Optimal Planning of Multiple Sources Included Energy Internet near User Side Based on Energy Router

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Abstract. Because of the situations that the interconnection among multi distributed energy system (DES) and interaction among electric, heating and cooling system are not given full consideration, optimal planning of energy internet near user side based on bi-level programming is studied in this paper. First, schematic structure along with mathematic models of each unit is proposed and load characteristic is analyzed. Considering the interconnection of multiple energy as well as multiple distributed system and the combined dispatch of multi energy flow, a bi-level programming model is then presented. The minimum of total annual cost is the objective of upper model whose decision variables are the capacity of each energy unit and minimum annual operating cost is the lower model's objective whose decision variables are the output of all energy units. Then, the elitist strategy genetic algorithm is employed to solve the upper model, and branch and bound algorithm is applied to optimizing lower model. The simulation results indicate that the proposed planning method of energy internet is effective, multiple energy flow interaction and multiple energy router interconnection are more economic than traditional combined cooling heating and electricity (CCHP) and can alleviate the mismatch of heat-to-electricity ratio between gas turbine and loads, and the multiple energy networks by which DES are interconnected contributes to higher economic benefits than single electric or heating network.

1. Introduction

There are many small-scale distributed energy systems on the user side, and the load has strong randomness and volatility, and the distance between "source" and "load" is relatively close. The construction of energy Internet on the user side can not only meet the user's electricity / heat / cold multiple energy needs, but also smooth the load curve, improve energy efficiency and absorb renewable energy. Related researches include CCHP system, integrated energy system and pan energy network [1-5]. For a single energy supply area, a general modeling method is proposed for optimal scheduling of CCHP microgrid considering the conversion of multiple energy flows [2]. The effectiveness of the model was verified by taking an office building as the test object. A distributed energy system planning method considering multiple energy interconnection and multiple energy flow coordination is proposed in [3]. The simulation results show that the system is more economical and efficient than centralized energy supply mode and conventional CCHP mode. For the interconnection of multiple regions, a planning method is proposed for interconnection of multi energy stations based
on 0-1 mixed integer linear programming [4]. However, there are few types of equipment available in the planning, and they are limited to the thermal mutual benefit between stations. An operation optimization model is established in the form of matrix with the minimum annual operation cost and carbon emission as the goal [5]. Two or three regional interconnection were considered successively, and different operation scenarios were compared and analyzed. The calculation examples show that multi regional interconnection and combined heat and power supply have more economic and environmental benefits. At present, there are few studies on the planning of energy internet. The energy internet structure is studied with power router as the core, and proposes the future distribution network configuration based on the electric energy exchanger [6]. Aiming at the problems of "energy transmission congestion" and "energy load balancing" in energy internet, routing strategies based on edge weight and load of adjacent nodes are proposed respectively [7].

Considering the interconnection of multiple energy sources, the mutual aid of multiple energy supply regions and the joint dispatching of multiple energy flows, a two-level programming model is established to configure the equipment in each energy router and to plan the network between energy internet. The optimization objectives of the upper and lower models are to minimize the annual cost and the lowest annual operation cost respectively; the genetic algorithm with elite retention strategy and branch and bound method are used to solve the proposed model, and the upper and lower levels are constrained by iterative calculation, so as to compare and analyze the impact of multi energy complementary and network interconnection on planning economy.

2. User side energy internet

2.1. Energy supply system structure and energy unit modeling
There are five types of energy units in the user side energy Internet, including energy production unit, conversion unit, storage unit, transmission unit and energy consumption unit. With energy router as the core, the user side energy internet is divided into several energy internet, and the system structure is shown in Figure 1.

![Figure 1. Schematic diagram of energy internet near user side.](image)

Each energy router includes energy production, conversion and storage units, which supply energy to local load through internal network. The energy routers can realize the mutual aid of electric energy and heat energy through power lines and thermal pipelines. In the cold season, the hot cold conversion unit in the energy router converts the heat transported by the thermal pipeline into the cooling capacity to supply the cold load.
Energy production unit generally uses natural gas, wind, light and other primary energy as input to produce electricity / heat / cold energy required by users. This paper mainly considers gas turbine, gas boiler and photovoltaic. Energy conversion unit is a kind of equipment which can realize the conversion of electricity / cold / heat and other energy flows. The input is usually high-grade potential energy (electricity), and the output is usually low-grade energy (hot and cold).

