Study on safety evaluation and optimal dispatching strategy of thermal-gas coupling system with photovoltaic wind power storage

Wenxian Zhu

Northeast Electric Power University, Jilin, Jilin, 132000, China

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Abstract: This study focuses on the safety evaluation and optimal dispatching strategy of the coupled system of generating light, wind and electricity storage (hereinafter referred to as "coupled system"). As a new energy system, the coupling system integrates biomass energy, light energy, wind energy, energy storage, electric energy, thermal energy and natural gas, aiming at improving the flexibility, reliability and economy of the energy system. Firstly, a safety assessment index system including system stability, reliability and vulnerability is constructed, and a quasi-dynamic safety assessment method combined with a quantitative risk assessment model is used to monitor key parameters in real time and predict the future trend of the system. Then, a multi-objective optimal scheduling strategy is proposed in this study, aiming at achieving efficient use of energy, minimum cost and environmental friendliness. This strategy comprehensively considers the interaction and coupling relationship of power, natural gas, heat and other subsystems, and uses genetic algorithm to solve the optimal scheduling model. The case analysis shows that by optimizing the scheduling scheme, the system operation cost is reduced by 15.6%, and the pollutant emissions are significantly reduced, including CO2 emissions by 20%, NOx by 25%, SOx by 15% and PM emissions by 30%. This study provides a scientific basis for the design and operation of the coupling system, ensures the safe and reliable operation of the system under various working conditions, and promotes the sustainable development of energy.

1. Introduction

As an important part of the new energy system, the coupled system of generating light, storing wind and electricity (hereinafter referred to as the "coupled system") is attracting more and more attention from academia and industry. By integrating biomass energy, light energy, wind energy, energy storage, electric energy, heat energy, natural gas and other energy forms, the coupling system realizes efficient utilization and mutual assistance of energy, which is of great significance for improving the flexibility, reliability and economy of the energy system.

However, the complexity and diversity of coupled systems also bring many challenges. Due to the mutual transformation and interaction of various energy forms, the safety problem of coupled system is increasingly prominent [1]. How to ensure the stable operation of the system under various working conditions and prevent the interruption of energy supply or accidents caused by faults has become an urgent problem to be solved. At the same time, the optimal scheduling strategy of coupled systems also faces many problems [2-3]. How to achieve efficient use of energy and minimize the cost under the premise of meeting the energy demand is the focus of the research on the scheduling strategy of coupled systems.

Therefore, it is of great significance to study the security evaluation and optimal scheduling strategy of coupled systems. On the one hand, safety assessment can provide scientific basis for the design and operation of the coupling system, and ensure the safe and reliable operation of the system under various working conditions. On the other hand, optimizing the dispatching strategy can improve the energy utilization efficiency, reduce the operation cost and promote the sustainable development of energy.

At present, scholars at home and abroad have made some research achievements in the safety evaluation and optimal scheduling strategy of coupled systems. However, due to the complexity and diversity of the coupling system, there are still many shortcomings in the existing research. For example, the security evaluation method is not perfect and it is difficult to accurately reflect the real-time security of the system; The optimal scheduling strategy is too simplified to meet the needs of the actual system. Therefore, this study deeply discusses the security evaluation and optimal scheduling strategy of the coupling system, and puts forward more scientific and effective methods and strategies to provide strong support for the design and operation of the coupling system.

2. Safety evaluation of coupled system

2.1. Construction of safety evaluation index system

A set of safety evaluation index system including system stability, reliability, vulnerability, etc. [4-5] is studied and constructed. Specific indicators are shown in Table 1 below:

Table 1 Safety evaluation index system of coupling system

Indicator category	Specific indicators	describe	appraisal procedure
System stability index	Voltage stability index	The ability to reflect whether the voltage of the power system can be kept within the allowable range after being disturbed.	It is evaluated by monitoring the voltage change rate of key nodes.
	Frequency stability index	The ability to measure whether the frequency of the power system can quickly return to the rated value when the load changes or fails.	It is evaluated by calculating the mean and standard deviation of frequency deviation.
	Thermal system stability index	The ability to evaluate whether the parameters such as temperature and pressure can be kept in a safe range when the supply and demand of the thermal system changes or the equipment fails.	Evaluate by monitoring the running state and parameter changes of key equipment.
System reliability index	Power supply reliability rate	Reflect the probability that the power system can continuously supply power within a certain period of time.	It is evaluated by counting the number of power outages, the time of power outages and the number of users affected.
	Gas supply reliability rate	Measure the probability that the natural gas system can meet the gas demand of users within a certain period of time.	It is evaluated by monitoring gas supply, pipeline pressure and user gas consumption.
	Reliability index of comprehensive energy system	Considering the reliability of power, natural gas, heat and other subsystems, the reliability of the whole coupling system is evaluated.	Through fuzzy comprehensive evaluation and other methods to evaluate.
System vulnerability index	Failure diffusion risk index	Evaluate the risk that a fault point in the coupling system will trigger a chain reaction, leading to a large-scale paralysis of the system.	By simulating the fault scenario and analyzing the fault diffusion path and influence range, it is evaluated.
	External attack vulnerability index	Measure the ability of the coupling system to resist malicious behaviors such as external network attacks and physical damage.	By evaluating the system's security protection measures, the number and severity of vulnerabilities.
	Natural disaster vulnerability index	Evaluate the resilience of the coupling system in the face of natural disasters such as earthquakes, floods and typhoons.	It is evaluated by analyzing the geographical location, structural strength and emergency response capability of the system facilities.

2.2. Safety evaluation method

Integrating the advantages of static and dynamic safety assessment, the quasi-dynamic safety assessment method is adopted, and the future trend of the system and its stability, reliability and vulnerability are predicted by monitoring key parameters in real time and establishing dynamic models. Based on probability theory and mathematical statistics, a quantitative model of risk assessment is established, historical data is analyzed to calculate failure probability and consequences, and technologies such as Monte Carlo simulation are used to quantify system risk [6]. Combining these two evaluation methods, the real-time state evaluation is carried out first, then the long-term risk is evaluated, and finally the overall security of the system is comprehensively evaluated with various indicators.

3. Optimal scheduling strategy of coupled system

3.1. Optimal scheduling strategy goal

The optimal scheduling strategy of the coupled system can meet the load demand of the system by reasonably allocating various energy resources, and at the same time, realize the efficient utilization of energy, the minimum cost and the environmental friendliness. According to the characteristics of the coupled system, this study puts forward a multi-objective optimal scheduling strategy, which comprehensively considers the interaction and coupling relationship of power, natural gas, heat and other subsystems, as well as the economy, reliability and environmental protection of the system [7].

The objectives of optimal dispatching strategy include economic objectives, aiming at minimizing system operating costs, such as fuel, maintenance and power purchase costs; Reliability goal, to ensure the stable operation of the system and meet the load demand, and to avoid the interruption of energy supply due to failure; As well as environmental protection goals, is committed to reducing carbon emissions and other pollutants and promoting the sustainable development of energy.

3.2. Construction of optimal scheduling model

(1) Objective function

In order to achieve the above objectives, this study constructs an optimal scheduling model for coupled systems. The model takes into account the interaction and coupling relationship of power, natural gas, heat and other subsystems, as well as various constraints of the system.

Assuming that the total operating cost of the system is C and the carbon emission is E, the objective function of the optimal scheduling model can be expressed as:

$$\min F = \alpha C + \beta E \tag{1}$$

Among them, α, β is the weight coefficient of economy and environmental protection respectively, which is set according to the actual situation of the system and the preference of decision makers.

(2) Constraint condition

1) Power subsystem constraint

$$\begin{cases} P_G - P_D - P_L = 0 \\ P_{G\min} \le P_G \le P_{G\max} \\ V_{\min} \le V \le V_{\max}, f_{\min} \le f \le f_{\max} \end{cases} \tag{2}$$

Among them, P_G is the generator output, P_D is the load demand, and P_L is the line loss. From top to bottom, it represents power balance constraint, generator output limit, voltage and frequency limit respectively.

