Photovoltaic Direct Drive Water-saving irrigation System and Its Optimization Design Method

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Abstract—Photovoltaic irrigation has been widely used in many areas without conventional energy sources. In order to solve the problem of unstable operation and poor irrigation uniformity caused by the diurnal variation of solar radiation, a photovoltaic direct-drive water-saving irrigation system with automatic regulation was proposed. By using automatic control technology and the method of zonal rotation irrigation, all the electric energy generated by solar panels can be converted into irrigation energy under different light intensities, so that the water-saving irrigation equipment can work stably in different regions and the irrigation uniformity is ensured in different regions. According to the characteristics of solar energy resources and photovoltaic water-pumping units, the optimum design method of photovoltaic water-saving irrigation system is put forward. The minimum capacity of solar panels can meet the irrigation demand of a certain area, which can guide the engineering design of solar water-saving irrigation, greatly improve the engineering quality and energy utilization rate. It has the advantages of simple design, low cost, stable operation and energy-saving ring.

1. Introduction
The supporting application of solar photovoltaic water extraction and drip irrigation, micro-sprinkler irrigation and other water-saving irrigation facilities can effectively solve the irrigation problems of grassland and arable land in some areas. It can not only improve the production but also save water and energy, reduce traditional energy consumption and build new power supply. Investment in facilities. Solar photovoltaic water pumping and irrigation conforms to my country's development strategy of building a "resource-saving" and "environment-friendly" society, and has broad
application prospects \[1\].

As the daily variation of solar energy radiation starts from zero in the morning, gradually increases, reaches a peak at noon, and then gradually decreases until it returns to zero at night, the instantaneous flow and pressure of the photovoltaic water pump also change according to this rule throughout the day. This leads to this uncontrolled photovoltaic water-pumping water-saving irrigation cannot insure that all water-saving irrigation equipment has the same water output in one day, which cannot meet the requirements of irrigation uniformity, At the same time, it cannot ensure that the irrigator works under the specified pressure, , causing the unstable operation of the irrigator and even affect the service life of the irrigator \[2-4\].

The above problems can be solved by adding water storage or energy storage devices between photovoltaic water-pumping and water-saving irrigation equipment. A certain volume of reservoir is equipped in the system to increase the irrigation guarantee rate, and the volume of the reservoir is compatible with the irrigation control area. The bottom elevation of the reservoir should be higher than the required pressure of the irrigator \[5-7\]. This method increases a large number of civil engineering projects, and they are not used for promotion and application. The configuration of a battery with a certain capacity in the system can achieve the purpose of stabilizing the flow and pressure, but its energy loss is 10% to 30%. At the same time, the battery pollutes the environment, and its service life is limited in the system configuration, and the use cost is high \[8\].

This paper proposes a water-saving irrigation system that directly drives water-saving irrigation by photovoltaic water extraction. Using automatic control technology, all the electrical energy generated by solar panels can be converted into irrigation energy under different light intensities, so that water-saving irrigation equipment can work stably in different regions, not only makes the flow pressure meet the requirements of water-saving irrigation equipment, but also ensures the irrigation uniformity of the entire photovoltaic water-pumping water-saving irrigation system. Compared with conventional water and energy storage methods, it greatly reduces the construction and operating costs of photovoltaic water-pumping and water-saving irrigation systems, and provides an important technical guarantee for water-saving irrigation powered by solar energy in the western region.

### 2. Composition of photovoltaic direct drive water-saving irrigation system

Photovoltaic water-pumping direct drive water-saving irrigation system consists of photovoltaic water-pumping equipment, automatic adjustment system and water-saving irrigation equipment. Photovoltaic water pumping equipment provides water supply for water-saving irrigation equipment through the automatic adjustment system. The outlet of the photovoltaic water pump is connected with the water-saving irrigation main pipe through a filter, the irrigation branch pipe is connected to the main pipe through a solenoid valve, and the irrigator is connected to the branch pipe, as shown in Figure 1.
Fig 1 Irrigation system of photovoltaic water pumping and saving

2.1 Photovoltaic water pumping equipment
The solar photovoltaic water pumping system is composed of solar panels, controllers and photovoltaic water pumps [9]. The solar panel is a device that directly converts the radiant energy of the sun into electrical energy. It has the advantages of easy installation, long service life and energy saving. The controller is a device that inverts the direct current generated by the solar cell array into an alternating current form to drive the water pump unit to work, it can control the working status of the water pump unit in real time according to the change of sunlight intensity, and adjust the output frequency in real time according to the change of sunlight intensity. The self-developed fuzzy PID algorithm is used to complete the maximum power tracking. Photovoltaic water pump is a device to lift water. According to the current working mode, the water pump in the solar photovoltaic water pumping system can be divided into two types: Direct Current water pump and Alternating Current water pump. The control of the Direct Current water pump unit is simple, but the cost is high. The Alternating Current water pump needs inverter to work. At this time, submerged pumps, centrifugal pumps, axial flow pumps and mixed flow pumps can be used.

