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Design and Research of Photovoltaic Grid-connected Demonstration Power Station System

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Abstract: The use of urban public facilities roof space for the construction of photovoltaic power stations, especially in the construction of school buildings, can facilitate scientific research and carry out science popularization. This paper introduces the system constitution and engineering design of the school's rooftop photovoltaic grid-connected demonstration power station, and analyzes and discusses typical operational data. In order to further understand and study the characteristics of different components, the system uses three types of components: monocrystalline silicon, polysilicon, and thin-film materials. There are six different materials and packaging processes. Correspondingly, six kinds of grid-connected inverters with maximum power tracking control were used respectively. The self-developed photovoltaic system data monitoring system can analyze the actual operation data. The demonstration project has a good operation effect and has exemplary significance and promotion value.
Keywords: on-grid, photovoltaic, equipment communication, monitoring system.

1. INTRODUCTION

In the many research directions on photovoltaic power generation systems, grid-connected photovoltaic power generation technology with photovoltaic batterys and buildings has been developed in the past ten years, which is an important direction to promote and apply solar power in cities. Buildings can provide enough area for photovoltaic systems without additional land; scattered power generation and local use, they avoid transmission and distribution losses, reduce transmission and distribution investment and maintenance costs; grid-connected photovoltaic generation systems and the power grids complement each other to provide power to the local load, which greatly improves the reliability of the power supply. The demonstration power station introduced in this paper is the national "solar photoelectric building demonstration project", its power is 100kWp, which is one of the earliest photovoltaic demonstration power stations in Tianjin. In order to get experience and provide relevant data, the project independently developed a photovoltaic system data monitoring system, and analyzed and discussed its typical actual operating data.

2. SUMMARY OF PHOTOVOLTAIC DEMONSTRATION POWER STATION

Tianjin is located between 38°34'-40°15' north latitude and 116°43'-118°04' east longitude, it has a long sunshine time and abundant solar energy resources, the annual sunshine time are more than 2400 hours, and the percentage of sunshine is about 65%; the total annual radiation is higher than 5860MJ/m^2. Longer sunshine percentage and annual radiation provide powerful natural conditions for solar photovoltaic power generation. The 100kWp photovoltaic demonstration power station was built on the roof of the teaching building; there are no obvious tall obstacles around the roof of the building, the light is good. The building area is about 3500m^2, and the available demonstration area of the roof is about 2300$m^{2.}$ The 100kWp photovoltaic demonstration power station system can be divided into 10kWp small-scale micro-grid, 10kWp emergency type, and 80kWp direct grid connection according to the photovoltaic component capacity and grid-connected mode. A total of three types of photovoltaic modules, single crystal silicon, polycrystalline silicon, and amorphous film, are adopted.

3. DEMONSTRATION POWER STATION DESIGN

In order to understand and study the respective characteristics of different components, the demonstration power station adopts three types of components: single crystal silicon, polycrystalline silicon and thin film materials, there are 6 different materials and packaging technology. Due to the non-uniformity of the voltage levels of different photovoltaic components, it is impossible to achieve grid connection with only one inverter. After a great quantity of surveys and considering the need to demonstrate the current advanced power electronics technology, the demonstration power station adopts six grid-connected inverters with maximum power tracking control. They form five different photovoltaic power generation subsystems with different capacity and type of photovoltaic components, respectively. According to the selected component types, power size and adopted system topological structure, the five photovoltaic power generation subsystems are named as: 10kWp single crystal silicon small-scale micro-grid subsystem, 10kWp polycrystalline silicon emergency system, 10kWp thin film direct grid-connected system A, 20kWp single crystal direct grid-connected system B, 50kWp polycrystalline direct grid-connected system C. The system structure of demonstration power station is shown in Fig.1, the first three subsystems are located in the micro-grid lab and the last two are located in the dynamic model lab. In order to analyze the influence of different sunshine radiation, ambient temperature and component temperature on the output power of the components, the demonstration power station is equipped with environmental monitoring systems, which adopts German SMA monitoring equipment, and it can simultaneously monitor solar radiation, component temperature, ambient temperature, wind speed and other parameters.

