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STUDY ON WIND-SOLAR COMPLEMENTARY WATER SUPPLY TECHNOLOGY FOR ARID PASTURES IN NORTH CHINA

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ABSTRACT

Arid pastures in northern China are scattered and large in area. Most pastures have no conventional energy power to provide stable living and production water for residents. In this paper, the typical pasture in northern China is taken as the research object. Relying on the abundant renewable energy resources and good complementarity of wind and solar energy resources, the technology of wind-solar complementary water supply for pasture is studied. In order to verify the applicability of wind-solar complementary water supply technology, water supply experiments were carried out in summer and winter in Siziwang Banner Pasture. The results show that the guaranteed rate of water supply in the experimental area using wind-solar complementary water supply technology is 142%, which fully meets the design requirements, and solves the problems of water consumption for living and production of the residents in the experimental area. It fully shows that the technology of wind-solar complementary water supply is an efficient solution to the problem of water supply in arid pasture, which provides reliable technical support for water supply in pasture.

Keywords: renewable energy resources, water supply technology, wind-solar complementary, pasture

NONMENCLATURE

WSC	wind-solar complementary
SR	*solar radiation*
P_w	wind turbine power,kW
P_s	solar array power,kW
Q	daily pumping water volume, m^3
H	total pumping head, m
ρ	water density, kg/m^3
g	gravity acceleration, m/s^2
η_1	pumping efficiency,%
η_w	wind turbine efficiency,%
η_s	solar cell efficiency,%
t	full load working hours of solar array , h
$\eta_{p\max}$	guaranteed rate of daily water supply, %
Q_h	daily water demand of the weakest solar day and the smallest wind in the whole year, m^3/d

1. INTRODUCTION

The pasture in northern China is located in the non-monsoon area, with an average annual precipitation of less than 400 mm and a shortage of surface water resources. Because of the high line loss and low benefit of power grid construction caused by the dispersal of herdsmen's residence in the region, the conventional energy is relatively scarce[1]. The water consumption of herdsmen and livestock is an urgent problem to be solved at present.However, there are abundant wind and solar energy resources in the vast northern pastures of China. These areas are very suitable for developing water supply mode powered by wind and solar energy. Therefore, the use of renewable energy is an effective way to solve the shortage of water resources in arid pastures[2-3].

The complementary combination of wind energy and solar energy rationally realizes the comprehensive utilization of natural energy resources and technology integration. Due to the strong complementarity between wind and solar energy, WSC technology makes up for the instability and low efficiency of wind energy and solar energy independent system[4-7].

2. COMPOSITION AND WORKING PRINCIPLE

As shown in Figure 1. The WSC water supply system consists of three parts: energy supply module, control module, pump and storage module. The energy supply module is composed of wind turbine and solar array. The control module is a control cabinet which integrates rectifier, DC bus, inverter and frequency converter. The pumping and storage module are composed of water well, water pump and water reservoir.

The control module controls the current conversion and interruption of wind turbine and solar array. It can also change the operation mode by setting time and power. The water pump is fixed in the well and transported to the water reservoir through the water pipeline. Wind and solar resources show obvious complementarity in summer and winter. In summer, solar water supply system is the main system, which works continuously in the effective solar energy resources time. The deep well water source is pumped continuously to the reservoir. When water is needed, open the valve of the reservoir and transfer the water to the water terminal. When solar energy resources are insufficient in winter, wind energy will be the main source of water supply to ensure the stability of water supply throughout the year.

