Research on economic benefits of “source, storage and load” in a multi-energy complementary combined cooling-heating-electricity system

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Abstract. In order to solve the randomness and volatility of new energy power generation, promote the local consumption of renewable energy, and maximize the economic efficiency of CCHP system, this paper combines the schedulable resources of energy production, energy storage and energy consumption into a "source storage" system, which can meet the demand of power supply, heating and cooling at the same time. The objective function is to minimize the daily operation cost of the cold heat electric hybrid energy system, and the power balance and equipment capacity of the system are constrained. Using the established mathematical model of the system framework, the particle swarm optimization algorithm is used to improve the CCHP programming model to obtain the adaptation curve and the hourly output of the optimal operation of the equipment with the maximum economic benefit. The operation and maintenance costs of the two modes are analyzed in depth. The results show that the optimization of "source storage and load" system not only improves the reliability of energy supply, but also reduces the cost of operation and maintenance and improves the economic benefits of the system.

1 Introduction

Energy is the foundation that supports the continuous development of the social economy and an important guarantee for safeguarding national strategic security. As the world's largest energy producer and consumer, China has been facing the problem of energy supply shortage and how to efficiently save energy and reduce emissions. Therefore, this paper optimizes the output of the equipment in the designed CCHP "source storage" system, effectively solving the randomness and volatility of new energy sources such as light energy, and combining the investment of energy storage equipment to maximize the utilization rate of energy to improve the economic benefits of system operation.

2 Economic dispatch of CCHP model combined energy storage

Multi energy complementary CCHP system is a comprehensive and complex new energy supply system, which has the characteristics of multi energy source, multi energy flow, multi coupling and multi load. The energy system includes power supply system, energy storage system, cooling and heating system, natural gas system and other energy supply systems, so as to realize the optimization of “source storage and load” system [3].

2.1 Energy supply framework for multi-energy complementary combined cooling heating and power system

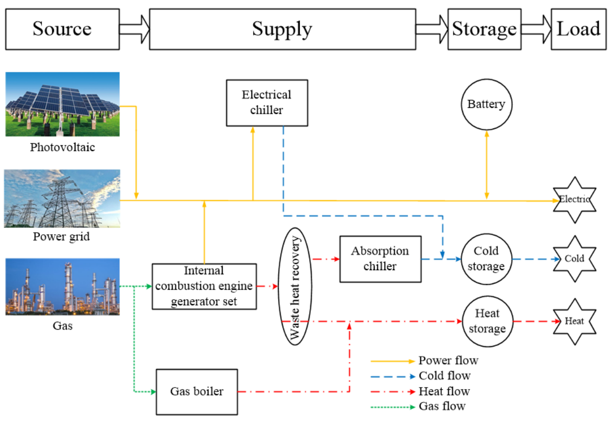

Fig 1. Energy supply framework for multi-energy complementary combined cooling heating and power system

Due to the intermittent and fluctuating characteristics of new energy such as wind and solar energy, the reliability of the system will be reduced when itis connected to the CCHP system, so energy storage equipment is needed to maintain the power and energy balance of the system.

The multi energy complementary CCHP system is rich in energy supply equipment, including micro gas turbine, waste heat boiler, absorption refrigeration unit,

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electric refrigerator unit, gas boiler, storage battery, heat storage (cooling) device and photovoltaic cell [4]. The micro energy grid exchanges electricity with the public power grid through the centralized power bus, and purchases electricity from the large power grid when the power supply of the system is insufficient, and sells electricity to the large power grid when the power supply of the system is surplus. The heat storage device can store excess high-temperature hot water and release energy when the heat production of the system is insufficient, and the role of the cold storage device is the same. The energy supply structure of the system is shown in Figure1.

