Design of zero-carbon campus energy system based on multi-energy complement and intelligent optimization

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Keywords: Multi-energy complementarity, Artificial intelligence, Zero carbon campus, Energy system.

Abstract. In order to achieve the goal of carbon neutrality, especially to guide and encourage young people to participate in this process, with the goal of achieving zero carbon emissions on campus. A multi-energy complementary green energy system composed of photoelectricity, wind energy, geothermal energy, and energy storage is comprehensively utilized to construct a campus comprehensive energy system, and intelligent energy scheduling is achieved through the operation of big data. MQTT, CoAP IoT protocol, and various industrial field control bus technologies such as ModBus, ProfiBus DP, CAN, MBus are adopted to achieve data acquisition, transmission, and control. A comprehensive management platform is established to explore the design of a new energy system for achieving zero carbon goals in university campuses.

1 Introduction

The goal of “carbon peaking and carbon neutrality” is leading and systematic to the green and low-carbon development of China and the world, which can bring multiple effects of environmental quality improvement and industrial development. Focusing on reducing carbon emissions, it is conducive to promoting the green transformation of energy utilization and accelerating the formation of green production methods. A research system will be constructed from three aspects: structural carbon reduction, technological carbon reduction, and low-carbon management. Taking the energy demand of university campuses as the object, On the basis of distributed energy applications, MQTT, CoAP Internet of Things Protocol and ModBus, ProfiBus DP, CAN, etc., are adopted to achieve data acquisition, transmission, and control. Multi energy coupling of photovoltaic power generation system, ground source heat pump system, wind power generation system, electric vehicle charging and swapping facility system, energy storage system, new energy microgrid management system, building DC distribution system, building flexible

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electricity management system, and heat pump system, achieving intelligent optimization and allocation through monitoring of operating data[1].

A multi energy complementary comprehensive energy system is a new generation of power system that takes distributed energy as its core, integrates renewable energy such as solar energy, wind energy, and geothermal energy, and extracts electricity from the new energy generation system to meet the power supply needs of end loads [2].From a technical perspective, the new power system has various characteristics, including strong randomness, complex variable properties, etc[3]. Essentially, it belongs to a class of nonlinear systems with strict requirements for control performance. If the control performance does not meet the standards, various problems will occur during the operation and use of the power system. From the application point of view, the focus of practical application is on the system design level. At present, various types of buildings on campus still have problems such as high resource consumption, high pollution emissions, and extensive construction methods. There is still a certain gap with the requirements of the “dual carbon” target. Campus buildings are selected as application scenarios, and system designs are specially formulated based on actual electricity demand.

2 System design

2.1 Application scenarios

The construction area of the project is about 1906.67 square meters, and the site area is about 3573.54 square meters. The building is a two-story brick concrete structure. Before the design and renovation, the building used municipal power supply, natural gas boilers for heating, and individual rooms were equipped with split air conditioning for cooling.

Fig. 1. Realistic scene before renovation.

2.2 Solar photovoltaic power generation system

Adopting a solar photovoltaic grid connected power generation scheme. According to the on-site situation, the installation method is to use a sloping roof and lay it flat. The expected installed capacity of the project is 132.48kW. The project uses high-efficiency monocrystalline silicon modules and 288 460Wp solar cell modules. The power generation system adopts a grid connected power generation mode, where the inverter outputs 220V/380V AC power and integrates the generated energy from the photovoltaic system into the 220V/380V low-voltage power grid, serving as the building's own power and auxiliary power source for the city, providing clean electricity for the load.

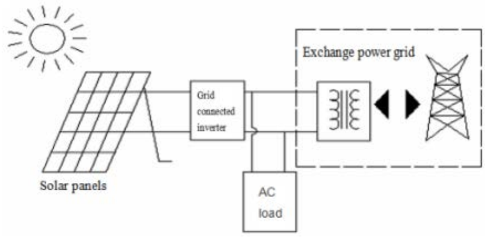

Fig. 2. Grid connected power generation system.

Grid-connected inverter adopts maximum power tracking technology to maximize the transmission of electrical energy converted by solar panels into the grid.The built-in display unit of the inverter can display various electrical parameters such as the voltage and current of the solar cell array, the output voltage, current, and power of the inverter, cumulative power generation, operating status, and abnormal alarms.At the same time, it has standard electrical communication interface, which can realize remote monitoring.It has the characteristics of high reliability, multiple grid protection functions (such as islanding effect), multiple operating modes, and no harmonic pollution to the power grid.In order to improve the efficiency of the entire grid connected power generation system, it adopts high-performance MPPT control technology.The output current of the solar cell is controlled by the DC/AC unit of the inverter, and the maximum output power of the solar panel is determined by the CPU to ensure that the solar cell operates at its maximum power output point under different sunlight and temperature conditions[4][5].

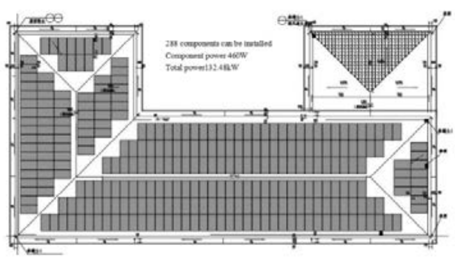

Fig. 3. Battery pack layout design.

2.3 Ground source heat pump system

The heat pump system consists of two ground source heat pumps, each with a winter power of 24.1kW and a summer power of 18.2kW, operating for 10 hours per day; Two ground source side circulating pumps, each with a power of 4kW, operate for 10 hours per day; Two system side circulating pumps, each with a power of 3kW, operate 24 hours a day in winter and 10 hours in summer.

Table 1. Daily electricity consumption in winter.