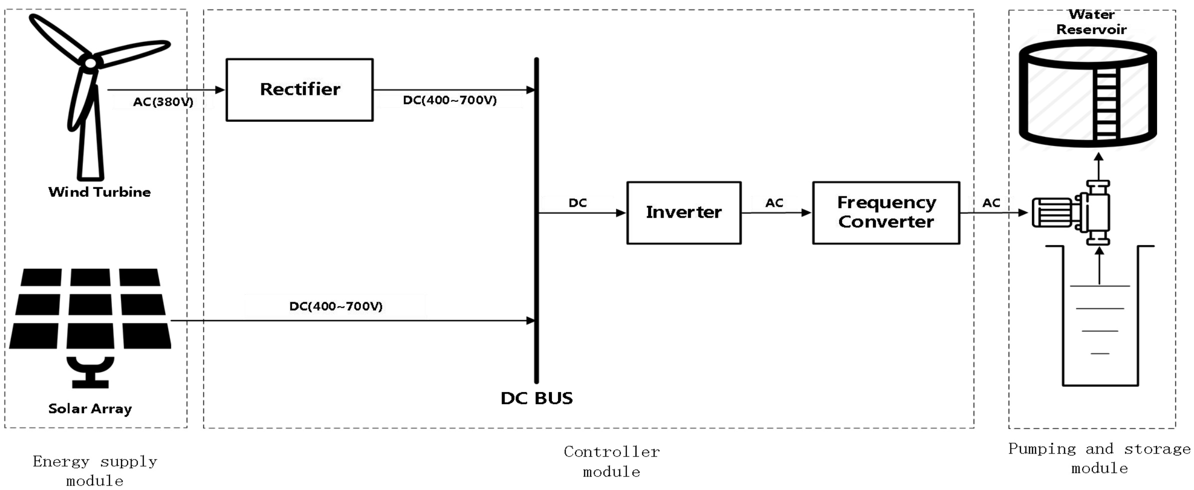

Fig 1 Schematic diagram of wind-solar complementary water supply technology

3. CALCULATION AND DESIGN

The key technology of WSC water supply system is WSC controller and optimization calculation method. By calculating wind energy, solar energy conversion energy and the energy needed for pumping water, the control module can match wind and solar energy scientifically and reasonably, which can not only save water supply cost, but also improve the operation life of water supply system and guarantee rate of water supply[8].

3.1 Calculation of wind turbine and solar array capacity

Daily pumping water volume Q is set according to the demand of application area. Wind turbines operate uninterruptedly. And the running time of solar array t is determined by local solar resources. The capacity of wind turbines and solar array are determined according to the following formulas:

$$P_{\mathrm{w}}=\left(\frac{Q}{24\times 3.6}H\times\rho\times \mathrm{g}\right)/(\eta_1\eta_{\mathrm{w}}) \tag{1}$$

$$P_{\mathrm{s}}=\left(\frac{Q}{\mathrm{t}\times 3.6}H\times\rho\times \mathrm{g}\right)/(\eta_1\eta_{\mathrm{s}}) \tag{2}$$

3.2 Matching design of control module

The rated voltage of wind turbine outlet is 380V. After rectifying, 400-700V DC current is obtained. The outlet voltage of solar array is 400-700V DC current. Two sets of lines are input to the inverter via DC bus, and then the pump is driven by frequency converter. The rated output voltage of wind turbines is 380V, which refers to the output voltage under the rated wind speed, but in practice the wind speed is changing, so the output voltage of wind turbines is also changing. In order to use wind energy in a larger range, DC-DC converter is used to maintain the rectified voltage to a certain value. As can be seen from Figure 1, this constant is the output voltage of the solar array[9].

4. EXPERIMENT AND RESULTS

4.1 Experimental conditions and equipment

The experimental area is located in Siziwang Banner pasture of Ulanchabu, which belongs to temperate grassland. Its main climatic characteristics are strong wind, drought, cold and rainfall of 100-400 mm. Herdsmen live dispersedly, and the production mode of animal husbandry is backward, which is a typical representative of arid pasture in the north. This experimental area involves 10 herdsmen families, and needs to solve the drinking water problem of 40 people and 2000 sheep. In order to meet the experimental requirements, 20 tons of daily water supply is required.

