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ENERGY SUPPLY CAPABILITY EVALUATION OF MULTI-ENERGY MICROGRID CONSIDERING RELIABILITY CONSTRAINTS

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ABSTRACT

Aiming at the problem that multi-energy microgrid involves the coupling of multiple energy sources and the difficulty of quantifying the supply capacity of each energy load, the evaluation methods of reliable energy supply intervals of multi-energy microgrid are proposed. Firstly, taking the multi-energy microgrid as the research object, a typical microgrid system model is constructed based on the energy hub model, and the concept of multi-energy microgrid energy supply capability is proposed. Secondly, considering the constraints of energy supply reliability, a reliable energy supply interval model of integrated energy microgrid is constructed. Thirdly, based on NSGA-2 multi-objective optimization, the solve method of reliable energy supply interval model of multi-energy microgrid is proposed. Finally, the effectiveness and practicability of the proposed model and method are verified by an example.

Keywords: multi-energy microgrid, energy supply capability, reliable energy supply interval, multi-objective optimization

1. INTRODUCTION

With the increasing consumption of fossil energy and human's attention to energy efficiency, using multi-energy system to centralize supply electricity, heat, gas and other energy sources will become the future development trend [1]. Due to multi-energy microgird involves the supply of various energy sources, and complementary characteristic exists between different energy sources, the energy supply capability can not be expressed by a specific numerical value. Comparing with the calculation of power supply capacity is important to analyze the supply capacity to load of distribution network, the calculation of energy supply capacity of microgrid is also important to analyze the energy supply capacity to load of microgrid system [2]. At the same time, comparing with power supply reliability is an important index to measure the continuous power supply capacity of distribution system, energy supply reliability of multi-energy microgrid is also important, which is the basis of multi-energy microgrid planning. Therefore, the research on the scientific description method of energy supply capacity of multi-energy microgrid and the evaluation method of energy supply capacity of multi-energy microgrid considering the constraints of energy supply reliability have become important problems to be solved urgently.

At present, the research on terminal load supply capability of energy supply system is mainly concentrated in distribution system. There are three main methods for evaluating the power supply capability of distribution network, which are the method based on power flow calculation [3], the method based on security criterion [4], and the method based on power supply reliability constraints [5]. The last method uses power supply reliability as flexible constraints, which is more conducive to tapping the power supply capacity of distribution network and improving the utilization efficiency of power grid assets. It can provide a reference for the evaluation of energy supply capacity of multi-energy microgrid in this paper. For the reliability evaluation of multi-energy microgrid, reference [6] establishes the energy transmission matrix based on the energy hub model, takes the loss of energy expectation as the evaluation index, and realizes the reliability evaluation of multi-energy system. Reference [7] considers the access location of distributed generation and electric vehicle, uses the energy hub model to analyze the energy supply-demand relationship of active distribution network, and establishes the analytic model

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of reliability evaluation. The above references has laid the foundation for the study in this paper. However, the existing research still has the following problems. Firstly, the traditional numerical representation method of power supply capacity can not describe the energy supply capability of multi-energy system. Secondly, the energy supply capability of multi-energy microgrid considering reliability constraint is still to be studied.

In view of the above problems, this paper establishes a reliable energy supply interval model of multi-energy microgrid, uses interval to describe the energy supply capability of multi-energy microgrid, and proposes the solution method of reliable energy supply interval. Finally, an example is given to verify the effectiveness and practicability of the proposed model and method.

2. MULTI-ENERGY MICROGRID STRUCTURE

The energy supply capability of multi-energy microgrid refers to the maximum energy supply capability of microgrid system under certain energy supply reliability constraints. In this paper, combined with energy hub model and the concepts of energy bus, the microgrid system is constructed as shown in Figure 1. The internal equipments of the microgrid system include combined cold heat and power system (CCHP), gas heat pump (GHP), central air-conditioning (CAC), electric and heat storage device, and distributed photovoltaic (PV).