2) Natural gas subsystem constraint

$$\begin{cases} Q_S - Q_D - Q_L = 0 \\ P_{g\min} \le P_g \le P_{g\max} \\ Q_{pipe\min} \le Q_{pipe} \le Q_{pipe\max} \end{cases} \tag{3}$$

Among them, Q_S is the supply of gas source, Q_D is the gas consumption of users, and Q_L is the pipeline loss. From top to bottom, it indicates gas balance constraint, gas pressure limit and pipeline flow limit respectively.

3) Thermal subsystem constraint

$$\begin{cases} H_G - H_D - H_L = 0 \\ T_{\min} \le T \le T_{\max}, P_{\min} \le P \le P_{\max} \end{cases} \tag{4}$$

Among them, H_G is the heat supply of heat source, H_D is the load demand, and H_L is the heat loss. From top to bottom, it indicates heat balance constraint, temperature and pressure limit respectively.

3.3. Optimal scheduling strategy

To solve the above optimal scheduling model, genetic algorithm is adopted in this study. The algorithm can find the optimal solution in the complex search space and meet the multi-objective optimization requirements of the system.

The specific implementation steps are as follows:

1) Initialize algorithm parameters, such as population size, iteration times, etc.

2) Generate the initial population, that is, a group of decision variables that meet the constraints.

3) Evaluate the initial population and calculate the objective function value of each individual.

4) According to the evaluation results, selection, crossover and mutation operations are carried out to generate new populations.

5) Repeat steps 3 and 4 until the number of iterations is reached or the optimal solution satisfying the termination condition is found.

6) Output the optimal solution, which is the optimal scheduling scheme of the system.

4. Case analysis

A typical comprehensive energy system of electricity, gas and heat is selected as a case study. The system includes power subsystem, natural gas subsystem and thermal subsystem, which are coupled with each other through energy conversion equipment, such as gas generator and cogeneration unit. The goal of the system is to meet the demand of electric power, natural gas and thermal load, and at the same time, realize the efficient utilization of energy, minimize cost and be environmentally friendly.

Genetic algorithm is chosen as an optimization tool to deal with complex multi-objective optimization problems. Parameter setting includes population size of 100, iteration of 500 times, crossover probability of 0.8 and mutation probability of 0.2. The population is initialized by randomly generating 100 individuals representing different scheduling schemes, and the objective function value of each individual considering economy, reliability and environmental protection is calculated as the evaluation basis. In the selection process, roulette method is used to select individuals according to fitness values, and then single-point crossover and random mutation operations are performed with set probability. This process is repeated until the preset number of iterations is reached or the optimal solution is found.

Table 2 Cost reduction percentage

Cost type	Cost reduction percentage
System operating cost	15.6%
Fuel cost	10.2%
Equipment maintenance cost	5.8%
Electricity purchase cost	7.3%

Table 2 shows that by optimizing the scheduling scheme, the overall operating cost of the system is reduced by 15.6%. Specifically, the fuel cost is reduced by 10.2%, the equipment maintenance cost is reduced by 5.8%, and the power purchase cost is reduced by 7.3%. This shows that the optimization measures effectively improve the energy efficiency and reduce the operating expenses, thus significantly reducing the overall operating cost of the system.

In the power system, the load demand usually peaks in the morning and evening, and is low at other time periods, and the demand for natural gas and heat also shows a similar pattern, especially in winter. The optimized supply strategy aims to match these fluctuations more accurately and improve the stability and efficiency of the system, such as increasing power supply during peak hours and reducing it during low hours. Comparing the data before and after optimization, it shows that the supply of the optimized system closely follows the demand change, which reduces the imbalance between supply and demand, makes the system run more stably and efficiently, and improves the overall performance (see Figure 1).