2.2 Objective function

In this paper, the lowest economic cost is chosen as the optimisation objective for the optimal dispatch model of a multi-energy complementary combined cooling, heating and power supply system with energy storage. The economic cost of the energy supply system consists of fuel cost C_{fuel} , grid purchase cost C_{power} and equipment maintenance cost C_{repair} . The mathematical expression for the operation and maintenance cost is as follow:

$$Cost = \min(C_{\text{fuel}} + C_{\text{power}} + C_{\text{repair}}) \tag{1}$$

2.3 Constraints

In winter, assuming zero customer cooling load, the electrical balance constraint and the heat balance constraint are as follows:

$$\sum_{i=1}^{n_{\text{GT}}} P_{\text{GT}}^t + \sum_{i=1}^{n_{\text{PV}}} P_{\text{PV}}^t + P_{\text{power}}^t = P_{\text{Load}}^t + P_{\text{bt}}^t \tag{2}$$

$$\sum_{i=1}^{n_{\text{GT}}} Q_{\text{GT}}^t + \sum_{i=1}^{n_{\text{GB}}} Q_{\text{GB}}^t = Q_{\text{Load}}^t + P_{\text{Heat}}^t \tag{3}$$

where P_{power}^t is the time-to-time power exchange between the combined supply system and the external grid; P_{Load}^t is the load value; P_{PV}^t is the power of the distributed generation equipment; P_{GT}^t is the power generated by the micro-gas turbine; P_{bt}^t presents the charging and discharging power of the battery, when $P_{\text{bt}}^t > 0$ means charging, otherwise means discharging. Q_{GT}^t is the heat value recovered by the micro gas turbine through the waste heat boiler; Q_{GB}^t is the heat production value of the gas boiler; Q_{Load}^t represents the total customer load; P_{Heat}^t represents the energy storage release power of the heat storage equipment.

During the summer months it is assumed that the heat load on the consumer is zero and that all of the recovered waste heat is used to cool the chiller, with the same electrical balance constraints as in winter and following heat balance constraints.

$$Q_{\text{AC,out}}^t + Q_{\text{EC}}^t = Q_{\text{Load}}^t + P_{\text{Cool}}^t \tag{4}$$

where, P_{Cool}^t denotes the power released from the energy storage of the cold storage equipment.

2.4 Model solving algorithms

Particle swarm optimization (PS0) is more effective than the original simulated bird swarm algorithm because the particles are better able to converge towards the solution space and land at the optimal solution location [5-6]. The basic idea of the particle swarm algorithm is to achieve the solution of the optimal solution through the collaboration and information sharing among the particles in the population.

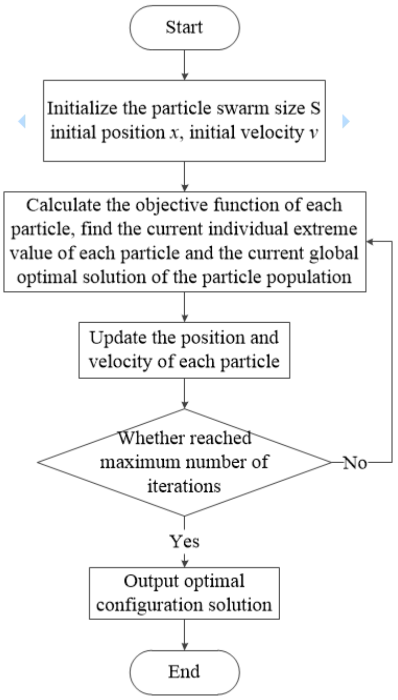

Fig 2. Particle swarm algorithm flow chart.

3 Case Simulation

3.1 Parameter setting

This case study is based on the winter and summer loads of a residential building in Beijing. In this paper, two storage modes are proposed for the system based on the characteristics of customer loads in different seasons and the types of energy storage devices:

Mode 1: The battery is charged when the combined supply system is sufficient or when the grid tariff is low, and discharged to meet the customer's electrical load during peak consumption periods.

Model 2: Heat/cool storage is added to model 1. In winter conditions, the customer's heat load is supplied by the waste heat recovered from the combined cooling-heat-electricity system and the gas boiler, with the heat storage device storing energy when the heat energy supply is sufficient and releasing it during peak heat load periods. In summer conditions, the customer's cooling demand is supplied by absorption chillers and electric chillers, with the storage units storing energy when it is available and releasing it during peak cooling periods.

