Power generation lighting device based on gravity potential energy of rainwater pipeline

Licai Cao¹, Zhihao Wang² and Xinhong Xiong¹*

¹Department of Mechanical Engineering and Automation, Wuhan University of Technology, Wuhan, Hubei, 430070, China
²Department of Mechanical Engineering and Automation, Wuhan University of Technology, Wuhan, Hubei, 430070, China
*Corresponding author’s e-mail: 10691907@qq.com

Abstract. China’s society is developing rapidly with many tall buildings rising in the city. When it rains, the huge gravitational potential contained in the water on their roof is often wasted, especially in the south where rainfall is abundant. Therefore, designing a device that relies on the water potential energy to generate electricity is conducive to make full use of the abundant mechanical energy. It is a novel green energy-saving method with a great prospect. In response to this situation, this project designed power generation device based on gravity potential energy of rainwater pipeline. The device consists of two parts: a collecting device and a power generating device. The rainwater collecting device is placed in the outlet pipe of the highest floor, which is accumulated for the power generating device. The power generation device is installed at the lowest floor outlet pipe, which is used to generate electricity by using the rain energy collected by the high-level collection device. Therefore, the power generating device has two working states: when the amount of water is large, the device maintains on, and the generator works continuously; when the amount of water is small, power generating works only after the water volume collected reaches a threshold value, so the device is in an intermittent working state. Based on the survey data and size of the device, we estimated the economics of the device. If the floor height is 30 m with 10 water pipes in each building, each pipe is equipped with one device, which can replace a street lamp. A street lamp consumes 0.3 degrees of electricity per hour. Assume that the lighting time is 10 hours, and then if this equipment is installed in a building, 10,950 kWh of electricity can be saved in one year, which shows the high economic and practical benefits of the device.

1. Research background and significance

1.1 Research background
In China, electricity is one of the most important basic industries for the national economy. Coal-fired power generation, as the most important type of power source since the founding of the country in 1949, has maintained a very high proportion of power transmission. At the same time, from the perspective of ensuring energy security, promoting sustainable economic and social development, and protecting the ecological environment, China is constantly developing new energy sources. Among them, renewable energy has been given new missions of energy saving, emission reduction, greenhouse gas emission control and air pollution prevention. In particular, wind power and solar
power generation continue to develop. Therefore, discovering and developing new sources of pollution-free energy has become an important direction for future energy development.

In a city with high-rise buildings, precipitation on the top of skyscrapers is often simply drained from the pipeline, thus wasting the considerable potential energy. People started research around 2000 in this respect, but the previous devices designed were mostly sewer generators. These ideas are scientific and feasible, but have many flaws: the sewer is a particular environment with many sundries in the water, such as hair and metal blocks, which may limit the movement of the impeller or even damage it, making it unable to function properly. The location of the sewer is also particular, so the generator cannot be easily disassembled, repaired and replaced, causing great limitations. Since the current generators are mostly simple power generation equipment, it is impossible for them to effectively generate electricity when the water is insufficient, so its efficiency is not high. In response to these major problems mentioned above, the project decided to install the power generation unit in the water supply pipeline and optimize and improve it to avoid the shortcomings mentioned above so as to make better use of this potential energy.

1.2 Research significance

(1) Reduce the grid power consumption of urban residents, reduce the power supply burden of the grid, thus making the grid better capable of supplying the necessary electricity for some cities;

(2) Use the energy around us, making full use of the free energy provided by nature to serve people;

(3) Follow the national measures in energy conservation and emission reduction policies. Saving energy and utilizing new energy is a development trend of society and an important measure to ensure energy security and promote sustainable economic and social development. Promote the establishment and implementation of the scientific concept of development, promote the whole society to save energy and reduce consumption, improve energy efficiency, accelerate the construction of an energy-saving society, an environmentally friendly and harmonious society, and improve energy efficiency and economic efficiency.

2. Design

2.1 Overall design ideas

The design is mainly divided into two parts: the energy storage device and the power generation device. The storage device is placed in the water inlet of the pipe to accumulate water on the roof that is supplied to the power generation device. The generation device is installed at the water outlet of the water discharge pipe, and utilizes high-potential water accumulated by the collection device to generate electricity.

According to the amount of rainwater, the design has two working states: when the water volume is large, the device maintains normally on, and the generator works continuously; when the water volume is small, the generation device is on only after the water collected exceeds the threshold, so the power generation part is intermittently on. The electrical energy generated by these two states is stored and used to continuously supply power to the lighting system. By adding power generation devices to buildings and using lighting power in public areas such as residential areas, the device reduces, to some extent, the power supply burden of residential areas or commercial areas, thereby saving energy.

2.2 Research content and key technologies

This design focuses on the following aspects of efficient conversion of rain energy potential:

(1) Efficient collection of rainwater for power generation: install the rainwater collecting device and connect it to the pipe inlet, and cooperate it with the power generating device below the pipe, which can continuously work and intermittently work, thus avoiding waste of energy caused by the failing of generator operation due to insufficient rainfall;
(2) Removing impurities from rainwater: place a layer of filter in the collection box to ensure that rainwater entering the power generation unit can generate electricity normally;

(3) When the water volume of the collecting device reaches the threshold value, the lower outlet automatically opens. Set the buoy and the mechanical linkage device. When the water volume increases, the buoy rises, spring is elongated, and the lower outlet automatically opens;

(4) Detachable design which is maintenance-convenient: The location of the collecting device is the inlet of the downpipe of the building, which is convenient for repairing and replacing components (such as replacing impeller of different sizes to adapt to the pipes). The main body of the power generating device is outside the downpipe. When it needs to be replaced, it can be taken from the outside.

