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Research on steady-state power distribution calculation technology of electrothermal coupled regional *energy system*

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Abstract. When large-scale power grids are connected to the power grid, it is conceivable that adverse effects on the operation and planning of power grids can be imagined. Therefore, wind power has characteristics such as intermittency, volatility, anti-peaking characteristics, and large prediction errors. At the same time, the ability to absorb wind power is also weakened by the contradiction between the peak load and the heating load. In addition, due to the thermo-electric coupling characteristics of the cogeneration unit, ie, "heating with electricity," this characteristic directly determines that its heat output severely limits the regulation of the electric output. The results of the study indicate that the co-production unit's electric power and thermal power are coupled. Strong nature, the peak load capacity of the unit is greatly affected by the heat load, and the electric power and thermal power distribution lacks a unified calculation and analysis method, which restricts the means of improving the peaking capacity of the unit by controlling the thermal power output of the unit, and through implementation, establishes the main power equipment, The steady-state power model of the thermal equipment, the steady-state power analysis and calculation method of the regional energy system of the power thermocouple, and the realization of adjusting the thermal load related parameters to improve the peak capacity of the thermal power unit.

1. Introduction

According to the planning goal, by the end of the “Thirteenth Five-Year Plan” period, the installed capacity of hydropower, wind power, and photovoltaic power generation in the State Grid Corporation will increase to 270 million kW, 220 million kW, and 110 million kW respectively, totaling 600 million kW, scenery, etc [1]-[2]. The issue of energy integration will be more prominent. The difficulties in the adoption of Fengpu Optoelectronics are, to a certain extent, hampered by the inconsistencies in the integration of this intermittent renewable energy source with traditional energy systems. Taking Northeast China as an example, the heating units account for a large proportion of the total installed capacity. In the winter heating season, due to the abundant wind energy resources at this time, its output tends to exhibit anti-peaking characteristics, and winds in the troughs and wind power. Under large-scale grid-connected conditions, there is a huge pressure on the peaking of the grid [3]. On the other hand, combined heat and power has obvious economic advantages over thermoelectric production, so the proportion of cogeneration units for further improvement in energy efficiency will increase further.[4]-[6]

In order to alleviate environmental pollution and improve the energy efficiency of the terminal, the integrated energy system has become an important direction for China's energy structure adjustment.

The electricity network and the heating network form an electro-thermally coupled energy system through the cogeneration unit. In this energy system, fuel is transferred to boiler water by boiler combustion, heated to form superheated steam, a part of steam is used for heating, and another part is used for generator power generation. The heating part is sent to the end user's heating load through the heating pipe network; the power generation part is sent to various power loads through the power grid. Due to the differences in the energy forms of heat and power, there are also great differences in response time scales. The thermal response time is slow, and the power response time is very fast. In other words, if the same cogeneration unit suddenly goes out of service, the situation reflected to the end-user is that the power load is immediately stopped and the heating load takes a while to cool slowly.[7]-[9]

The cogeneration units participate in the power peak adjustment. The thermal power unit continuously adjusts as the power load changes, generating more power during the peak load period and generating less or even not generating power when the load level is low. Due to the limitation of the adjustment range of the heat-generating machine itself, the change in the power generation of the heat-generating unit will cause a change in the heat production, and it may not satisfy the heat supply quality.

The heating quality directly reflects the indoor temperature at the heating end. However, the change of the actual operation mode of the thermal power unit will not always immediately affect the indoor temperature of the heating end. This is the thermal hysteresis of the heating system. Therefore, by analyzing the relationship between the output of the thermal power unit and the indoor temperature, the thermal power unit participates in the system peaking method.[10]

The use of thermal hysteresis in the heating system essentially changes the continuous and stable operation of the heating system. When the heat generated by the thermal power unit changes, it causes temperature fluctuations in the heating network and the hot building to form a thermal dynamic change process of the heating system. This method requires the heating unit to participate in system peaking while ensuring the heating quality. purpose.

The factors affecting the indoor temperature change are influenced by factors such as solar radiation and outdoor temperature, in addition to the heating of the heat-generating unit. Even in the continuous and stable operation mode of the thermal power unit, the indoor temperature will periodically fluctuate within a certain range. And a certain range of different indoor temperatures can meet the human body's thermal comfort requirements. This is to change the way of the continuous stable operation of the traditional thermal power unit and make it possible to participate in system peaking.