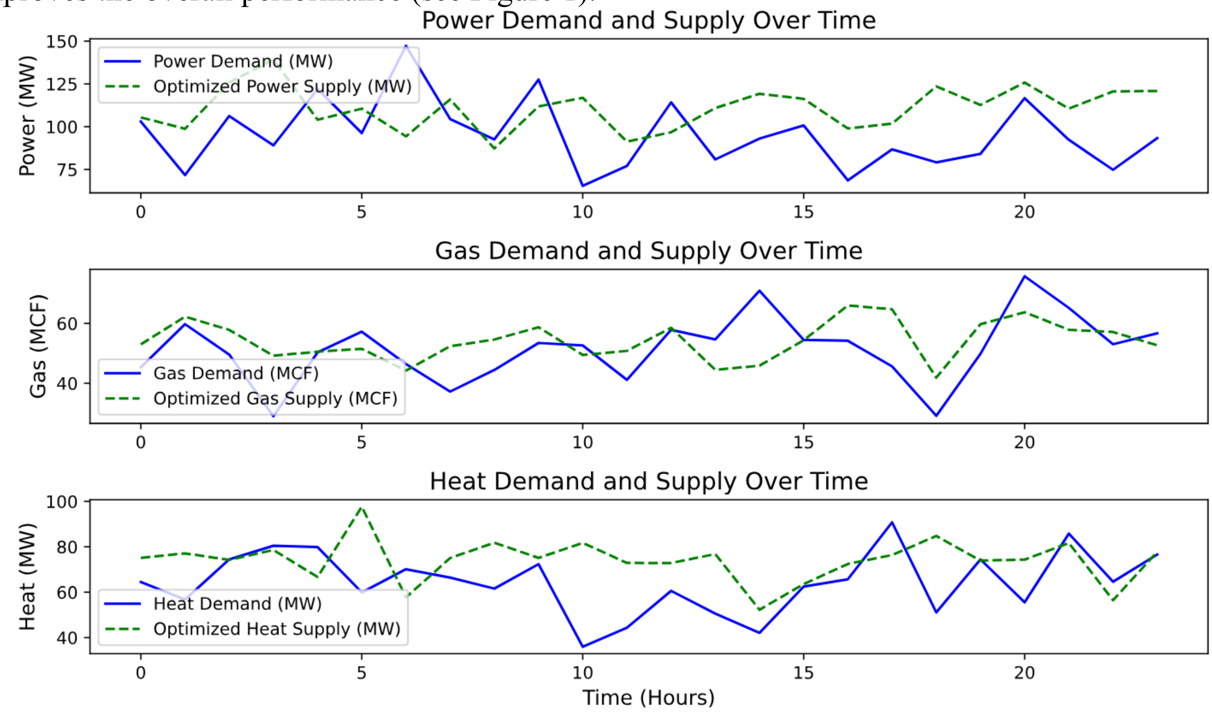

Figure 1 Changes of system supply and load demand with time

The optimized comprehensive energy system of electricity, gas and heat has significantly reduced the emission of various pollutants through the application of genetic algorithm scheduling scheme (see Table 3). CO2 emissions decreased by 20% to 800.4 tons, NOx by 25% to 375.19 tons, SOx by 15% to 255.64 tons, and PM emissions decreased by 30% to 140.07 tons. This not only reflects the improvement of energy efficiency, but also has a positive impact on slowing global warming, improving air quality, protecting ecosystems and improving public health.

Table 3 Comparison of pollutant discharge before and after optimization

pollutant	Emissions before optimization (ton)	Optimized emission (ton)	Change in emissions (%)
CO2	1000.50	800.4000	20.0
NOx	500.25	375.1875	25.0
SOx	300.75	255.6375	15.0
PM	200.10	140.0700	30.0

5. Conclusion

By constructing a set of safety evaluation system including system stability, reliability and vulnerability, and using quasi-dynamic safety evaluation method, combining probability theory and mathematical statistics, a quantitative risk evaluation model is established to comprehensively evaluate the safety of the system. At the same time, in view of the complexity and diversity of the coupling system, a multi-objective optimal scheduling strategy is proposed, which comprehensively considers the interaction and coupling relationship of power, natural gas, heat and other subsystems, as well as the economy, reliability and environmental protection of the system. The genetic algorithm is used to solve the optimal scheduling model, and the goals of efficient utilization of energy, minimum cost and environmental friendliness are realized. The results of case analysis show that the overall operating cost of the optimized system is reduced by 15.6%, the pollutant discharge is significantly reduced, the system supply closely follows the demand change, and the stability and efficiency of the system are improved. These research results provide scientific basis for the design and operation of the coupling system, and have positive significance for promoting the sustainable development of energy.

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