(5) Through the synergy of the ratchet clutch and the flywheel, the unidirectionality of power transmission and the sustainability of power generation are achieved.

3. Overall design

3.1 Functional design
1) The device has the function of temporarily storing rainwater for the purpose of accumulating energy.
   2) It has the function of filtering stones, leaves and other large objects to prevent damaging of the impeller.
   3) It has the function of automatically intermittently releasing water and releasing energy. Electricity is not needed to control its opening and closing, making it simple and efficient.
   4) It has the function of one-way transmission of energy.
   5) It has the function of storage power for lighting.

3.2 Structural design
1) Energy storage part
   Strainer
   Water storage tank
   Spring
   Water outlet
   Water inlet
   Bursting tube
   Buoy
   Water stop plug
At the beginning, the water stop plug blocks the outlet. As the rainwater flows in, the float floats up. When the water pressure above the water stop plug is less than the spring force, water is being stored. When the water storage reaches a certain height, the float lifts the lever and the spring force increases. When the spring force is greater than the water pressure on the water stop plug, the water stop plug moves upward and starts to release water. When the float drops to the position shown in the figure, the water stop plug again plugs the water outlet for the next water storage. In order to prevent the situation in blockage, a safety pipe is specially set at the side of the water inlet to ensure that the rainwater falls smoothly.

2) Power generation part
   Water inlet
   Guide plate
   Impeller
   Water outlet
   Gear case
   Flywheel
   Ratchet clutch

Figure 1 Structure of the energy storage part
1) This part mainly consists of the impeller, gear set, overrunning clutch, flywheel and generator. The rainwater flows down, driving the impeller and the gear set to rotate. At this time, the ratchet clutch is in the transmission state, which drives the inertia flywheel to rotate, providing a relatively long-lasting power for the generator.

2) When the rainwater flows through the impeller in a short time but not continuously, the flywheel keeps rotating due to inertia. At this time, the impeller has stopped rotating, and the ratchet clutch is disconnected. So the mechanical energy stored in the flywheel is only transmitted to the generator, which greatly improves power generation efficiency.

3) Lighting section
The electrical energy generated is stored for lighting in the residential and commercial area.

4. Feasibility analysis

4.1 Calculation of impeller speed
Based on the energy conversion formula, we initially determined the ideal speed that the impeller can achieve at different installation heights and conversion efficiencies. This shows the energy stored in the rainwater in abundant. When the installation height reaches 30m of the ordinary residential building, the conversion rate reaches 50%, and the impeller speed reaches 5.42m/s, the demand for power generation can be fully met.
4.2 Calculation of power generation parameters of brushless motor
The transmission ratio of the impeller to the generator is 1:4. When the ideal speed of the impeller is 20 r/s, the generator speed can reach 5000 rpm per minute, which meets the working requirements of the generator.

5. Innovation
(1) This design has two states: intermittent working state and continuous working state. Set rainwater collecting device, and release the water to the power generating device when its volume reaches the threshold in order to realize efficient collection of rainwater and power generation;
   (2) Place a filter in the collection box to reduce the damage of the device to the device;
   (3) Set the buoy and the mechanical linkage device to realize the automatic opening of the outlet below the collection box when the water volume reaches the threshold;
   (4) The combination of the ratchet clutch and the inertia flywheel makes possible the buffer of mechanical energy so that the generator can have a relatively stable power input;
   (5) Both the collection device and the power generation device can be directly installed on the existing water supply pipe for easy disassembly and maintenance.

6. Conclusion
The paper analyzes the shortcomings and improves the existing generator that use potential energy today by making it more efficient in power generation, more convenient in disassembly and maintenance, safer and more reliable. It can also be applied to various types of pipelines, thus wider range of applications.

By designing a power generation device that utilizes the potential energy of rainwater in the downpipe, we develop a new green energy source for achieving energy conservation and emission reduction. The device uses the mechanical energy that is often wasted. Its promotion can reduce the dependence on the traditional electric energy source to a certain extent, thereby achieving a more harmonious integration of people and nature.

Acknowledgments
First and foremost, I would like to show my sincere gratitude to my partner and teachers, who give me support during the research. Instead, I am extremely grateful for my parents for their constant encouragement.

References
[1] Rui Huang, Jiaming Gu, Wei Wang. (2016) Design of power plant based on building drainage pipe. Mechanical and Electrical Information, 468: 73-75.
[2] Ya Zhou. (2017) Model design of tidal power generation device. Forum on Science and Technology, 119: 130-132.
[3] Shu Zhu. (1989) A New Energy Device-Pipeline Power Generation. Marine Electric & Electronic Engineering, 64: 71-74.
[4] Shu Zhu. (2018) Design and Research of Rainwater Resources Hydropower System for Super High-rise Buildings. Water Resources and Power, 423: 168-171.
[5] Chenguang Tu, 2015. Intermittent pressure drainage system. http://www.xjishu.com/zhuanli/12/CN105019538_3.html.