International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 580

OPTIMIZATION OF PLANNING AND OPERATION FOR A LOW-CARBON CITY ENERGY SYSTEM

Xuan Wang[1*], Fengying Yan[2*], Gequn Shu[1], Hua Tian[1], Rui Wang[1]

1 State Key Laboratory of Engines, Tianjin University, No.92, Weijin Road, Nankai District, Tianjin, 300072, China

2 School of Architecture, Tianjin University, No.92, Weijin Road, Nankai District, Tianjin, 300072, China

ABSTRACT

The energy consumption of cities is an important carbon emission source, so it is significant to develop a high efficiency energy system for the whole city. This study proposes an optimization process of planning and operation for low-carbon city energy system. The process is divided into four steps： estimation of city energy demand, optimization of energy technology selection and operation, minimum energy station number optimization, and site and network optimization. Based on these, most parts of the flow are tested by the data from a local government, showing its practicability.

Keywords: planning, operation, optimization, energy system, low-carbon city,

NONMENCLATURE

Abbreviations

CCHP	Combine cooling, heating and power
PV	Photovoltaic
ARS	Absorption refrigeration system

1. INTRODUCTION

Cities have great effects on climate change and are also the most important emission source of anthropogenic greenhouse gases (about 65–75%) [1]. The largest carbon source in city is energy consumption by human activities, so it is very important to develop a high efficiency energy system for the whole city. Because of a great diversity of different energy flow and their complex interrelationship, optimal planning and operation of comprehensive energy systems has become one of the research hotspots [2].

However, most of the current researches on optimization of comprehensive energy system focused on building-level. For example, Alvarado [3], Ming [4], Xuan [5] all developed an optimization model for planning and operation of a building energy system, which can all make optimal decision of energy technology selection and running schedule, while they focused on part-load efficiency of equipment, demand respond and energy quality, respectively. Compared to building-level, researches on city-level are relatively few [6]. When considering the whole city level, it not only brings great increase of optimal variables, but also leads to the problem of energy station number, site selection, urban energy network and so on, which makes the problem much more complex.

Recently, there are a few studies focusing on larger scale levels. For examples, Jin et al. [7] developed a methodology of expansion planning in existing district energy system and a case study of Ningbo Hi-Tech District, China was analyzed to show the practicability of their method. Julien et al. [8] proposed a density-based clustering algorithm to divide a large scale optimization problem into multiple sub-problems. In each cluster the planning of energy system is optimized and then at the upper level the whole energy optimization problem is solved considering the network losses.

However, there is still few study focusing on the whole city-level, and the entire process of city-level optimization is not very clear. Consequently, in this work a process of optimization for city-level energy system planning and operation is proposed. Based on these, most parts of the flow are tested by the data from a local government.

Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).

2. THE MAIN FRAMWORK OF PLANING

In this work, we propose a process of optimization for low carbon city energy system as shown in Figure. 1. First of all, different kinds of energy demand for the whole city such as electricity load, heating load and cooling load should be estimated. There are various methods to calculate the load of city-level, while we propose a simple way to evaluate the load approximately, which will be introduced in detail in section 3.1. Then by modifying the optimization model for building-level, the energy technologies are decided as well as their operation schedule. However, since the city-level is much larger than the building level, there cannot be only one energy station. Consequently, the next step should be the optimization of the number of energy stations. In this stage of our planning process, just the minimum number of energy stations is decided, aiming at making all the stations work around rated load, which will be described specifically in section 3.3. Based on this, the preliminary site of energy station can be selected and then the network including whether increasing the number of energy stations should be optimized further.

