An optimal dispatching method for integrated community energy systems based on the economic optimality

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Abstract. In order to strengthen the community energy interconnection and promote the optimization and complementation of various energy sources, the scheduling of the integrated community energy system (ICES) has become the basic work of the development of community energy systems. At the same time, the economic dispatch of ICES is an important measure to accept new energy and improve the economic performance of community energy consumption. Without a suitable economic dispatching method, the system cannot fully accept new energy, which will cause the decrease of overall efficiency of the integrated energy system. For the object of economic optimization, this work proposes a holistic optimization dispatching method of several energy devices (electric boilers, hot water tanks and heat pumps) to minimize the operation cost of ICES. Considering that under low temperature the utilization rate of heating equipment is relatively high, a typical season, winter is selected to build operation constraints models. Example analysis shows that the proposed ICES optimization dispatching method provides an appropriate dispatching scheme for the planner of the ICES. This optimization dispatching method not only reduces the operation cost, but also promotes the consumption of renewable energy.

1. Introduction
With the continuous penetration of the concept of energy interconnection, energy utilization is developing towards multi energy coordination and multi energy complementarity. Energy internet has become an important trend of integration of multiple energy networks [1]. The traditional system operation mode that power, heat, and natural gas networks are independent from each other is unable to adapt to the current way of energy production and utilization [2]. To change the situation, in recent years, the global power interconnection, the regional multi energy system and the distributed multi energy system interconnection have gradually become the 3 main ways to realize the energy internet. ICES is exactly an important carrier of the regional multi energy system and the distributed multi energy system interconnection. The core concepts of ICES are multi energy complementation and energy cascade utilization [3].

Because of the high costs of the clean energy equipment, the optimization dispatching model for integrated energy system with the goal of minimizing fossil energy consumption [4,5] cannot guarantee the sustainable development level of the system. To give full play to the economic benefits of the integrated energy system, it is necessary to introduce economic optimal index for leading the integrated energy system from high emission energy consumption to low emission energy consumption.
The existing researches on integrated energy optimization dispatching are mostly aimed at integrated energy systems with combined heat and power (CHP) systems. The coupling relationship between natural gas and power system in the United States is deeply analyzed in [6] and the power risk assessment method considering the operation constraints of natural gas pipelines is proposed. [7] put forward a dispatching method for power units considering wind power randomness. Authors in [8] proposes a dynamic model for the natural gas - power hybrid system. Considering wind power access, authors in [9] puts forward a solution for the combination problem of power system units. Considering the volatility of wind power output, an optimization model for heat and power scheduling in the microgrid is proposed in [10]. At this stage, most of the integrated energy systems are powered by electricity, solar, wind, or geothermal energy. These integrated energy systems usually contain renewable energy equipment, energy saving equipment and electrical energy replacement equipment.

Researches on integrated energy optimization dispatching for the above three types of equipment are relatively few.

This paper focuses on the optimization dispatching method of community integrated energy systems. An optimization dispatching model of the integrated energy system is proposed in Section 2. Considering that most of the equipment studied in this paper is heating equipment, winter is selected to build constraint model. In section 5, the simulation results show that the model and algorithm proposed in this paper presents a suitable optimization dispatching scheme for integrated energy systems.

2. Optimization dispatching model

In order to meet the demand of electric load and cold / heat load in the community, based on all kinds of daily load forecast value, operation dispatching of integrated energy system utilizes the optimization algorithm to get the dispatching plan for the next day (24 hours) for all kinds of energy supply equipment and storage equipment.

2.1. Objective function

In this paper, the economy of system operation is considered, and the mathematical model of economic optimization is built. Based on the best economic criterion, the objective function is the cost function of the integrated energy system, which is the cost of electricity purchased in the community operation. At the same time, subsidized revenue from renewable energy generation is considered. The objective function is summarized as (1):

$$C = \sum_{t=1}^{T} S_t P_t^G M - \sum_{n=1}^{N} \sum_{t=1}^{T} S_{n}^{Rn} P_{t}^{Rn} M$$

Where $C$ is the total cost, $T$ is the total interval number of optimization dispatching for integrated energy system, $M$ is the number of hours per dispatching interval. In this paper, $M = 1$. $S_t$ is the time-of-use electricity price, $P_t^G$ is the power of the grid connected line. $S_{n}^{Rn}$ is the subsidized price of $n$\textsuperscript{th} renewable energy equipment. $P_{t}^{Rn}$ is the power generation power of $n$\textsuperscript{th} renewable energy equipment.

