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Research Article

Performance Monitoring and Analysis of the Photovoltaic Power Generation System Based on the PCI Data Acquisition Card

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Abstract: In order to analyze the performance monitoring of the photovoltaic power generation system and achieve the optimal control between the energy storage and consumption, the paper has built a multifunctional performance monitoring system based on the virtual instrument technology. The voltage, current, power, environmental temperature and light intensity are collected via the 1716L-PCI data acquisition card and displayed in real time. After the analysis of the collected data, the system explores the performance of the photovoltaic power generation system. Meanwhile, in order to improve energy use efficiency, the system has set different control modes, including automatic mode, manual mode and custom mode, to discuss the optimal control between the load and the storage energy. The experiment results show that the system has flexible control ability, feasible analysis results and pratical value.

Keywords: Energy use efficiency, optimal control, PCI data acquisition card, performance analysis

INTRODUCTION

In recent years, the photovoltaic technology and industry have been developing rapidly due to the adequate funds and support policies provided by the Government (Feng, 2009). The solar panel is the main component of the photovoltaic power generation system and its performance directly affects the quality of the overall system, but its peformance monitoring technology has been lagged far behind (Haifeng *et al*., 2012).

Haifeng *et al*. (2012) used the singlechip to collect data and transmitted them to the host computer. The host computer was written in Visual Basic and achieved the data storage and management. Tao (2008) simulated solar light by using short arc xenon lamp and used LABVIEW to achieve data acquisition and analysis. He also used MATLAB to transform test results from the non-test condition to the standard condition. Zhilong (2008) built the solar panel performance monitoring platform by using 6221-PCI data acquisition cards (DAQ) and other devices. He achieved collection, storage and analysis of the solar panel voltage and current values. However, functions of host computers above aren't comprehensive, because most were limited to the acquisition of the soalr panel's voltage, current and power and neglected to analyze the whole photovoltaic power generation system. On the other hand, the monitoring system above didn't optimize the use of stored energy, which is hard to improve the system's efficiency of power energy.

Compared to various collection devices and host computers and based on virtual instrument, the PCI data acquisition card and LabWindows/CVI; software platform are connected to collect and manage various parameters of the photovoltaic power generation system in the study. The host computer analyzes the system performance based on the collected data. Finally, the system creatively achieves optimal control by setting different control modes, which provides an effective way to improve the energy utilization efficiency and achieves energy saving.

COMBINATION OF PCI DAQ AND LABWINDOWS/CVI BASED ON VIRTUAL INSTRUMENT

VI, short for Virtual Instrument, uses powerful computer resources to make hardware technology software and discrete components modular, which reduces the complexity of the program development and increases functionality and flexibility of the system. VI has automated detection and control functions, which can complete heavy and high-precision detection tasks. At the same time, it can analyze, count, judge and process large amount of data, which is of great significance for the performance monitoring of the photovoltaic power generation system. It can not only greatly reduce the detection time and improve test efficiency, but also undertake agilely control and improve the system's automation (Zhilong, 2008).

LabWindows/CVI, based on VI, is an ANSI C development environment. It combines C Language's strong and flexibility with software tool magazine of VI, including a variety of buses, data acquisition and analysis library. A monitoring system established by it,

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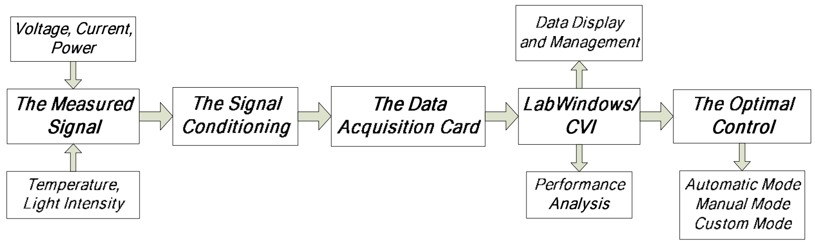


Fig. 1: The workflow of the monitoring system

can make application program operate independently outside the development environment and built convenient user interaction system interface (Jianxin *et al*., 2006).

To achieve various parameters collection and optimal control output, the 1716L-PCI DAQ, with a powerful PCI bus-mastering, is selected for the monitoring system. It features a unique circuit design and complete functions for data acquisition and control, including 16-channel analog input, 16-channel digital input and 16-channel digital output, which meets the monitoring system requirement. What's more, the card with 16-bit A/D conversion and 250 kHz sampling rate, will improve the accuracy and instantaneity of the system. Therefore, 1716L-PCI DAQ is selected to establish PC-DAQ data acquisition system. The workflow of the monitoring system is shown in Fig. 1.

