THERMODYNAMIC MODELLING AND CONTROL STRATEGY OF SMART GRID THERMAL ENERGY STORAGE POWER STATION BASED ON COMMUNICATION TECHNOLOGY

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As a modern power grid that integrates advanced communication technology, sensor measurement technology, and intelligent control technology, the smart grid has good economy, reliability, and stability. Building a strong smart grid has important strategic significance for developing the national economy and improving Comprehensive National Power. The balance of electricity supply and demand, as a physical feature of the power system, determines the energy matching relationship between generation and consumption. Unreasonable power generation may lead to unmet electricity demand, as well as excess electricity and waste of resources. The energy storage has solved the problem of imbalance between supply and demand in most environments. The energy storage equipment provides a buffer space for electric energy, effectively adjusts the time unevenness of power grid load, realizes peak shaving and valley filling, and reduces the operation cost of the power grid. Taking the aboveground energy storage power station as the research object, the 3-D unsteady model of the small and medium-sized compressed energy storage system was established by using the FLUENT simulation software, and the correctness was verified through experimental methods. The influence of different environmental temperatures, chamber inflation flow rate, the thermodynamic characteristics of the surface condition and working chamber of the and energy storage were studied. The results show that the environmental temperature and expansion flow of oil storage chamber have important effects on its thermodynamic characteristics, while the surface conditions of oil storage chamber wall have little effect on its thermodynamic characteristics.

Key words: *communication technology, smart grid, thermodynamic modelling, thermal energy storage power station*

Introduction

As a clean and efficient secondary energy source, the application of electricity covers various fields of human production and life. Electrification has become an important symbol of the advanced level of modern society and an important reflection of a country's level of development. However, with the changes in the energy landscape and the expansion of the power grid, a power revolution has gradually begun. In the face of new trends in power development, State Grid of China (SGCC) has closely combined with the new situation of China's energy and the new demand for electricity services. At the *2009 Extrahigh Voltage Transmission International Conference* held in Beijing in May 2009, the concept of building a strong smart grid in

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China was officially announced [1]. As the future development direction of the power grid, the smart grid needs to support various demands of the new power industry and achieve a highly integrated power grid with *power flow, information flow, and business flow*. It has the following characteristics: strong resource optimization and configuration capabilities, significantly improved load-bearing capacity in the ultra-high voltage transmission network topology, and transmission over long distances, low losses, and high efficiency. Promote the development of new energy and maintain stable operation of the power grid. Large-scale utilization of wind and PV power generation reduce dependence on traditional fossil fuels and achieve energy conservation and emission reduction. The reliability and stability of power grid operation have been further improved. Highly intelligent inter regional power dispatch. Due to the uneven distribution of primary energy and the difference of regional economic development, intelligent dispatching and global optimal allocation of renewable energy power generation have become the top priority. In the future, more clean energy is needed. As a green and environmentally friendly transportationol, electric vehicles are gradually replacing other tools in people's lives. A sound smart grid system requires relevant supporting facilities to provide electric vehicles for charging and discharging. Large-scale integration of electric vehicles will lead to changes in the voltage and frequency of power grid, which will have a certain effect on the safety operation of power grid. Therefore, the power grid needs to meet the needs of new power users. Review the rapid interaction between client side requests and the power grid [2]. Intelligent grid should provide high quality information platform to publish real-time electronic information system, train users to be reasonable and efficient in accordance with power system timing and cost. With the development of wide area measurement systems and new energy generation technologies, demand side users are no longer just consumers in the power grid system, but will participate more in the operation and management of the system. Users can independently become microgrid systems to participate in online bidding and become electricity producers to gain benefits. In order to cope with the trend of increasing peak load throughout the year, the country has vigorously developed wind and PV power generation technologies, while continuously improving the utilization rate of fossil fuels. The total installed capacity of power generation is constantly increasing, but the problem is that the maximum load utilization hours throughout the year are decreasing year by year. Due to the difficulty of storing a large amount of electricity, the production and consumption processes must be completed simultaneously, and the balance of electricity supply and demand will directly affect the operational safety of the power grid. At the same time, due to the lack of effective power generation plans, excessive installed capacity also leads to resource waste, increases operating and maintenance costs, and neglects the economy and efficiency required by smart grids [3].

