Technical Requirement Analysis of Regulation Characteristics of CSP Station with Heat Storage System

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Abstract. Using solar energy to generate thermal power is often called concentrating solar power (CSP), is a grid friendly clean energy utilization mode with unique development advantages. Large capacity heat storage system with relatively mature technology and low cost can be configured to ensure stable and controllable output of power generation. The method can be. Solar thermal power generation has become a strategic emerging industry supported by many countries around the world. Spain, the United States, India, South Africa and other countries have carried out commercial operation of power technology with solar thermal, and installed capacity is growing steadily. China has also given key support to CSP generation technology, which has been vigorously developed. As the most promising new energy technology, CSP generation from molten salt heat storage tower is one of the main technical approaches of CSP generation. The key is to store the absorbed solar heat through thermal storage materials and release it stably for a long time, so as to achieve continuous and stable power generation independent of solar radiation changes. Through analysis, this paper puts forward the key technology research and scheme of molten salt regenerative CSP generation system, promotes the research on the bidirectional relationship between CSP station and power grid, and realizes the innovation of renewable energy technology. Relevant research results and technical schemes can be popularized and applied in demonstration power stations, and can also be used for operation control of newly-built molten salt heat exchange and storage tower power stations in the future.

1. Introduction
Solar thermal power generation, also known as concentrating solar power (CSP) generation, is a grid friendly clean energy utilization mode with unique development advantages. Large capacity heat storage system with relatively mature technology and low cost can be configured to ensure stable and controllable output of power generation. At present, solar thermal power generation mainly includes three technical paths. Solar parabolic trough, solar tower power generation power generation and solar disc power generation. Among them, parabolic trough power generation has developed most rapidly and has realized large-scale commercial operation. There are also examples of commercial operation of tower power generation. Dish power generation is still in the demonstration stage. CSP generation has become a strategic emerging industry supported by many countries around the world. The commercial operation of CSP generation technology achievements in Spain, the United States, India,
South Africa and other countries has been carried out in an all-round way, and the installed capacity has increased steadily. China also gives key support to photothermal power generation technology. Photothermal power generation technology has been clearly included in the "outline of national medium and long-term scientific and technological development plan (2006-2020)", and has been vigorously developed.

As the most promising new energy technology, CSP generation technology with heat storage makes solar power generation no longer affected by the change of solar radiation, has high stability, and can generate electricity continuously at night. As the most promising new energy technology, molten salt heat transfer and storage tower CSP generation is one of the main technical ways of CSP generation. The key is to store the absorbed solar heat through heat storage materials and release it stably and for a long time, so as to finally realize continuous and stable power generation without relying on the change of solar radiation. It is a grid friendly renewable energy power generation technology worthy of large-scale promotion. At present, a 20MW tower CSP station with 15 hour heat storage has been built in Spain. The power station has three years of successful operation experience and realized 24-hour continuous power generation in July. So far, Badaling demonstration power station of Institute of electrical engineering of Chinese Academy of Sciences and Delingha demonstration power station of Zhejiang central control have adopted water as heat transfer working medium without heat storage.

Through analysis, this paper will put forward research and repair on the key technologies of CSP generation system with molten salt heat storage, promote the research on the two-way relationship between CSP station and power grid, and promote the innovation of renewable energy technology. The relevant research results and technical schemes can be applied and popularized in the demonstration power station, and can also be used in the operation control of the new molten salt heat transfer and storage tower power station in the future.

2. The Development of Research Work on CSP Generation

However, there is a lack of in-depth research on the operation characteristics and output regulation characteristics of photothermal power station. Foreign mature commercial photothermal power plants have accumulated rich experience in the operation characteristics of various modes of various types of photothermal power plants, while the domestic technology in this field is still blank. There are few studies at home and abroad on the interaction between photothermal power station and power system, the adaptability of the regulation characteristics of photothermal power station to power grid and the response to power grid dispatching demand. The photothermal power station with heat storage system can smooth the fluctuation of solar irradiation and realize all-weather continuous operation. However, the influence of the heat storage, capacity ratio of heat storage system and release rate and the coordinated operation of heat storage system and various subsystems of photothermal power station on the output regulation characteristics of photothermal power station is still lack of research. Moreover, there is no tower CSP station with molten salt heat storage in China, which lacks practical operation experience, making China's large-scale CSP generation technology and power station construction lag behind European and American countries. Therefore, it is necessary to deeply understand the operation characteristics of photothermal power generation system and master the regulation characteristics of photothermal power station, so as to fill the domestic gap. Promote the development of CSP generation technology in China, so as to realize the large-scale development, utilization and commercial operation of CSP generation.