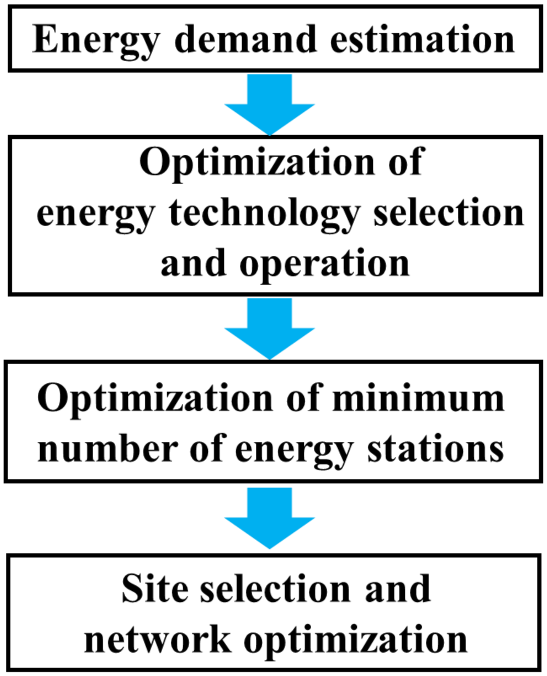


Figure 1. A process of optimization for low carbon city energy system

3. METHOD AND APPLICATION

In this part, the first three steps in Figure 1 are described in more detail and tested by applying the energy data of a small city in south China from the local government, showing the feasibility of the optimization process for low-carbon city energy systems. In future work, we will continue to do the fourth step.

3.1 Energy demand estimation

As mentioned above, there are various methods to calculate the load of the whole city. Therein, the most popular way may be spatial load forecasting which is calculated based on the characters of urban land [9], but it needs a great deal of work. In this work, we use a simple method to evaluate the city load approximately. Firstly, the electricity load of the whole city is obtained from the central power supply station of the city. The city is in the south of China, so there is no central heating because of the warm weather and nearly all the residents use common air conditioning (heat pump) which consumes electricity to keep warm in winter and cool in summer, according to the information from the government.

Figure 2 and 3 compare the electricity load of several typical days in heating and cooling season with those in base season (March, October and December in Figure 2 and April-May in Figure 3). It can be found that in base season, the electricity load of different days is quite similar, while the load in heating season increases as the weather becomes cooler and cooler in Figure 2 and that in cooling season increases as the weather gets hotter and hotter in Figure 3. Therefore, it is assumed that the consumed electricity for heating is the load of heating month minus that of the base month. Similarly, the consumed electricity for cooling is the load of cooling month minus that of the base month. After that, dividing by the average COP of heating and cooling the heating and cooling load can be evaluated approximately.

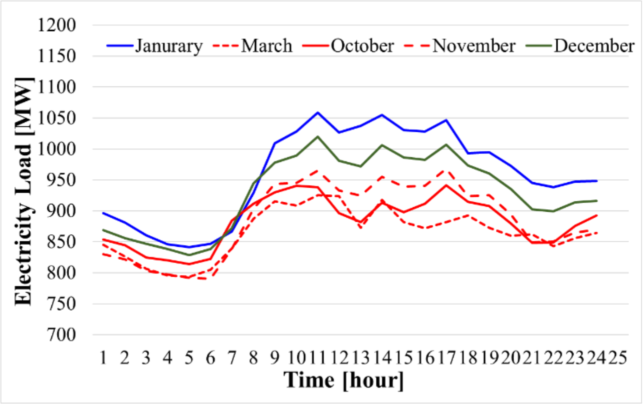


Figure 2. The comparison of electricity load between heating season and base season

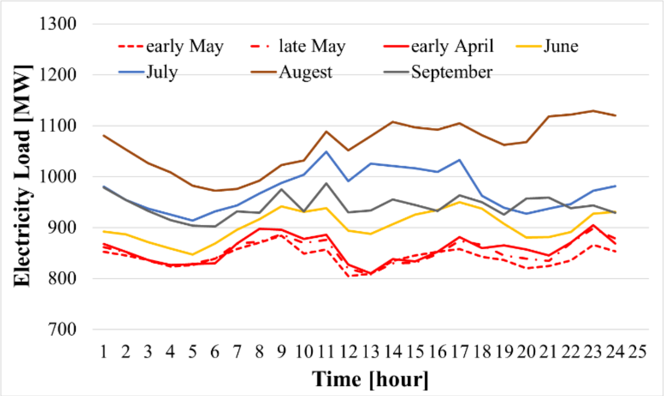


Figure 3. The comparison of electricity load between heating season and base season

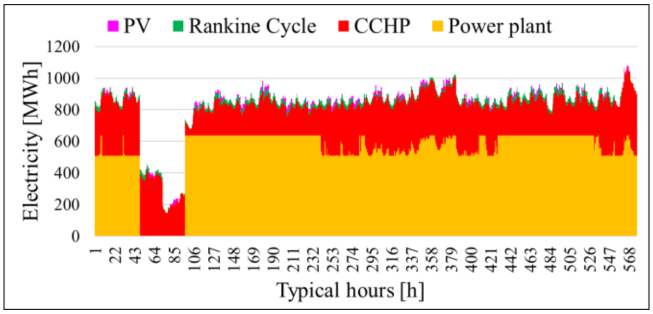
3.2 Optimization of energy technology selection and operation

