm was proposed, which compensated for the shortcomings of the single algorithm and increase the tracking speed.

The remainder of this paper is organized as follows: In Section 2, the idea of the automatic solar tracking method is presented. In Section 3, the specific design of the topological structure of the system and the control strategy of single-phase PV grid-connected system are described in sufficient details. Section 4 gives the hardware and software designed according to the proposed method; In Section 5, the experimental results are discussed and presented. Finally, Section 6 concludes the paper with pertinent observations.

2. Automatic solar tracking method

In this paper, a two-stage tracking photoelectric sensor was designed based on the combination of pin-cushion two-dimensional PSD and silicon photocell. Meanwhile the tracking mode was chosen depending on the change of light intensity. When the light intensity is greater than the threshold, photoelectric tracking is selected; when the light intensity is less than the threshold, solar trajectory tracking is selected. The implementation of photoelectric detection tracking and solar trajectory tracking are summarized as follows.

2.1. Photoelectric detection tracking

In the photoelectric detection tracking, the pin-cushion two-dimensional PSD is applied as photo-detector. In the test, the pin-cushion PSD was put in an opaque box to remove the influence of stray light. Note that the height of the box was optimized. The transparent hole was perpendicular to the centre of the pin-cushion PSD at the top of the box. Furthermore, a flat convex lens was placed at the orifice to reduce the edge effect. The outer surface of the box was coated with aluminium film to prevent the influence of the dark current on the pin-cushion PSD due to the high temperature of the shell. Four silicon PV cells of the same size were placed around the small box to judge the size of light intensity and completed initial tracking of the sun on a sunny day. According to the magnitude of the light intensity, the smooth conversion between the photoelectric detection tracking and solar trajectory tracking can be realized. The photoelectric detection tracking can comply with the requirements of 0.1° in various weather conditions, which meets the requirements of the system design.

Figure 1 shows the structure of pin-cushion two-dimensional PSD, when a beam of light hits the photosensitive surface of pin-cushion PSD, its four pins will output a weak current signal of µA-level according to the position of the spot. In order to obtain an analog signal that can be input to the STM32, the current signal of pin-cushion PSD needs to be converted into a voltage signal and amplified. Taking $I_1$ of the pin-cushion PSD four-way signal as an example, the signal processing circuit is shown in Figure 2.

![Figure 1. The structure of pin-cushion PSD.](image1)

![Figure 2. I/V conversion circuit that using $I_1$ as an example.](image2)

$$\begin{align*}
X &= \frac{(I_1 + I_2) - (I_3 + I_4) L}{I_1 + I_2 + I_3 + I_4} \div L \quad (1) \\
Y &= \frac{(I_1 + I_4) - (I_2 + I_3) L}{I_1 + I_2 + I_3 + I_4} \div L \quad (2)
\end{align*}$$
where, $I_1$, $I_2$, $I_3$ and $I_4$ represent the current signals related to the spot position from the four electrodes of the pin-cushion PSD. When the geometric coordinate centre of the pin-cushion PSD photosensitive surface is used as the origin of the plane coordinate system to establish the plane coordinate system, where $X$ and $Y$ represents the position coordinates of the spot in the coordinate system. The parameter $H$ represents the height of the box, which can be expressed using the following formula:

$$H = \sqrt{X^2 + Y^2}.$$  

(3)

The parameter $L$ represents the photosensitive surface side length of pin-cushion PSD. $\beta$ represents the solar elevation angle and $\alpha$ represents the solar azimuth. The two parameters can be calculated with the following formulas:

$$\beta = \arctan(X/Y),$$  

(4)

$$\alpha = \arctan(L/H).$$  

(5)

When the spot is at the geometric centre of the pin-cushion PSD photo-surface, the panel is facing the position of the sun presently, and then the STM32 controls the mechanisms to track the sun.