With the reform of the global energy structure, RES such as wind power, solar energy, and hydro power have been developing rapidly. However, because of the inherent intermittent and unsteady stability of the renewable energy system, the utilization of renewable energy has always been in a low level. In order to improve the conversion efficiency of renewable energy and improve the stability of energy efficiency, large-scale energy conservation has become an important means of large-scale renewable energy utilization.Compressed energy storage (CAES) technology has rapidly developed with its advantages of large energy storage capacity, fast response, and high energy storage efficiency. A compressed air storage power station using a low voltage or power supply coupled from an electric grid to drive the generator to work, converting electrical energy into compressed air and storing energy in a gas storage chamber; during the peak demand of power grid, the wind speed puts into the generator for power generation, drives the generator set to generate power and *feed*s it to the power grid. Gas storage chambers are equipment used in compressed energy storage systems to store compressed air, typically using underground rock (salt) caves, abandoned mines, steel gas storage tanks, *etc*. In small and medium-sized compressed energy storage systems, aboveground steel energy storage power stations are generally used as containers for storing compressed air. Accurate estimation of the change of temperature in oil storage rooms not only ensures its stable operation in a safe state, but also has an important effect on the optimization design of oil storage rooms and the selection of key equipment such as compressors and turbines. Taking the above ground steel storage room of compressed energy storage system as the research object, the numerical simulation is used to analyze the thermodynamic characteristics of the storage room of compressed energy storage system. Based on the detailed physical and mathematical analysis, using GAMBIT and ANSYS numerical simulation software, the overall distribution and change of temperature in the steam turbine and the internal working fluid under the influence of various difficulties during the actual operation of the compressed energy storage system are analyzed. thus ascertaining the thermodynamic characteristics of steam turbine and internal working fluid [4].

Methods

Composition of smart grid

The traditional power grid is a rigid system that lacks elasticity in the transmission process. As a centralized system, the real-time control decision-making of the traditional power grid is poor, lacks system information sharing, and has a low level of intelligence. The development of the power industry plays a crucial role in the socio-economic development. Traditional power grids have to some extent constrained the development of productivity, and power reform is urgent [5, 6]. Intelligent grid is a modern power grid which combines advanced grid measurement, communication technology, analysis and decision technology, automatic grid technology, power grid technology, and basic equipment of power grid. The constructed new power grid has intelligent features such as observability, controllability, real-time analysis and decision-making, adaptability and self-healing. Energy balance is the complexity of the body, and the balance of energy and demand is the core of the body. This balance can be divided into long-term supply and demand balance and short-term supply and demand balance. Long-term power planning and demand balancing solve the power supply planning problems, such as power supply planning, power supply planning, and external power supply planning. Short-term and balanced demand solves the technical problems of power system, such as power scheduling, frequency control, and power management. The author starts from the short-term balance of power supply and demand, and manages and controls the power demand side system. The current main real-time energy and power control is shown in fig. 1.

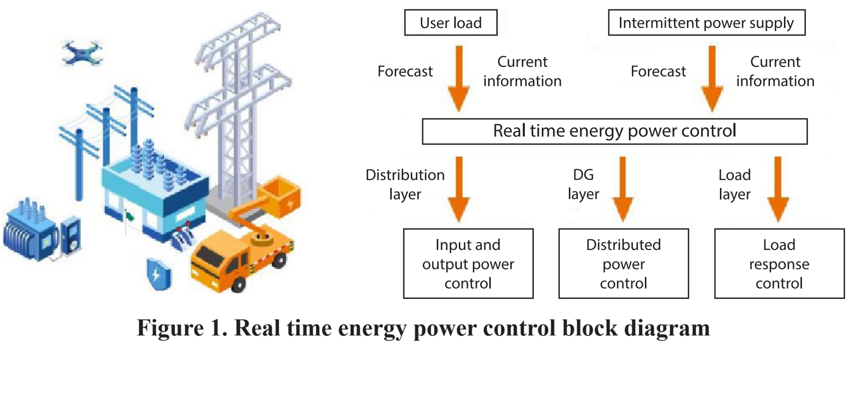

Figure 1. Real time energy power control block diagram

Based on the current information of user load and intermittent power generation composed of various RES, short-term and long-term predictions are made, and power control is carried out based on the predicted results. This is manifested in stable input and output power control at the distribution network level, distributed generation (DG) level distributed power control, and load response control at the load level [7]. However, the control effect based on predictive information depends on predictive accuracy. As a high order, strongly coupled, and multi-dimensional power system, the modelling and solving process is very complex. Regarding load response control at the load level, in addition setting time-of-use electricity prices that affect user electricity consumption behavior and alter the load curve, the introduction of energy storage systems can also achieve peak shaving and valley filling from the grid side. From this point of view, the author studies the influence of the charging and discharging behavior of the Lead-acid battery as the energy storage device on smoothing the load curve and reducing the operation cost of the power grid.