For example, the heat output of a thermal power unit at different times of the day can be changed. When the load is at a peak, the thermal power unit increases its output. At this time, the heat output is large and the indoor temperature is increased. A certain amount of heat is stored in the heat grid and the thermal structure; when the load is low, the thermal power unit stops or reduces heat generation. Release heat from thermal grids and thermal buildings to meet heating needs. [11]

Therefore, to use the thermal hysteresis of the heating system to improve the peak shaving capacity of the cogeneration unit, it is necessary to clearly understand the power distribution of the electricity-heat coupled energy system. Set up steady-state power models for major power equipment and thermal power equipment, and grasp steady-state power analysis and calculation methods for thermal energy-coupled regional energy systems, and realize the coordinated control of heating networks and power networks to improve power grid utilization Unit capacity for peaking. [12]

Accurately calculating the steady-state power distribution of the thermodynamically coupled regional energy system helps to study the interaction between the power system and the thermal system, helps to analyze the various forms of energy distribution in the entire energy system, and can effectively study the total energy. The use of efficiency, thereby improving energy efficiency. [13] Take advantage of the comprehensive energy system, adjust the heat supply appropriately, effectively use the thermal inertial characteristics of the thermal network, improve the peaking capacity of the combined heat and power unit, thereby dissipating more clean electric energy, reducing grid peaking input, and improving cleanliness Energy efficiency, reduce the total capital investment, improve energy efficiency.

2. Study of the influence of thermal load parameters on peak shaving capacity of cogeneration units

The operating parameters of the boiler unit are mainly superheated steam pressure, superheated steam and reheated steam temperature, steam drum water level, boiler evaporation amount, and oxygen content of flue gas. For example, when the steam flow rate required by the unit turbine is changed, the boiler steam pressure, steam temperature, and water level all change with other conditions unchanged. At this time, it is necessary to make corresponding adjustments to the boiler's water supply volume, fuel volume, and air volume (ie, combustion) so that the boiler's evaporation capacity can be adapted to the turbine's load. The operating parameters are kept within the rated value or within the specified range.

The stability of the steam pressure during operation of the boiler depends on the balance between the boiler evaporation and the external load. If the boiler evaporation is greater than the amount of steam required by the external load, the vapor pressure rises; otherwise, it decreases. When the boiler evaporation is equal to the amount of steam required by the external load at each instant, the steam pressure remains stable.

The change in steam pressure reflects the imbalance between boiler evaporation and the amount of steam required for external loads. The amount of evaporation depends on the exothermic state of fuel combustion. Therefore, under normal circumstances, both external disturbances and internal disturbances cause changes in the vapor pressure, which can be adjusted by adjusting the combustion method: the vapor pressure is reduced and the combustion is enhanced; the vapor pressure is raised and the combustion is weakened. In an abnormal situation, when the steam pressure rises sharply and the combustion is too late to be adjusted, the superheater trap door can be opened or the steam can be vented to the empty exhaust valve to depressurize as quickly as possible.

Whether the steam temperature changes depends on how much steam (including desuperheated water) flows through the heat exchanger and how much heat the flue gas passes to it at the same time. If the balance of the above relation can be maintained at any time, the steam temperature will remain unchanged; and when the balance is destroyed, the steam temperature will change. The greater the degree of imbalance, the greater the change in steam temperature.

According to the principle of energy conversion of cogeneration units, the mathematical relationships between fuel, steam and electricity are established, a typical heat load model is established, the relationship between heat load temperature and heat consumption is studied, and heat supply is studied when the heat load temperature fluctuates within a certain range. The changes in the heat supply and power generation capacity of the unit were studied, and the methods for improving the peak shaving capacity of the cogeneration units by rationally adjusting the heat supply were studied.

3. Study the working mechanism of back pressure turbines and establish a steady-state model for back pressure steam turbines considering factors such as fuel, steam and electricity

Heated steam turbines include back-pressure turbines, steam turbines with regulated extraction, dual-use condenser heating, and condensed-gas turbines with low vacuum heating. This project mainly studies commonly used back pressure turbines. Back-pressure steam turbines use exhaust gas to heat outwards, and their exhaust pressure is usually higher than the exhaust pressure of condensing steam turbines. Although the unit mass of steam is reduced within the steam turbine, there is no loss of cold source, so the use of this unit has a high utilization of heat energy. When the back press operates, heat and electricity cannot be adjusted independently. Often, heat is used to set the electricity, and the electricity supplied by the grid is missing. Therefore, the size of the heat load has a greater impact on the economics of back pressure turbines. Figure. 1 is a schematic diagram of a back pressure steam turbine thermal system. After the steam enters the back pressure turbine expansion work, the exhaust steam is directly led out for use by external users.

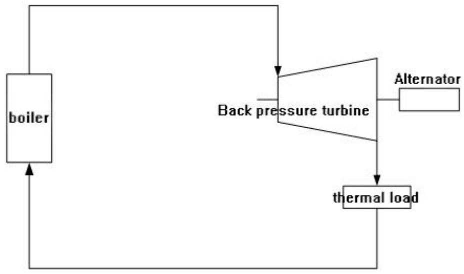

Figure 1. Schematic diagram of back pressure steam turbine thermal system.