DATA ACQUISITION MODULE OF THE PHOTOVOLTAIC POWER GENERATION SYSTEM

The photovoltaic power generation system, using the photovoltaic effect, directly converts the solar radiation into the electric energy, including the solar panel, storage battery, solar controller, inverter, DC loads and AC loads (Qihui, 2008), shown in Fig. 2.

In order to study the performance of the photovoltaic power generation system and its best working environment, this module collects the entire system's voltage and current values, including the current flowing into the solar controller from the solar panel and its voltage, the current flowing from the solar controller to the storage battery and its voltage, the current flowing through loads and their voltages.

Usually test voltages are greater than 10V, while 1716L-PCI DAQ allows the maximum voltage range is ±10V, so voltages should go through conditioning before collected. The study will describe collection

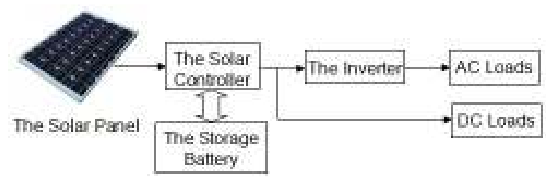


Fig. 2: The structure of the photovoltaic power generation system

methods according to the experimental devices, whose main parameters are listed in Table 1.

The method of collecting the solar panel's voltage and current: The voltage generated by the solar panel is about 17.6V, so two parallel resistances R_1 and R_2 are used to gather the voltage and one series resistance R_3 is used to gather the current, shown in Fig. 3. Then use the analog input of PCI DAQ to collect voitage values U_1 and U_2 of the resistors R_1 and R_2, so the voitage U_{panel} and current I_{panel} is:

$$U_{panel} = \frac{R_1 + R_2}{R_2} \cdot U_1 \tag{1}$$

$$I_{panel} = U_2 / R_3 \tag{2}$$

In order to reduce the measuring error and power loss caused by resistances, the value of $R_1 + R_2$ should be as large as possible and R_3 must be as small as possible. But meanwhile, the value of R_1/R_2 should be as large as possible to ensure the accuracy of the collected voltage. So, these two facts taken together, R_1 = 20 kΩ, R_2 = 1 kΩ, R_3 = 0.2 kΩ

The method of collecting the storage battery's voltage and current: Similar to the measurement of the solar panel's voltage and current, the way to measure the battery voltage and current values is shown in Fig. 3, so its voltage $U_{battery}$ and current $I_{battery}$ is:

Table 1: The parameters of the devices

The solar panel		The solar controller		The storage battery		DC Load (LED lights)	
Power	30W	Rated Charging Current	10A	Rated Voltage	12V	Rated Voltage	AC 100-250V
Operating Voltage	17.6V	Rated Load Current	10A	Rated Current	7.2AH	Rated Power	3W

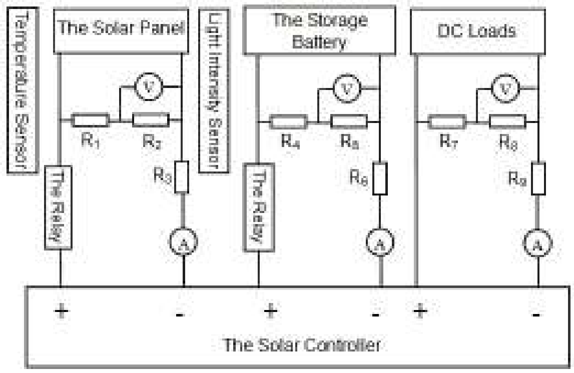


Fig. 3: The data acquisition system

$$U_{battery} = \frac{R_4 + R_5}{R_5} \cdot U_3 \quad (3)$$

$$I_{battery} = U_4 / R_6 \quad (4)$$

where, R_4 = 20kΩ, R_5 = 1kΩ, R_6 = 0.02 kΩ

The method of collecting DC loads' voltage and current: The measurement circuit of DC loads' voltage and current values is shown in Fig. 3, so its voitage U_{load} and current I_{load} is:

$$U_{load} = \frac{R_7 + R_8}{R_8} \cdot U_5 \quad (5)$$

$$I_{load} = U_6 / R_9 \quad (6)$$

where, R_7 = 0.5kΩ, R_8 = 0.01 kΩ, R_9 = 0.01 kΩ.

