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Review on the development of solar geothermal complementary power generation system

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Abstract. Nowadays, due to the burning of fossil energy has many negative impacts on the environment, people are looking for new sustainable energy sources that can replace fossil energy, and among them, geothermal energy and solar energy are more prominent, but the two energy sources alone have certain shortcomings, and since complementary solar geothermal energy systems compensate for some of the shortcomings of the two energy sources, much research has been done in this field. This essay summarizes the conclusion from those studies and identify the shortcomings. The largest losses in the system are always in the solar power system. The component with the highest losses may be the evaporator or the trough solar collectors with over 50%. In a solar-geothermal complementary power system, the two energy sources promote each other and the system is more efficient in the summer than in the winter. In a solar-geothermal Organic Rankine Cycle power generation system, Supercritical Organic Rankine Cycle can be a better option than subcritical Organic Rankine Cycle for solar geothermal hybrid power production and cost control. And hybrid power plants benefits will increase over time

Keywords: Solar energy, Geothermal energy, Sustainable energy, Cleaning energy, Combination of solar and geothermal energy

1. Introduction

Both geothermal energy and solar energy sources are clean but have some drawbacks. The use of solar power generation alone has the disadvantages of intermittency and low power generation capacity, while the use of geothermal energy generation alone has the disadvantages of high equipment development costs and construction difficulties. Therefore, combining the two sources of energy can realize the advantages of the two resources in a complementary manner. A review of the literature revealed that Solar power systems are mainly based on the combination of trough solar collectors and Organic Rankine Cycle (ORC) generation. And geothermal energy is also used in the study of geothermal energy power generation system with ORC. It can be seen that ORC is present in both power generation systems and therefore the main research question in this paper is also the analysis of ORC and these experimental results. It is also necessary to compare the efficiency of the complementary generation system with that of the stand-alone system in order to prove the value of the complementary generation system. At the same time, it is necessary to find the units with the highest losses in the entire power generation system. The purpose of improving the system is to make it more efficient, and reducing losses is the key to improving efficiency. The components that are most likely to be lost in the literature are summarized, and then suggestions for improvement are made based on their characteristics.

2. Situation of the solar energy and geothermal power generation system

2.1. Solar Thermal Power Systems

According to the different types of solar collectors, which can be divided into trough-type solar thermal power generation system, dish-type solar thermal power generation system and tower-type solar thermal power generation system [1].

Table 1. Performance comparison of three solar thermal power generation [2].

	Trough	Dish	Tower
Installed capacity	1-320MW	1-200MW	5-25 KW
Level of commercialization	commercialized	demonstration stage	pilot phase
Cost/$.W-1	2.7-4.0	2.5-4.4	1.3～12.6
System Reliability	high	moderate	low

Table 1 is a comparison of three types of solar power technologies, through which solar thermal power generation is optimal in terms of capacity, level of commercialization, cost, and system reliability. The current mainstream of the field is also on trough collectors. Researchers and scholars all over the world have done a lot of research on trough solar collectors. Yang Lipo et al. designed a system that combines a trough collector with a gas turbine, and the study showed that the efficiency of the trough collector and the gas turbine of the combined system were both improved [3]. Qian Yu et al. combined solar collectors with coal-fired power generation, and found that the integrated power generation efficiency was increased by 10.3% through calculation [4]. In addition, compared with the study by Qian Yu et al. that combined fossil energy sources, Liu Yaodong et al. combined solar trough collectors with multi-walled carbon nanotube-heat-conducting oil nanofluids , which are therefore also cleaner [5]. Optical efficiency reaches a maximum of 84.1 per cent at a concentrator width of 2.5 m, and compared to the previous two, the contact medium in this study was changed from air to heat transfer oil nanofluids, so the insulation capacity was increased and the heat loss was reduced. However, the main problems of the current trough solar collectors still have the disadvantages of a large footprint land use, small solar energy utilisation, etc. However, the main problem of the current trough solar collector still has the disadvantages of large footprint, small land use, small solar energy utilisation, etc., which requires continued research on the material of the collector, to find the material that has a large solar energy absorption rate and can reduce the footprint.