2.1. International CSP Generation

By the former Soviet Union, the design idea of tower CSP generation was put forward in the 1950s, and its research began in the 1970s. Solar one power station in the United States is the first 10 MW tower solar power station in the world. Later, solar two added heat storage devices on its basis to prolong the power generation time. At present, Spain is the country with the most extensive application of tower photothermal power station technology. Throughout the world, the technical
exploration stage of solar tower thermal power generation has been relatively mature and is moving towards commercialization. At present, there are four tower optical thermal power stations that have been put into commercial operation in the world [1,2], namely PS10, PS20, Ivanpah power station of the United States and gema solar power station of Spain. PS10 is the first commercial tower photothermal power station in Europe, with an installed capacity of 11mw. PS20 is built on the basis of PS10 power station. The first tower solar power generation system uses water as the heat transfer medium. Gema solar power station is the world's first commercial tower power station using molten salt as the heat transfer and heat storage medium, with a capacity of 19.9mw.

Molten salt heat storage technology uses raw materials such as nitrate as heat transfer medium to store or emit energy through the conversion between the heat energy emitted by the sun and the internal energy of molten salt. It is generally combined with CSP generation system to make the CSP generation system have energy storage and night power generation capacity to meet the needs of power grid peak shaving. It is a technology with strong economic advantages. The heat transfer mechanism of molten salt storage and release is the key problem of CSP generation with heat storage system. At present, the institutions engaged in relevant research mainly include the National Solar Energy Laboratory of the United States and the National Research Bureau of new technology, energy and environment of Italy [3,4]. The research mainly focuses on the reliable and stable operation of molten salt system and improving the efficiency of the whole molten salt heat transfer and storage system. A lot of research has been done on how to prevent freezing and blocking of molten salt, salt drainage and electric preheating, as well as the thermal efficiency of molten salt pump, molten salt system and thermophysical properties of molten salt. In terms of integration and operation control of tower photothermal power station with molten salt heat storage, there are mature commercial tower photothermal power stations with heat storage system with molten salt abroad, and have mastered the construction and integrated operation experience of tower photothermal power station with molten salt heat storage. The research on the optimization selection and regulation characteristics of various operation modes of the power station is not deep enough. There is little research on the evaluation of the regulation capacity of the photothermal power station, the adaptability of the power station to the power grid, and the power station's response to the power grid demand.

2.2. CSP Generation in China

In the mid-1970s, China built a 1kW tower CSP generation simulation device in Tianjin. In 2005, Nanjing built the first tower solar power station with a rated power of 70kw in China, marking that China has made preliminary achievements in the field of tower solar energy. At the end of January 2007, Beijing Yanqing tower CSP generation project was officially launched, and construction began in 2009. The whole system was successfully commissioned and generated from May to August 2012 [5]. It is the first megawatt tower CSP station in Asia. Since the end of 2009, the solar power park has been developed in Golmud and Delingha, Qinghai, which is the first large-scale tower CSP generation project in China in recent 20 years. At present, the commercial operation of heat storage system with molten salt for photothermal power generation in China is still under exploration. Relevant scholars have also carried out relevant research work on the operation mechanism of photothermal power generation system. Relying on Beijing Yanqing 1MW tower CSP generation test power station [6], researchers of Institute of electrical engineering, Chinese Academy of Sciences established dynamic simulation models for cavity heat absorber and steam accumulator, and carried out thermodynamic characteristic analysis. North China Electric Power University studied the hydrodynamic characteristics of the heat absorber for water / steam working medium. There are few studies on heat storage system with molten salt. At present, there are few large-scale commercial tower photothermal power stations with molten salt heat storage [7], so they still lack experience in the operation mode of the power station, and have not yet deeply understood and mastered the regulation characteristics of the photothermal power station with heat storage system. Starting with the operation mechanism of CSP station with heat storage, Tsinghua University has studied and established a CSP station model for power grid dispatching through abstraction and simplification. The model describes
the energy flow and its main operation constraints in photothermal power station [8,9], which is suitable for power grid dispatching. However, the model is too simplified to fully reflect the dynamic characteristics and operation mode of photothermal power station.

3. Analysis of Key Research Requirement of CSP

3.1. Analysis of Key Tasks
Heat storage system is a key subsystem of photothermal power station with smooth output and adjustable capacity. The energy transfer mechanism between heat storage system and other subsystems of photothermal power station is the basis for studying the output characteristics of photothermal power station, which involves heat transfer, engineering thermodynamics and so on. The focus is to start with the study of the temporal and spatial coupling of related heat conduction, as shown in figure 1.

![Figure 1. Operation mechanism and energy conversion.](image)

3.1.1. Operation Mechanism and Energy Conversion Control of Heat Storage System with Molten Salt.
The control principle and method of heat release and storage of heat storage system are the key to determine the output regulation characteristics of optical thermal power station. Therefore, revealing the energy transfer mechanism of heat storage system with molten salt and determining the heat release and storage control principles and methods of heat storage system with molten salt are the key points of the research, so as to provide a theoretical basis for the regulation and control of the whole tower molten salt power station.

- Energy transfer mechanism and dynamic model of heat storage system and other subsystems.
- Control principle and control of heat release and storage process of heat storage system with molten salt.