### 2.2. Solar trajectory tracking

The solar trajectory tracking system used solar elevation-azimuth angle pattern based on the horizontal coordinate system. This pattern can determine the solar trajectory with the help of astronomical formulas. Using the solar trajectory, the STM32 can control the mechanisms to produce the sun tracking (Jing, Kaihua, & Li, 2009). Firstly, the GPS module is used to obtain the current time, latitude and longitude information of the installation location of the tracking device. Choose the highest precision of Wang Bingzhong’s declination angle algorithm (Wang & Liu, 1991) and the Lamm time difference algorithm (Lamm, 1981), then according to the calculation formula of solar elevation angle and the solar azimuth, calculate the solar elevation angle and the solar azimuth. Selecting the interval time is 20 min, and then calculate the solar elevation angle and the solar azimuth. Finally, calculate the angular difference between the two times. Last but not least, the tracking device is driven by STM32 to make the deviation value within the allowable range, and the solar panel is facing the sun to achieve the goal of automatic solar tracking. The two formulas for calculating the solar elevation angle $\theta_H$ and the solar azimuth $\theta_A$ are as follows:

$$\theta_H = \arcsin(\sin \varphi \sin \theta + \cos \varphi \cos \theta \cos \omega),$$  

(6)

$$\theta_A = \arccos((\sin \theta_H \sin \varphi - \sin \theta) / \cos \theta_H \cos \varphi),$$  

(7)

where, $\varphi$ represents the latitude of the tracking device; $\theta$ indicates the solar declination angle, which can be calculated with the following equation:

$$\theta = 23.45^\circ \times \sin[360 \times (284 + n)/365],$$  

(8)

where $n$ represents a day of the year, $\omega$ represents the solar hour angle, it can be expressed by the following formula:

$$\omega = 15^\circ \times (12 - t),$$  

(9)

where $t$ represent the different time of the day, the value ranges is chosen from 0 to 24 h.

### 3. Topological structure and control strategy

#### 3.1. Topological structure of PV power generation system

This paper designs a topology suitable for the PV power generation system, as shown in Figure 3, because the boost range of single-stage Boost converter is too narrow, in the case of low power, it is usually possible to use a cascaded Boost converter to achieve the desired boost effect (Choudhury & Nayak, 2016), so the front stage is a cascaded Boost converter circuit, the MOS tube model of the cascaded Boost converter is IRF3205, its withstand voltage value is up to 55 V. The output voltage can be adjusted by adjusting the duty cycle. If D1 indicates the duty cycle of Q1, the formula for output voltage is as follows:

$$V_o = \frac{1}{(1 - D_1)^2}V_{dc},$$  

(10)

where $V_{dc}$ is the output voltage of a solar panel. The last stage is the H6-type inverter topology (Das & Sheeja, 2017), the H6-type inverter topology consists of six MOS switches. The model of MOS switch tube is IPW60041C6, its pressure-resisting values is up to 650 V. The H6-type inverter topology can suppress the leakage current and solve the leakage current problem of single-phase PV grid-connected inverter without transformer effectively. Its overall efficiency is much higher than that of the traditional the H4-type inverter topology (Rizzoli et al., 2016). L filters are usually used in grid-connected inverters with low-power and high switching frequency. In this paper, a low-power grid-connected PV power generation system was designed. Under the condition of satisfying the design requirements of the system, it is very
appropriate to select L-type filter. When connected to the grid, the output voltage of the solar panel is converted into a 360 V DC high-voltage input the H6-type inverter topology through the cascaded Boost converter. Set the basic parameters as follows (Xiong, 2009): $V_{dc} = 36$ V, $V_o = 360$ V, the rated power is 300 W, calculate the duty cycle $D_1$ is 0.684, the switching frequency of Q1 is set to 20 kHz, and set the output-load to $432 \Omega$. Through Matlab/Simulink software to build the model of main circuit and analysis the simulation result, the simulation result is shown in Figure 4, we can see that the voltage waveform appeared a peak in the time of 0.05 s, then it enters a stable state after around 0.1 s. It is evident that the cascaded Boost converter can achieve the desired effect.