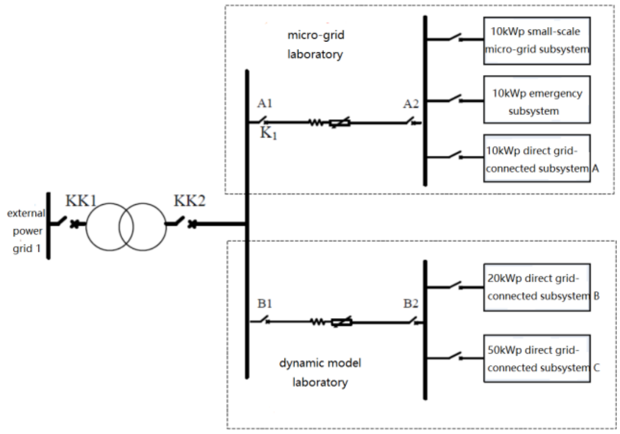


Fig.1 system structure of photovoltaic demonstration power station

The installation type of photovoltaic components and buildings of this demonstration power station is fixed installation. In order to obtain the maximum annual solar radiation amount of the photovoltaic component square matrix, after calculation and reference to related data of NASH website, the RETCrenn4 software is used for calculation, the installation incidence of all photovoltaic component s in the demonstration power station is set to 35 °.

3.1 Small-scale micro-grid subsystem

The small micro-grid subsystem consists of single crystal silicon photovoltaic array and photovoltaic grid-connected inverter, battery and battery bidirectional inverter, power station monitoring interface, etc., and the system AC side is merged into three-phase 380V AC line. The system structure diagram is shown in Fig.2.

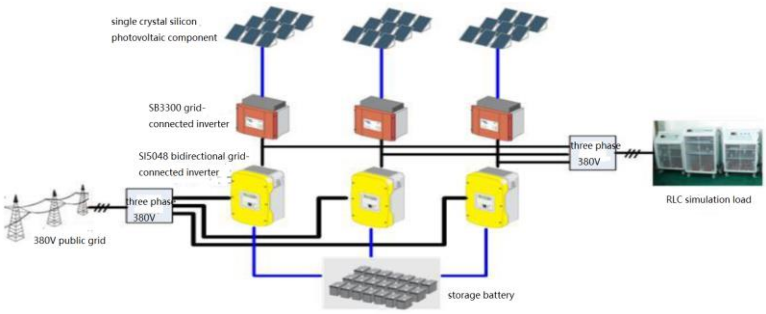


Fig.2 small-scale micro-grid subsystem

This small-scale micro-grid subsystem is a grid-connected power generation system based on photovoltaic power generation units and energy storage power generation, supplemented by external network power supply. It can work in island operation mode or grid-connected operation mode, and can achieve flexible switching between the two modes. The photovoltaic system adjusts its own photovoltaic power output by self-checking the internal AC bus voltage and frequency conditions, and the energy storage inverter can carry out fast conversion of power bidirectional flow. The subsystem uses sixty 180W single crystal silicon photovoltaic components, amounts to 10.8kWp. In inverter configuration aspect, the single-phase inverter is merged into design ideas of the three-phase power grids A, B and C, respectively, the SB3300 branch-type grid-connected inverter of Germany SMA Company is selected. The use of this grid-connected inverter can make our system design more concise, efficient and optimized. The energy storage system uses 24 FLA batteries in series and is connected to the DC side of three energy storage inverters SI5048, The battery battery parameters is 2V/490Ah and the energy storage system capacity is 48V/490Ah.

3.2 Emergency subsystem

The emergency photovoltaic system consists of polycrystalline silicon photovoltaic battery matrix, grid-connected inverter, battery; power station monitoring system, etc., the system AC side is merged into the three-phase 380V AC power grid. When the power grid is in normal operation, the system is merged into the external power grid; photovoltaic can be used to provide energy supply for the battery and the external network, when the external network stop, the uninterrupted power supply to the emergency load can be guaranteed, the system structure is shown in Fig.3.

