Research and design of photovoltaic power monitoring system based on Zig Bee

Lijuan Zhu¹,³, Zhonghua Yun²,³, Bianbawangdui²,³*, Bianbaciren²,³

¹Tibetan Information Technology Engineering Research Center, Tibet University, Lhasa 850000, China
²School of Engineering, Tibetan University, Lhasa 850000, China
³Information Technology Experimental Teaching Demonstration Centre, Tibet University, Lhasa 850000, China

*Corresponding author e-mail microzhulijuan@163.com

Abstract. In order to monitor and study the impact of environmental parameters on photovoltaic cells, a photovoltaic cell monitoring system based on ZigBee is designed. The system uses ZigBee wireless communication technology to achieve real-time acquisition of P-I-V curves and environmental parameters of terminal nodes, and transfer the data to the coordinator, the coordinator communicates with the STM32 through the serial port. In addition, STM32 uses the serial port to transfer data to the host computer written by LabVIEW, and the collected data is displayed in real time, as well as stored in the background database. The experimental results show that the system has a stable performance, accurate measurement, high sensitivity, high reliability, can better realize real-time collection of photovoltaic cell characteristics and environmental parameters.

1. Introduction
In recent years, energy shortages and environmental pollution problems have become the world's increasingly prominent contradictions, forcing people to understand the development of new energy [1]. The solar energy is an important part of the renewable energy, it is increasingly attracting domestic and attention for its safety, clean, low failure rate, low pollution rate and other advantages. The performance of many photovoltaic (PV) products is very different, but the main factors affecting the output power of PV cells are temperature and irradiance [2]. In order to make more efficient use of solar energy and monitor the working state of PV cells in time, it is of great significance to introduce wireless remote monitoring into the power generation monitoring system [3].

This paper focuses on the characteristics of PV cells. Firstly, In order to get I-V curves of PV cells, the I-V circuit is designed, the temperature, humidity, light intensity and other sensors are used as the terminal nodes to acquire the environmental data in real time. The I-V circuit mainly detect different working points of the PV cells to monitor P-I-V parameters. Secondly, the data is sent to coordinator through ZigBee network, the coordinator communicate with STM32 through serial port. Finally, through the communication between GPRS technology and remote monitoring center, the data can be monitored in time to ensure security. In addition, the STM32 processor use serial port to transmit data to PC programmed by LabVIEW, and in the PC real-time display, if the data is greater than or less than the
threshold, then the alarm device starts and the collected data is stored in the Database. The experiment proves that the system has stable performance, accurate measurement, high data reliability, high sensitivity, overcoming the inconvenience of cable transmission, and better real-time acquisition of P-I-V curves and environmental parameters of PV cells.

2. Mathematical model and Simulation of PV module structure

The PV effect is the conversion of light into electrical, it is equivalent to a current source and a diode in parallel [4], the circuit is shown in Fig.1. The model of a PV cell is governed by Eq. (1) and Eq. (2).

\[ I = I_{ph} - I_d - I_s \]  
\[ I = I_{ph} - I_d \left( \exp\left(\frac{q(U + IR_s)}{NkT}\right) - 1 \right) - \frac{U + IR_s}{R_s} \]  

Where \( I_{ph} \) is the photocurrent, \( I_d \) is the dark saturation current, \( R_s \) is the series resistance, \( R_{sh} \) is the shunt resistance, \( N \) is the ideality factor of the diode, \( T \) is the temperature of the cell, \( q \) is the magnitude of the electron charge, \( k \) is the Boltzmann constant, \( U \) is the output voltage, \( I \) is the current [5]. The short-circuit current and open-circuit voltage of PV cells are obtained by using approximate method. Approximate condition: \( R_{sh} \) tends to infinity, while \( (U + IR_s)/R_s \) is negligible, PV model can be recorded as Eq. (3).

\[ I = I_{ph} - I_d \left( \exp\left(\frac{q(U + IR_s)}{NkT}\right) - 1 \right) \]  

The PV cell is under uniform irradiance, 1000W/m², 950W/m² and 900W/m², The operating voltage is 17.6V, open circuit voltage is 21.6V, output current is 1.70A, short-circuit current is 1.95A. The simulation shows that the P-I-V curves of the PV cell, as is shown in Fig.2.

Fig.1 Equivalent circuit model of a PV cell.