2.2. Load characteristic analysis
Due to the objective law of production work and rest, large supermarkets and office areas have higher load in the daytime and lower load at night, which is just opposite to the load characteristics of residential areas. Considering the interconnection of three types of regions in the planning, it can realize the complementarity of different load characteristics, alleviate the mismatch of various load peak and valley periods, improve the energy comprehensive utilization efficiency and equipment utilization rate, and finally improve the system economy. The energy supply area of each energy router is limited, and it is close to the load point. Its location has little impact on the planning economy. At the same time, there are few candidate locations. Each area has certain requirements for the environment and land occupation. Therefore, the site survey method is adopted to determine the location of each router in combination with the actual situation.

3. Planning mode of energy internet near user side
The annual operation cost should be included in the goal of energy router configuration and energy network planning. The annual operation cost is calculated by the optimal output of each unit in 24 hours of a typical day. The multi energy flow optimal scheduling is based on the installed capacity of each energy unit. The two factors restrict each other, and the optimal planning scheme is obtained by repeated iterations. This process is matched with the bilevel programming model, and its model is:

\[
\begin{align*}
\min F &= F(x, w) \\
\text{s.t.} & G(x) \leq 0 \\
\min w &= f(x, y) \\
\text{s.t.} & g(x, y) \leq 0
\end{align*}
\]

The goal of the upper level planning is to minimize the annual cost. The annual cost includes the equipment investment cost and the system annual operation cost in the lower level planning, and its constraint is the allowable installation capacity of each energy unit, which can be given by:

\[
\begin{align*}
C_{j,s}^{\text{min}} \leq C_j \leq C_{j,s}^{\text{max}} \\
\text{P}_{r,j,k} \leq \text{P}_{r,j,k} \leq P_{r,j,k}^{\text{max}}
\end{align*}
\]

The lower level planning aims to minimize the annual operation cost of the system, including fuel cost, operation and maintenance cost, interaction cost with distribution network and environmental cost. The constraints of the lower level planning are the system power balance (electric, thermal and cold) and the output limit of the energy unit, which can be given by:

\[
\begin{align*}
\phi_{l,j} &= \sum_{i} \text{p}^{\text{OUT}}_{i,j,m_i} - \sum_{i} \text{p}^{\text{IN}}_{i,j,n_i} + \sum_{k} \text{p}^{\text{buy}}_{i,k,j} + \sum_{k} \text{p}^{\text{end}}_{i,k,j} \\
\psi_{l,j} &= \sum_{i} \text{h}^{\text{OUT}}_{i,j,m_i} - \sum_{i} \text{h}^{\text{IN}}_{i,j,n_i} + \sum_{k} \text{h}^{\text{dis}}_{i,k,j} + \sum_{k} \text{h}^{\text{end}}_{i,k,j} \\
\epsilon_{l,j} &= \sum_{i} \text{c}^{\text{OUT}}_{i,j,m_i} + \text{C}^{\text{dis}}_{l,j}
\end{align*}
\]
4. Solution of planning mode of energy internet near user side
The improved genetic algorithm with elite retention strategy, adaptive crossover rate and mutation rate can be used to solve the upper level programming problem, and the lower level programming can be solved by branch and bound method:

\[
\min c^T x \\
x^T A x = b \\
\min \{ x_i \in [x_{\min}, x_{\max}], i \in I \\
x_j \in \{0,1\}, j \in J \}
\]

(4)

The optimization variable \( x \) includes the input and output of various energy units in typical day optimal scheduling, scheduling factors and the interactive power between the system and the distribution network; the equality constraints include the energy balance of the system and the energy balance of each unit; the inequality constraint includes the operation constraints of each energy unit.

5. Conclusions
In this paper, a user side energy Internet planning method based on bilevel programming is proposed. The modeling method is feasible. Compared with the traditional energy supply mode and the conventional CCHP system, the energy supply mode considering the combined dispatching of electricity / heat / cold energy flow has higher economic benefits. The coordination and mutual assistance of multiple energy internet can effectively alleviate the problems such as the mismatch between load and gas turbine power ratio, the mismatch between peak and valley periods of electric heating (cooling) load, and realize the complementarity of load characteristics in different regions. It is more economical for energy local area networks to realize interconnection through network than without network connection, and it is more economical to connect energy internet through multiple electric or thermal networks than through single power grid or heat supply network.

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