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Research on comparative advantages of SPV pumping irrigation systems

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Abstract. Agricultural production relies heavily on irrigation, and water pumping for irrigation consumes a great amount of electricity every year in China. Meanwhile, more land in remote areas is barren because of lack of electricity and access to irrigation. Till now, most research works have been focused on the technological aspects of SPV irrigation system, very few studies were reported on economic and financial aspects of the system. The main barrier to promotion and application of SPV irrigation systems seemed the high initial investment. To analyse and clarify the comparative advantages of SPV facilities, the life cycle cost, energy consumption and pollution emission of pump stations powered by SPV, electricity and diesel was calculated respectively through a case study. The initial investment ratio of SPV, electricity and diesel pump station is 12.7:9.3:1, while the life cycle cost ratio of them becomes to 1:1.59:1.88, the SPV turned out to be economical, energy saving and environmental friendly. Policy suggestions on encouraging the construction of photo-electric complementary pumping stations and financial support to water users are put forward to make good use of SPV systems and release the financial burden from the initial investment.

1. Introduction

Agriculture is the largest water user in China. More than 60% of the water consumption is used for agricultural irrigation [1]. Because of topographic limitation, the majority of irrigation water needs pumping to farm fields. In 2015, about 60% of the total irrigation area was watered by pumping. The installed capacity of electromechanical drainage and irrigation was 52 GW; the power consumption for irrigation and drainage is about 6% of the total consumption [2]. Meanwhile, more land in remote areas in China is barren because of lack of electricity and access to irrigation. This is partially why China, as a big agricultural country, still imports grain. Solar power is clean, renewable and widely available energy. With the development and application of SPV in irrigation, we could cultivate more land and increase grain production. If part of the pump stations in China were powered by solar energy, it would save a great amount of electricity and a big bill of power every year. Till now, most research works have been focused on the technological aspects of SPV irrigation system, very few studies were reported on economic and financial aspects of the system. In most of the studied cases, the investment was from government subsidy or other sponsors [3], [4], [5], [6]. There is basically a consensus that SPV system is beneficial to public, not to water users, because SPV facilities are more expensive than conventional ones. This situation is not only happening in China, but also in other developing countries, like Bangladesh, Indonesia, and India [6], [7], [8].

The experimental irrigation area of the study is located in the Jiangdong base of Zhejiang irrigation experiment center station in Xiaoshan district, Hangzhou, covering an area of 8ha, of which 4.27ha is

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fruit and vegetable farm and the rest 3.73ha is rice field. Taking the reseeded area into account, the annual planting area is about 13.6ha. The fruit and vegetable farm is irrigated by drip and spray micro irrigation, while the rice field is irrigated by low-pressure pipelines. The irrigation pressure is h=13.86m, and the total head required is about 50m. In order to improve the efficiency of irrigation system, the irrigation area is divided into 15 alternate irrigation areas. The irrigation flow required is 15m^3/h. The test base originally had an electric water pumping station. During the infrastructure upgrading in 2017, the location of the water intake was moved, the old pump station had to be reconstructed. After analysis and comparison, it was decided to rebuild the pump station with SPV. The water source is from the river on the north side of the base. A water tank with a volume of 56 m^3 was built on the roof of the main building as a storing and regulating container [9].

The objective of the study is to reveal the advantages of SPV pump system through calculating and analyzing the life cycle cost, energy consumption and pollution emission of pumping stations powered by SPV, electricity, and diesel engine on the basis of the case study. As the area, planting structure and technology of the irrigation area have not been changed after the reconstruction of the pumping station, the production and output value were assumed to be unchanged.

2. Benefit analysis to SPV pumping stations

To compare the characteristics of different power pump stations comprehensively, the economic benefit, energy saving and pollution emission were calculated and analysed respectively.