2.2. Constraint conditions

In different seasons, due to the varieties of weather conditions, the energy equipment of the integrated energy system and its operating conditions are very different. In this paper, the system operation constraint model of integrated energy system optimization dispatching in winter is discussed.

In winter, the optimization dispatching of integrated energy system is mainly to meet the demand of electric load and heat load in the community. The main considering electric heating equipment and energy saving equipment include the regenerative electric boiler system, the heat pump system and hot water tanks [11, 12].

Constraints of the supply and demand balance of electric loads:
$P_t^G + \sum_{n=1}^{N} P_t^{Rn} = L_t^E + P_t^{HPh} + P_t^B$  (2)

Where $L_t^E$ is electric load demands outside the energy storage equipment in the community, $P_t^{HPh}$ is the power consumption of heat pumps for heat supply and $P_t^B$ is the power consumption of regenerative electric boilers.

Constraints of the supply and demand balance of heat loads:

$$\sum_{i=1}^{N_{HP}} Q_{t,i}^{HPh} + \sum_{i=1}^{N_B} Q_{t,i}^{BH} + Q_{t}^{HWT} = L_t^H$$  (3)

Where $N_{HP}$ is the available table number of heat pump, $Q_{t,i}^{HPh}$ is the heat supply of $i^{th}$ heat pump, $Q_{t,i}^{BH}$ is the heat supply of $i^{th}$ regenerative electric boiler, $Q_{t}^{HWT}$ is the heat supply of $i^{th}$ hot water tank and $L_t^H$ is the total load demand.

Operation constraints of the electric boiler:

$$U_{t,i}^{BHWT} Q_{t,i}^{BHWT} \leq Q_{t,i}^{BHWT} \leq U_{t,i}^{BHWT} Q_{t,i}^{max}$$  (4)

$$U_{t,i}^{BH} Q_{t,i}^{BH} \leq Q_{t,i}^{BH} \leq U_{t,i}^{BH} Q_{t,i}^{max}$$  (5)

$$U_{t,i}^{B} Q_{t,i}^{min} \leq Q_{t,i}^{B} \leq U_{t,i}^{B} Q_{t,i}^{max}$$  (6)

Where $U_{t,i}^{BHWT}$ is the pattern setting of the electric boiler during heating, $U_{t,i}^{BH}$ is the pattern setting of the electric boiler during thermal storage and $U_{t,i}^{B}$ is the pattern setting of the electric boiler during standby. $Q_{min}^{BHWT}$ and $Q_{max}^{BHWT}$ are the capacity restrictions of the electric boiler during heating, $Q_{min}^{BH}$ and $Q_{max}^{BH}$ are the capacity restrictions of the electric boiler during thermal storage and $Q_{min}^{B}$ and $Q_{max}^{B}$ are the capacity restrictions of the electric boiler during standby.

Operation constraints of the hot water tank:

$$W_{t}^{HWT} Q_{t}^{HWT} \leq W_{t}^{HWT} \leq W_{max}^{HWT}$$  (7)

$$U_{t}^{HWT} Q_{t}^{HWT} \leq Q_{t}^{HWT} \leq U_{t}^{HWT} Q_{t}^{max}$$  (8)

Where $W_{min}^{HWT}$ and $W_{min}^{HWT}$ are the limits of heat storage for the hot water tank. $U_{t}^{HWT}$ is the pattern setting for the hot water tank. $Q_{min}^{HWT}$ and $Q_{max}^{HWT}$ are operation capacity limits of the heat storage tank during heat release.

Operation constraints of the heat pump:

$$U_{t}^{HP} Q_{t}^{HPH} \leq Q_{t}^{HPH} \leq U_{t}^{HP} Q_{t}^{max}$$  (9)

Where $U_{t}^{HP}$ is the pattern setting of the heat pump. $Q_{min}^{HPH}$ and $Q_{max}^{HPH}$ are the operation capacity limits of the heat pump.