The collection method above is simple, practical and economic, but the choice of resistances requires experience and need to carry out several experiments. Besides, relays in the collection system shown in Fig. 3, is aimed to achieve synchronous acquisition with the host computer. That is to say, when the host computer begins collecting data, relays start, the acquisition system feeds through and the data begin uploading to the host computer.

The method of collecting temperature and light intensity: The environmental temperature and light intensity are the main factors to affect the power of the solar panel, so the LM35 temperature sentor and BH1750 light intensity sentor are used to complete real-time acquisition of these parameters, which helps to further study the relationship between the performance of the photovoltaic power generation system and the environment.

LM35 temperature sentor has a measuring range of 0~100°C, high precision, reaching ±0.5°C and linear variable coefficients, that is, when the temperature increases 1°C, the output voltage rises 10 mV. The output power +5V of the PCI DAQ is used to supply energy for the sentor and one analog input port is used to collect the sentor output signal. If the output voltage value is U_7, the environmental temperature T is:

$$T = U_7 / 0.01 \quad (7)$$

BH1750 light intensity sentor, commonly used at present, has a digital output port and a standard I^2C bus interface. It covers a wide illumination range of 0~65535Lx and build in 16bit AD conversion.

However, there is only one serial data line for data read and write in I^2C bus interface, while the digital signal read and output of 1716L-PCI DAQ is separate, that is to say, there are some ports for data read and other ports for data output. Therefore, the DAQ input port cannot directly connect the light intensity sentor output. We have carried out some experiments to collect the data by DAQ, but all didn't receive good results. Thus, the light intensity sensor is connected with the singlechip to collect data.

THE HOST COMPUTER SYSTEM WITH MULTIFUNCTION

After collecting variable data via the 1716L-PCI DAQ, we set the configuration of the card itself to transfer the data to the LabWindows/CVI, such as DRV_DeviceOpen function (used to open the device), DRV_MAIConfig function (used to specify the input voltage range), DRV_MAIVoltageIn function (used to obtain voltage values) and DRV_DeviceClose function (used to close the equipment). Then functions of LabWindows/CVI software receive, display and store the data. For example, the OpenCom function is used to open PC ports and the ComRdByte function is used to receive data.

The module of real-time data acquisition: The real-time acquisition module is one of the main functions of the monitoring system. One of the interfaces is shown in Fig. 4. In interfaces, some information, including channels and sampling frequency, should be set to configure the DAQ. After that, the interfaces will collect data and display voltage, current and power curves of the solar panel, battery and load. Meanwhile, specific numerical values of various voltage, current, power, temperature and light intensity can be obtained and shown.

Database and historical data query module: In order to facilitate user to analyze the performance of the photovoltaic power generation system, the database is built to store the data, including the acquisition date, time, power, current and voltage, sampling frequency, temperature and light intensity. When users want to query and analyze, they can push the "History" button to visit the history query interface and database.

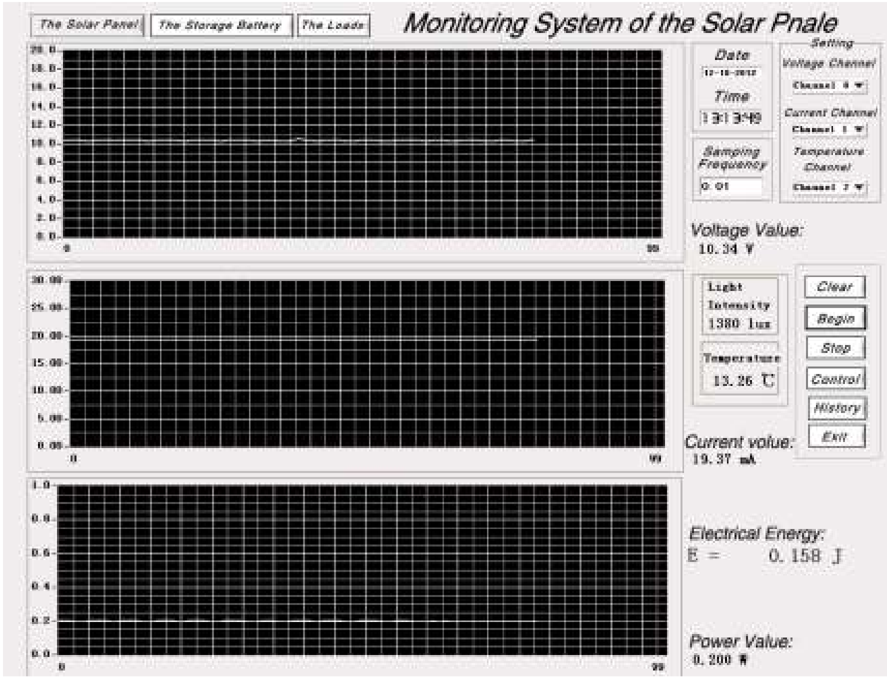
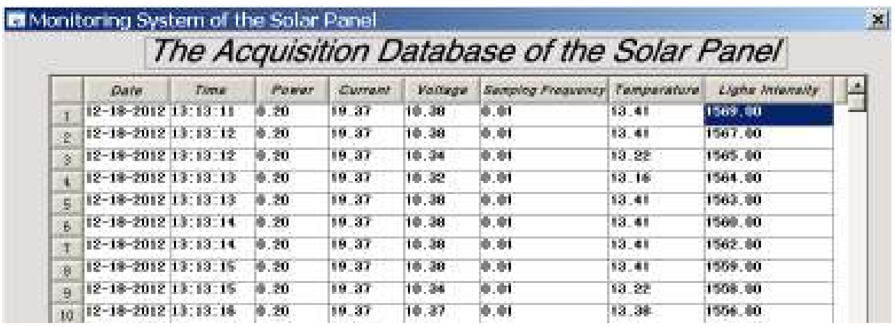