Equipment name	Number of devices	Equipment power（kW）	Operating hours/day	Load factor	Electricity consumption（kWh）
Ground source heat pump	2	24.1	10	0.5	241
System side circulating pump	2	3	24	0.5	72
Ground source side circulating pump	2	4	10	0.5	40

Table 2. Daily electricity consumption in summer.

Equipment name	Number of devices	Equipment power（kW）	Operating hours/day	Load factor	Electricity consumption（kWh）
Ground source heat pump	2	18.2	10	0.67	243.88
System side circulating pump	2	3	10	0.67	40.2
Ground source side circulating pump	2	4	10	0.67	53.6

2.4 Distributed small-scale wind power generation system

A decentralized small-scale wind power generation system utilizes wind power to drive the rotation of wind turbines and generate electricity, converting the kinetic energy of wind into electrical energy. Low wind speed sites should use full power wind turbines, while high wind speed sites should choose doubly fed wind turbines, which can be arranged vertically or horizontally. The system consists of wind turbines, generators, inverters, operation control and monitoring equipment, etc. The full power wind turbine is composed of wind turbines, permanent magnet synchronous motors, full power converters, etc. The system framework is shown in Figure 4.

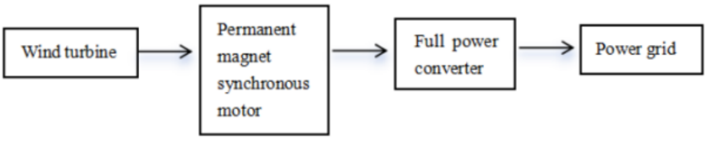

Fig. 4. Block diagram of full power wind power generation system.

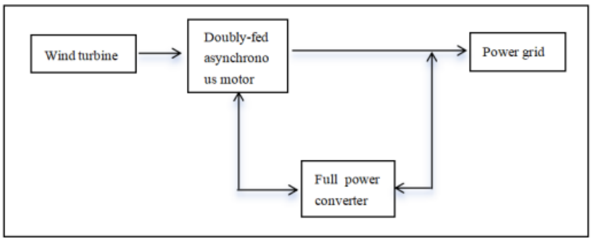

Fig. 5. Block diagram of doubly fed wind power generation system.

2.5 Energy storage system

The energy storage system, in conjunction with photovoltaic power generation applications, includes photovoltaic modules, photovoltaic controllers, battery packs, battery management systems, inverters, and corresponding energy storage joint control and scheduling systems.

The photovoltaic module array utilizes the photovoltaic effect of solar panels to convert light energy into electrical energy, and then charges the battery pack. The inverter converts direct current into alternating current to power the load. The intelligent controller continuously switches and adjusts the working state of the battery pack based on changes in sunlight intensity and load. On the one hand, it sends the adjusted electrical energy directly to the DC or AC load, and on the other hand, it sends excess electrical energy to the battery pack for storage. When the power generation cannot meet the load demand, the controller sends the electrical energy from the battery to the load to ensure the continuity and stability of the entire system operation. The inverter system consists of several inverters, which convert the DC power in the battery into standard 220V/380V AC power and connect it to the user's low-voltage power grid or send it to the high-voltage power grid through a transformer. The battery pack plays a role in both energy regulation and load balancing in the system[6]. It converts the electrical energy output by the photovoltaic power generation system into chemical energy and stores it for use in case of insufficient power supply.

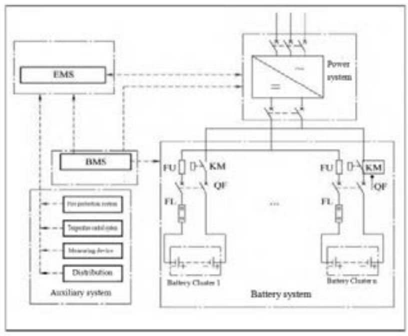

Fig. 6. Block diagram of energy storage system.

3 New energy microgrid management system

The new energy microgrid management system should have functions such as real-time monitoring and regulation, power balance control, operation optimization, fault detection and protection, and power quality management.The system consists of a host, intelligent network control equipment, terminal display equipment, terminal data acquisition equipment, and dedicated management platform software. The system framework is shown in Figure 7.

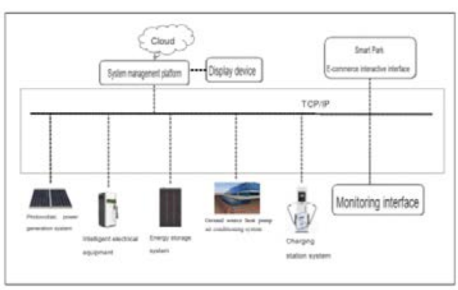

Fig. 7. Block diagram of new energy microgrid management system.

Key points of system design:One is that the platform can adopt a cloud network edge architecture, and the system should adopt technologies such as the Internet of Things, cloud edge collaboration, big data, AI intelligent analysis, etc.The second is to support both grid connected and off grid operation modes. When operating in grid connected mode, the system can adopt PQ constant power control mode, and in case of mains power failure, the system should operate in off grid mode.The third is to support system equipment status assessment, health management, system fault prediction and diagnosis. The fourth is to support docking with “source network load storage” devices such as converters and energy storage units, achieving plug and play functionality of the devices[7].

 https://doi.org/10.1051/itmconf/20257701045

The operating interface of the management system is shown in Figure 8.

Fig. 8. Management interface.

4 Conclusion

Due to space limitations, this article does not provide a detailed discussion of each subsystem, but only briefly introduces the system composition, design points, and actual effects. Although the experimental project is relatively small in scale, it fully realizes the coupling of distributed energy, which helps us explore energy conservation in larger scale and more complex buildings. At the same time, its replication and promotion value in campus buildings is significant.

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