Fig.2 The P-I-V curves for different irradiances.
In Fig. 2, the PV characteristic is nonlinear in response to change in irradiance. Fig. 2 (a) show I-V curves of a PV cell for various values of illumination: as the illumination increases, the open-circuit voltage and short-circuit current of the PV cell both increase, when 0<U<U_m, the current is almost constant, but the voltage varies significantly, when U_m<U<U_{oc}, the current of the PV cell drop sharply, while the voltage change slowly. Fig. 2 (b) shows P-V curves of a PV cell for various values of illumination: note that there is a maximum power point P_m.

3. The overall design of the PV monitoring system

The monitor system is composed of host computer and lower computer. The lower computer consists of ZigBee wireless network, I-V circuit, temperature and humidity sensor, light intensity sensor and so on. The host computer analyzes and stores data into the database. The system structure diagram is shown in Fig. 3.

![Fig.3 System block diagram.](image_url)

In Fig.3, the ZigBee network is composed of a coordinator and lots of terminal nodes. Firstly, each terminal node joins the ZigBee network, and transfers the data such as volt ampere, temperature, humidity and luminance to the coordinator, and then the coordinator is sent to the STM32 processor via serial port, at the same time, through the communication between GPRS technology and remote monitoring center, so that the collection of information to be timely monitoring. In addition, the STM32 processor uses serial port to transfer data to the PC which is written by LabVIEW.

4. Hardware Design of PV Monitoring System

The light intensity sensor adopts BH1750, which is much cheaper than radiometer. In document [6], the light intensity can be approximately obtained by the method of the conversion between the light intensity and radiation intensity. The temperature and humidity sensor adopt DS18B20 and DHT11. The acquisition of P-I-V curves are accomplished by designing circuits.

4.1. Collect V-I data and their circuits

The voltage signal acquisition circuit is shown in Fig. 4. The current signal acquisition circuit is shown in Fig. 5.

![Fig.4 Voltage signal acquisition circuit.](image_url)
The output voltage \((U_m)\) of the PV cell can be obtained by Eq. (4). \(U_{adc}\) is the collection of data, In this paper, the solar panel open-circuit voltage is 21.6V, The output voltage \((U_{out})\) of LM358 is range from 0V to 1.5V, In Fig. 4, the follower \(U_\text{s} = U_{out}\), then the \(U_s\) voltage range is also range from 0V to 1.5V, while the ADC of ZigBee output voltage is range from 0 to 2.97V, so \(R1 = 62k\Omega\), \(R2 = 4.7\) k\(\Omega\).

\[
U_\text{s} = \frac{U_{adc}(R_1 + R_2)}{R_2}
\]  

(4)

The current signal acquisition uses a Hall current sensor of HCS-LSP-20A [7]. According to the basic parameters of Hall sensor, the output voltage of the sensor is obtained by using Eq. (5), where IP ranges from 0 to 2A, IPN is the rated current, and it is 20A, \(U_0\) is the output voltage of the Hall current sensor, so the range of \(U_0\) is between 2.5V to 2.7V.

Eq. (6) is obtained by Fig.5, and the ADC of ZigBee output voltage range is between 0 to 2.97V. So \(R5 = 32k\Omega\), \(R6 = 470k\Omega\), \(R7 = 39k\Omega\). According to the \(U_0-IPN\) linear relation graph in the manual of HCS-LSP-20A Hall current sensor, Eq.(7) can be obtained by open-circuit voltage and short-circuit current of the PV cell, and then the current value \(I_m\) is calculated.

\[
U_0 = 2.5 \pm \frac{IP}{IPN} \times 2
\]  

(5)

\[
U_{\text{adc}} = \frac{R_6 V_0}{R_5} - \frac{R_7}{R_5} \times (-3.3)
\]  

(6)

\[
I_m = \frac{(2.162 U_{\text{adc}} - 5.411706)}{0.22}
\]  

(7)

4.2. Collecting environment parameter and circuit and ZigBee wireless network

The circuit schematic diagram of BH1750 [8] is shown in Fig.6. SCL and SDA are connected to CC2530 of P0.4 and P0.5. Use DS18B20 [8] and DHT11 [8] to detect temperature and humidity, DS18B20 circuit schematic diagram is shown in Fig.7, DQ pin connected CC2530 P0.6. The circuit schematic diagram of DHT11 and DS18B20 is similar. DHT11’s DQ pin connected CC2530 P0.7. ZigBee technology has the characteristics of short distance, low cost, flexible throughput and easy operation. Its chip CC2530 CPU uses an enhanced 8051 microprocessor [9]. The circuit schematic diagram is shown in Fig.8.
Fig. 6 BH1750 circuit schematic.