Fig. 4: The real-time data display system



Monitoring System of the Solar Panel

The Acquisition Database of the Solar Panel

	Date	Time	Power	Current	Voltage	Sampling Frequency	Temperature	Lighs Intensity
1	12-18-2012	13:13:11	0.20	19.37	10.38	0.01	13.41	1569.00
2	12-18-2012	13:13:12	0.20	19.37	10.38	0.01	13.41	1567.00
3	12-18-2012	13:13:12	0.20	19.37	10.34	0.01	13.22	1565.00
4	12-18-2012	13:13:13	0.20	19.37	10.32	0.01	13.16	1564.00
5	12-18-2012	13:13:13	0.20	19.37	10.38	0.01	13.41	1563.00
6	12-18-2012	13:13:14	0.20	19.37	10.38	0.01	13.41	1560.00
7	12-18-2012	13:13:14	0.20	19.37	10.38	0.01	13.41	1562.00
8	12-18-2012	13:13:15	0.20	19.37	10.38	0.01	13.41	1559.00
9	12-18-2012	13:13:15	0.20	19.37	10.34	0.01	13.22	1558.00
10	12-18-2012	13:13:16	0.20	19.37	10.37	0.01	13.38	1556.00

Fig. 5: The database

In the "History" interface, users can reproduce the voltage, current and power curves of the query time in the left charts. If users want to get the specific numerical values, they can access to the database, as shown in Fig. 5.

The module of the system performance analysis: In order to help users analyze the performance of the system, a special interface is designed, shown in Fig. 6. After collecting the soalr panel's voltage, current and power with the help of the rheostat ect, users can enter this characteristics analysis interface.

In the interface, by specifying the power of simulation, user can get current-voltage characteristic curve and voltage-power curve and their corresponding fitting curve expressions. Besides, more accurate curves can be obtained through the analysis of the error and change of simulation power.

Meanwhile, some information about the performance is shown in the bottom of the interface, which helps users to further study the photovoltaic power generation system.

- **Open-circuit voltage V_{OC} and short-circuit current** I_{SC}**:** The intersection point of the current–voltage characteristic curve and V-axis is the open-circuit voltage and that of the current–voltage characteristic curve and I-axis is the short-circuit current. By comparing the change of these parameters under the standard light intensity condition, users can tesk whether the performance has got worse.
- **Optimun operating voltage V_m, optimun operating current** I_m **and maximum output power** P_m**:** Calculating points on the curve corresponding to the power values according to the same step length. The maximum value is the maximum output power and the point corresponding to the voltage and current is the optimun operating voltage and the optimum

