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A STUDY OF HYBRID SOLAR-GEOTHERMAL POWER GENERATION SYSTEM

Yu-shi Wang, Jia-ling Zhu*, Yi-fan Sui, Yu-jiao Lei

Key Laboratory of Efficient Utilization of Low and Medium Grade Energy of Ministry of Education (Tianjin University), Tianjin 300072, China

*Corresponding author: zhujl@tju.edu.cn; Tel.: +86-(0)22-27401823; fax: +86-(0)22-27401823.

ABSTRACT

Aiming at the defects of low-efficiency power generation of medium-low temperature geothermal power plants, a medium-low temperature hybrid solar-geothermal power generation system was proposed. Through MATLAB simulation calculation, the performance analysis of the stand-alone geothermal plant and the hybrid solar- geothermal plant (HSGP) was carried out. According to ambient temperature, solar radiation intensity and geothermal resources, this paper selected areas with typical meteorological conditions for time-by-time simulation. The results show that the HSGP has better performance than the stand-alone geothermal power plant. When the power-increasing operation scheme is adopted, the HSGP in the Lhasa area has the largest increase in power generation compared to the stand-alone geothermal power plant, and the annual average monthly increase percentage is 3.0%. When the geothermal water-saving operation scheme is adopted, the HSGP in Xi'an area has the largest amount of geothermal water saving compared to the stand-alone geothermal power plant, and the annual average monthly savings is 4.0%. The simulation results provide a theoretical basis for the location and performance evaluation of the HSGPs.

Keywords: hybrid, solar-geothermal, power plant, performance analysis, power-increasing, geothermal water-saving

NONMENCLATURE

Abbreviations	
ORC	Organic Rankine cycle
HSGP	Hybrid solar-geothermal plant

Symbols	
Q	Quantity of heat, w
W	Work, kw
θ	Incident angle, °
A	Condenser opening area, m^2
I_b	Direct solar radiation, W/m^2
Subscripts	
collector	Solar collectors
solar	Solar energy
geo	Geothermal water
loss	Heat loss
wf	Working fluid

1. INTRODUCTION

The power generation cost of a stand-alone solar power plant is high, and the power generation is unstable due to the influence of solar radiation intensity. The stand-alone geothermal power plant is greatly affected by the distribution of geothermal resources, and the geothermal grade decreases as the mining continues. Stand-alone solar or geothermal power plants do not provide a consistently stable source of electrical energy. In order to make better use of solar energy and geothermal energy, domestic and foreign scholars have carried out extensive research on hybrid solar-geothermal power generation systems.

In the past few decades, researchers have tried many ways to combine the two energy sources in hybrid power systems. In general, they can be divided into the following categories: solar energy for overheating of working fluid [1], solar energy is used for geothermal hot water preheating [2] (increasing geothermal water

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temperature or increasing geothermal steam content), steam overheating [3], or multiple coupling structure superposition [4]. Different hybrid modes are applicable to different geothermal reservoirs, geothermal power plant scales and main power cycle forms of power plants. Lentz and Almanza et al. [5] proposed a hybrid power generation system based on the existing Cerro Prieto geothermal power plant in northwestern Mexico. The system was used to study the influence of the placement direction of the solar concentrator on the system performance.

The thermal performance analysis, technical economic evaluation and optimization design of the hybrid power plant are increasingly developed. Cheng et al [6][7]conducted an in-depth evaluation of coupled energy generation, and compared the power generation and power costs of a HGSP, a stand-alone solar power plant, and a stand-alone geothermal power plant. Taking the meteorological conditions in Australia as an example, the effects of ambient temperature, solar irradiance and other parameters on the thermal performance of the power plant were analyzed. Zhang et al. [8] proposed a hybrid power generation system that increases solar superheater, and analyzed the feasibility of applying a hybrid power generation system with fixed heat collection area to Tibet.

Most of the methods for improving the efficiency of geothermal power generation mentioned in the domestic and foreign literatures are based on high-temperature geothermal resources, while there are few studies on medium-low temperature geothermal resources with more reserves in China. Based on typical geological conditions and meteorological conditions in China, there are few studies on site selection and performance evaluation of the HSGPs. This paper constructed a model of the hybrid solar-geothermal power generation system for air-cooled power plants with different geothermal and solar resources. The hourly simulation calculations were carried out in four areas of Tianjin, Xi'an, Lhasa and Guangzhou to compare the advantages of the HSGP in terms of net power generation and saving geothermal water.