Research subjects

The development of distributed power grid has accelerated the pace of energy storage. The small and medium-sized compressed energy storage system using ground energy storage power stations as gas storage chambers is one of the important technologies suitable for distributed grid energy storage energy storage. The author takes the above ground steel gas storage chamber in the existing small-scale compressed energy storage experimental platform of the research group as the research object, adopts the FLUENT numerical simulation method to establish a 3-D unsteady model of the gas storage chamber, and studies the overall temperature distribution of the outer wall and the change law of the temperature and pressure of the internal working medium in the process of charging and energy storage of the system. The gas storage device in this small compressed energy storage system consists of two 1 m^3 regular cylindrical gas storage tanks, which are directly placed on the laboratory floor. The outer walls of the gas storage tanks are not insulated and are directly exposed to the environment. The structure and materials of the two gas storage tanks are identical, and the relevant parameters of the gas storage tanks are shown in tab. 1.

Table 1. Relevant parameters of gas storage chamber

Calculation parameters	Unit	Parameter value
Energy storage power station volume	[m^3]	1
Diameter of gas storage chamber	[mm]	800
Energy storage power station length	[mm]	2580
Wall thickness of gas storage chamber	[mm]	24
Storage chamber materials	[–]	Q345R
Energy storage power station inlet diameter	[mm]	20
Outlet diameter of gas storage chamber	[mm]	20
Design pressure of gas storage chamber	[MPa]	7.0

Numerical calculation

According to the process and flow characteristics of the gas storage unit, Gambit preprocessing software was used to model and mesh the structure of the gas storage unit. In order to improve the quality of grid distribution in oil storage room, the tank body of oil storage room was divided. The simple and regular gas storage chamber main body and inlet pipe-line areas on the tank body are divided using structured cooper grids, while the more complex areas are divided using unstructured grids. The total number of grid divisions is approximately 440000.

Using FLUENT software for mathematical model solving and calculation, and using TECPLOT software for image post-processing of the results. The author used a 3-D non-stationary model for numerical simulation, using standard k-ε simulation of turbulent gas phase flow using a dual equation model. The study fluid is compressible, so the implicit pressure (PISO algorithm) based on the pressure in solvent separation is adopted. Using the *shell thermal conductivity coefficient* method to control the heat transfer between the wall surface of the steel soil gas storage tank and the surrounding environment, while considering the total heat resistance of the oil storage tank body, effectively reducing the number of plates and simplifying the structure. Select the fifth type of mixed boundary condition, fully considering the convection and radiation heat transfer between the outer wall of the gas storage tank and the surrounding environment. Due to the fact that the base of the gas storage tank is placed on the laboratory floor, it is necessary to simultaneously consider the heat conduction between the bottom of the gas storage tank and the ground. Due to the need for at least 1.5 hours to complete a single energy storage process, in order to ensure convergence within the maximum iteration steps, the time step size was independently verified and taken as 0.01 second. In addition, the initial heat transfer conditions of the gas storage chamber are shown in tab. 2.

Table 2. Initial heat transfer conditions of energy storage power station

Parameter	Unit	Numerical value
Ambient temperature	[K]	300
Ambient humidity	[%RH]	50
Ambient pressure	[MPa]	0.1
Initial pressure of gas storage chamber	[MPa]	0.1
Initial temperature of energy storage power station	[K]	300
Emissivity of the wall outside the gas storage room	[–]	0.71
Convective heat transfer coefficient of outdoor gas storage wall	[$Wm^{-2}K^{-1}$]	2.46
Inflation flow rate	[kgs^{-1}]	0.018

Results and analysis

Model correctness verification and analysis of the entire inflation process of the thermodynamic characteristics of the gas storage chamber

In the existing small scale compressed energy storage experiment platform, k-type thermocouples are used to measure the temperature of the outer wall of the oil storage room 1 m from the ground, and the pressure sensor installed on the upper part of the oil storage room is used to measure the pressure of the inner working fluid. As shown in fig. 2, the trend of temperature changes on the outer wall of the energy storage power station at a distance of 1 m from the ground, based on simulated and experimental data, during the inflation process of the system. From fig. 2, it can be seen that the temperature data of each point in the gas chamber is close to the experimental data, so numerical simulation results can reflect the external wall temperature of the gas chamber. In the first stage of inflatable energy storage, the temperature of steam storage increases rapidly, and then the rising speed gradually decreases. Finally, the