The subsystem adopts thirty-six 270W polycrystalline photovoltaic components, it amounts to 9.7kWp. In inverter configuration aspects, Beijing Rijia inverter is selected, which can realize fast switching of grid connection to islet to ensure uninterrupted power supply of important loads. The energy storage system uses eighteen 12V/100Ah lead-acid batteries connected in series and connected to the grid-connected inverter (power regulator), the energy storage system capacity is 216V/100Ah.

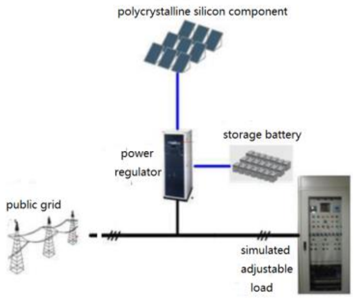


Fig.3 Emergency system

3.3 Direct grid-connected subsystem A

The direct grid-connected system A consists of a thin film photovoltaic battery matrix, a grid-connected inverter, a power station monitoring system, etc., and the AC side is merged into a three-phase 380V AC line. The system structure diagram is shown in Fig.4.

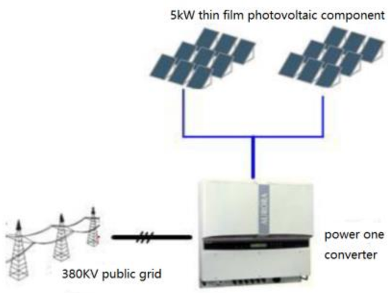


Fig.4 Direct grid-connected subsystem A

The subsystem adopts a grid-connected photovoltaic power supply system structure, which saves the battery pack for power storage. Its working mode is that the electric energy generated by the system during the day is directly input into the power grid and participate in power supply to the load. It has the advantages that sunlight resources are not wasted, station construction costs and maintenance costs are low. The subsystem adopts fifty-five 90W Wuhan Rixin and one hundred and thirty-two 40W Jinneng thin-film battery components, it amounts to 10.23kWp. The use of two-way photovoltaic components makes it easy to compare component performance. In inverter configuration aspects, PowerOne three-phase direct grid-connected inverter is selected; it has two independent DC inputs and is equipped with a protection component against reverse current. When no DC input is detected for a long time, the system automatically enters the stop condition.

3.4 Direct grid-connected subsystem B

The direct grid-connected system B consists of single crystal silicon photovoltaic cell array, grid-connected inverter, power station monitoring system, etc., and the AC side is merged into a three-phase 380V AC line. The system structure diagram is shown in Fig.5.

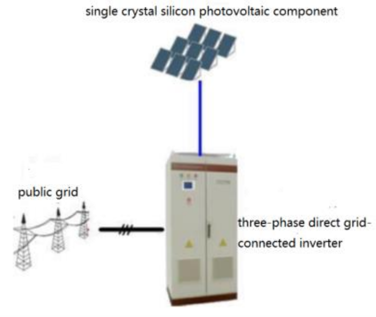


Fig.5 20kWp grid-connected power generation system

The subsystem uses one hundred and five 190W single crystal silicon photovoltaic components, it amounts to 19.95kWp. In inverter configuration aspets, Beijing Rijia three-phase inverter cabinet is selected to show the advanced power electronics technology in China, and the performance is compared with foreign inverters, which played an exemplary role in the promotion of inverters in China, moreover, this subsystem can also be used as an experimental verification platform for the independent research and development of inverters in our school.

3.5 Direct grid-connected subsystem C

The direct grid-connected system C consists of a polycrystalline silicon photovoltaic cell matrix, grid-connected inverter, power station monitoring system, etc., and the AC side is merged into a three-phase 380V AC line. The system structure diagram is shown in Fig.6.

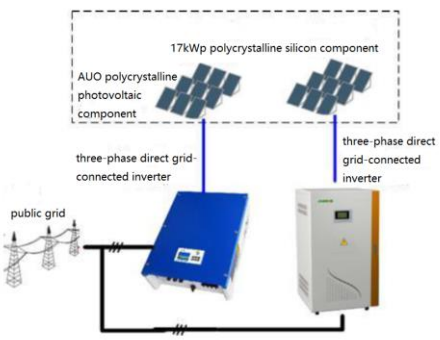


Fig.6 system structure diagram of direct grid-connected C

The subsystem adopts two hundred and ten 235W polycrystalline silicon photovoltaic component, it amounts to 49.5kWp. It is divided into two groups: one hundred and thirty 30.55 kWp and eighty 18.8 kWp. The first group uses a three-phase grid-connected inverter with 17kW two-way DC input; the second group uses a 33kW three-phase inverter with one DC input.