2.1. Economic benefit

No matter what kind of energy the pumping station is applying, the water requirements of the irrigation area shall be completely satisfied. The planting structure, farming techniques, yield and output value of the irrigation area shall not be changed due to the adjustment of pumping power type. Therefore, the study focused on the cost of irrigation water.

To calculate and compare the cost of irrigation systems, comprehensive consideration should be given to the construction cost, operation maintenance cost and fuel power cost of the whole life cycle of the irrigation system. The life cycle cost evaluation methods including the life cycle cost present value method (CPV) and the life cycle cost annual value method (AV) could be applied for calculation and analysis [10].

$$\mathrm{CPV} = \sum F \times (1+i)^{-n} + A \times \frac{(1+i)^n - 1}{i(1+i)^n} \quad \text{..... (1)}$$

Where, F- Investment, including initial and reset investment, in 10k RMB;

A- Annual operation and maintenance cost, in 10k RMB;

i-The interest rate, take 6% in the case study;

n- Time of payment, in annual terms.

$$\mathrm{AV} = \mathrm{A} + P \times \frac{i \times (1+i)^n}{(1+i)^n - 1} \quad \text{..... (2)}$$

Where: AV-Average annual cost in the life cycle, in 10k RMB;

P-Present value of investment, including initial investment and the present value of each reset investment, in 10k RMB.

The life cycle is consistent with the land circulation cycle, i.e. 20 years. The equipment scrapped in advance would be reset according to the original value. The equipment investment, annual operation and maintenance cost of the pump stations are listed in table 1, the useful life of the pumping devices is as follows, 20 years for SPV pumps, 10 years for electric pumps, and 5 years for diesel pumps. The data was from the newly built SPV pump station and the old electric pump station. The data of the diesel pump station was from market investigation.

The CPV and AV of solar, electric and diesel power pumping stations were calculated separately according to equations (1) and (2). The initial investment of the SPV pump station is much higher than that of the two other pump systems. It seems that the SPV pump is very expensive, but the calculation

of full cost of whole life cycle given out a totally different conclusion because of high electricity or diesel bill. The SPV pump CPVs=104.70kRMB, the electric pump CPV_e=166.94 kRMB, and the diesel pump CPV_d=196.48 kRMB.

Table 1. Cost of pump stations(10k RMB).

Kind of power	Initial Investment	Operate & maintain cost	Annual power cost
Solar energy	7.6	0.25	0
Electricity	5.6	0.30	0.41
Diesel	0.6	0.55	1.02

The average annual value of SPV pump station AV_s=9.13 kRMB /a, that of the electric power pump station AV_e=14.55kRMB /a, and that of the diesel pump station AV_d=17.13 kRMB /a. The life cycle cost of electric pump station and diesel pump station is 59.41% and 87.62% higher than that of the SPV pump station respectively. The annual cost of different pump stations was clearly shown in Figure 1.

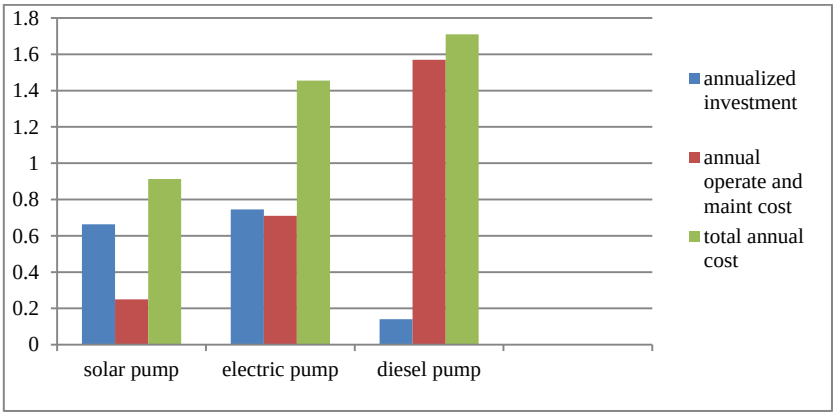


Figure 1. Annual cost of pump stations (k RMB).