2.2 Automatic adjustment system
The automatic adjustment system monitors the pressure of the water transmission pipeline in real time. When the main pipe pressure reaches the set value, the solenoid valve on one branch pipe is opened. When the light intensity increases and the pressure of the main pipe increases to a certain extent, the automatic adjustment system controls to open the solenoid valve on the other branch pipe, the irrigator on the branch pipe starts to work, and the pressure of the main pipe will drop immediately, to ensure that the irrigator can work normally; when the light intensity decreases, the pressure of the main pipe drops to a certain extent, the automatic adjustment system controls the closing of all the branch pipes. The solenoid valve, the irrigator on the branch pipe stops working, and the pressure of the main pipe will rise immediately to ensure that other irrigators can work normally. The automatic adjustment system controls the opening and closing of the solenoid valves installed on each branch pipe according to the change of the pressure of the main pipe, so as to achieve the purpose of stabilizing the pressure of the main pipe and make the irrigator work stably.

According to the solar energy resources and the field layout, determine the irrigation volume of each branch pipe, convert the irrigation volume of the branch pipe into the opening time of the branch
pipe through the required flow of the irrigation device during normal operation, and automatic adjustment system to open the solenoid valve on each branch pipe. At the same time, the working time of each branch is timed. When the working time reaches the set value, close the branch pipe, open the non-working branch pipe to achieve the propose of equal irrigation of each branch pipe, thereby controlling the uniformity of irrigation.

2.3 Water-saving irrigation equipment
In China's vast arid, semi-arid areas and economically underdeveloped areas, the stable development of agriculture and animal husbandry production will rely on the development of highly water-saving irrigation. Sprinkler and drip irrigation technology is one of the most water-saving fine irrigation techniques. Sprinkler and drip irrigation are also environment-friendly irrigation techniques; Drip irrigation can effectively control the irrigation volume of each plant, and drip irrigation technology make the utilization rate of irrigation water reach more than 90%, which can not only save water, but also save energy and increase production, so as to maximize the utilization efficiency and benefit of water and solar energy resources.

3. Optimal design method of photovoltaic water-pumping direct drive water-saving irrigation system

3.1 Optimized design ideas
In order to make efficient use of energy, in the photovoltaic water pumping direct drive water-saving irrigation system, meeting the irrigation demand of a certain area with the minimum solar panel capacity is the optimization goal of the system. The optimal design idea is shown in Figure 2. According to the area to be irrigated and the irrigation water quota, the total water demand in the irrigation period is obtained, and then the average daily water demand in the irrigation period is determined according to the irrigation period, and the rated flow of the water pump is determined in combination with the local solar resource situation; According to the situation of the water source well and the loss of water-saving irrigation equipment along the way, the rated head of the water pump can be determined; After determining the power of the water pump, the required power can be determined according to the solar energy resources.
Fig.2 Optimum design method of photovoltaic direct drive water-saving irrigation system

The number of irrigation branches also has a certain impact on the cost of the system. The more the number of irrigation branches, the higher the uniformity and fineness of the irrigation, and the higher the cost; the fewer the number of irrigation branches, the lower the cost, and the lower the uniformity and fineness of irrigation. However, the total flow of the irrigator connected behind a single branch pipe cannot be higher than the rated flow of the water pump. According to experimental experience, it is advisable to set 4-6 branch pipes on the irrigation area in a single day.

3.2 Determination of the rated flow of water pump
Irrigation quota, irrigation period and other parameters should be determined according to local irrigation test data, water balance calculation results or local related quota standards\(^{[10]}\), the rated flow of the water pump is determined according to the following formula.

\[
Q = \frac{\sum_{i=1}^{n} S_i M_i}{n \cdot T \cdot t}
\]  

(1)

Where: \(Q\) is the rated flow of the water pump, m\(^3\)/h; \(S_i\) is the i-th irrigation area of crops, hm\(^2\); \(M_i\) is the i-th irrigation quota of the crop, m\(^3\)/hm\(^2\); \(n\) is the number of irrigation; \(T\) is the irrigation period, d; \(t\) is the working hours of photovoltaic water pumping day, h.

3.3 Determination of the rated head of water pump
The rated head of the water pump is determined according to the following formula.

\[
H = d + H_p + \sum \Sigma H
\]  

(2)

Where: \(H\) is the rated head of the water pump, m; \(d\) is the height difference from nozzle to groundwater surface, m; \(H_p\) is the working pressure head of the irrigator m; \(\Sigma H\) is the total head loss along the way, m.
According to experience in the project, the total head loss along the way is about 15% of the net head, and the net head is the sum of the water surface height difference from the irrigator to the groundwater level and the working pressure head of the irrigator.

