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Multi-energy Based on Coupling System Cooperative Optimization Strategy

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Abstract: Under the situation that non-renewable resources are depleting on a global scale, a multi-energy interconnection, interoperability and mutual aid energy interconnection system emerges as the times require. The realization of multi-energy interconnection system, multi-energy complementarity, source-network-load coordination, and safe and reliable energy supply are the core and key of the energy Internet project. The main purpose of this paper is to study multi-energy sources based on the cooperative optimization strategy of coupled systems. In this paper, combined with the coupled element model and the DC power flow model of the power grid, the bidirectional sensitivity matrix of the gas-electric coupling system is established, and the mutual influence relationship between the two energy subsystems is revealed. Experiments show that the IE system of the electricity-heat-cooling-air synergistic optimization mode covers more types of energy networks, more types of energy conversion, better effect of energy cascade utilization, higher energy utilization efficiency, and can meet the energy needs of users type is more comprehensive.

1. Introduction

At present, the global use of energy is in a period of rapid development. In order to cope with problems such as energy shortage and climate warming, it is necessary to improve the level of interconnection between different energy types, so as to improve the overall utilization rate of energy and save energy consumption. Therefore, a single form of energy will gradually diversify, and the development and utilization of an IE system is a major measure to comprehensively promote energy reform. The gas-electric coupling system is a comprehensive energy system that combines electricity and natural gas systems, connecting two independent energy subsystems through coupling elements. Research hotspots [1-2].

In related research, Gupta introduced an adaptive multi-sensing (MS) framework for densely deployed solar energy harvesting wireless node networks [3]. Kishore studied the energy efficiency of traditional cooperative compressed sensing (CCCS) schemes, focusing on balancing the trade-off between energy efficiency and detection accuracy in cognitive radio environments [4]. The results show that losses due to compression can be recovered collaboratively, increasing the overall energy efficiency of the system.

In this paper, based on the cooperative optimization strategy of coupled systems, the research on multi-energy is carried out. In order to analyze the interactive effects of power and natural gas load disturbances on the IE system, this paper proposes a bidirectional sensitivity analysis method for gas-electric coupling systems using gas-fired generator sets as energy coupling elements. Combined with the coupled element model and the DC power flow model of the power grid, the bidirectional sensitivity matrix of the gas-electric coupling system is established, and the mutual influence relationship between the two energy subsystems is revealed.

2. Design and Research on

2.1. The Problem of Coordinated Development of Multiple Energy Sources

My country's current multi-energy coordinated development faces three problems:

(1) The utilization rate of renewable energy is low. The abandonment of large-scale renewable energy is a difficult problem for the development of the renewable energy industry, but the installed capacity of renewable energy power generation is growing rapidly. Construction leads to waste of resources. Many power generation countries are in the lead in the utilization of renewable energy. For example, the western states of the United States are the development models of various energy complementary, using a variety of power generation forms to avoid the instability caused by a single power source, and use wind, light and heat. Energy has been developed efficiently and collaboratively. Compared with this, the biggest problem of domestic new energy power generation is poor stability, which cannot guarantee full-capacity power generation at any time, thus affecting the stability of the power grid, so there will be the "three abandonment phenomenon" that plagues my country's new energy industry [5-6].

(2) The power structure is unreasonable. Due to the limitation of technical factors such as energy storage technology and power generation technology, thermal power has long been the main form of power supply. Although the proportion of renewable energy power generation has increased, it has always been used as a supplement. Under the premise of relatively stable consumption levels, although there is competition between traditional energy and information energy, it is not a complete substitution relationship. It is possible to achieve common development and advantages. Complementary. The installed capacity of renewable energy is increasing year by year, but the utilization hours of the units are still insufficient. This is because electricity involves all fields of people's livelihood development, blindly There are many risks in increasing renewable energy power and reducing thermal power generation [7-8].

(3) There is no clear coordinated development model among various power generation forms. The coordinated development of multiple energy sources is still in its infancy. The relevant policies and development plans only include the macro development direction, and there is no very detailed deployment and arrangement. Coordinated development lacks a development framework tailored to local conditions to constrain the behavior of various entities related to multi-energy power generation, and the corresponding guarantee mechanism and development principle system are not

clear enough [9-10].

In addition, the collection and utilization of energy data and power data provide decision support for collaborative development. With the upgrading of energy metering devices and various terminal equipment, the data collection technology is becoming more and more advanced. Relevant departments can discover customer behavior characteristics and energy by integrating a large amount of data such as energy production, energy consumption, smart device operation, and user information. Supply and demand and other important information, get useful information to guide production [11-12].