3.2. Control strategy of single-phase PV grid-connected system

In this section, the research focused mainly on the maximum power point tracking method of PV cell and control strategy of PV grid-connected inverter. On this basis, a composite MPPT algorithm was proposed. The algorithm can effectively solve the shortcomings of slow tracking and poor stability of a single algorithm. And the grid-connected inverter adopts the control strategy of voltage outer loop feed-forward control and current inner loop control. The specific analysis is as follows.

3.2.1. MPPT controls method of PV cell

In this paper, MPPT technology is used to further improve the photoelectric conversion efficiency of solar cells. When the solar panel is facing the sun, the system stops working, and then performs the operation of maximum power point tracking. In (2016), Zhu proposed a modified constant voltage algorithm. The idea of this method is to compensate open circuit voltage $U_{oc}$ for temperature changes. Inspired by this idea, a composite algorithm is proposed combined the modified constant voltage algorithm with the modified variable step-size incremental conductance algorithm. Taking into account the effect of temperature on open circuit voltage, a corresponding open circuit voltage is set within a certain temperature range, and when the solar panel is in a temperature range, the open circuit voltage is automatically adjusted to a corresponding voltage. Under normal circumstances, the working voltage corresponding to the maximum power point of the PV array under certain conditions is about 0.78 times of the open circuit voltage, so choosing the $0.78U_{oc}$ as the reference value located near the maximum power point quickly (Wang, 2017). This solves the problem of misjudgment and MPPT power loss in the traditional fixed step. Figure 5 shows the control flow chart of the algorithm. The algorithm compensates for the shortcomings of a single algorithm, which has a high response speed. The simulation model was built using Matlab/Simulink to verify the effectiveness of the algorithm. The simulation results are shown in Figure 6. Algorithm 1 represents the composite MPPT
algorithm while algorithm 2 represents a single MPPT algorithm. The curves shows the output power of the solar panel under the conditions of 37.5°C, 800Lux and 25°C, 1000Lux. It can be seen from the figure that the composite MPPT algorithm has good response characteristics and stability compared with the single algorithm.

3.2.2. Control method of PV inverter for grid-connected system

To ensure that the grid-connected PV power generation system works reliably, the output current of PV power generation system must be in the same phase as the grid. The grid-connected inverter adopts double loop

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**Figure 5.** Control flows chart of the algorithm.

**Figure 6.** The waveform of output power with MPPT algorithm.
control scheme (voltage outer loop feed-forward control and current inner loop control) (Bosio et al., 2016), H6-type inverter topology controls block diagram is given in Figure 7. Firstly, detect the boost circuit output voltage. Second, the output voltage is compared with a given voltage to get a deviation, then generate the reference current value through PI regulation, and compare the current reference value with the actual detected source current to get the deviation. By comparing with the triangular wave after processing the deviation through PI control, the deviation acts on the SPWM signal generator, then the SPWM waves are obtained (Yang & Wu, 2018). Subsequently, the SPWM signal acts on H6 bridge inverter through the power tube after being amplified (Wu, Ji, & Hu, 2016). Finally, after the process of power amplification, the system generates the same frequency and phase current. Figure 8 shows the simulation results of the AC grid-connected power generation system using an instantaneous current control scheme under standard conditions.

4. Hardware and software design of the system

In this section, the research focused mainly on the design of system’s hardware and software. The hardware part gives the overall block diagram of the system. Subsequently, several important circuits of the system are analysed and given, including the sampling circuit of DC voltage and current, the sampling circuit of AC voltage and current for inverter, and drive circuit and PWM generation circuit. The software section gives a detailed analysis of the overall work-flow of the system.

4.1. Hardware design of the system

The overall structural block diagram of the PV grid-connected power generation system is shown in Figure 9. This figure mainly includes the controller, the automatic solar tracking, the grid-connected power generation system and the human–computer interaction.

