Status and Future Development Prospects of CSP

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Abstract. As a type of energy which is clean, renewable and pollution-free, solar energy possesses a large amount of reserves but its energy flux density is low. Concentrating Solar Power (CSP) technology is an effective way of utilizing solar energy, which can be a replacement of thermal power. By ways of realizing peak load regulation in the grid, and greatly improving the transmission capacity of the power grid, CSP can provide a solution to the problem of abandoning wind and light in northwest China, and promote the sustainable development of clean energy in the whole country. In this paper, the key technologies of CSP are reviewed, and the present developing situations at home and abroad are summarized. In addition, the problems of CSP industry are analyzed and a series of solutions are proposed. Finally, the future directions of CSP and several improving measures are prospected.

1. Introduction

With the development of the economy, every country is facing many problems such as environment, energy and economy, especially the shortage of energy has affected the harmonious development of the society. With China's economic becoming the second largest in the world and the total energy consumption increasing significantly, there is a serious structural crisis in China's energy structure [1,2]. But China has a vast territory and abundant solar energy resources. According to long-term observations of more than 700 meteorological stations, the annual total solar radiation in all parts of China is roughly between $3.35 \times 10^3 \sim 8.4 \times 10^3 \text{MJ/m}^2$, which is equivalent to the heat generated by $114\text{kg} \sim 287\text{kg}$ standard coal [3,4]. However, the flow density of solar radiation per unit area is low, and the direct utilization method is inefficient. The best technical route to improve the solar energy utilization rate is to concentrate and reuse. Concentrated solar technology and heat storage technology can be intermittent solar energy into a continuous high quality of schedulable foundation energy, it will be a revolution in the process of energy production, alternative thermal power, achieve peak shaving, a sharp rise in the power grid transmission capacity, can solve abandon the abandoned some of the light problem, clean energy for sustainable development to provide a solution. In this paper, the key technologies of CSP are reviewed, and the present developing situations at home and abroad are summarized. In addition, the problems of CSP industry are analyzed and a series of solutions are proposed. Finally, the future directions of CSP and several improving measures are prospected.

2. The key technology of CSP

Concentrator solar thermal power technology refers to the use of concentrator to collect solar energy to heat the heat transfer working fluid to a certain temperature, through the heat exchange equipment
to transfer heat to the working fluid in the power loop or directly generate superheated steam, and finally into the turbine generator set to do work and output power. Its schematic diagram is shown in FIG. 1[5]. The concentrated solar thermal power generation system generally consists of five parts: solar thermal collection system, heat absorption and transport system, heat storage system, steam generation system, and power generation system[2]. It mainly involves optics, thermodynamics, materials science, mechanical engineering and other disciplines, and its development and utilization of key technologies mainly include: concentrated solar energy technology, solar tracking technology, heat storage technology, operation control technology and so on.

![Figure 1. Schematic diagram of CSP generation technology system.](image)

Concentrator is a method to increase the temperature of the solar collector by focusing solar radiation on the focus or focal line through the solar concentrator[3]. According to the concentrating mode, concentrated solar thermal power generation technology mainly includes trough type, tower type, linear Fresnel type and dish type[6].

Trough solar concentrator system uses parabolic mirror to focus the solar radiant energy on the vacuum collector tube located at the focal line, and heats the flowing working medium in the vacuum collector tube. The heated working medium conducts heat exchange with the low boiling point medium in the heat exchange system to generate steam, which drives the steam turbine generate electricity[7].

Tower solar concentrating system is a kind of large-surface reflector that focuses the reflection of solar radiation on the receiver, which converts the absorbed solar radiation energy into heat energy, and then into the heat exchange system and energy storage system, and finally into the thermal power machine to do expansion work and drive the generator to generate electricity[8].

Linear Fresnel solar thermal power generation technology is a technology that utilizes a linear Fresnel reflective collector to collect solar energy and generate high temperature and high pressure steam to drive a turbo generator for power generation[9,10].

The disk type system focuses the solar radiation energy on the stirling generator installed at the focal point through the disk concentrator, so as to realize the conversion of solar radiation energy to electric energy[11].

3. The status of CSP
In 1950, the former Soviet Union designed the world's first small tower solar thermal power test station, and carried out basic exploration and research on solar thermal power generation technology[12]. In the 1970s, due to the impact of the oil crisis, a group of scholars began to research and explore future energy solutions, and many countries took solar thermal power generation as the focus of research. Since the operation of SEGSI, the first thermal power station in California in the 1980s, people's enthusiasm for the development of solar power stations has been greatly stimulated [13,14,15]. Since 1991, global solar-thermal power generation has entered the stagnant stage for 16 years, until 2006 to start the first CSP project in Spain, global solar-thermal power recovery[16,17], the world set off a new investment and construction boom of field, CSP total scale continued to rise in recent years, the
whole industry chain of field in the stage of vigorous development. Throughout 30 years of development, the technology level of CSP is developing towards large-scale and large-scale\[^{18,19}\].