2.2. Sensitivity analysis

The economic benefit of a project could be affected by a various factors. As general, the most sensitive negative factors are the increase of investment and interest rate when the output of the project is certain. The prices of electrical and diesel pump equipment are relatively stable as the technology and market is mature for long time. Nevertheless, SPV is an emerging technology, the price of solar panel decreased obviously with the mature of the technology and boosting of production. So, for SPV irrigation system, the variation of price means the decrease of investment, it is sure a positive sensitive factor. In this study, only increase of interest rate is considered as the main sensitive factor.

Suppose the interest rate increased to 10%, while other factors kept the same. The CPV, VA of the different irrigation systems would be changed as follows:

CPVs=97.28 k RMB, CPVe=112.46 k RMB, and CPVd=147.12 k RMB;

AVs=11.43 k RMB, AVe=13.21 k RMB, and AVd=17.28 k RMB.

The life cycle cost of electric pump station and diesel pump station is 15.60% and 51.23% higher than that of the SPV pump station respectively. The result of sensitivity analysis shown that with the increase of interest rate, cash becomes more valuable, the economic advantage of SPV has waned relatively, but is still there. The SPV system not only has the advantage, but also has certain flexibility.

2.3. Energy-saving benefit

The year of 2017 is a typical average year in Hangzhou, with a precipitation of 1550mm, very near to the average value of the area. Therefore, the precipitation data of 2017could be applied as the basis to calculate the average annual irrigation demand. In the irrigation season of 2017, from April to October, the days without rain was 138d. Considering the sun light radiation conditions, the working time was about 100d and the daily working time was about 6 hours. The annual working time of the system was about 600 hours, and the total amount of pumping water could be about 12,000 m^3 [9]. According to the experiment recording, the drip irrigation water amount for the peach tree field was about 1,500 m^3, and the water for vineyard drip irrigation was about 1,600m^3, with a total of 3,100m^3 for the fruit farm. And the rice field is fallow in 2017. That means the SPV pump station had not been fully utilized in 2017.

The Electricity price was 0.908 RMB/ kWh, diesel price was 6.1RMB/L in the irrigation season of 2017 in Hangzhou. Suppose the thermal efficiency of diesel engines were g=0.3 kg/kWh, belt transmission efficiency 80%, the energy saving benefit of SPV pump station was analyzed as shown in table 2. During the test period of 2017, the actual operation time of the SPV pump station was 155 hours, and lifted 3,100 m^3 of water. Compared to the old electric pump station, 1,163 kWh of electricity and a power bill of 1,056 RMB were saved. Compared to a diesel pump of the same function, 434 liters of diesel and a fuel bill of 2,647 RMB could be saved. If the SPV pump station were fully utilized, 4,500 kWh of electricity and 4,086 RMB, or 1680 liters of diesel and 10,248 RMB could be saved in the year of 2017. If 10% of the irrigation pumps in China were powered by SPV, 380 Gwh of electricity and 345 billion RMB of power bill could be saved annually.

Table 2. Energy saving benefit of SPV pump station.

Item	Lifting water(m^3/a)	Electric pump		Diesel pump	
		Electricity saving(kWh)	Cost saving (RMB)	Fuel saving (l)	Cost saving (RMB)
Real saving	3,100	1,163	1,056	434	2,647
Potential saving	12,000	4,500	4,086	1,680	10,248

2.4. Emission reduction benefit

In the coal-dominated power generation and supply power grid, the benefit of emission reduction is obvious when renewable and clean energy such as solar power is used instead of electricity from the grid [11]. In the test pump station, the energy saved could be calculated according to the average coal power conversion rate of standard coal 360gce /kWh, which could save about 1,620 kg of standard coal per year, and reduce 4,258 kg of carbon dioxide, 13.77kg of sulfur dioxide, 12.00 kg of nitrogen oxides and 4,00kg of soot emission annually [12]. If 10% of the irrigation pump stations in China were powered by SPV, $137*10^6$ tons of standard coal could be saved every year. Meanwhile, $360.00*10^6$ tons of carbon dioxide, $1.20*10^4$ tons of sulfur dioxide, $1.00*10^4$ tons of nitrogen oxides and $3.00*10^3$ tons of soot emission could be reduced annually. The solar power is surely clean and environmental friendly energy!