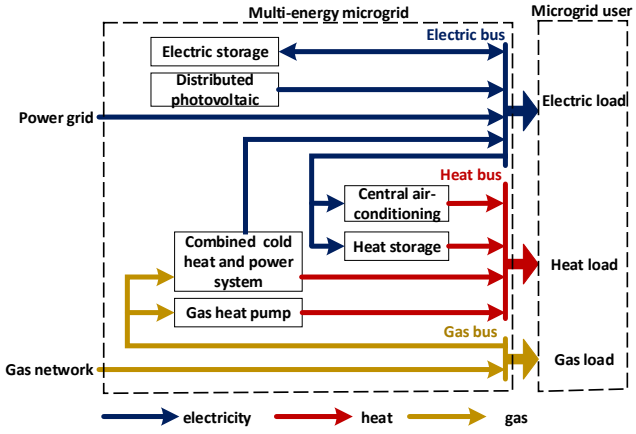

Fig 1 Structure of multi-energy microgrid

3. MULTI-ENERGY MICROGRID RELIABLE ENERGY SUPPLY INTERVAL

The concept of reliable energy supply interval of integrated energy microgrid is proposed in this paper, aiming at describing the energy supply capability of microgrid system under the condition of satisfying the constraints of energy supply reliability. The element of energy supply interval is vector, which represents the supply capability of microgrid system for each energy source, and the dimension of vector represents the type of energy in microgrid system. A multi-energy microgrid providing electricity, heat and natural gas is taken as an example in this paper. The element of the reliable energy supply interval is expressed as vector $[L_e, L_h, L_g]$. Therefore, the reliable energy supply interval is the aggregation of situation meeting users' demand for electricity, heat and gas.

In essence, calculating the reliable energy supply interval of multi-energy microgrid is to find the three-dimensional boundary of the maximum load of electricity, heat and gas can be supplied by microgrid system. This paper uses multi-objective optimization algorithm to solve this problem, and the objective function is as follows.

$$\max F = (L_e, L_h, L_g) \tag{1}$$

In the evaluation process, the optimization objective is electricity, heat and gas energy supply capability achieving Pareto optimality. The constraints are as follows.

(1) Reliability constraint: Represents constraints on the continuous energy supply capability of microgrid systems.

$$LOEE^{elec} \le LOEE^{elec}_{max} \tag{2}$$

$$LOEE^{heat} \le LOEE^{heat}_{max} \tag{3}$$

$$LOEE^{gas} \le LOEE^{gas}_{max} \tag{4}$$

where $LOEE^{elec}_{max}$, $LOEE^{heat}_{max}$, $LOEE^{gas}_{max}$ are the maximum loss of energy expectation of electricity, heat and gas can be allowed in microgrid system.

(2) Energy balance constraint: a real-time balance of electricity/heat/gas energy supply and demand in the multi-energy microgrid should be achieved:

$$L_e = E_{in} + \sum E_{mg,p} - \sum E_{mg,c} \tag{5}$$

$$L_h = H_{in} + \sum H_{mg,p} - \sum H_{mg,c} \tag{6}$$

$$L_g = G_{in} + \sum G_{mg,p} - \sum G_{mg,c} \tag{7}$$

where L_e, L_h, L_g are energy supply capability of electricity, heat and gas; E_{in}, G_{in} are inputs of external power grid and natural gas network; $E_{mg,p}$, $E_{mg,c}$, $H_{mg,p}$, $H_{mg,c}$, $G_{mg,p}$, $G_{mg,c}$ are production and consumption of electricity, heat and gas in microgrid system.

(3) Operation constraint: Including the operation constraints of the devices in microgrid system and the input constraints of external power grid and gas network. The specific constraints need to be determined according to the actual situation.