3.6 Environmental monitoring system

The environmental monitoring system consists of Sunny SensorBox of SMA Company, radiation sensor, ambient temperature sensor, wind speed sensor, component temperature sensor and RS485 Power Injector. Each sensor is used to test various environmental parameters; Sunny SensorBox converts the analog quantity collected by each sensor into digital quantity, and transmits the sensor data to the SMA communication device (Sunny BoyControl) through the RS485 interface stipulated by the SMA communication protocol; RS485 Power Injector supplies power for the Sunny SensorBox and is installed indoors, SBC is connected to the host computer via RS232, which can upload data to the host computer and display it in real time through the program interface. The system structure diagram is shown below.

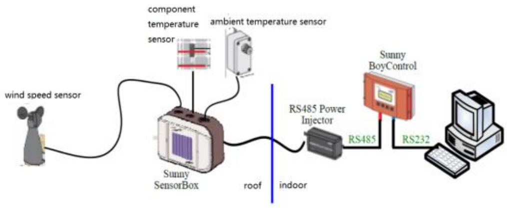


Fig.7 structure diagram of the environmental monitoring system

4. DEVELOPMENT OF DATA MONITORING SYSTEM

4.1 Hardware design of monitoring system

The 100kWp photovoltaic demonstration power station system adopts two sets of data collection systems respectively, the micro-network laboratory central monitoring system and the dynamic model laboratory central monitoring system. The parameters that can be collected by the monitoring system are: DC voltage, DC current, DC power, AC voltage, AC current, output power, power grid frequency, daily generated energy, total generated energy, radiation quantity, ambient temperature, component temperature, and wind speed. The grid-connected inverter is the core of each subsystem unit, and saves almost all operation data, therefore, the monitoring system takes the grid-connected inverter as the core monitoring object, and collects data through the controller and communication interface. The hardware structure of the monitoring system is shown in Fig.8 and Fig.9.

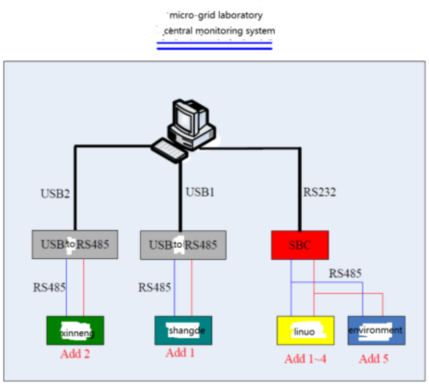


Fig.8 monitoring system diagram of micro-grid laboratory

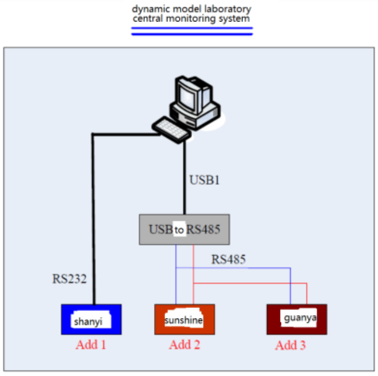


Fig.9 monitoring system diagram of dynamic model laboratory

4.2 Software design of monitoring system

The monitoring system uses the inverter in each subsystem as the monitoring objects, and communicates with each inverter through the serial port, and realizes real-time collection of various operational data. The 100kWp photovoltaic demonstration power station uses six different inverter devices; they have its own communication protocol and way, and collect data saved in the inverter and achieve remote control of the inverter. The communication ways of each inverter device are shown in Table.1.

