Design and Energy Efficiency Management of Cascade Hydropower System

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Abstract. Under the background of energy shortage and environmental pollution, the development and utilization of building hydropower power generation and utilization of resources positively respond to the construction of national sponge city. In this paper, the concept of building cascade hydropower is put forward from the view of making full use of building water energy, and the upper computer of building cascade hydropower power management system is built by using LabVIEW software platform. The calculation and measurement error of hardware circuit is reduced, and the design of building cascade hydropower power management system is completed. The feasibility and advantage of building cascade hydroelectric power generation system are verified through field test.

1. Introduction

With the problem of one-off energy shortage becoming more and more prominent, it is a serious threat to the survival and development of human society. In recent years, a lot of hot topics have emerged in the research direction of smart grid and micro-grid. The demand for new energy generation technology is increasing, and the research on distributed energy and clean and renewable energy is becoming more and more in-depth [1]. Common clean and renewable sources of energy, including wind, solar and hydro, can be used to generate electricity. These small distributed sources generate less electricity and are installed on the proximity principle and in combination with buildings by adopting off-net working mode [2], [3].

With the continuous growth of population and the rapid development of society, the problems of water shortage, urban waterlogging and environmental deterioration are becoming more and more serious [4]. The development of urbanization and industrialization has increased the impermeable areas in urban areas, and caused a series of problems in urban areas. The deterioration of water quality, urban waterlogging, rain island effect and heat island effect make the infiltration and storage function of Rain Water decrease in urban areas [5]. The utilization of building water resources can not only produce good economic and social benefits, but also produce good ecological and environmental benefits. In this paper, the precipitation data of Xiamen from 2015 to 2016 and the water consumption of residents are analyzed, and the calculation of available building water resources is analyzed to evaluate the benefits of the utilization of building water energy resources.

It can be seen from the above Figure 1 that monthly precipitation in Xiamen is unevenly distributed, mainly in the spring rain season, rainy season and summer, accounting for 75% of the annual precipitation, which is due to the influence of typhoon weather in summer and Meiyu season in southern China. During this period, we can make full use of the peak load of hydraulic energy and accumulate water energy on the top of the building. When the peak wind and solar power supply is insufficient, as a backup power supply, it play the role of peak regulation. The collection and utilization of Rain Water and the filtration and classification of water in buildings can effectively...
reduce the investment in urban flood control, drainage and sewage treatment, and can also reduce runoff pollution [6].

![Precipitation in every quarter of Xiamen](image.png)

**Figure 1.** Precipitation in every quarter of Xiamen

2. Design of building cascade hydropower system

2.1. Design of building hydropower system

At the top of the building, the Rain Water is confluent in the upper reservoir, and the turbine is installed at the bottom of the building. The reservoir is connected with the turbine through pipes, and the blade of the turbine is driven to rotate by the potential energy of water, thus generating electric energy. Rain Water flows into the lower reservoir after passing through the turbine. It can be used as the living water for human being by electroflocculation treatment [7]. The purpose of building cascade hydropower system is to make full use of water energy and improve the utilization ratio of water energy under the premise of 220 V output voltage of hydrogenerator.

In the field test, the type of hydraulic generator is SLF series oblique strike permanent magnet synchronous generator. The parameters of the motor are shown in Table 1.

| Type    | SLF-4  | Phase  | Single phase |
|---------|--------|--------|--------------|
| Power   | 500w   | Volts  | 230v         |
| Waterhead | 6-15m  | Q.Max  | 0.005-0.05m³/s |
| Rpm     | 1500r/min | INS.Cl | E level     |

In the case of satisfying the above two conditions, the working head of the turbine with 220 V output voltage is selected to install the turbine. There is no need to unload the turbine at this time, and the maximum utilization of electric energy can be achieved.

After continuous debugging, the output voltage of SLF-4 series turbine can reach 220 V when the working head is 10 meters. Taking the experimental building as an example, the height of the building is 27 meters, the water storage device is installed on the top of the experimental building, the No. 1 turbine is installed on the fourth floor platform, and the No. 2 turbine is installed on the second floor platform. The building water resources are collected in the water storage device after filtration device. In order to prevent the water from blocking the roof, the water storage device should be provided with overflow hole.

Inspired by cascade hydropower station, this paper designs a building cascade hydropower system. The turbine of each floor can be stabilized by 220 V output voltage after on-site debugging, and then connected to the same bus bar. The bus can be connected to AC load, or it can be reduced to 12 V by transformer, and the battery can be charged by AC/DC module.

2.2. Hydropower power management system based on LabVIEW
As a standard data acquisition and instrument control software, LabVIEW has been widely accepted by academics, industry, and research laboratories [8]. The user can set parameters on the front panel, use the block diagram to implement VI logic functions, and connect functions, constants, etc. [9]. The programming of LabVIEW is to create a new VI file and complete the module selection and related programming of the front panel, the module selection and design of the block diagram, and the connection between each module. Users can design their own desired interface format on the front panel according to their own needs, and add the necessary modules for each string element, numerical element, and Boolean element, and then find the corresponding module in the block diagram for connection and Compilation of related programs [10].