Fig. 7 DHT11 and DS18B20 circuit schematic.

Fig. 8 CC2530 circuit schematic.
5. Software design of PV monitoring system

The software includes two parts: host computer and lower computer. The lower computer software is written in C language. Firstly, the P-I-V parameters and environment parameters of the PV cell are collected from each terminal node, and the data is transmitted to coordinator through ZigBee wireless network. Secondly, in STM32, we design the GPRS, the serial communication program and so on. In addition, the STM32 processor uses serial port to transmit data to PC written by LabVIEW, then the data is analyzed, processed and displayed in real time by the host computer, and the collected data is stored in the database.

5.1. Lower computer software design

DS18B20 and DHT11 adopt the "1-wire bus" interface communication system, and it is necessary to use IO port to simulate the related timing. BH1750 is a digital sensor for a two wire serial bus interface, using the FC interface. The P-I-V curves of the PV cell are obtained by controlling the signal acquisition circuit. The coordinator transfers the information collected by each terminal node to the STM32 processor through the serial port and displays it on the TFT liquid crystal display. The main program flow chart is shown in Fig.9.

The ZigBee communication network consists of a coordinator and multiple terminal nodes, each terminal node is responsible for collecting the voltage, current, power, temperature, humidity and illumination of the PV cell, the data is transmitted to the coordinator via the ZigBee wireless network. Because ZigBee wireless network has the characteristics of ad hoc networks, it can increase the network nodes according to the demand. The flowchart of each terminal node and coordinator is shown in Fig.10.

---

**Fig.9** Flowchart of lower machine software.
In Fig.9, after the system is powered on, the main program will complete a series of initialization work, loading serial port, GPRS driver and so on. Followed by the terminal node and coordinator network is completed, the collected data of each terminal node is transmitted to STM32 through coordinator. Finally, when STM32 receives the data, it will send it to the PC through the serial port, and communicate with the remote monitoring center through the GPRS communication technology.

The I-V signal acquisition program mainly collect analog signals, and convert it into digital signals. Each sampling of the program starts at the open point of the PV cell, and a set of data is collected at intervals of 0.1s. After entering the acquisition state, the $U_{adc}$ & $U_{lade}$ are converted to digital signals, the output voltage and current of the PV cell are obtained by using Eq.(4) and Eq.(7), and the output power of the PV cell is obtained by using the formula $P=UI$. Then the P-I-V characteristic curve of the PV cell is fitted by MATLAB, and analyzed.

In Fig.10, after the ZigBee network is initialized. Firstly, each terminal node requests to join the ZigBee network. Secondly, the coordinator finds the network request and carries out networking. After that, each terminal node sends the collected data to the coordinator, and the coordinator sends it to STM32 through the serial port.

5.2. PC software design

The host computer of the system uses the virtual instrument software LabVIEW of NI as the development platform, it consists of two parts, the front panel and the program block diagram, has great advantages in data acquisition and human-computer interaction[10]. The software flow of the host computer is shown in Fig.11.

![Flowchart of host computer software](Image)

In Fig.11, first of all, set the baud rate, serial number, data selection etc. Secondly, to identify the data of each terminal node sent by the lower computer, an identifier ‘F’ is designed, in the data processing part, when the identifier ‘F’ is read and recognized, the data is received, displayed and processed in real time, and stored in the database. Finally, using waveform icon control, the data collected by each terminal is bundled, so that each data is displayed in graphic form. When the received P-I-V parameters are greater than or less than a certain value, the alarm control is started.
6. Experiment and analysis of monitoring system

6.1. Lower computer test
The physical testing process of the lower computer is shown in Fig. 12, after the STM32 is powered on, the data collected by each terminal node is displayed on the TFT-LCD, and the STM32 refreshes the data every 1s, it can clearly understand the current PV cell voltage, current, power, and the surrounding environment information. If the voltage, current and power value exceeds the predetermined value, it will cause the buzzer to alarm. At the same time, it will communicate with the remote monitoring center through the GPRS technology, so that the collection information can be monitored in a timely manner.