3.1.2. Operation Mode and Output Characteristics of Tower Optical Thermal Power Station Based on Heat Storage with Molten Salt.
The molten salt heat storage for tower type optical thermal power station is still under research and analysis, and the operation characteristics of the system are not well understood. The tower photothermal power station with molten salt heat storage is a complex control object with multivariable and multi-objective. The system is complex and there are many operation modes. The working principle and dynamic characteristics of each mode are very different, which has a great impact on the power output and regulation capacity of the power station.

- Shutdown and startup characteristics of tower photothermal power station with heat storage under different environments.
• Operation mode and output characteristics of optical thermal power station under different working conditions.
• Multi mode optimal selection and switching control of optical thermal power station.

3.1.3. Regulation Characteristics of Tower Photothermal Power Plant Based on Molten Salt Heat Storage. There are no research results on the regulation capacity and response capacity of optical thermal power station to power grid demand. According to the multi-mode and multi-objective operation control characteristics of tower optical thermal power station with molten salt heat storage, it is necessary to study the multi-mode regulation characteristics of tower optical thermal power station with molten salt heat storage and its regulation ability in response to the demand of power grid. It provides a basis for the grid connected operation of optical thermal power station and meeting the requirements of grid adaptability.
• Regulation characteristics of optical thermal power station with different capacity configurations of heat storage system.
• Under multi-mode, the regulation characteristics of tower optical thermal power station based on heat storage system with molten salt in response to power grid demand.

3.2. Analysis on the Progress of CSP Generation
The implementation plan of the research needs to start with the theoretical research of mechanism and dynamic characteristics to study the CSP generation capacity of molten salt tower. The analysis on the progress is shown in figure 2.

![Diagram](image)

**Figure 2.** The analysis on the progress

Firstly, by studying the operation mechanism of heat storage system with molten salt and its coordinated operation characteristics with each subsystem, the mechanism model and dynamic characteristics of heat release and storage process of heat storage system with molten salt are obtained, and the control principles and methods of heat release and storage rate of heat storage system with molten salt are mastered.
Secondly, starting from the energy conversion mechanism, the control strategy of the operation of the heat storage system with molten salt and its coordinated operation with other systems of the power station is studied, and the various operation modes of the photothermal power station with different operating modes, the regulation characteristics of the power station with different operating modes are obtained.
According to the multi-mode regulation characteristics of the power station, the regulation capacity of the photothermal power station with heat storage system is evaluated, and then the regulation characteristics of the photothermal power station in response to the power grid demand are analyzed.

4. Conclusion
Through the research on the regulation characteristics of tower photothermal power station with heat storage system with molten salt, the operation mechanism of heat storage system with molten salt is mastered, and the mutual coupling and correlation mechanism among heat storage system, concentrating and absorbing system and thermal power conversion power system is revealed. On this basis, the operation mode and output characteristics of tower optical thermal power station with heat storage system with molten salt are studied, the multi-mode optimization selection method and regulation characteristics of tower optical thermal power station with molten salt heat storage under different working conditions are proposed, and the regulation capacity of optical thermal power station in response to power grid demand is mastered. The research results can provide theoretical basis and technical support for the friendly grid connection of high-capacity tower CSP generation and give full play to the role of power dispatching, which has very important practical significance.

References
[1] Usaola J 2012 Operation of concentrating solar power plants with storage in spot electricity markets IET Renewable Power Generation 6(1): 59–66.
[2] Tan L P, Singh B, Date A, et al. 2012 Sustainable thermoelectric power system using concentrated solar energy and latent heat storage 2012 IEEE International Conference on Power and Energy (PECon).
[3] Ramteen S, Paul D 2010 The value of concentrating solar power and thermal energy storage IEEE Transactions on Sustainable Energy 1(3): 173-183.
[4] Powell K M, Edgar T F 2011 Control of a large scale solar thermal energy storage system 2011 American Control Conference on O’Farrell Street, San Francisco, CA, USA.
[5] Xu E Sh, Gao W, Xu H, et al. 2012 Simulation of dynamic characteristics of steam accumulator for Badaling tower solar thermal power generation Chinese Journal of Electrical Engineering 32(8): 112-118
[6] Wu Y T 2012 Heat transfer and storage of molten salt and its application in solar thermal power generation New Materials Industry (7): 20-26
[7] Xu N, Tian J, Li X, et al. 2015 Analysis of optimal installed capacity of single tower of tower solar thermal power plant Solar Energy (12): 50-55
[8] Chen R Z, Sun H B, Li Zh Sh 2014 Power grid dispatching model and grid connection benefit analysis of thermal storage optical thermal power station Power System Automation 38(19): 1-7
[9] Jin H Y, Sun H B, Guo Q L, et al. 2016 Solar thermal power station with large-scale heat storage. Multi day self dispatching method of wind power combined system Power System Automation 40(11): 17-23