3.4 Determination of the solar photovoltaic cells capacity

The water power required for irrigation can be calculated according to the rated flow and rated head of the water pump, and then corrected according to the type of water pump selected in the project, the local solar resources and the setting of the photovoltaic array. The solar photovoltaic cell capacity is determined by the following formula.

\[ P = \frac{1}{3.6} \rho Q \cdot H / k_1 k_2 k_3 k_4 k_5 \]  

Where: \( p \) is the capacity of the solar photovoltaic cell. \( W \); \( \rho \) is the water density, \( \text{kg/m}^3 \); \( g \) is the main force acceleration, \( \text{m/s}^2 \); \( Q \) is the rated flow of water pump, \( \text{m}^3/\text{h} \); \( H \) is the rated head of water pump, \( \text{m} \); \( k_1 \) is Flow correction coefficient; \( k_2 \) is the water pump type correction coefficient; \( k_3 \) is the electric drive correction coefficient; \( k_4 \) is the solar resource correction coefficient; \( k_5 \) is the tracking correction coefficient of photovoltaic array.

\( k_1 \) is selected according to the parameters listed in Table 1.

| correction factor | flow \( \text{(m}^3/\text{h}) \leq 2 \) | flow \( \text{2~5 m}^3/\text{h} \) | flow \( \text{5~10 m}^3/\text{h} \) | flow \( \text{>10 m}^3/\text{h} \) |
|------------------|-----------------|-----------------|-----------------|-----------------|
| \( k_1 \)        | 0.70            | 0.75            | 0.80            | 0.85            |

For positive displacement pumps: when the flow is greater than or equal to 5 \( \text{m}^3/\text{h} \), \( k_2 = 0.75 \sim 0.85 \); when the flow is less than 5 \( \text{m}^3/\text{h} \), \( k_2 = 0.65 \sim 0.75 \). For centrifugal pump: when the flow is greater than or equal to 5 \( \text{m}^3/\text{h} \), \( k_2 = 0.85 \sim 0.95 \); when the flow is less than 5 \( \text{m}^3/\text{h} \), \( k_2 = 0.70 \sim 0.85 \).

For the Direct Current drive system, \( k_3 = 0.80 \sim 0.90 \); for the Alternating Current drive system, \( k_3 = 0.70 \sim 0.80 \).

\( k_4 \) is selected according to the parameters listed in Table 2.

| correction factor | solar energy resources \( \geq 1740 \text{ kW} \cdot \text{h} / (\text{m}^2 \cdot \text{a}) \) | solar energy resources \( 1400 \sim 1740 \text{ kW} \cdot \text{h} / (\text{m}^2 \cdot \text{a}) \) | solar energy resources \( 1160 \sim 1400 \text{ kW} \cdot \text{h} / (\text{m}^2 \cdot \text{a}) \) | solar energy resources \( < 1160 \text{ kW} \cdot \text{h} / (\text{m}^2 \cdot \text{a}) \) |
|------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| \( k_4 \)        | 0.9                     | 0.8                     | 0.7                     | 0.6                     |

\( k_5 \) is selected according to the parameters listed in Table 3.

| correction factor | fixed type | Single axis tracking | dual-axis tracking |
|------------------|------------|----------------------|-------------------|
| \( k_5 \)        | 1          | 1.1 \sim 1.15        | 1.17 \sim 1.22    |

4. Conclusion

Solar water-saving irrigation technology is a technology with broad application prospects and great social and economic value. In the remote areas lacking power supply in Northwest China, the development of solar water-pumping and water-saving irrigation technology can not only make full use of widely distributed green energy, develop irrigation agriculture and animal husbandry, but also protect the ecological environment on which humans depend.

The photovoltaic water-pumping direct drive water-saving irrigation system, which is composed of photovoltaic water-pumping equipment, automatic adjustment system and water-saving irrigation...
equipment, uses automatic control technology and adopts a district rotation irrigation method to ensure the stable operation of the irrigator and irrigation uniform in each area. It has the advantages of simple design, low cost, stable operation, energy saving and environmental protection. At the same time, the optimized design method in this article can guide the engineering design of solar water-saving irrigation, and greatly improve the engineering quality and energy efficiency.

Under the premise of ensuring the normal and stable operation of photovoltaic water-pumping and water-saving irrigation equipment, according to the water demand law of crops, and in combination with crop irrigation system, timely and appropriate automatic irrigation can be implemented, and integrate the intelligent irrigation system and automatically controlled photovoltaic water-pumping and water-saving irrigation. The combination of systems and the development of a high-guaranteed intelligent photovoltaic water-pumping and water-saving irrigation system is the focus of the next step.

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