3. Optimization algorithm

The main idea of particle swarm optimization (PSO) algorithm comes from social cognition theory, which shows the characteristics of swarm intelligence and achieves the task of group optimization by evaluating, comparing and imitating these three processes. The decision space of the population is $N$ dimension, the size of the particle swarm is $M$ and the position of the $i^{th}$ particle is expressed as $X_i^f = (x_{i,1}^f, x_{i,2}^f, \ldots, x_{i,N}^f)$, the velocity can be expressed as $V_i^f = (v_{i,1}^f, v_{i,2}^f, \ldots, v_{i,N}^f), i = 1, \ldots, M$. The position and velocity of the particle are updated according to the equation below:

$$v_{i,j}^f = \omega v_{i,j}^{f-1} + c_1 rand_1 (p_{i,j}^{f-1} - x_{i,j}^{f-1}) + c_2 rand_2 (g_{j}^{f-1} - x_{i,j}^{f-1})$$  (10)

$$x_{i,j}^f = x_{i,j}^{f-1} + v_{i,j}^f$$  (11)

Where $\omega$ is the inertia weight coefficient; $c_1$ and $c_2$ are the acceleration factor; $rand_1$ and $rand_2$ are the random real number between (0,1); $p_{i,j}^{f-1}$ is the $j$ dimension of the $i^{th}$ particle in the optimal position of the $i-1$ generation. $g_{j}^{f-1}$ is the $j^{th}$ dimension of the most position of the $i-1$ population (the position of the guiding particle).
4. Case study
The optimization dispatching method of community integrated energy systems is researched based on a new community in the north of China.

The simulation data includes electric loads, PV output, heat loads, the peak and valley price information and the performance parameters of the heating equipment. In this community, electric power sources are the power grid and the renewable energy. The heating equipment includes heat pumps, hot water tanks and electric boilers. The quantities and basic performance parameters of each energy device are shown in Table 1.

Table 1. Basic performance parameters of heating facilities.

| Name          | Capacity | Quantity |
|---------------|----------|----------|
| Electric boiler | 2000 kW  | 6        |
| Hot water tank | 605 m³   | 4        |
| Heat pump     | 1260 kW  | 3        |

The peak periods of electricity consumption in the city are 08:30 - 11:30 and 18:00 to 23:00. The peak time electricity price is 1.276 yuan / (kWꞏH). The normal periods are 07:00 - 08:30 and 11:30 - 18:00. The normal time electricity price is 0.812 yuan / (kWꞏH). The valley period is 23:00 - 07:00. The valley time electricity price is 0.427 yuan / (kWꞏH).

Figure 1 shows the load curves in 24 hours of a typical day and the photovoltaic generation curve is as Figure 2. Under the traditional operation mode, the daily running cost of the community is 16850 yuan.
5. Results and discussion

Results were calculated by MATLAB software and the parameters of PSO set as follows: the number of particle groups is 100, the maximum number of iterations is 1000, the individual acceleration factor is 2 and the global acceleration factor is 2.

Based on the load curves and the photovoltaic generation curve, the simulation results are as Figure 3.

As can be seen in Figure 3, When there is a surplus in renewable energy generation (such as in 12:00-15:00), the remainder electric energy is converted into other forms of energy for promoting the renewable energy consumption. Part of the excess electricity is utilized to supply heat loads and the rest is converted into heat energy stored in heat pumps. It is found that the optimization dispatching method proposed in this paper is apt to promote the consumption of distributed energy. At the same time, the total cost is 16020, which reduces by 4.9% compared to that of the traditional mode.

6. Conclusions

This paper researches the optimization dispatching method of ICES to minimize the total operation cost of ICES. Based on the goal of economic optimization, an economic dispatch model is established. At the same time, an operation constraint model is constructed considering the mathematical models of typical equipment. A particle swarm optimization algorithm with good global search capability is applied to solve the dispatching model. According to the results and analysis, it is shown that the optimization dispatching method proposed in this paper can promote the consumption of renewable energy and reduce the operation cost of the community.

In this paper, winter is selected as the typical season. In the future, other seasons will be researched to verify the effectiveness of this method. At the same time, environmental protection goals will be taken into account.

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