4. SOLUTION METHOD OF RELIABLE ENERGY SUPPLY INTERVAL

4.1 Operating strategy of multi-energy microgrid

Under normal operation condition, the electric load is firstly supplied by CCHP and PV. If the output is insufficient, using electric storage or purchasing electricity from external power grid. Heat load is firstly supplied by CCHP and GHP. If the output is insufficient, using CAC or heat storage. All energy sources firstly supply the same type of load or store in storage devices. Secondly, the rest can participate in energy conversion.

4.2 State model of equipment units

The state model of equipment units is established based on Monte Carlo simulation method in this paper. The duration from the units normal working state to failure state is:

$$T_{f,k} = -\left(\frac{1}{\lambda_k}\right)\ln \mu_k \qquad k \in [1,2,...m] \tag{11}$$

where λ_k is the failure rate of kth equipment unit; and μ_k is a random number between 0 and 1.

The failure duration of equipment units obeys Weibull distribution:

$$T_{r,k} = \alpha_k \left(-\ln \mu_k\right)^{1/\beta} \qquad k \in [1,2,...m] \tag{12}$$

where α_k is the failure repair time of kth equipment unit; β=6.

4.3 Solution method of reliable energy supply interval

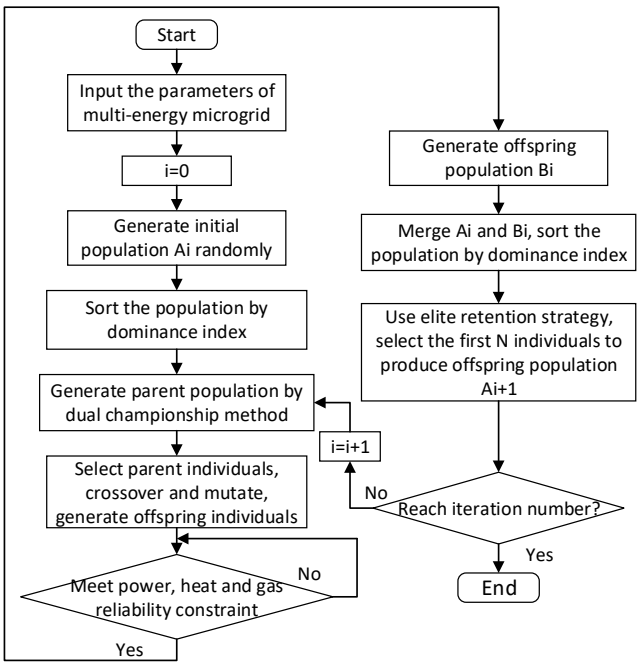

Fig 2 Flow chart of NSGA-2 algorithm

In this paper, NSGA-2 multi-objective optimization algorithm is used to find the reliable energy supply boundary of multi-energy microgrid. The flow chart is shown in Figure 2.

5. CASE STUDY

5.1 Case overview

Taking an multi-energy microgrid as an example, the system structure and equipment units are shown in Figure 1. The device parameters in the microgrid system are shown in Table 1, and the failure probability and repair time of each device are shown in Table 2. According to the local conditions, heating season is from December 1 to April 1, summer is from June 1 to October 1, and the rest of the year is transitional season. The installed capacity of PV in microgrid system is 4MV. The daily energy load curves are shown in Figure 3.

Table 1 Parameters of microgrid equipments

Devices	Capacity
CCHP	2MW
CAC	2MW
GHP	1MW
PV	4MW
Electric storage	3MW·h
Heat storage	1MW·h
Input of external power grid	3.15MW
Input of gas network	500m^3/h

Table 2 Fault parameters of microgrid equipments

Devices	Failure rate(f/a)	Failure repair time(h)
CCHP	4	24
CAC	1	3
GHP	0.6	2
External power grid	0.82	7.32
Gas network	0.9	20
PV	0.4	20

5.2 Result of reliable energy supply interval

Using the method mentioned above, the reliable energy supply interval of the microgrid system is calculated. The boundary of the reliable energy supply interval is the Pareto front obtained by the multi-objective optimization algorithm, which can reflect the energy supply capability of the multi-energy microgrid considering reliability constraints. When the reliability constraints are set as the loss of energy expectation of electricity is less than 1MW H/a, the loss of energy expectation of heat is less than 5MW H/a, and the loss of