The solar array operates at a fixed inclination. According to the local solar resources, the full load hours are 5 hours and the water supply flow is 4 m^3/h. According to the calculation of 3.1 subsections, the installed capacity of wind turbine is 2 kW and that of solar array is 3 kw. The experimental equipment is shown in Table 1.

Tab 1 experimental equipment

Experimental equipment	Model	Company
SR recorder	CMP3	Kipp&Zonen
anemometer	Davis Cup Anemometer	Decagon Devices
flowmeter	LDG-SIN	SINOMESURE

4.2 Experimental method

The SR recorder is installed beside the solar array and adjusted to the same inclination angle. The flowmeter is installed at the entrance of the reservoir to facilitate data acquisition. The installation height of the anemometer is the same as that of the fan, and it is monitored 24 hours in real time.

As a typical month in mid-summer and mid-winter, the continuous experimental of SR and wind speed as well as corresponding pump water volume was carried out. The data acquisition time was once an hour, and the flow rate was taken as the average of that hour. The experiment mainly studies the operation of the WSC water supply system all day in summer and winter, and whether it can meet the design requirements.

4.3 Results and discussions

According to Fig 2 , Fig 3 and Fig 4, the average SR in July was 784.98w/m^2/d and the average daily pumping capacity was 23.82m^3. The total water pumping capacity of solar water pumping unit can reach 738.42 m^3 in the whole month. The average SR in December was 518.88w/m^2/d, and the average daily pumping capacity was 13.6m^3. The total water pumping capacity of solar water pumping unit can reach 422.84 m^3 in a month.

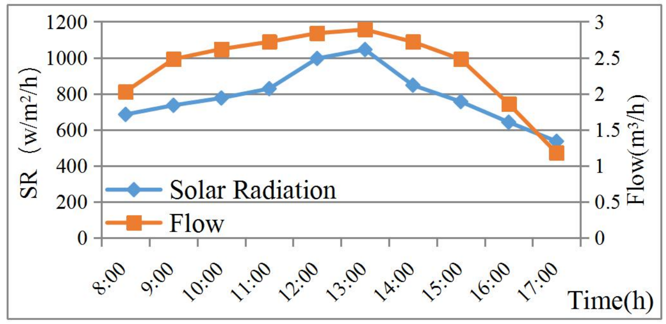

Fig 2 Diurnal variation of solar radiation and water flow in July

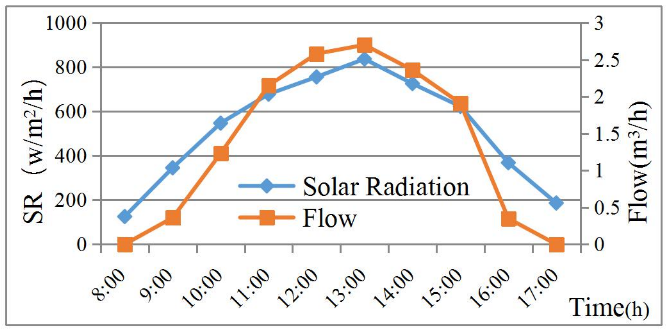

Fig 3 Diurnal variation of solar radiation and water flow in December

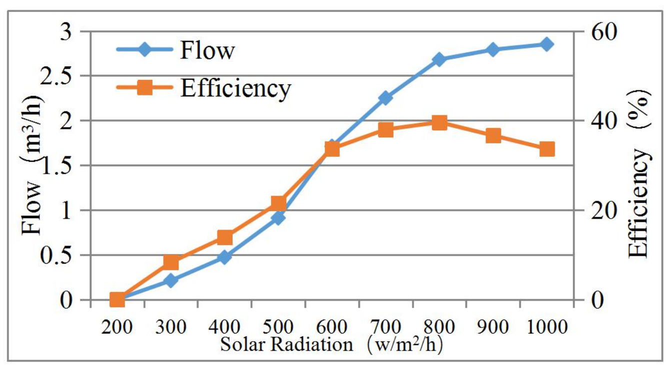

Fig 4 Characteristic of 3 kW solar water pumping system

According to Fig 5 and Fig 6, the average wind speed in July was 4.3m/s, and the average daily pumping capacity was 14.9m^3. The average wind speed in December was 6.2m/s, and the average daily pumping capacity was 29.6m^3.