2. MODELING METHODOLOGY

2.1 Description of the hybrid solar-geothermal power generation system

As shown in Fig.1, the hybrid power generation system mainly includes components such as evaporators, steam turbines, air-cooled condensers, working fluid pumps, and solar collectors. The hybrid

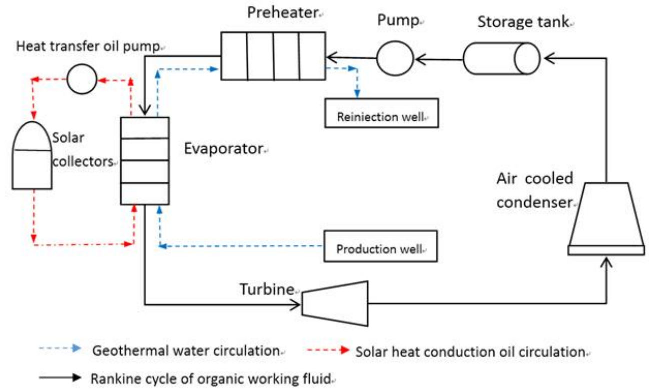

Fig. 1. Schematic diagram of the hybrid solar-geothermal power generation system

power generation system includes geothermal water circulation, solar heat conduction oil circulation and Organic Rankine Cycle (ORC). For geothermal water circulation: the geothermal water from production well firstly enters the evaporator, conducts heat to the working fluid, and undertakes evaporation and overheating of part of the working fluid. After that, the geothermal water flows into the preheater and preheats all the working fluid. Finally, geothermal water is injected into the reinjection well. For the solar heat transfer oil cycle: the heat transfer oil is heated in the solar collectors, and then flows into the evaporator to conduct heat to the working fluid, and undertakes evaporation and overheating of part of the working fluid.

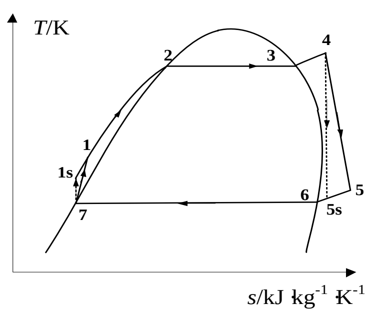

Fig. 2. T-S diagram of an ORC system

The basic working principle of ORC is shown in Fig. 2. The phase of working fluid changes after being heated by geothermal water and heat transfer oil in the evaporator (1-4). The high temperature and high pressure working gas then enters the steam turbine to produce work through expansion (4-5), which drives the generator to generate electricity. The exhaust gas is condensed into liquid in the air-cooled condenser (5-7), and will be pressurized after entering the working fluid pump (7-1).

2.2 Thermodynamics analyses

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The following thermodynamic model is used to analyze thermodynamic performance of the hybrid solar-geothermal power generation system.

For the hybrid power generation system, the heat absorption of the working fluid from the geothermal heat source can be expressed as

$$Q_{geo} = m_1(h_4 - h_1) = m_{geo}c_{p,geo}(T_{geo,in} - T_{geo,out}) \quad (1)$$

In the evaporator, the mass flow rate of the working fluid heated by the geothermal heat source is

$$m_1 = \frac{m_{geo}c_{p,geo}(T_{geo,in} - T_2 - \Delta T_p)}{(h_4 - h_2)} \quad (2)$$

The heat absorbed by the working fluid from the solar heat source is [9]

$$Q_{solar} = Q_{collector} - Q_{loss,total} - Q_{loss,piping} \quad (3)$$

Where $Q_{collector}$ is the effective solar radiation absorbed by the receiver, Q_{loss}, total is the heat loss of the absorption tube, and Q_{loss}, piping is the heat loss of the solar tube. Effective solar radiation absorbed by the receiver can be calculated by

$$Q_{collector} = AI_b\eta_{optical}IAM(\theta) \quad (4)$$

Where A is the louver opening area, I_b is the solar normal direct irradiance, $\eta_{optical}$ is the collector optical efficiency, and IAM(θ) is the incident angle correction factor.

In the evaporator, the mass flow rate heated by the solar heat source is

$$m_2 = \frac{Q_{solar}}{(h_4 - h_2)} \quad (5)$$

The total mass flow rate of the working fluid is

$$m_{wf} = m_1 + m_2 \quad (6)$$

The condenser heat transfer equation is

$$Q_c = m_c c_{p,c}(T_{c,out} - T_0) = m_{wf}(h_5 - h_7) \quad (7)$$

Steam turbine work volume and working fluid pump power consumption were obtained using Eqs.(8) and (9), respectively.

$$W_t = m_{wf}(h_4 - h_5) \quad (8)$$

$$W_p = m_{wf}(h_1 - h_7) \quad (9)$$

The net power output of the system is

$$W_{net} = W_t - W_p \quad (10)$$

3. RESULTS AND DISCUSSION

In this paper, the operation schemes of the HSGP are divided into power-increasing type and geothermal water saving type from two aspects of increasing power output and reducing energy input. In the power-increasing type, when the power demand is high during the day and the solar radiation is available, the geothermal well maintains a constant geothermal water flow, and the heat collecting system absorbs solar energy as much as possible, thereby increasing the system power. In the geothermal water saving type, the power generation of the HSGP is the same as that of the stand-alone geothermal power plant, and the geothermal water flow is reduced by inputting additional heat by the solar energy, thereby saving geothermal water resources.