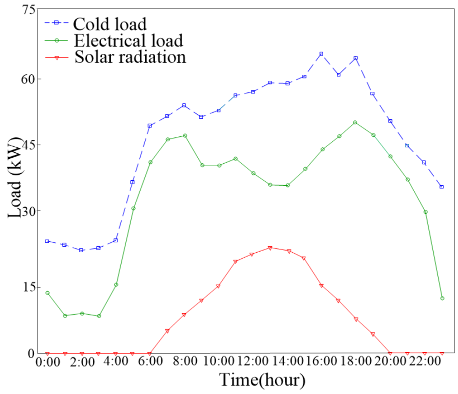

Fig 3. Load and solar radiation density variation curve of a typical day in summer

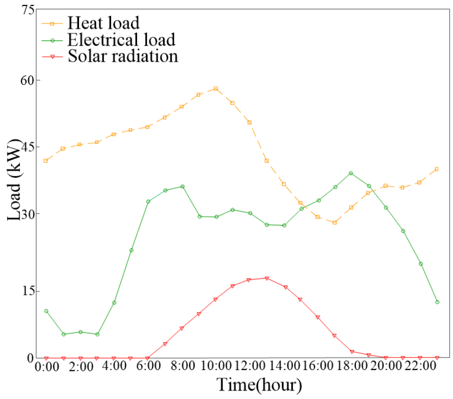

Fig 4. Load and solar radiation density variation curve of a typical day in winter

Table 1. Price of each energy source.

Energy	Price (yuan/kW)		
	Peak time	**Ordinary time**	**Valley time**
Electricity	1.0181	0.6370	0.3496
Gas	0.312	0.312	0.312

Table 2. Economic parameters of energy storage equipment.

Economic parameters	Battery	Heat storage	Cold storage
Storage consumption rate	0.01	0.02	0.02
Input efficiency	0.98	0.95	0.92
Output efficiency	0.98	0.95	0.92
Unit investment cost (yuan / kW)	544	102	136
Maintenance cost factor	0.01	0.01	0.01
Life (years)	5	20	20

3.2 Optimization result

3.2.1 System optimisation result

The iterative process of the particle swarm a1gorithm is shown in Figure 5. The fitness has basically converged after 20 iterations, proving that the iterative calculation has obtained the optimal solution.

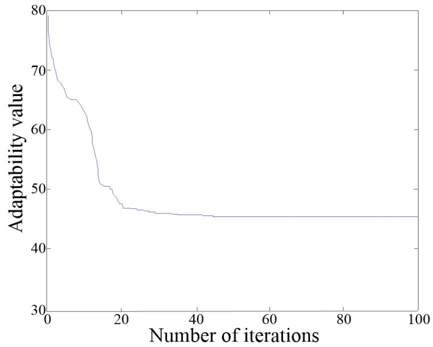

Fig 5. Adaptation curve of particle swarm algorithm

3.2.2 Operation and maintenance result

The maintenance costs are greater in summer than in winter, while the operating costs are 1ower than in winter. Under winter conditions, the heat load can be supplied directly from the recovered waste heat and the gas boiler, whereas under summer conditions, the cold load is supplied with an additional energy conversion, with the system using waste heat from the internal combustion engine to drive the chiller and using the electric chiller to makeup for the shortfa11. As a result, maintenance costs are higher in summer thanin winter. In addition, the overa11 customer load is lower in winter than in summer, so the operating costs are 1ower than in winter. Table 4 shows a comparison of the operating and maintenance costs of the equipment in both modes.

Table 3. Main equipment emission index.

Energy storage models	Season	Running cost (yuan)	Maintenance cost (yuan)	Total cost (yuan)
Model 1	Winter	897.23	18.32	954.42
	Summer	861.65	51.25	961.27
Model 2	Winter	915.14	17.89	948.61
	Summer	881.42	53.83	937.94

3.2.3 Output curve of each equipment

The output graph of each equipment shows that the power storage equipment is more suitable for operation in winter and the cooling storage equipment is more suitable for operation in summer. When the system is equipped with both electricity and heat/cooling storage devices, the operation and maintenance cost is the lowest, and it shows obvious peak-shaving and valley-filling characteristics. Thus, energy storage is an important guarantee for the reliable and efficient operation of the multi-energy complementary combined cooling, heating and power system.