2.2. Current Situation Analysis

Through the analysis of the research status of the above-mentioned energy coordinated development, we can see that:

(1) In the context of the Energy Internet, the coordinated development of multiple energy sources is the trend of future development, and is a higher requirement for energy development from energy conservation, emission reduction and environmental protection;

(2) Energy utilization technology is an important guarantee for the coordinated development of multiple energy sources. As a supplementary policy support, my country should strengthen its innovation capability and technical level, and at the same time formulate relevant policies that are conducive to energy development [13-14];

(3) There is no clear model for the coordinated development of multiple energy sources. The practical application of inter-regional energy synergy and complementarity between multiple energy sources is still in its infancy. The research in this paper can further solve this problem.

2.3. Comprehensive Energy System Benefit Evaluation Index System

The operation characteristics and interrelations of the whole process of source-load-storage are considered, which is helpful for better evaluation: comprehensive energy system benefit, and some targeted improvement measures are proposed. When selecting benefit evaluation indicators, follow the five basic principles of scientificity, representativeness, difference, comparability and qualitative combination, so as to be able to evaluate the comprehensive energy system benefits scientifically and reasonably, as follows:

(1) Scientific principles

The setting of the comprehensive energy system benefit evaluation index not only includes various evaluation information, but also needs to satisfy the correctness and integrity of the basic concept, characteristics and operation structure of the comprehensive energy system. At the same time, the selected relevant evaluation indicators follow the principle of scientificity, which can further reveal the development rules of each energy subsystem, introduce the comprehensive benefits of the evaluation system scientifically, and provide corresponding investment planning support tools for various types of comprehensive energy systems [15-16].

(2) The principle of representation

When collecting and arranging relevant evaluation information, it is not advisable to select too many evaluation indicators on the basis of following the principle of representativeness. The selected benefit evaluation indicators should be interdependent and affect each other, which can reflect the benefits of the entire IE system, and further reflect the benefits of a single energy subsystem. At the same time, based on the strong coupling between the various energy subsystems, the collection and arrangement of the relevant evaluation indicators can be avoided, resulting in a large repetition and double counting, which makes the final comprehensive energy system benefit evaluation result deviated from reality. Phenomenon.

(3) The principle of difference

However, the evaluation indexes that can characterize each energy subsystem are intertwined and complicated, and the redundancy among each index is high. However, when selecting the evaluation indicators of each energy subsystem, the principle of differentiation is followed, combined with the content and characteristics of each energy subsystem, and the evaluation indicators that are not affected by each other are screened. Sexual indicators help to propose improvement measures and programs in a targeted manner.

(4) The principle of comparability

Since the IE system involves multiple energy subsystems of electricity, heat, cooling, and gas, the data sources of each evaluation index are very different, and there are certain differences among the participating subjects. When selecting the benefit evaluation indicators, it is necessary to further clarify the classification, detailed measurement, and unified caliber, so as to facilitate the evaluation of the benefit evaluation of the entire IE system. At the same time . During the coordinated operation of the entire energy subsystem, following the principle of comparability, the external characterization indicators on both the source and storage sides of the IE system are considered globally, and the procedural internal characterization indicators on the load side are considered, which helps to evaluate and analyze the comprehensive benefits of the system.

(5) The principle of combining qualitative and quantitative

During the operation planning of the comprehensive energy system construction project, on the one hand, it is constrained by relevant national and regional policies, which directly affects whether the comprehensive energy system construction project can be carried out in an orderly manner; on the other hand, due to the characteristics and focus of each energy subsystem itself different, resulting in different impacts on the entire energy system. Therefore, when selecting comprehensive energy system benefit evaluation indicators, follow the principle of combining qualitative and quantitative indicators to evaluate all aspects of benefits [17-18].

2.4. Reliability Model of Gas-Electric Coupling System

The natural gas transmission and distribution pipeline network system is regarded as an independent component A, the gas turbine is regarded as an independent component B, and the gas-electric coupling system formed by the connection of the two is regarded as a series system, as shown in Fig. 1 shown,

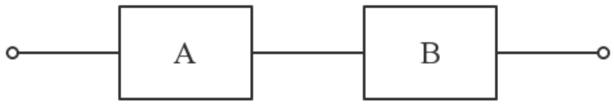

Figure 1. Tandem system connection model

Let SA and SB denote the probability of normal operation of components A and B, respectively, and FA and FB to denote the probability of failure of components A and B, respectively, then we have:

$$S_A + F_A = 1 \tag{1}$$

$$S_B + F_B = 1 \tag{2}$$

A requirement for the system to operate successfully is that both A and B must be functioning properly at the same time. According to the concept of the series equivalent principle, the system reliability SU and unreliability FU are calculated as:

$$S_U = S_A S_B \tag{3}$$

$$F_U = 1 - S_A S_B \tag{4}$$

For a system with n elements in series,

$$S_U = \prod_{i=1}^{n} S_i \tag{5}$$

$$F_U = 1 - \prod_{i=1}^{n} S_i \tag{6}$$

In this paper, the above principles are used to equate the uncertainty of the natural gas transmission and distribution network system with the random failure of the gas turbine. Let the failure rate and repair time of the gas turbine be λgt (times/year) and γgt (hours/times), respectively. Then the equivalent availability rate pAeq(t) and the equivalent unavailability rate pUeq(t) are expressed as follows:

$$p_{Aeq}(t) = (1 - p_{ng}(t)) \times \frac{8760}{\lambda_{gt}(t) \times \gamma_{gt}(t) + 8760} \tag{7}$$

$$p_{Ueq}(t) = (1 - p_{ng}(t)) \times \frac{8760}{\lambda_{gt}(t) \times \gamma_{gt}(t) + 8760} \tag{8}$$

3. Experimental Research on

3.1. Energy Hub Theory

The energy hub theory constructs a multi-energy coupled linear model of a regional comprehensive energy system including source, grid, load, and storage. This theory is widely used in the related research of IE system.

The energy forms demanded by users include electricity, cold, heat, etc., while the externally supplied energy includes electric energy, natural gas, heat energy, wind energy, light energy, etc. Equation (9) describes the modeling method based on the energy hub theory:

$$\underbrace{\begin{bmatrix} L^{\alpha} \\ L^{\beta} \\ \vdots \\ L^{\chi} \end{bmatrix}}_{L} = \underbrace{\begin{bmatrix} \eta^{\alpha\alpha}\upsilon^{\alpha\alpha} & \eta^{\beta\alpha}\upsilon^{\beta\alpha} & \cdots & \eta^{\chi\alpha}\upsilon^{\chi\alpha} \\ \eta^{\alpha\beta}\upsilon^{\alpha\beta} & \eta^{\beta\beta}\upsilon^{\beta\beta} & \cdots & \eta^{\chi\alpha}\upsilon^{\chi\alpha} \\ \vdots & \vdots & & \vdots \\ \eta^{\alpha\chi}\upsilon^{\alpha\chi} & \eta^{\beta\chi}\upsilon^{\beta\chi} & \cdots & \eta^{\chi\chi}\upsilon^{\chi\chi} \end{bmatrix}}_{C} \underbrace{\begin{bmatrix} P^{\alpha} \\ P^{\beta} \\ \vdots \\ P^{\chi} \end{bmatrix}}_{P} \tag{9}$$

In the formula: the P vector is the energy input variable, which represents the energy of all input systems; the L vector is the load output variable, which represents all the terminal loads; the C matrix is the coupling matrix, and each element in the matrix represents the energy of a certain input system and the terminal load. The corresponding conversion relationship is determined by the characteristics of the energy conversion equipment and the energy distribution coefficient; α, β, ..., χ represent different forms of energy; ηαχ represents the efficiency of energy α to energy χ conversion; The proportion of energy allocated to energy conversion equipment.

As a variable, the energy distribution coefficient describes the energy flow path of the system at a certain time. From the perspective of collaborative optimization theory, redundant energy flow paths provide space for the complementarity and economic dispatch between different types of energy. The energy distribution coefficient needs to be Satisfy the following constraints:

$$\begin{cases} \sum_j \upsilon^{ij} = 1 \\ 0 \le \upsilon^{ij} \le 1 \end{cases} \tag{10}$$

3.2. Reliability Evaluation Algorithm of Gas-Electric Coupling System

The evaluation steps are as follows:

(1) Input the data calculated by the gas-electric coupling system, that is, the equivalent parameters of the gas-fired unit, the original data of the conventional unit, and the load data. Let the number of simulated samples j = 1.

(2) Randomly generate a random number uniformly distributed in (0,1), simulate the operating state sequence stp(j) of the conventional unit, and calculate the output power Pgt(j) and Ptp(j) of the gas unit and the conventional unit.

(3) Calculate the total power generation, judge the load reduction of the system, and count the reliability indicators under j sampling.

(4) Verify that the simulation process is over sampling. If j>Jmax, the simulation process ends; otherwise, let j=j+1, go to (2).

The reliability assessment process is shown in Figure 2:

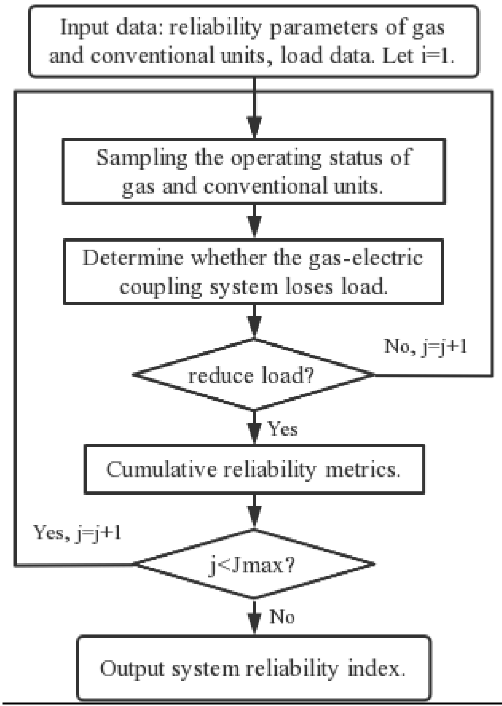

Figure 2. Flow chart of reliability assessment of gas-electric coupling system

4. Experimental Analysis on

Based on the analysis of three typical IE system collaborative optimization modes: electricity-heating collaborative optimization mode, electricity-heating-cooling collaborative optimization mode and electricity-heating-cooling-air collaborative optimization mode, from the energy network composition, system module composition, system The three modes are compared and analyzed in terms of the composition of the energy storage module, the composition of the system energy output module, and the main components of the system.

4.1. Composition of Energy Network

The integrated energy (IE) system of the power-heat collaborative optimization mode includes the power grid and the heat pipe network; the power-heat-cool collaborative optimization mode includes the power grid, the heat pipe network and the cold pipe network; the power-heat-cooling-gas collaborative optimization mode includes the power grid, the heat pipe network, The cold pipe network and gas pipe network are shown in Table 1:

Table 1. Comparison of energy network composition of typical IE systems

System Type	Power Grid	Heat Pipe Network	Cold pipe network	Tracheal Network
E-T co-optimization	√	√	×	×
E-H-C co-optimization	√	√	√	×
E-H-C-A co-optimization	√	√	√	√

4.2. System Module Configuration

Three typical integrated energy systems can be divided into four modules: input, conversion, storage and output.

4.3. Operating Principle of the System Energy Input Module

The energy input modules of the three typical IE systems are all composed of natural gas pipeline networks and large power grids, mainly including natural gas power input systems and large power grids.

4.4. Operating Principle of the System Energy Conversion Module

The IE system mainly includes 8 types of energy conversion, namely: clean renewable energy → electric energy (A); natural gas → chemical reaction → electric energy (B); natural gas → heating → electric energy (C); natural gas → waste heat → thermal energy (D); natural gas → waste heat → cold energy (E); electric energy → thermal energy (F); electric energy → cold energy (G); electric energy → natural gas (H). As shown in Table 2, the electric-heat collaborative optimization mode includes A, B, C, D, and F; the electric-heat-cooling collaborative optimization mode includes A, B, C, D, E, F, and G; The cooling-air coordination N optimization modes include A, B, C, D, E, F, G, and H.

Table 2. Comparison of energy conversion types involved in a typical IE system

System type	A	B	C	D	E	F	G	H
E-T co-optimization	√	√	√	√	×	√	×	×
E-H-C co-optimization	√	√	√	√	√	√	√	×
E-H-C-A co-optimization	√	√	√	√	√	√	√	√

4.5. Main Components of the System

The IE system of the electricity-heat synergistic optimization mode includes wind turbines, photovoltaic generator sets, CHP co-supply systems, fuel cells, energy storage devices and electric heating equipment; The optimization mode adds electric refrigeration equipment, and the CHP co-generation system is upgraded to a CCHP triple-generation system; the electricity-heat-cooling-air synergistic optimization mode adds electricity-heating-cooling synergistic optimization mode compared with the electric-heat-cooling synergistic optimization mode, as shown in Table 3 shown:

Table 3. Comparison of main components of a typical IE system

System type	E-T co-optimization	E-H-C co-optimization	E-H-C-A co-optimization
Wind Turbine	√	√	√
Photovoltaic unit	√	√	√
Joint supply system	CHP	CCHP	CCHP
The fuel cell	√	√	√
Energy storage device	√	√	√
Electric heating equipment	√	√	√
Electric refrigeration equipment	×	√	√
Electric gas equipment	×	×	√

To sum up, the IE system of the electricity-heat-cooling-air synergistic optimization mode covers more types of energy networks, more types of energy conversion, better effect of energy cascade utilization, higher energy utilization efficiency, and the types of user energy needs that can be met are more comprehensive.

5. Conclusion

In recent years, new energy has entered a period of rapid development on a global scale. If China wants to change from an energy power to an energy power, it needs to pay more attention to the healthy and sustainable development of multiple energy sources. Although the proportion of fossil energy in the energy structure is relatively large at present, from the perspective of the long-term goal of sustainable development, the proportion of new energy will continue to increase, and a scientific development model is needed among various energy sources. As the main energy consumer, the power generation industry shoulders the important responsibility of energy structure adjustment. The development of new energy power generation enterprises in my country is relatively late and in the early stage of development. In the future, in the transformation to large-scale, the coordinated development of multi-energy power generation is indispensable.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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