According to China's 3,000-meter deep ground temperature distribution map [10], it can be seen that the four areas used for simulation calculations have different geothermal resources and can provide geothermal water with different temperatures. The geothermal water temperatures available in Lhasa, Guangzhou, Tianjin, and Xi'an are 125°C, 115°C, 105°C, and 95°C, respectively. The direct normal radiation intensity and ambient temperature data of the four regions are derived from the dynamic simulation results of the typical meteorological year database in TRNSYS16Z. The parameters used for the simulation calculation are shown in Table 1.

3.1 Hybrid Solar-Geothermal, Scenario 1: Increased power generation

Table 1. Main parameters used in simulation calculation.

Parameter	Value	Parameter	Value
Solar field area	2000m^2	Concentrator opening width	5m
Heat exchanger minimum temperature difference	10℃	Working medium superheat	3℃
Organic working media	Isopentane	Specular reflectance ρ	0.93
Absorption tube absorption rate α	0.96	Glass tube transmittance τ	0.95
Working fluid pump isentropic efficiency	80%	Turbine Isentropic Efficiency	75%

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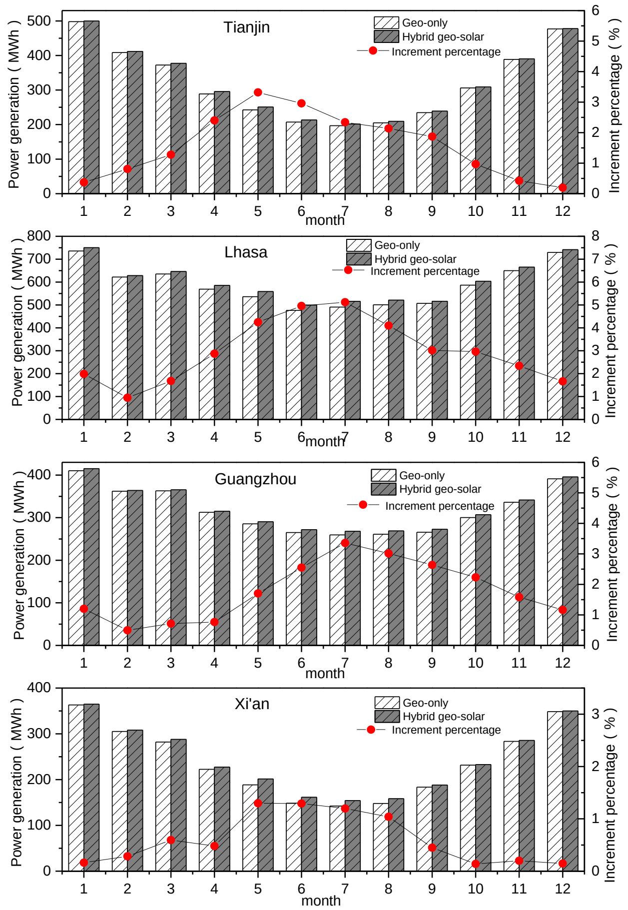

Fig. 3. Stand-alone geothermal plant and hybrid power plant time-by-time simulation calculation results, Scenario 1.

The fig.3 shows the results of simulation calculations for the four regions of Tianjin, Lhasa, Guangzhou, and Xi'an using the power-increasing power generation scheme. It can be seen from the figure that the stand-alone geothermal power plants in the four regions have lower power generation in the higher temperature summer season and higher power generation in the lower temperature winter. Therefore, we can see that the amount of power generated by a stand-alone geothermal power plant is greatly affected by changes in ambient temperature. By comparing the power generation of the stand-alone geothermal power plants in the four regions, we can see that the Lhasa region has the highest power generation and the Xi'an region has the lowest power generation. This is mainly because the annual average temperature in Lhasa is lower than that in Xi'an, and the temperature of geothermal water that can be supplied is higher than that in Xi'an.

After the solar energy is coupled into the geothermal power plant, by comparing the percentage increase of the power generation in the four regions, it can be seen that the HSGP in Lhasa has the largest increase in power generation, and the monthly average increment percentage is 3.0%. This is because the annual sunshine duration and sunshine intensity in Lhasa are better than the other three regions. After being coupled with solar energy, the percentage increase in power generation ranked from biggest to smallest: Lhasa, Tianjin, Guangzhou and Xi'an. In summary, the HSGP in Lhasa can generate more electricity than a stand-alone geothermal power plant. Therefore, if the power-increasing scheme is adopted, the Lhasa area is most suitable for the construction of the HSGPs.