Use LabVIEW to first write the user login module interface and block diagram, and then write the serial port operation, including the serial port configuration, data receiving and sending, serial port close to achieve the communication between LabVIEW and the serial port. Recompile the various parameter measurement modules and calculation modules of the building cascade hydropower system, including the basic parameter measurement module, the power module, the voltage fluctuation and flicker module, the electricity monitoring module and the blackout recording module. The front panel of the voltage fluctuation and flicker module is shown in Figure 2.

Finally, each sub-module is connected with the user login module to complete the design of the upper computer for the power management system of the cascade hydroelectric power generation system.

3. System hardware platform and field test

In order to further verify the advantages of building cascade hydropower system, this paper builds a hardware experimental platform to carry out related experiments. The hardware of building cascade hydroelectricity system includes hydraulic turbine and micro hydropower load regulator. The output of the hydroelectric generator does not need to pass through the distribution box, as long as it is loaded by the micro-hydroelectric load controller.

The field test is conducted in an experimental building. Firstly, a water storage device is installed on the top of the experimental building to store energy. The first turbine is installed on the fourth floor of the laboratory building. The second turbine is installed on the platform on the second floor of the experimental building, and the top water storage unit is connected directly to the first turbine through the water diversion pipeline. The outlet of the first turbine is connected to the second turbine through the diversion pipeline through the hemisphere-type water collection device to achieve two-stage power generation. The output current and output voltage of the two turbines were collected by the current transformer and the voltage transformer respectively and transmitted to the serial port via FPGA and AD7606. Finally, the data analysis and calculation of serial port are read by LabVIEW. The field experiment is shown in figure 3.
The experiment is divided into two levels of power generation system, the first level of the working head is 10.1 meters, the second level of the working head is 10.4 meters. Because there is no need to unload the output of hydraulic generator in building graded power generation system, the system has improved the utilization of water energy and did not cause power loss due to unloading.

The wiring diagrams of the power supply system, protection system and acquisition system of the building cascade hydroelectric power generation system are shown in Figure 4.

The experimental data is collected by the host computer LabVIEW. Reading the power module can obtain experimental power data. Table 2 shows the experimental data of a single-stage hydropower system. Table 3. shows the experimental data of a hierarchical hydropower system. The specific data are shown below.

In the field experiment, the data comparison of the hierarchical generation system to the single stage generation system is shown in Table 4.
Table 2. Data analysis of single-stage hydropower system

| Number of measurements | Apparent power (VA) | Active power (W) |
|------------------------|---------------------|-----------------|
| 1                      | 87.89               | 78.22           |
| 2                      | 83.38               | 70.87           |
| 3                      | 82.14               | 69.81           |
| 4                      | 81.93               | 69.64           |
| 5                      | 84.42               | 74.29           |
| 6                      | 89.70               | 79.07           |

Table 3. Data analysis of graded hydropower system

| Number of measurements | Apparent power (VA) | Active power (W) |
|------------------------|---------------------|-----------------|
| 1                      | 54.67/57.74         | 47.02/49.66     |
| 2                      | 51.69/53.21         | 44.61/45.80     |
| 3                      | 55.96/58.61         | 48.19/50.89     |
| 4                      | 54.11/56.79         | 46.21/48.56     |
| 5                      | 51.92/54.03         | 44.45/46.06     |
| 6                      | 52.06/56.84         | 44.75/48.69     |

Table 4. Comparative analysis of data

|                             | Apparent power (VA) | Active power (W) |
|-----------------------------|---------------------|-----------------|
| Single stage power generation | 84.91               | 73.65           |
| Graded generation stage I    | 53.40               | 45.87           |
| Graded generation stage II   | 56.20               | 48.28           |

From Table 4, it can be seen that the active power of the single-stage hydropower system of the building is 73.65W, and the active power of the building's cascade hydropower system is 94.15W. At the same height of the water head, the multi-level hydraulic system emits 27.83% more power than the single-stage hydraulic system, which has obvious advantages, thus verifying the feasibility of the building's cascade hydropower system.

4. Conclusions

The LabVIEW software platform was used to compile the upper computer of the cascade hydroelectric power management system in the building. Functions such as the user's login authority, communication configuration of LabVIEW and serial port, measurement of basic parameters, monitoring of power, calculation and analysis of voltage fluctuation and flicker, power monitoring and blackout record were specifically implemented. Finally, through the combination of sub-VI and login interface, the user interface design is completed.

This paper introduces the hardware part of the building cascade hydropower system, and sets up the hardware experimental platform to carry on the field test. Finally, the experimental data were collected and analyzed to verify the advantages of building cascade hydropower system.

5. References

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