The pumping flow is positively correlated with SR and wind speed, and the average SR in summer is significantly higher than that in winter, and the water supply amount of solar energy in winter varies greatly due to the fluctuation of SR, so the water supply capacity of solar energy in summer is higher than that in winter. As shown in fig 6 and fig 7, the average wind

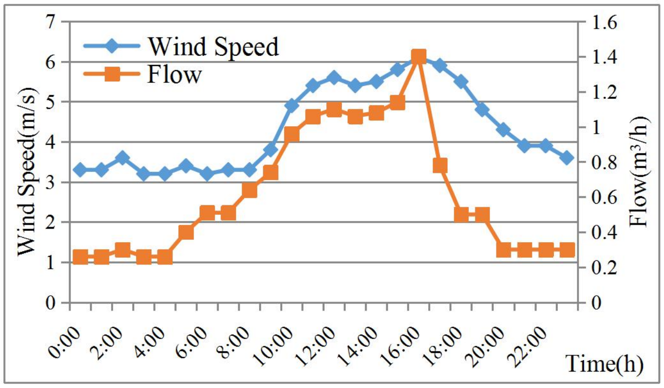

Fig 5 Diurnal variation of wind speed and flow in July

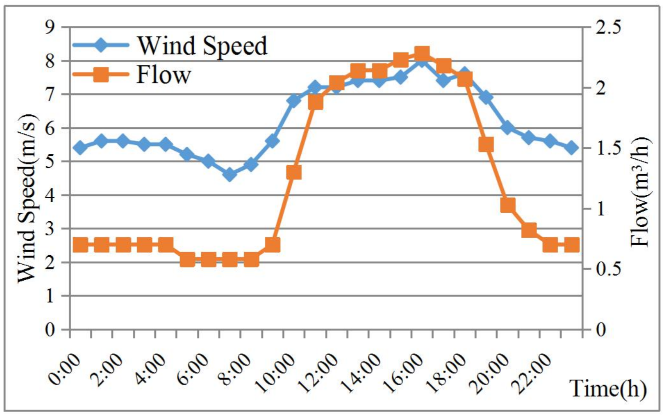

Fig 6 Diurnal variation of wind speed and flow in December

speed in winter is greater than that in summer, so the water flow of wind energy supply in winter is significantly greater than that in summer. The complementarity of wind and solar energy resources is very effective in stabilizing water supply capacity, ensuring water supply capacity at different periods of the year. And in Fig 5, when the SR is about 700w/m^2/d, the pump efficiency reaches the highest 39%. With the increase of SR, the pump efficiency decreases. Therefore, according to the different solar energy resources, reasonable matching of pumps is also very important.

In order to verify whether the WSC water supply system meets the design requirements in this experiment, the guaranteed rate of water supply is calculated as follows:

$$\eta_{p\max} = \frac{Q_h}{Q} \times 100\% = \frac{13.6 + 14.9}{20} \times 100\% = 142\% \quad (3)$$

The calculation results show that the water supply guarantee rate is 142%, which can satisfy the water supply of the experimental area for the whole year.

5. CONCLUSIONS

The excellent complementarity of wind energy and solar energy resources in the annual water supply is confirmed through the typical monthly experiments in summer and winter, and the 142% water supply guarantee rate ensures the stability and efficiency of the water supply for human and livestock in the experimental area. The clean and renewable use of new energy also protects the pasture ecological environment and avoids the high energy consumption and pollution emissions caused by other conventional energy sources.

In future work, it is necessary to further study the complementary operation of WSC water supply technology in daytime and night, so as to enhance the complementarity of wind and solar resources.

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