For the design of grid-connected power generation system, the following several important circuits of the system are analysed and given.
4.1.1. Sampling and processing circuit of DC voltage and current
The output voltage of the solar panel is sampled through the method of the resistor divider, and the circuit is shown in Figure 10. A voltage signal with a range of 0–3.3 V is sampled, and then it is input to STM32 for processing. The current transformer is used to collect the DC current signal; the current transformer model is ACS758, which has the advantages of ultra-low power loss, proportional output voltage and current, high reliability, etc. The collected current signal is processed to a voltage signal with a range of 0–3.3 V, and the processed signal is sent to the STM32 for processing. The circuit is shown in Figure 11.

4.1.2. Sampling and processing circuit of current and voltage for inverter
The output voltage and current of the inverter is all power signals. The sampling and processing circuits were mainly used to sampling, filtering and scaling the intense signals. Finally, get a voltage signal with a range of 0–3.3 V, and then the signal is sent to STM32 for digital processing. The current transformer selects ACS712 type, because the inverter output is a AC signal, and then the circuit formed by TL072 is converted into a DC voltage signal based on +1.5 V (Zhou, 2017), so that the output signal can meet the requirements of the controller. The sampling circuit is shown in Figure 12. The voltage transformer selects SPT204A type, the input rated current is 2 mA, the rated output current is 2 mA, and the voltage signal is converted into the current signal. The secondary edge is the current–voltage conversion circuit, and the sampling circuit is shown in Figure 13. The current limiting resistance (Rs) is used to compensate for the phase shift, and the diode in the circuit is used to protect the operational amplifier. TL084 is selected as the operational amplifier, which has the advantages of high stability and high precision. Note that the sampling circuit of grid reference signal is the same as that of an inverter parameter acquisition circuit, so it is not described again.

4.1.3. Drive circuit and PWM generation circuit
In this paper, TLP250 integrated circuit is selected as the driving circuit of MOSFET. All the driving circuits of MOSFET in this system are designed based on TLP250 chip, which has the advantages of small size, high speed and output over-current protection. The specific design schematic diagram corresponding to the single-tube driving circuit is shown in Figure 14. In the output of STM32, it is necessary to add the buffer circuit to increase the driving capacity. The buffer circuit is designed based on chip 74HC245, which has the potent anti-jamming capacity (Hu & Tan, 2008). The control signal of the cascaded Boost converter in this system is a PWM signal. The PWM signal generation circuit is designed based on the chip TL494, as is illustrated in Figure 15.

4.2. Work-flow of the software
According to the method of automatic solar tracking and grid-connected, the software is used to control the whole system when the grid-connected power system
is made available for operation (Zhang et al., 2009). At the beginning of the program, the system is reset. That is to say that each module is initialized and the light intensity is detected through the silicon photocell. Then the output voltage and current signals of solar panel are collected and processed. The processed signals are input to STM32F4 and the driving signals are sent out. Then determine whether the tracking time is in the current time between sunrise and sunset: only if the condition is satisfied, call the MPPT subroutine; otherwise, call the automatic solar tracking subroutine. Then decide whether or not to start the inverter subroutine: if the condition is satisfied, call the inverter control algorithm, otherwise, return to prejudge the intensity of the sunlight. The output SPWM is adjusted by STM32F4, and acts on H6 inverter. Finally, the interruption is cleared. The light intensity is re-judged to distinguish day and night according to approximate time of sunrise and sunset, which controls mechanisms of tracking to turn back to the benchmark position, and perform another automatic light-seeking and PV grid-connected process.

5. Experiment and results

According to the above theoretical analysis and design of the software and hardware of the system, this section mainly tests the effectiveness and the precision of the automatic solar tracking. The results of the grid-connected current and the grid voltage are also given. Finally, The human–computer interaction interface is designed which monitor the overall operation of the system in real time.