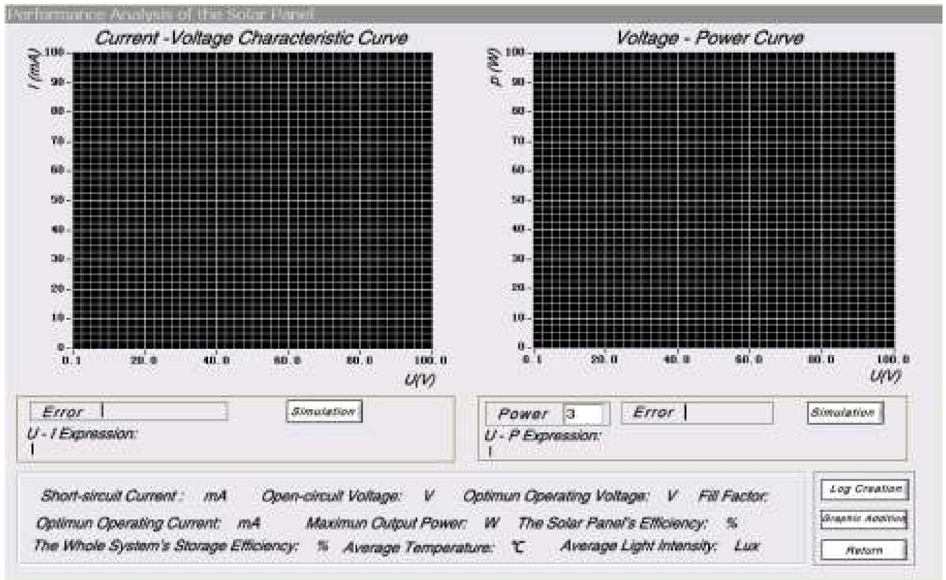


Fig. 6: The performance analysis system

operating current. By taking some measures, like the maximum power tracking technology, to make the soalr panel work on this point, will effectively improve the utilization efficiency of solar energy.

- **Fill factor FF:** The ratio of maximum power and the product of open-circuit voltage and short-circuit current is called fill factor, which directly affects the conversion efficiency of the solar panel and is one of important parameters to characterize the quality of the photovoltaic power generation system:

$$FF = \frac{P_m}{V_{OC} \cdot I_{SC}} = \frac{V_m \cdot I_m}{V_{OC} \cdot I_{SC}} \tag{8}$$

- **Solar panel efficiency η:** When the solar panel is exposed to sun, the ratio of output electric power and incident light power is called the solar panel efficiency or photoelectric conversion efficiency:

$$\eta = \frac{P_m}{A_t \cdot P_{in}} = \frac{V_m \cdot I_m}{A_t \cdot P_{in}} = \frac{FF \cdot V_{OC} \cdot I_{SC}}{A_t \cdot P_{in}} \tag{9}$$

where, A_t is the total area of the solar cell, including graphics area of the gate line. P_{in} is a unit area of the incident light power. When measured, P_{in} takes standard intensity (AM1 solar light and 25°C) $P_{in} = 100$ mW/cm^2.

The greater the solar panel efficiency, the higher photoelectric conversion efficiency of the photovoltaic power generation system and the better the performance of the system.

- **The whole system's storage efficiency δ:** The ratio of the electricity stored by the battery and the electricity converted from the solar panel within a certain period is called system storage efficiency. The greater its value is, the stronger the ability of storing energy, which is the basis of improving utilization efficiency of the solar energy:

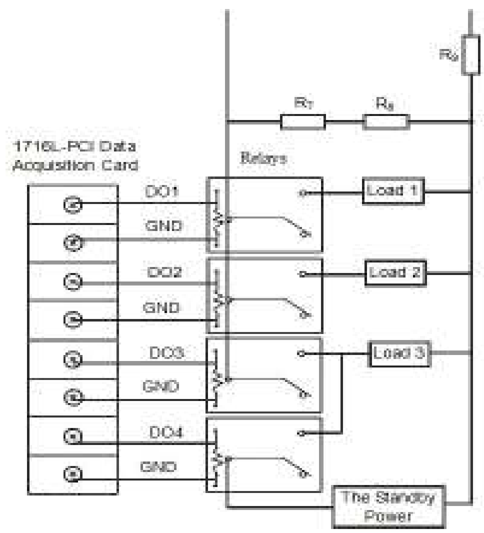


Fig. 7: The optimal control system

$$\delta = E_B / E_S \tag{10}$$

where, E_B is the electrical energy stored in the battery within a certain period and E_S is the electrical energy obtained by the solar panel within the period.