3.1. The status of international CSP

By the end of 2019, the world has built 6451 MWe, and the United States and Spain are the leaders in the global CSP market \[^{20,21}\]. The global cumulative installed capacity of CSP from 2012 to 2019 is shown in Figure 2, by the end of 2019, the proportion of CSP capacity in all countries is shown in Figure 3. In 2018, the global installed capacity of CSP increase greatly, mainly due to the completion and operation of several large-scale commercial CSP plant in emerging, such as Morocco, China, South Africa, Israel and Saudi Arabia \[^{22,23}\].

![Figure 2. From 2012 to 2019, the global cumulative installed capacity of CSP](image1)

![Figure 3. By the end of 2019, the proportion of installed CSP capacity ratio in the world](image2)

3.2. The status of China CSP

Since 1980, China put forward the related policy and planning for development of industry of concentrated solar \[^7\], after more than 30 years of technology research and development and practical application, key technology and equipment in concentrated heating, high temperature heat storage technology, photoelectric conversion, tracking technology, control technology, power plant construction, operation and maintenance has accumulated rich experience. At present, the installed capacity of CSP plant is relatively small, and few solar thermal power stations have entered into commercial operation, which is in the stage of system test demonstration and industrialization construction \[^{12,17,21}\].
4. Problems and solutions of CSP
Currently, the CSP stations that have been built have high production and manufacturing costs, and there is a deviation between the actual CSP conversion efficiency and the theoretical design value. There is still a lot of room for optimization and improvement in technology. In trough, linear Fresnel, and tower concentrating technologies, trough collectors have high efficiency, but there are also problems with complex supporting structures and difficulties in installation and construction. At the same time, due to the large windward area of the reflector, the potential deformation induced by the wind poses a great challenge to the efficient and safe operation of PTC. In trough, linear Fresnel concentrating collection technology, the single-axis tracking method is mainly used. In order to reduce the optical error, the dual-axis tracking system needs further research. In the tower-type concentrating collection technology, since the primary reflector is far away from the heat sink, there is a high requirement for tracking accuracy.

4.1. Heat transfer media
In the research of heat transfer media, synthetic oil, molten salt, and water are mainly used as working fluids in CSP stations that have been built. Test stations with other working fluids are under verification. The decomposition of synthetic oil above 400°C limits the thermodynamic cycle efficiency further improved. Molten salt can increase the operating temperature to 550°C, but the problem of molten salt freezing below 240°C has not been well solved, the cost is relatively high. The condensation of molten salt can use electric heating, also can use concentrator heating. DSG technology can significantly reduce power costs, but there is a problem of gas-liquid two-phase flow, which is a difficult control problem. In recent years, supercritical carbon dioxide is being studied as a new heat transfer medium.

4.2. Uneven distribution of energy flow
The circumferential temperature difference brought about by the uneven flux distribution will cause significant deformation of the collector tube structure. In extreme cases, the vacuum will fail. In the linear Fresnel concentrating system, the reasonable optimization of the secondary mirror structure, the main mirror field profile and the line of sight of the main mirror field reflected light can effectively improve the uniformity of the energy flow distribution of the collector tube, but the concentration will be lost. The optical efficiency of the optical system.

4.3. Heat loss
The heat loss of trough and linear Fresnel concentrators is mainly caused by radiant heat loss. The geometric parameters and material composition of the concentrator can be changed to suppress radiant heat transfer and reduce heat loss. Although reducing the emissivity of the heat-absorbing tube wall is the best choice, it is technically difficult. Even if a low emissivity is achieved, this characteristic is not easy to maintain during long-term operation. The radiation heat transfer in the linear Fresnel concentrating heat collection system can be achieved through the method of multi-layer isolation of radiation or adding a glass cover at the opening of the secondary concentrator to suppress the radiant heat loss by modifying the radiation characteristics of the glass cover. In addition, the circulation loop can be reduced, and the use of a small diameter heat absorption tube is a good solution to reduce heat loss.

4.4. Enhanced heat transfer
Among the many enhanced heat transfer technologies for heat transfer fluids, LVGs have obvious advantages in enhancing heat transfer. While the heat transfer capacity is significantly improved, the pressure drop only slightly increases, and in some cases even decreases. However, the results of literature show that the heat transfer enhancement rate of LVGs is up to 8%. Mwesigye et al. introduced a parabolic trough solar concentrator receiver with perforated plates. By optimizing the structure, the modified thermal efficiency was only increased by 1.2%-8%. In the high-efficiency
receiver of a solar parabolic trough concentrator introduced by Reddy et al., a porous energy-saving heat sink structure was proposed, which increased the heat transfer efficiency by about 17.5%.

5. Conclusion
Worldwide, CSP technology is an ascendant undertaking, with development and setbacks. The CSP industry has broad development prospects in terms of technology, economy, and power system adaptability. Although CSP technology temporarily has certain technical risks and high electricity prices, with the continuous advancement of technology and the gradual localization of core equipment, it will surely occupy an important position in the future renewable energy power generation market and will surely become the future energy solution.

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