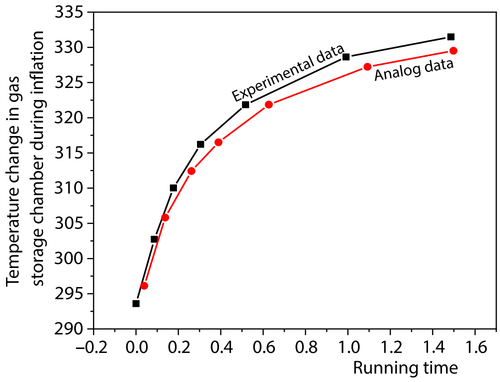

Figure 2. Temperature changes in the energy storage power station during inflation process

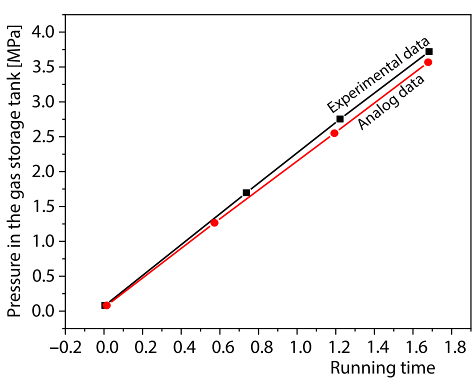

Figure 3. Pressure changes in the gas storage chamber during inflation process

temperature of the oil storage room gradually increased, and at the end of the power storage room (about 1.5 hours), the maximum working fluid temperature of the oil storage room was 331.06 K.

As shown in fig. 3, during the expansion process, the variation of water pressure in the gas storage chamber between experimental and experimental data is shown. From fig. 3, it can be seen that the simulated data of fluid pressure in the gas storage room is close to the experimental data, and the numerical simulation results can reflect the pressure of fluid pressure acting in the gas storage room and the numerical simulation results can reflect the pressure of fluid pressure acting in the gas storage room. As the rising cost of energy storage technique increases, the pressure in oil storage unit increases approximately linearly, with the increasing stability in quantity. At the end of the power volume (about 1.5 hours), the maximum working fluid in the gas chamber is 3.32 MPa.

Impact of different factors

As shown in fig. 4, under the same other boundary conditions, the gas storage chamber is placed at different environmental temperatures. At the completion of inflation and energy storage (taking about 1.5 hours), the outer wall temperature and internal working fluid pressure of the gas storage chamber at a distance of 1 meter from the ground are measured.

As shown in Figure 5, the effects of the expansion flow rate on the temperature and pressure of the storage chamber during expansion and the energy storage process of the turbine blade are studied by [8, 9]. As the flow expansion increases, the pressure in the gas chamber increases linearly, and the temperature in the gas chamber increases rapidly before gradually increasing. The continuous increase in inflation flow rate leads to an increase in the work done by the compressor, an increase in the exhaust temperature of the compressor, and an increase in inflation flow rate. The energy of compressed air entering the energy storage power station per unit time continuously increases, resulting in a continuous increase in the temperature of the Energy storage power station.

The changes in surface conditions such as wind speed, surface roughness, and dirt on the wall of the gas storage chamber can cause changes in the heat transfer conditions between its surface and the surrounding environment, thereby affecting the thermodynamic dynamic characteristics of the working fluid inside the gas storage chamber. However, the above surface conditions actually change the heat transfer coefficient, emissivity and other heat transfer pa-

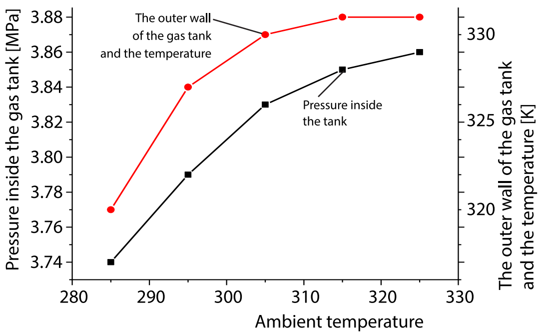

Figure 4. The influence of environmental temperature on the wall temperature and internal pressure outside the gas storage room