Table.1 collection of communication protocols and ways for each inverter device

order number	system name	device name	interface	protocol	communication mode
1	small-scale micro-grid	SMA	RS232	SMA self-defined protocol	question and answer mode
2	emergency	LBBB Rijia	RS485	self-defined protocol	automatic upload
3	direct grid-connected A	PowerOne	RS485	self-defined protocol	question and answer mode
4	environment	SensorBox	RS232	SMAself-defined protocol	question and answer mode
5	direct grid-connected B	17000TL	RS232	self-defined protocol	question and answer mode
6	direct grid-connected C	SG30K3	RS485	self-defined protocol	question and answer mode
7		GSG-20KTL-TV	RS485	self-defined protocol	question and answer mode

Table.2 send data frames

1byte	2byte	2byte	2byte	1byte	1byte	1byte	2byte	1byte
start bit	protocol number	destination station number	source station number	order	parameter	EXT	check sum	end bit

Table.3 receive data frames

1byte	2byte	2byte	2byte	1byte	1byte	nbyte	1byte	2byte	1byte
start bit	protocol number	destination station number	source station number	order	parameter	data	EXT	check sum	end bit

In this paper, the LBBB Rijia inverter in the 10kW emergency subsystem is taken as an example to carry out the communication protocol and software flow explanation. Rijia inverter communication is realized by RS485 bus, the baud rate is 19200bps, one start bit, no parity check, and one stop bit. The protocol consists of ASCII code in hexadecimal. The data frames for sending and receiving are shown in Table 2 and Table3. The start bit in the data frame is 02H, the stop bit is 0DH, and the parameter refers to the parameter type, the code is a~z.

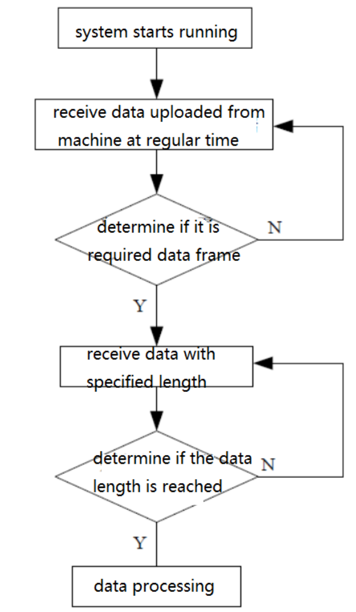


Fig.10 communication process of LBBB inverter

Once the system starts running, the inverter will continuously send operational data information to host computer through the RS485 bus, host does not have to send the data frame of data. Each cycle includes a, c, g, and h four parameters, each parameter is a complete data frame. The parameter a contains all operation data information of the inverter, so it only needs to receive the data frame containing the parameter a. In this paper, the data frame stop bit as the limit to determine the data frame, and starts receive data, and determines whether the ninth byte is 61H (hexadecimal of parameter a), if yes, continue to receive the data frame for a specified length (157 bytes) and then carry out corresponding data processing, and extract the required operational data information; if not, then abandon the data frame and wait for the data frame header again. The monitoring interface corresponding to the subsystem is shown in Fig.11.

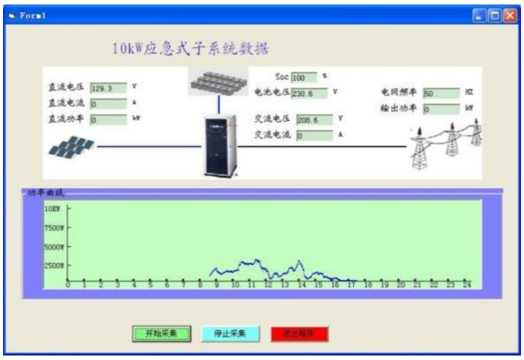
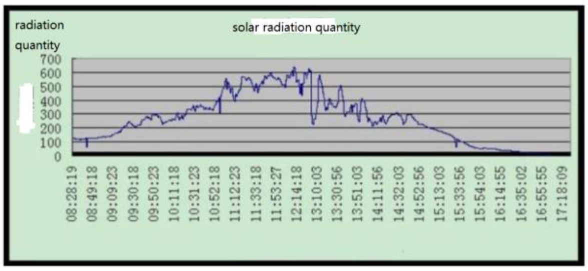