- **Average temperature and light intensity:** The average values of temperature and light intensity collected by the system in the query period, which helps user analyze and study the environment

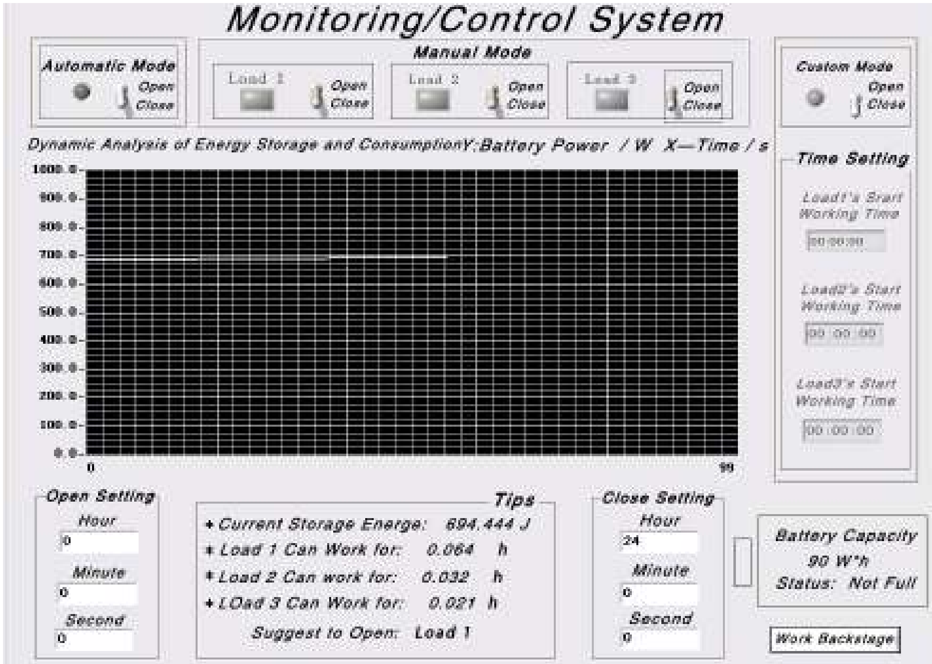


Fig. 8: The interface of the monitoring/control system

factors' effect on the performance of the photovoltaic power generation system.

OPTIMAL CONTROL OF ELECTRIC ENERGY USE

In order to improve utilization efficiency of solar energy, the optimal control system (shown in Fig. 7) has been designed.

On the optimal control system, relays are connected to the digital output channels of the PCI DAQ and high-low level output voltage are controlled by the host computer to achieve relays on and off. The system has designed three optimal control modes, including automatic mode, manual mode and custom mode, shown in Fig. 8.

Automatic mode, the default control mode of the system, is set mainly based on load priority (When the load has a higher priority, this load is more important for user. For example, the priority of the electric lamp is higher than washing machine in the evening under normal circumstances.) and necessary use time etc. When the stored energy inadequate, the system will not make loads with lower priority work until it has met the working time of loads with higher priority. This mode not only achieves the optimal allocation of energy, but also best meets users' demand on loads work.

Users can also select the manual mode. In order to facilitate users to set this mode, the system shows the total energy stored until now. Users can set this mode accordig to the system and actual situation. This mode allows users determine the utilization of the stored energy, which reflects the humane management of the monitoring system and effectively improves the solar energy's utilization efficiency.

As for custom mode, it is the most flexiable control mode of the system. Users can set different start time for various loads according to their need.When the end time arrives, the system will close loads automatically, which achieves the purpose of maximum energy conservation and efficient use of the stored solar energy.

In the optimal control system, a backup power supply circuit is also designed. When the storage electrical energy is unable to meet the control mode set by users, the system will automatically employ the standby power and convert into the automatic mode, which guarantee the stability of the entire control system.

Acording to the power supply of the solar panel, several 3W LED lights are chosen to experiment. In the experiment, LED lights are set to work for eight hours every day. Therefore, when the stored energy is less than 172800J, only one LED light is opened by the automatic mode; when the stored energy is larger than 172800J but less than 259200J, two LED lights are opened automaticly; when the stored energy is larger than 259200J, three LED lights are opened automaticly at the same time.

CONCLUSION

Applying 1716L-PCI data acquisition card and LabWindows/CVI software, a multifunctional monitoring system of the photovoltaic power generation system is built and achieves optimal control of storage energy. First, the monitoring system collects real-time data of the solar panel, battery, loads and environment and sends them to the host computer through the PCI DAQ. Next, the data is displayed and managed by the host computer. Then, the system further analyzes the collection and storage data to get a series of performance indicators, which provides the basis for analyzing the photovoltaic power generation system. Finally, in order to guarantee the utilization efficiency of the solar energy and better meet the users' requirement of loads work time, three optimal control modes, including automatic mode, manual mode and custom mode, are designed to manage the output of power. The study shows that, the monitoring system has flexible control ability, reliable analytical results and high practical value.

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