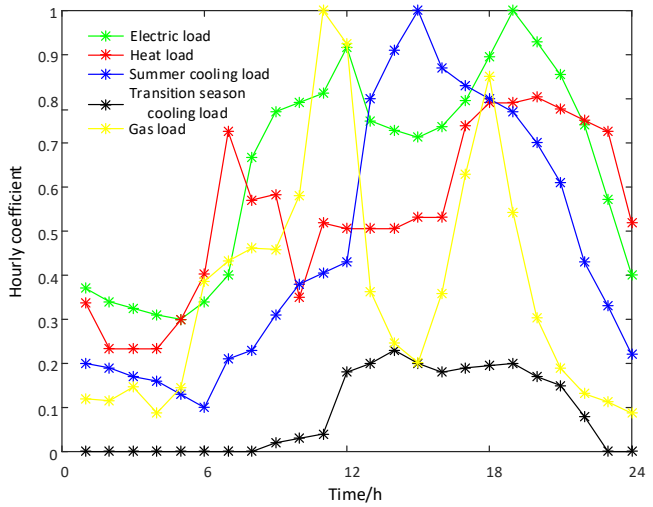

Fig 3 Hourly coefficient of each kind of load

energy expectation of gas is less than 500m^3/a, the reliable energy supply interval is calculated as shown in Figure 4.

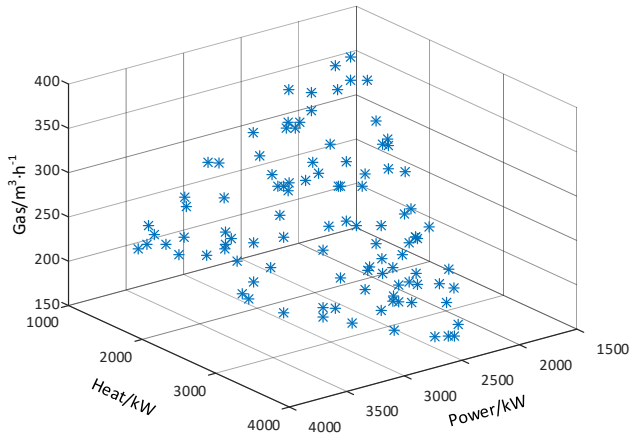

Fig 4 Reliable energy supply interval boundary of multi-energy microgrid

According to the calculation results, because of complementary relationship existing among energy sources, the electricity, heat and gas supply capability is negatively correlated with each other. In order to reflect this relationship more clearly, the energy supply capability of two energy sources is calculated when the other one is limited to a fixed value. The two-dimensional cross section of the three-dimensional reliable energy supply interval is obtained. The results are shown in Figure 5.

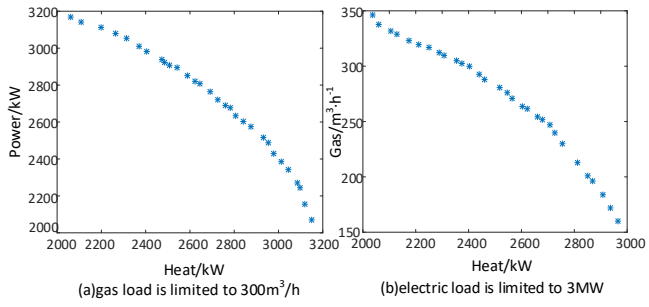

Fig 5 2D reliable operation interval boundary

6. CONCLUSIONS

Aiming at the evaluation method of energy supply capability of multi-energy microgrid, this paper presents a reliable energy supply interval model to describe energy supply capability, and proposes a method to calculate reliable energy supply interval. The case shows that the model and method proposed in this paper is practical and effective. According to the results of the case, the energy supply capability of multi-energy microgrid is negatively correlated with each other.

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