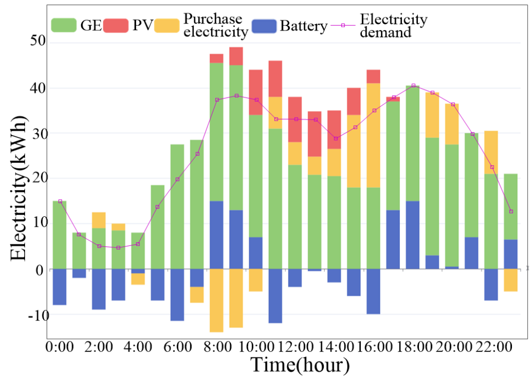

Fig 6. Electricity supply and demand of typical winter day in mode 1

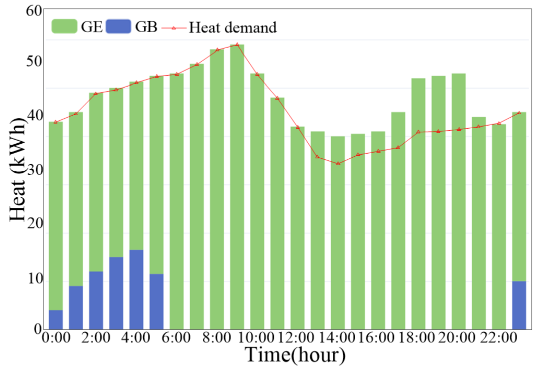

Fig 7. Heat supply and demand of typical winter days in model

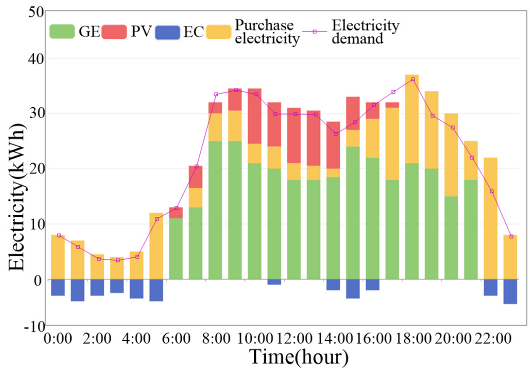

Fig 8. Electricity supply and demand of typical summer day in mode 2

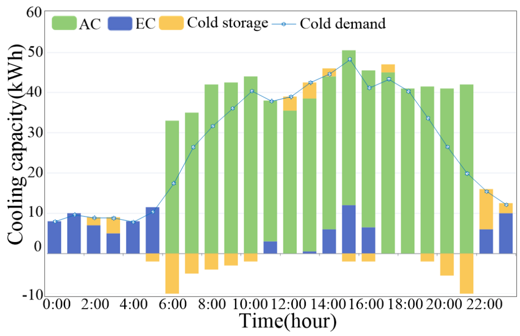

Fig 9. Cold supply and demand of typical summer days in model 2

4 Conclusion

This paper focuses on the optimisation of the operation of a multi-energy complementary cooling-heating-electricity "source-storage-load" system based on a particle swarm algorithm, which combines multiple energy sources, combined supply systems, energy storage systems, and customer load sides, to realise the complementary characteristics of multiple energy sources and achieve energy cascading. A particle swarm algorithm is used to optimise the operation of the system, using data from a typical day in winter and summer as input, and to allocate the hourly output of each piece of equipment in operation with the highest economic efficiency as the goal, and to analyse the operation and maintenance costs of the equipment. Based on the analysis of the simulation results in this paper, the system can effectively improve the total energy efficiency of the system, reduce the pressure on the public grid, improve the reliability of the energy supply system, promote the local consumption of renewable energy and alleviate the energy crisis, providing a research direction for the construction of a clean, efficient, reliable and intelligent multi-energy complementary cooling-heating-electricity combined supply system, which is also an important means to optimise the energy structure, innovate the energy utilisation mode and develop an environmentally friendly society.

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