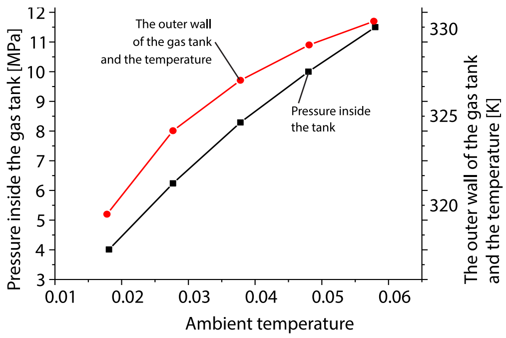

Figure 5. The influence of inflation flow rate on the wall temperature and internal pressure outside the gas storage room

rameters of the gas storage chamber wall, so it is necessary to discuss the influence of different heat transfer coefficients and emissivity on the thermodynamic characteristics of the gas storage chamber [10]. As shown in fig. 6, in the same area of other areas, only the heat transfer coefficient of the external wall of the gas unit is changed. After the completion of inflatable energy storage (about 1.5 hours), measure the external wall temperature and internal working fluid pressure of storage room 1 meter underground. With the increase of heat transfer coefficient, the temperature and pressure in oil storage room decrease a little. The higher the heat transfer coefficient is, the less its influence is. As the heat transfer coefficient between the outer wall of the gas storage chamber and the surrounding wall increases, the heat dissipation of the gas storage chamber increases, which leads to the decrease of the internal temperature of the working fluid in the gas storage chamber and the decrease of the working fluid pressure in the gas storage chamber. As shown in fig. 7, in the same area of other areas, only the emissivity of the external wall of the gas chamber has changed. When inflation and energy storage are achieved (about 1.5 hours), the temperature of the outer wall of the gas chamber at the distance of 1 m from the ground and the pressure of the inner working medium change. With the increase of Emissivity, the temperature of external wall and the pressure of internal working medium inside the gas chamber decrease. The higher the emissivity, the smaller the effect on the temperature

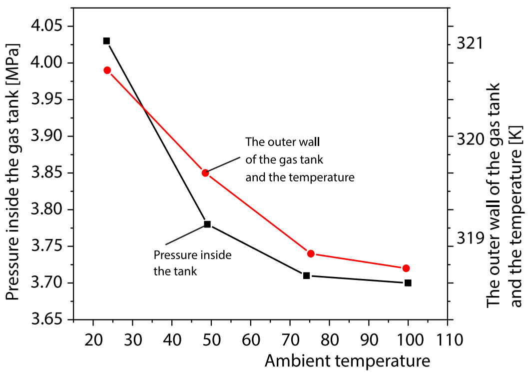

Figure 6. Effect of heat transfer coefficient on outdoor wall temperature of gas storage

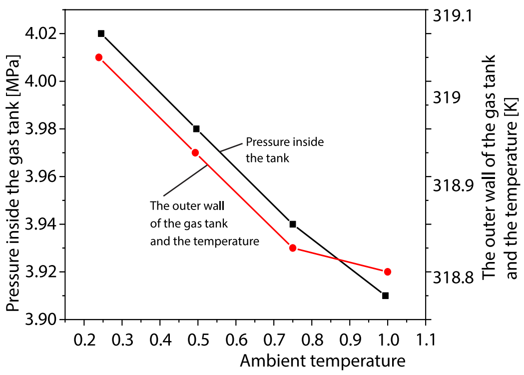

Figure 7. Effect of emissivity on temperature and pressure in gas storage chamber

of the external wall of the gas chamber, and the smaller the effect on the internal pressure. The influence process of emissivity on thermodynamic properties of gases is similar to heat transfer coefficient, but the influence of emissivity on thermodynamic properties of gases is less than heat transfer coefficient.

Conclusion

The steam turbine is an important part of the energy storage of the steam turbine. During the operation of the system, the changes of thermodynamic characteristics such as temperature and pressure of working fluid in gas storage room have a significant impact on the overall operation and safety of the system, especially on small and medium-sized compressed energy storage systems using above ground steel energy storage power stations as gas storage chambers. Using FLUENT numerical simulation as the research method, taking the steel air chamber above the ground of the compressed energy storage system as the research object, a 3-D unsteady model of the air chamber under time-varying conditions was established, the influence of multiple factors such as different external environmental conditions, the influence of the expansion flow of oil storage room, the surface conditions of the external wall of the oil storage room, and the conditions of the oil storage room itself on the thermodynamic characteristics of the oil storage room were obtained.

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