Fig.11 monitoring system sub-interface

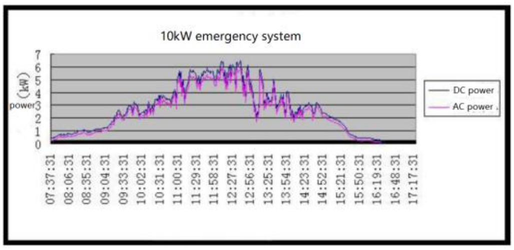
The monitoring system can displays the current value of the monitored parameters in real time and automatically records them in the corresponding Excel file. The recorded parameters include: voltage and current the photovoltaic matrix; AC side voltage, current, power, power grid frequency; daily power generation, total power generation; solar radiation quantity, ambient temperature, etc. The recording time cycle is 1 minute. At the same time, for the main parameters in the subsystem (such as the current output power), the monitoring system can draw it as a curve to observe the system output power changes over time.

5. OPERATIONAL DATA ANALYSIS

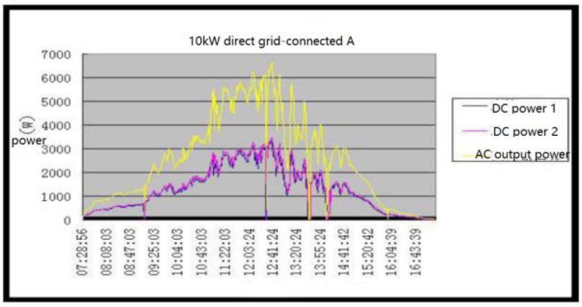
The one-day operational data acquisition record was carried out for the 100kWp photovoltaic demonstration power station with the central monitoring system, the following is the curve obtained from the operating parameter record data of each subsystem, as shown in Fig.12.



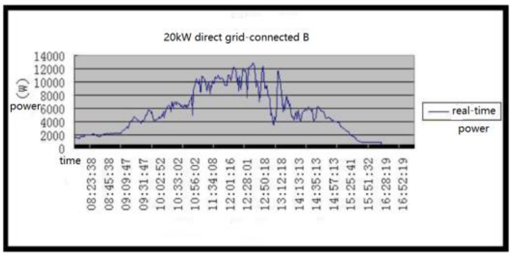
(a) radiation quantity monitoring of environmental monitoring systems



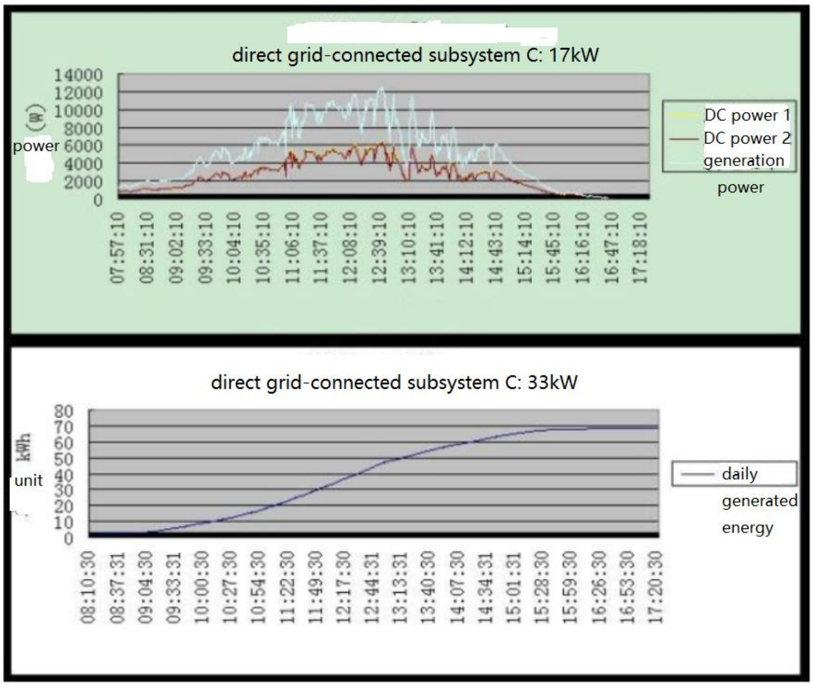
(b) 10kW emergency subsystem



(c) 10kW direct grid-connected system A



(d) 20kW direct grid-connected subsystem B



(e) 50kW direct grid-connected system C

Fig.12 operation data of 100kWp photovoltaic demonstration power station

On that day, the urban area of Tianjin was cloudy, the peak of solar radiation quantity was 631W/m^2, and the peak power of 10kW photovoltaic system was 6.7kW, it appeared in the period from 12:30 to 14:30, and the daily power generation of 33kW direct grid-connected system generated electricity had reached 68.3kWh. It can be seen from the above data that the photovoltaic power generation system without energy storage device is more affected by season and weather.