5.1. Effective test of automatic solar tracking

The automatic solar tracking effective test is to test the power of the PV module in the presence or the absence of light-seeking. Select another solar cell with the same characteristic parameters to make the best position as a fixed position. According to the volt-ampere characteristic relationship, select several time points of the day and recording the power emitted by the PV modules at these points in time. The experimental results are presented
Table 1. The measured, theoretical and error values of solar elevation and azimuth (unit: degree).

| Time | Measured values of elevation | Measured values of azimuth | Theoretical values of elevation | Theoretical values of azimuth | Error values of elevation | Error values of azimuth |
|------|-----------------------------|----------------------------|---------------------------------|-------------------------------|--------------------------|--------------------------|
| 8:00 | 35.52                       | -89.95                     | 35.89                           | -90.76                       | -0.37                    | 0.81                     |
| 9:00 | 47.45                       | -80.27                     | 47.97                           | -81.12                       | -0.52                    | 0.85                     |
| 10:00| 59.11                       | -66.89                     | 59.65                           | -67.79                       | -0.54                    | 0.9                      |
| 11:00| 69.53                       | -43.69                     | 69.80                           | -44.54                       | -0.27                    | 0.85                     |
| 12:00| 74.84                       | -0.81                      | 74.63                           | -0.00                        | 0.21                     | -0.81                    |
| 13:00| 70.02                       | 43.47                      | 69.79                           | 44.51                        | 0.23                     | -1.04                    |
| 14:00| 59.39                       | 66.56                      | 59.63                           | 67.74                        | -0.24                    | -1.18                    |
| 15:00| 47.62                       | 80.03                      | 47.95                           | 81.06                        | -0.33                    | -1.03                    |
| 16:00| 35.37                       | 89.84                      | 35.86                           | 90.69                        | -0.49                    | -0.85                    |

Figure 17. The waveform of grid voltage and grid-connected current.

Figure 18. Human–computer interaction interface.
in Figure 16. It is evident that the system can significantly increase the output compared to the fixed power generation system.

5.2. Precision verification of automatic solar tracking

For automatic solar tracking system, the higher the tracking accuracy is, the higher the verticality of the solar panel with the sun’s rays will be. At the same time, the power generation has also a higher efficiency. This subsection mainly verifies the tracking accuracy of the designed system. The experimental method is tantamount to compare and analyse the height angle and azimuth values of the actual tracking system with the theorectical values of the altitude and azimuth angles found on the Era Shuttle Calendar. The date of the experiment was 20 July 2018. The results are presented in Table 1. It can be seen from the table that the error values of height angle and azimuth angle are less than 1.2, which meet the expected tracking accuracy of the system.

5.3. Result of grid-connected

The grid-connected current waveform and the grid voltage waveform are recorded by the FLUKE1760 three-phase power quality recorder. The results are presented in Figure 17. It can be observed from the figure that the phase of the grid-connected current is the same as that of the grid voltage. Moreover, the desired results are obtained by this experiment.

5.4. Human–computer interaction interface

In this study, a monitoring system was introduced for developing PV power generation system in the laboratory with Labview (Bayrak & Cebeci, 2014). The parameters and the parameter changes at time, geographic, etc. were monitored in real time thanks to Labview DAQ card. Output voltage and current generated from the PV system and the measured values of solar elevation angle and azimuth angle were also monitored with developing Labview software. The writing operation of the data file is performed by the host computer, and display the various data in real time in the front panel as well as save the data in a file. The human–computer interaction interface is presented in Figure 18.

6. Conclusion

A low-power grid-connected PV power generation system based on automatic solar tracking is proposed and designed in this paper. It is evident from the experimental results that the composite algorithm which proposing performs reliably and quickly, that the automatic solar tracking system has a higher level of accuracy. Moreover, the single-phase grid-connected PV power generation system designed in this paper is stable, safe and reliable; such design as this is not only easy to be implemented, but also meets the requirements.

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References

Bayrak, G., & Cebeci, M. (2014). Monitoring a grid connected PV power generation system with labview. In International Conference on Renewable Energy Research & Applications (pp. 562–567). Madrid: IEEE.

Bosio, F. D., Pastorelli, M., Ribeiro, L. A. D. S., Lima, M. S., Freijedo, F., & Freijedo, F. (2016). Current control loop design and analysis based on resonant regulators for microgrid applications. Conference of the IEEE, Industrial Electronics Society, IECON 2015, IEEE (pp. 005322–005327).