After a lot of researches, it was found that the characteristics of trough collectors are a good match for the organic Rankine cycle .The basic principle is to use a low-temperature heat source to form high-temperature steam to push the turbine to do work and then generate electricity. The advantages of this system are that power generation can be controlled by varying the flow rate of the fluid and that the power station equipment is small. However, the circulation efficiency of the system is low and the investment costs are high. The solar ORC power station still in operation is the Saguaro power plant in the United States, which has a trough collector area of 10,000 square meters, an installed capacity of 1 MW, and a maximum temperature of 300 °C at the outlet of the solar collector [6].

2.2. Geothermal Power Systems

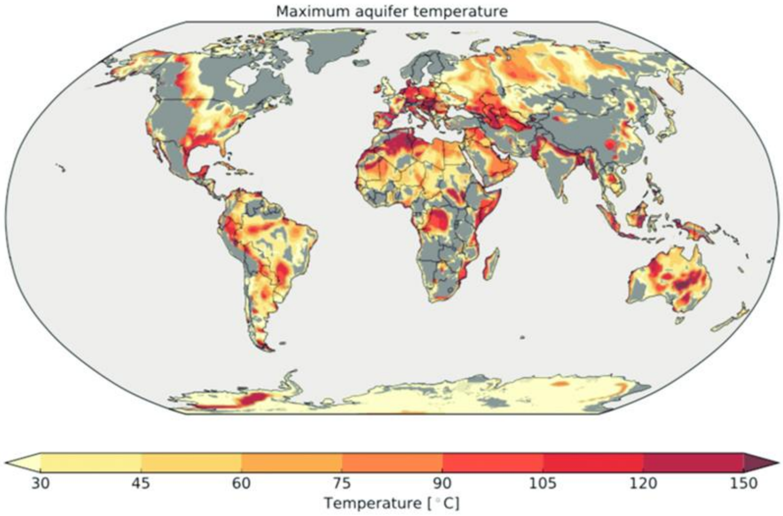

Figure 1. Global distribution of geothermal resources

Geothermal power generation system is similar to the solar thermal power generation system in that they also use the steam to promote the turbine to do work and then drive the power generation, but the difference lies in the different heat source. In the geothermal power generation system, the heat source should be the geothermal resources. By type, it can be categorized into geothermal dry steam power generation, hydrothermal geothermal power generation, and dry heat rock power generation; by temperature, it can be divided into high-temperature geothermal resources (>150°C), medium-temperature geothermal resources (90-150°C), and low-temperature geothermal resources (25-90°C). As can be seen from Figure 1, the Geothermal resources globally are still dominated by low and medium temperature geothermal resources.

Duplex electricity in the field of geothermal energy has given rise to the formation of geothermal energy ORC power generation technology since water at 100°C is suitable for duplex power generation systems and the global geothermal resource is dominated by low and medium temperature heat sources. There is a lot of research going on in this area. Typical geothermal dual-plant cycle power systems include single-stage ORC cycles and two-stage ORC cycles [7]. For the two-stage ORC cycle structure, Shokati et al [8] analyzed the single-stage ORC cycle, two-pressure ORC cycle, two-liquid ORC cycle, and Kalina cycle in terms of system energy, energy efficiency, and economy, and found that the two-pressure ORC cycle generating system has the largest net power output. Guzovic et al [9] used a dual-pressure ORC cycle power generation system instead of a single-stage ORC cycle power generation system based on a medium-temperature geothermal resource (100-180°C) in the Croatian region, and showed that the thermal efficiency of the dual-pressure ORC cycle system was slightly lower than that of the single-stage ORC cycle, but the system efficiency and the net work output increased by 25% and 20.89%, respectively. The advantages of this system are its simple and flexible capacity, more stable cycle, long operating life, and low heat source temperature requirements. However, it has some disadvantages such as lower energy rating and lower thermodynamic conversion efficiency.

3. Establishment of the solar geothermal complementary power generation system

3.1. Solar geothermal -ORC complementary power system

Independent geothermal power generation and independent solar power generation have their limitations. If, the two power generation technologies are combined, they can overcome some defects of independent power generation, so as to find a method that is both economical and able to give full play to the advantages of the two types of energy sources. Both power generation systems are well matched to ORC.

This creates a solar geothermal ORC power system, and many scholars have carried out in-depth research on this power generation system.