As an important multi-energy coupling element, a combined heat and power unit (CHP) can generate both electrical energy and thermal energy. It can be divided into two types: constant thermal power ratio (such as back pressure type units) and variable thermal power ratio (such as pumping condensation type units). The thermoelectric ratio characteristics are shown in Figure. 2.

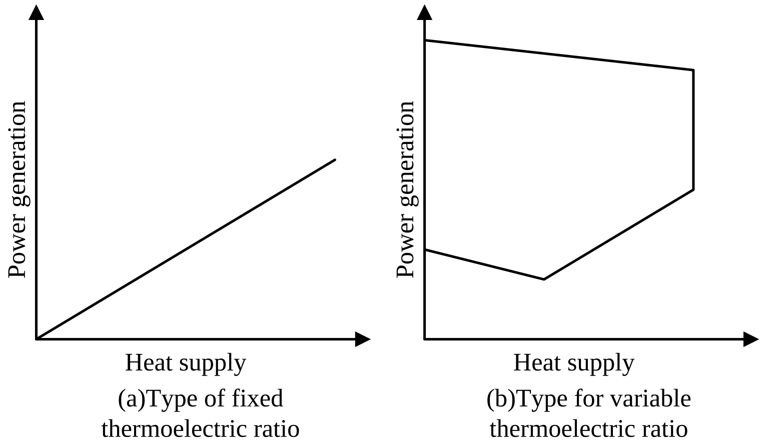

Figure 2. Type of thermoelectricity ratio of cogeneration unit.

The The relationship between the thermal output ratio and the thermal output ratio is

$$c_m = \Phi_{CHP} / P_{CHP} \tag{1}$$

The thermoelectric ratio of the thermal power ratio is variable, which can be expressed as a certain operating mode.

$$Z = (\eta_e F_{in} - P_{CHP}) / \Phi_{CHP} \tag{2}$$

In the formula, it is the fuel input rate. However, in the actual operation of a certain period of time, remain unchanged.

4. Study the thermal process of long steam pipes and establish a thermal model under set conditions

The The main difference between different energy flow networks is the difference in branch characteristics. The electricity-heat coupled integrated energy system, power network, and heat-reserved branch model are as follows.

The branch of the power network is mainly composed of resistors, reactances and capacitors. In the form of communication, it can be expressed as

$$\dot{U}_k = Z_k \dot{I}_k \tag{3}$$

Where: $\dot{U}_k$ is a complex voltage; $\dot{I}_k$ is a complex current; Z_k is equivalent impedance based on RLC parameters.

For the heating network, a hydraulic model considering the steady flow of the thermal medium and a thermal model considering the temperature drop along the way are established. In the calculation of the hydraulic thermal-mechanical coupling calculation model for the heat-transfer medium flow, the following simplifications are made: The heat medium in the tube is a one-dimensional stable flow, that is, the heat medium parameters only change along the length of the tube along the axial direction, and the cross-section thermal medium parameters do not change with time; All are placed horizontally, ignoring the influence of gravitational potential energy; thermal media is a single-phase material and phase change is not considered.

The model of the heating network branch is divided into two parts: the hydraulic model and the thermal model.

The static hydraulic model of a general pipeline is

$$h_f = K\dot{m}|\dot{m}| \tag{4}$$

In the formula, $\dot{m}$ is the branch flow; h_f is the branch pressure drop caused by the friction; K is the impedance coefficient. In addition, the branch pressure drop is also related to height, accessories, pumps, etc. In order to simplify the problem, it is considered that the heights of the nodes are equal, and the attachments have been converted into pipes. There are no pumps on the branches outside the heat source.

The static thermal model of the general pipeline is

$$\Phi = C_p\dot{m}_q(T_S - T_O) \tag{5}$$

$$T_{end} = (T_{start} - T_a)e^{\frac{\lambda L}{C_p\dot{m}}} + T_a \tag{6}$$

$$(\sum \dot{m}_{out})T_{out} = \sum(\dot{m}_{in}T_{in}) \tag{7}$$

In the formula: Φ is the heat obtained by the load or the heat source; C_p is the specific heat capacity of the water; $\dot{m}_q$ is the flow rate through the load or the heat source; T_S is the temperature at the water supply side of the corresponding node; T_O is the temperature at the water return side of the corresponding node; T_{start} is the beginning of a certain branch road The water temperature; T_{end} is the water temperature at the end of the branch; T_a is the ambient temperature; L is the length of the branch pipeline; λ is the heat transfer coefficient per unit length of the pipeline; T_{out} is the temperature of the water actually flowing out of a node; T_{in} is the temperature of the water actually flowing into the node.