3. The characteristics of SPV pumping stations and applicable scenario

No matter which kind of energy is used, the pump is the core of the pumping system. As long as there is enough energy, the pump unit could be driven to operate and lift water. From this perspective, solar energy seems to be suitable for all occasions that require pumping irrigation. Nevertheless, compared to conventional energy sources, SPV pump stations have the following short comings:

(1) High investment is the main barrier to application of SPV [6], [7], [8], [13].
(2) Highly dependent on sunlight and low electricity guarantee rate is another constraint.
(3) The land requirement of system installation limited the power capacity [13].
(4) Difficulty and high cost of power storage limited the scale of development.

(5) Technical requirements for operation and maintenance hindered the application of SPV in remote communities [6].

To this end, SPV is not a substitution to all pump station's power, but a supplement to conventional energy. Upon analysis, SPV is suitable for the following occasions:

(1) Irrigation areas far from power grids

Near or far, distance is a relative concept. The route mileage and voltage level should be considered comprehensively. If the electricity is from the municipal power network, the connection cost is normally affordable. If the electricity is from a high-voltage power grid, even if it is near a pylon (Hypothetically permissible), it could be a "project" that needs to be approved separately. The "project" requires design and construction by qualified professional institutions, and could be costly.

(2) Small and medium sized irrigation areas

Despite the experience of building large-scale pumping stations, and even far away in Africa, considering the engineering reliability, economy and irrigation guarantee rate, it is not the best choice to build large-scale SPV irrigation projects, at least nowadays.

(3) Commercial crop irrigation areas

There are experiences of solar pump stations to irrigate rice field in Bangladesh [6], Indonesia [7], and India [8], however, it is most applicable to irrigation areas with small water demand per unit area, high added value of agricultural products, and low proportion of water cost to the output value. For grain farms, the per hectare water consumption is usually as high as 4,500m^3-7,500m^3, while the output is limited because of relatively low grain prices. Therefore, it is not appropriate to use SPV pump station to irrigate large scale grain field.

(4) Irrigation areas with condition to build a water tank

SPV pumping systems rely heavily on sunlight, and energy storage is costly. If there is a water tank storing and regulating water flow, instead of energy storage and regulation, the function of the pump station and the irrigation guarantee rate could be improved obviously and affordably.

4. Conclusions and suggestions

SPV pumping system is flexible and widely adaptable. In addition to water lifting irrigation, the SPV system could also supply power for lighting, light and sound for repellent of insects, birds and beasts. According to the life cycle analysis, the total cost of construction, operation and maintenance of SPV pump station is significantly lower than that of the conventional powered pump station. It is technically feasible, economically reasonable, and has the benefit of energy saving and emission reduction.

The research and development is required for new pump products adapting to SPV power characteristics. To promote the technology, the new products need to be standardized, serialized and modularized. Continuously improving of product quality, system reliability and durability, simplifying the technical requirements of installation, operation and maintenance would help the promotion and marketing of the technology.

It is suggested to encourage the construction of solar-electric complementary pump station [14]. When the sunlight is weak and insufficient to drive the pumps, the grid electricity takes part in water pumping, improving irrigation guarantee rate, and stabilizing the quality and output of agricultural products. In the non-irrigation seasons and periods, the SPV system generates and transmits electricity to the power grid, shortens the investment payback period, improves the investment efficiency, and makes contributions to energy conservation and emission reduction. Financial institutions should be encouraged to provide convenience and low rate loan to SPV irrigation developers to release their high investment burden.

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