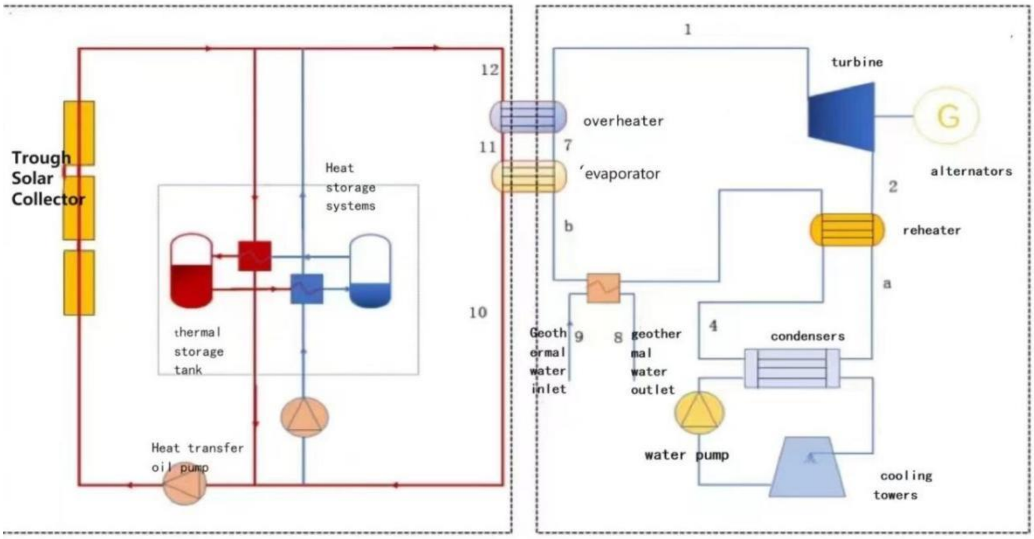

Figure 2. Diagram of the working principle of the solar geothermal ORC power system [10]

Figure 2 shows the working principle of the Solar Geothermal Organic Rankine Cycle power system constructed by Leng Weiting [10]. Experiments were carried out at design conditions of DNI = 600 W/m2, SM = 1.8, and TES hours = 2.5 h. The results show that the system generates the highest power when the evaporation temperature is 127.3°C, corresponding to an evaporation pressure of 2.2 MPa. However, there are some disadvantages to this system. The system's energy loss is very large, and when the solar radiation is small, in order to collect the required heat, it is necessary to increase the area of the collector field, which, in turn, highlights the disadvantages of the solar collector even more. Responding to these deficiencies, scholars' studies have also responded accordingly. Firstly, Lu Jiawei [11] designed a new type of geothermal energy and solar energy complementary combined cooling, heating and power system, and designed different coordinated operation modes of Type I and Type II absorption heat pumps to meet the user load demand. Compared to Leng, Lu's design has more gas boilers, lithium bromide absorption refrigeration systems, heat exchanger systems. This reduces energy loss in terms of increased energy utilization and allows for the use of gas boilers for regulation when solar radiation is low. In addition, Rafika MAALI et al. [12] find that the general solar geothermal energy ORC power generation system's main source of irreversibility was the parabolic through collector. They reduce exergy destruction by optimizing polynomial regression analysis, which is more direct than Lu's method.

The common point of the system constructed by the three is that the whole system is constructed with an ORC cycle and all of them use the trough solar collector as the collector device. While the system's efficiency is limited to a certain interval, it is also because the system's exergy destruction is too large, so it is also possible to join the same as Lu to make up for the collector to absorb solar energy, but the efficiency will be higher than the gas boiler, and it is also possible to select a more suitable fluid as the ORC work material.

3.2. Supercritical ORC and subcritical ORC Solar Geothermal power system

Supercritical ORC has a higher conversion rate than normal cycles due to better adaptation in heat exchangers. And Cheng Zhou et al. [13] used ASPEN HYSY to carry out simulation experiments, set up supercritical ORC coupled power generation system, subcritical ORC coupled power generation system, stand-alone solar power generation system, stand-alone geothermal power generation system several groups and from the perspective of technology, economy, and characteristics to make comparisons. The results of the study were made more rigorous and convincing by having a comparison group. And the experimental results show that when the solar energy exergy input exceeds 66%, the supercritical ORC coupled generation system has a higher power generation level performance than the subcritical ORC coupled generation system, and both are higher than the two independent power generation systems, and the cost of the supercritical ORC coupled generation system is lower than the subcritical one. Characteristic value analysis shows that the maximum output of the subcritical ORC-coupled plant and the supercritical ORC-coupled plant exceeds that of the two stand-alone plants by 15% and 19%, respectively. So, it can be seen that Supercritical ORC can be a better option than subcritical ORC for solar geothermal hybrid power production.