Equation (5) represents the relationship between heat and temperature; Equation (6) represents the temperature relationship of the water at the start and end of the branch, indicating the presence of heat loss; Equation (7) represents the hot water at the node Ideally, the temperature of the water flowing into the node is different, and the temperature of the water flowing out of the node is the same.

5. Research on Steady State Power Distribution Model and Its Solution Algorithm for Thermal Power Coupling Network

5.1. Thermal power coupling network steady-state power distribution model

Taking energy as the main line, comprehensive consideration is given to the steam pipe network and power grid, as well as energy production equipment and energy consumption equipment, to form a unified node branch network. The branch is the energy transmission link and the node is the energy conversion link. The ability of the branch to transmit energy is generally determined by the performance parameters of the branch itself and does not change with time. Node state variables are parameters to be evaluated.

Based on the power flow equation of the electric network, the output power of the generator node is further expanded, represented by the amount of coal per unit time of the boiler, and the load power of the motor of the load node is represented by the amount of raw material of the chemical plant per unit time. Since the power generation and the electricity load are both steam-related expressions, a steam pipe transmission model is established to form an energy network equation including coal, heat, and power. As shown in Figure 3.

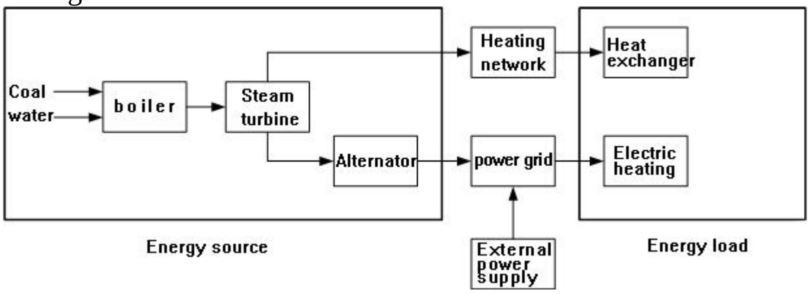

Figure 3. Electrothermal comprehensive energy system.

The solution of the energy network equation is essentially the solution of a set of nonlinear algebraic equations. The joint solution solves all the equations of different energy flows together as a whole, specifically

$$F(x)=\begin{Bmatrix} f_1(x_1) \\ f_2(x_2) \\ \ldots \\ f_n(x_n) \\ g(x_1,x_2,\cdots,x_n) \end{Bmatrix}=0 \tag{8}$$

It is assumed that the multi-energy flow system is composed of energy flow subsystems, i is the subscripts represent different subsystems, x is the state variables, $f_i(x_i)=0$ is the equations of the independent part of the energy flow system i , and $g(x_1,x_2,\cdots,x_n)=0$ is the equations of the coupling part.

5.2. Solution

The energy network equation solver solves other variables under certain conditions or variables. In different energy domains, a mature and widely used solution model and algorithm has been developed for a single energy flow network, such as node admittance matrix, power flow model and rapid decomposition method in power networks, solution loop solution method in hydraulic calculations, and solutions. The nodal equation method and the deducted section equation method. For the multi-energy flow system, there are no widely used solution models and algorithms. There are two commonly used joint solutions and decoupling solutions.

Equation (8) can be solved using the Newton-Raphson method. In the concrete solution, the known variables, state variables, reference nodes, etc. of different nodes need to be determined, and related problems related to numerical solution are involved. The benefits of the unified solution are intuitive and easy to understand. The problem is that the values and characteristics of different energy flow systems are very different. The Jacobian matrix may be irreversible.

The decoupling solution is solved $f_i(x_i)=0$ separately for each energy flow subsystem i and then iterated through the coupling equations $g(x_1,x_2,\cdots,x_n)=0$ until the convergence criteria are met.

The advantage of the decoupling solution is that it can use the solution methods and procedures of existing networks. The disadvantages are that the number of iterations is relatively large, and it is difficult to ensure the convergence when the coupling is tight.

6. Summary

In this paper,calculate the power distribution of a power thermocoupled energy system, adjust the relevant parameters, such as: modify the terminal heat load temperature, pipe network insulation characteristics, observe the changes in power generation output of the cogeneration unit, analyze the interaction between the thermal system and the power system Investigate the conditions and methods for improving the peak shaving capacity of the combined heat and power unit by controlling the thermal system. Due to the strong coupling of electric power and thermal power of the combined heat and power unit, the peak load capacity of the unit is greatly affected by the heat load, and the electric power and thermal power distribution lacks a unified calculation and analysis method, which restricts the increase in peak load capacity of the unit by controlling the thermal power output of the unit. Through the implementation of this paper, a steady-state power model of major power equipment and thermal equipment is established, and a steady-state power analysis and calculation method for the regional energy system coupled with thermal power is grasped, and the peak load adjustment capability of the thermal power unit is improved by adjusting the relevant parameters of the heat load.

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