6. CONCLUSION

The 100kWp photovoltaic demonstration power station selected various photovoltaic modules and multiple grid-connected inverters in the program design, and formed diversified system topological structure. By interpreting the communication protocols of different inverters and developed data monitoring system, this paper can realize real-time collection and recording of various operation data in the system, and laid a foundation for relevant experiments and data record analysis. This paper gives the power output and generated energy for different time within one day of system operation. The completion and operation of the 100kWp photovoltaic grid-connected demonstration power station provides references for the construction of related projects, and it has a significant promotion and demonstration significance for the application of solar grid-connected photovoltaic power generation technology in China's cities.

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REFERENCES

[1] Yang Renhua, Huang Wei, Guan Li, Liu Lingfu. Structure and Operation Control of Micro-grids[J]. Advances of Power System & Hydroelectric Engineering, 2010, 26 (01): 48-55.

[2] Zhao Bo, Li Peng, Tong Hangwei, Zhang Xuesong, Fan Yuanliang. Survey on Development from Distributed Generation to Microgrid[J]. Zhejiang Electric Power, 2010, 29 (03): 1-5.

[3] Fan Yuanliang, Zhao Bo, Jiang Quanyuan, Cao Yijia. Peak Capacity Calculation of Distributed Photovoltaic Source with Constraint of Over-voltage[J]. Automation of Electric Power Systems, 2012, 36 (17): 40-44.

[4] Gong Yingfei, Lu Zongxiang, Qiao Ying, Wang Qiang. An Overview of Photovoltaic Energy System Output Forecasting Technology[J]. Automation of Electric Power Systems, 2016, 40 (04): 140-151.
[5] Song Xiaohui, Guo Zhizhong, Guo Huaping, Wu Shuanghui, Wang Zhaoqing, Wu Changan. A New Forecasting Model Based On Forest For Photovoltaic Power Generation[J]. Protection and Control of Power System, 2015, 43
[6] Huang Xing, Jin Xinmin, Tong Yibin, Liang Jiangang. A Microgrid Control Method With Fast Resynchronization Capability[J]. Journal of Beijing Jiaotong University, 2012, 36 (05): 7-13.
[7] Wang Xiaohuan, Zhang Chunjiang. Study of Control Strategy for Seamless Transfer of Grid-Connected Distributed Generation Systems[J]. Transactions of China Electrotechnical Society, 2012, 27 (02): 217-222.
[8] Wang Chengshan, Yang Zhangang, Wuzhen. Design and Implementation of a Practical Small-scale Photovoltaic Micro-grid System[J]. Electrician Abstracts, 2011, 31 (06): 6-10.
[9] Yang Zhangang, Wang Chengshan, Che Yanbo. A Small-scale Microgrid System with Flexible Modes of Operation[J]. Automation Of Electric Power Systems, 2009, 33(14): 89-92+98.
[10] Chen Wei, Shi Jing, Ren Li, Tang Yuejin, Shi Yanhui. Composite Usage of Muti-type Energy Storage Technologies in Microgrid[J]. Automation Of Electric Power Systems, 2010, 34 (01): 112-115.
[11] Huan Long, Zijun Zhang, Yan Su. Analysis of daily solar power prediction with data-driven approaches[J]. Applied Energy, 2014, 126.
[12] Fei Wang, Zhao Zhen, Zengqiang Mi, Hongbin Sun, Shi Su, Guang Yang. Solar irradiance feature extraction and support vector machines based on weather status recognition model for short-term photovoltaic power forecasting [J]. Energy & Buildings, 2015, 86.