3.2 Hybrid Solar-Geothermal, Scenario 2: Geothermal water saving

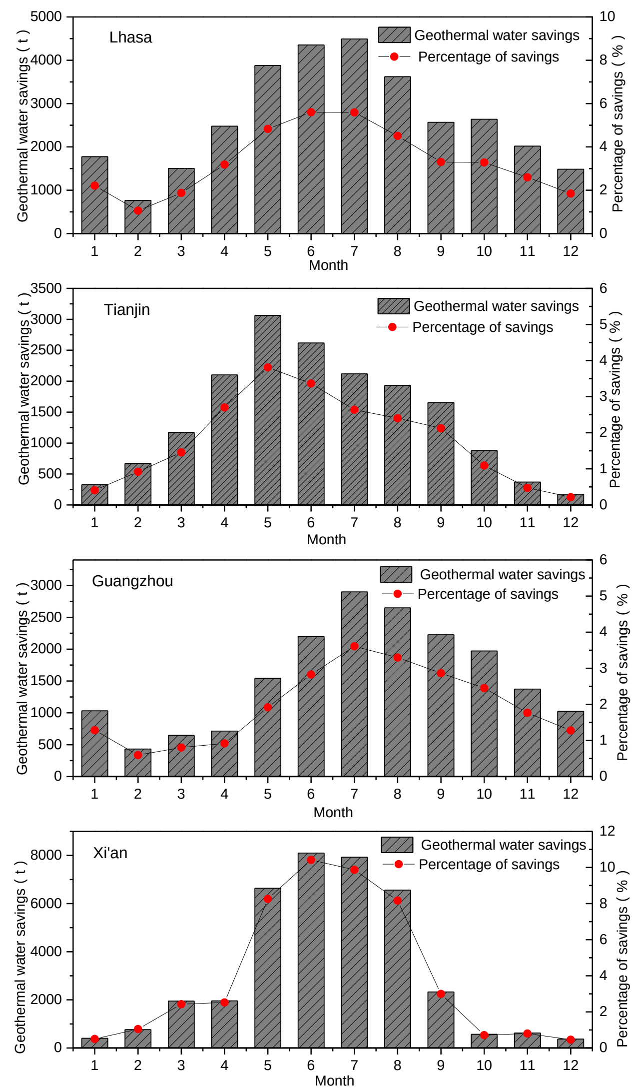

Fig. 4. Stand-alone geothermal plant and hybrid power plant time-by-time simulation calculation results, Scenario 2.

The fig.4 shows the results of simulation calculations for the four regions of Tianjin, Lhasa, Guangzhou and Xi'an using the geothermal water-saving power generation scheme. The flow rate of geothermal water in

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a stand-alone geothermal power plant is constant, and the flow rate of geothermal water is 30 kg/s throughout the year. After being coupled with solar energy, the amount of power generation is constant, and the consumption of geothermal water is reduced. It can be seen from the figure that the HSGPs in the four regions have a large amount of geothermal water saved in the summer with higher temperature; in the winter with lower temperature, the amount of geothermal water saved is smaller. This is because the summer solar radiation intensity is higher than that of winter, and the heat from the solar radiation can replace the heat of the geothermal water more.

After the solar energy is coupled into the stand-alone geothermal power plant, by comparing the percentage of geothermal water savings in the four regions, it can be seen that the HSGP in Xi'an has the largest amount of geothermal water savings, and the monthly average of the amount of geothermal water saved is 4.0%. This is because the temperature of geothermal water in Xi'an is the lowest, and the heat of the same amount of solar radiation can replace more geothermal water. After being coupled with solar energy, the amount of geothermal water savings ranked from biggest to smallest is: Xi'an, Lhasa, Guangzhou and Tianjin. Therefore, if the geothermal water saving scheme is adopted, the Xi'an area is most suitable for the construction of the HSGPs.

4. CONCLUSIONS

In terms of the purpose of coupling into solar energy, the HSGP has two operation schemes: power increase type and geothermal water saving type. Through the monthly analysis of the calculation results of the two schemes, the following conclusions are drawn:

(1) The monthly power generation of a stand-alone geothermal power plant varies, with lower power generation in the summer and higher power generation in the winter. Lhasa is best suited to build geothermal power plants by comparing the power generation of stand-alone geothermal power plants in four regions.

(2) If the power-increasing scheme is adopted, summer is better than winter in terms of annual power generation increment. Lhasa is best suited to build HSGPs by comparing the incremental power generation in the four regions.

(3) If the geothermal water saving scheme is adopted, the summer is better than the winter in terms of geothermal water saving. Xi'an is best suited to build HSGPs by comparing the amount of geothermal water savings in the four regions.

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