Choudhury, T. R., & Nayak, B. (2016). Comparative steady state analysis of Boost and cascaded Boost converter with inductive ESR losses & capacitor current behaviour. International Journal of Power Electronics & Drive Systems, 7(1), 159–172.

Das, A., & Sheeja, G. (2017). Photovoltaic H6-type transformerless inverter topology. Conference of the IEEE, India Conference. IEC CCT 2017, IEEE (pp. 1–6).

Haryanti, M., Halim, A., & Yusuf, A. (2014). Development of two axis solar tracking using five photodiodes. EECCIS (pp. 40–44). Indonesia: IEEE.

Hu, Z. H., & Tan, X. Y. (2008). Research on a new hybrid multilevel inverter. Power Supply Technologies and Applications, 11(12), 14–19.

Jing, X., Kaihua, W., & Li, M. (2009). All-weather automatic solar tracking method applied in forest fire prevention. IEEE, 8(1), 805–809.

Kannan, N., & Vakeesan, D. (2016). Solar energy for future world: A review. Renewable & Sustainable Energy Reviews, 62(6), 1092–1105.

Lamm, L. O. (1981). A new analytic expression for the equation of time. Solar Energy, 26(5), 465–465.

Li, L. B. (2016). Photovoltaic grid-connected inverter technology (pp. 127–128). Beijing: Chemical Industry Press.

Racharla, S., & Rajan, K. (2016). Solar tracking system – a review. International Journal of Sustainable Engineering, 10(2), 72–81.

Rizzoli, G., Mengoni, M., Zarri, L., Tani, A., Serra, G., & Casadei, D. (2016). Comparison of single-phase H4, H5, H6 inverters for transformerless photovoltaic applications. Conference of the IEEE, Industrial Electronics Society, IECON, IEEE (pp. 3038–3045).
Shi, D., Sun, L. Q., & Zhang, E. Y. (2013). Design of two-dimensiona
PSD signal processing system based on TMS320 F2812. Instrument Te
chique & Sensor, 7(4), 35–34.
Sonkar, N., Edla, P. J., & Gupta, B. (2013). Hybrid automatic solar
tracking system for different types of solar cells: A review. Inte
rnational Journal of Engineering Sciences & Research Tech
ology, 2(10), 2690–2693.
Wang, X. (2017). Research on a kind of single-phase PV grid-
connected inverter based on H6 bridge. Shanxi: Shanxi Univer-
sity of Science and Technology.
Wang, B. Z., & Liu, G. S. (1991). Recalculation of astronomical
parameters are commonly used in insolation observation. Acta En-
ergiae Solaris Sinica, 12(1), 27–32.
Wu, J. M., Ji, P., & Hu, X. S. (2016). Two-stage single-phase PV
grid-connected system and its simulation research. Journal of An-
ing Teachers College(Natural Science Edition, 22(3), 57–60.
Xiong, W. (2009). Design and research of 300W low-power PV grid-
connected power generation system. Tianjing: TJU.
Yang, H., & Wu, J. M. (2018). A research on the simulation of
single-phase photovoltaic grid connection system based on
MATLAB. Journal of Changzhou Institute of Technology, 31(2),
27–30.
Yuan, F. (2016). Control of photovoltaic power generation
capacity by solar tracking system based on a photoelectric
sensor. Sensor Letters, 14(12), 1198–1202.
Zhang, X., Sun, L. L., Xu, P., Zhao, W., & Cao, R. X. (2009). Research
on common mode current suppression in single-phase non-
isolated photovoltaic grid-connected system. Acta Energiae
Solaris Sinica, 30(9), 1202–1208.
Zheng, T., & Zhang, B. C. (2012). High precision solar track-
ing with imaging on CCD. Industrial Control Computer, 25(2),
38–39.
Zhou, N. (2017). Research and design of H6 topology single-phase
photovoltaic grid-connected inverter. Zhejiang: Zhejiang Uni-
versity.
Zhu, J. (2016). An improved method for maximum power point
tracking of PV cells based on constant voltage method. Power
Electronics, 2(18), 248–249.