4. Losses and performance analysis of Solar Geothermal complementary power generation system

A summary of these studies reveals that the largest variations in the percentage of losses in coupled generation systems are found in solar power systems, with a difference of more than 15% between summer and winter. Components with the largest share of losses in the coupled system may be biased due to the effects of geoclimatic and geothermal source temperatures. The experimental results of Wang Yu et al [2] showed that the evaporator accounted for the largest percentage of exergy destruction, while experiments by Wan Pepe et al [7] showed that the exergy destruction of the trough collector is the largest percentage and to be more than 50%. Therefore, as shown by the experimental results, the drawbacks of the trough solar collectors are now also highlighted in the complementary systems. As a matter of that, the most fundamental way to improve the efficiency of the system is still to use more suitable materials to reduce the heat loss from the solar collector.

Moreover, Leng Weiting [10] and Wang Yushi et al showed that complementary systems are the most efficient and longest-running in the summer, and the least efficient and unstable in the winter. In the coupled power generation system, the two energy sources have a mutually reinforcing effect. In the summer months, geothermal energy is naturally more efficient due to the high temperatures as well as the high intensity of solar radiation, while in the winter months, it is less efficient due to the low intensity of solar radiation as well as the low temperatures. It can be seen that temperature has an impact on the complementary power generation system, and mainly on the geothermal power generation sub-system, so the insulation capacity of the system also becomes particularly important. Therefore, in order to ensure the temperature loss of geothermal resources, reduce the output of geothermal power generation system in winter and increase the output share of solar power generation system, geothermal power generation system can be constructed by choosing materials with better thermal insulation performance, so as to reduce the loss and improve the efficiency of the system.

5. Conclusion

In terms of complementary power systems, the highest losses are found in the solar power system. However, due to the different temperatures and flow rates of many experimental geothermal sources, the components with the highest losses are likely to be either the evaporator or the trough solar collector, both of which are more than 50%, but the trough solar collectors' losses account for the biggest change with 19%-25% in summer and 4%-9% in winter, which is due to the fact that current technology underutilizes solar energy and cannot control its loss. Therefore, there is a need to use more suitable materials to increase the utilization of solar energy and to reduce solar energy losses.

The improvement in power generation performance through coupled solar energy is more significant in summer than in winter. This is because of the significant reduction in geothermal energy input during summer, owing to higher environmental temperatures. Conversely, in winter, the environmental temperatures are lower, and the geothermal energy input is higher. It also follows that Solar energy inputs significantly contribute to increased geothermal energy use.

Characteristic value analysis shows that the maximum output of the subcritical ORC-coupled plant and the supercritical ORC-coupled plant exceeds that of the two stand-alone plants by 15%and 19% respectively, and are higher than stand-alone solar power systems and geothermal power systems. Therefore, supercritical ORC can be a better option than subcritical ORC for solar geothermal hybrid power production and cost control. As a result, the use of solar-geothermal complementary ultra-organic ORC power generation systems is more efficient when setting up a power plant.

Compared to stand-alone power plants, hybrid power plants have higher levelised cost of electricity and longer payback periods, but the NPV of hybrid power plants is slightly higher than that of stand-alone geothermal power plants, which suggests that hybrid power plants are more profitable than stand-alone power plants in the long run.

There are still some shortcomings in this research area. First of all, it Lacks life expectancy of solar geothermal energy generation systems. Over time, the nature of the geothermal resource for geothermal energy may change circulation may also be affected. Therefore, it is necessary to carry out a dynamic study of the whole life cycle of the complementary power generation system. More importantly, regional factors and cost constraints still haven't been addressed. Not all areas are rich in both geothermal and solar energy, and the development costs of the systems are still high, with geographic constraints still unbroken.

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