6.2. Host computer test
The front panel interface of the host computer is shown in Fig. 13, where the system displays the voltage, current, power and the surrounding environment in real time in the form of curves and numbers, and also designs the alarm system and the function of storing data. The first curve represents temperature; the second curve represents humidity; the third curve represents light intensity; The fourth curve represents the voltage, when the voltage value is less than 2V, low voltage alarm starts, when the voltage value is greater than 21V, high voltage alarm starts; The fifth curve represents the current, when the current value is less than 0.3A, low current alarm starts, when the current value is greater than 1.7A, high current alarm starts; The sixth curve represents power, when power is less than 2W, low power alarm starts. As it can be seen from the diagram, if a certain time to change the PV cell and the sensor surrounding environment, the system can sensitively reflect the changes of voltage, current and environmental parameters. The block diagram of the program function module is shown in Fig. 14.

Fig. 12 Experimental process diagram.

Fig. 13 Front panel interface.
6.3. Summary of the Experimental study
The experiment was carried out at the experimental building of Tibet University in June 25, 2017. And compare the partial data obtained by this system with the data measured by the corresponding instrument, the result is shown in Tab.1. Due to the limited space, some data are given in Table 1.

![Program block diagram](image)

**Fig.14** Program block diagram.

![PV output characteristic curve](image)

**Fig.15** PV output characteristic curve.
7. Conclusion
In this paper, a monitoring system based on ZigBee technology is designed for PV power generation system. Firstly, the I-V signal acquisition circuit is designed, and the environmental parameters are monitored. Secondly, the collected data is sent to coordinator through ZigBee wireless network, coordinator and STM32 communicate with each other through serial port. In addition, the use of serial port realizes the communication between GPRS technology and remote monitoring center, so that the collection information can be monitored in a timely manner, and the safety and reliability of the operation of the PV cell can be improved. Finally, the main controller uses serial port to transfer data to the PC which is programmed by LabVIEW, which is processed in the host computer, displayed in real time and stored in the back-end database.

The I-V signal acquisition is mainly to detect the different working points of PV cells, in order to draw the P-I-V characteristic curves, the environment detection is mainly to detect the temperature, humidity and light intensity of the surrounding environment of PV cells. The experiment proves that the system has stable performance, accurate measurement, high data reliability, and overcome the inconvenience caused by the wired transmission, and can get a better PV system parameters and output characteristic curve, has greater experimental value.

Acknowledgments
This work was supported by the innovative training program for college students of Tibet University (201710694015); the Science Foundation of Tibet Autonomous Region(2016ZR-15-8); the innovation Support Program for Young Teachers of Universities in Tibet Autonomous Region(QCZ2016-26); the Youth Scientific Research Foundation of Tibet University(ZDPJZK1508); the plateau communication research innovation team of Tibet University.
Corresponding author: Bianbawangdui
References
[1] Yunyan Hu, Ruiying Zhang, Jun Wang. Development status and Prospect of solar photovoltaic power generation in China[J]. Journal of Hebei University of Science and Technology, 2014,(01):69-72.
[2] Qinglong Zhao, Minghua Zeng, Yuanliang Wang. Analysis of photovoltaic cells model and key factors research [J]. Chinese Journal of Power Sources, 2016,(10):1969-1972.
[3] Tao Hu, Jianjun Tan, Yong Huang, Xianbo Sun, Jinqiao Yi. Research on Applying Multi-Sensor Data Fusion in Photovoltaic Array Monitoring System[J]. Computer Engineering & Science, 2012,(10):166-171.
[4] Tian Xu, Xiaqiang Chen. Research and Simulation of Parallel Branch Photovoltaic Power Generation System[J]. Journal of Zhengzhou University (Engineering Science), 2016,(02):25-28.
[5] Fei Feng, Fangsheng Wu, Jianfu Chen, Weishan Wang. Measurement System of Photovoltaic volt-ampere characteristic [J]. Computer Measurement & Control, 2016,(10):39-41.
[6] Xianjie Song, Rongsheng Hu. Conversion of light intensity and irradiance[J]. LAMPS AND LIGHTING , 1997,(01):20-21.
[7] Fuan Li. Design and Experiment of Closed Loop Hall Effect Current sensor[D]. Wuhan: Huazhong University of Science and Technology, 2013.
[8] Zhao Zhang. The design of intelligent Home control system based on STM32[D]. Nanchang: Nanchang Hangkong University, 2014.
[9] Sung W T, Hsu Y C. Designing an industrial real-time measurement and monitoring system based on embedded system and ZigBee[J]. Expert Systems with Applications, 2011, 38(4):4522-4529.
[10] Xianjun Wang. Serial port sampling data processing using LabVIEW[J]. Electronic Measurement Technology, 2014, 37(3):107-111.