The optimization model of energy technology selection and operation for city-level is based on that for the building-level by modifying some constraints. The most import modification is the addition of central energy supply technologies such as the power plant and distinguishing them from distributed energy technologies. The central energy supply technologies are restrained to work above 80% load in this optimization stage in order to keep high equipment efficiency, while the distributed energy technologies do not need because with optimization of distributed energy station number in the third stage, they can always run around rated load. The building-level optimization model can refer to our former research [5].

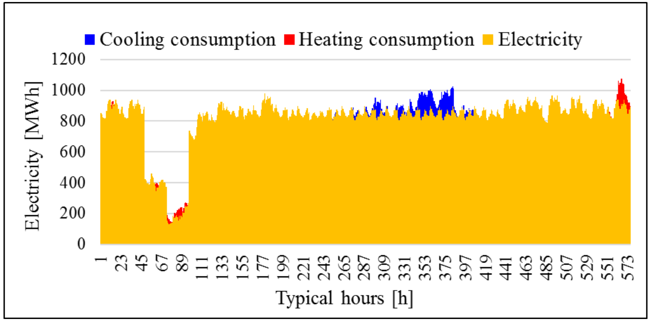
Table 1 shows the optimization results of the technology selections under the target of minimum carbon emission. It can be found that distributed energy technology of CCHP (combined cooling, heating and cooling) just accounts part of the electricity supply, and a lot of electricity is offered by central power plant. Figure 4-6 describe the operation of all the technologies for electricity, heating and cooling during the whole year. There are 576 typical hours in our model, which represents 24 hours in one day, two days in one month, and 12 months in one year. In these figures, the power plant only runs above 80% load, otherwise it will shut down. According to our calculation results, the carbon emission of the optimal operation can reduce by about 2.6% compared to the original operation of the small city. The carbon emission reduction is not very obvious, because in this model the electricity generating efficiency of the CCHP is assumed to be much lower (0.4) than that of power plant (0.47) which only supplies electricity. On other hand, the city has lots of industry, so the heat and cooling load of the city is much smaller than electricity load, which makes the advantages of CCHP cannot fully realize.

Table 1. The optimization of technology selection

Technology	**Capacity (MW)**
Power plant	639
PV	400,000 m^2
CCHP	424
Heat pump	179
Single-effect ARS	115
Double-effect ARS	196
Absorption heat pump	509
Direct heating	191



(a) supply



(b) demand

Figure 4. The supply and demand of electricity

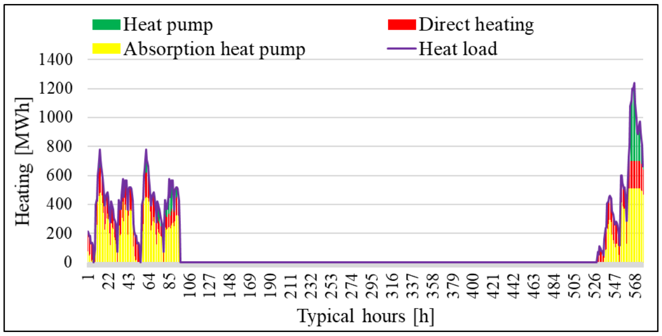


Figure 5. The supply and demand of heating

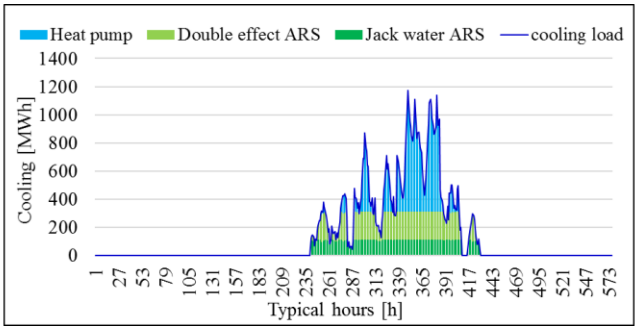


Figure 6. the supply and demand of cooling

3.3 *Optimization of the minimum number of energy stations*

With the optimization of energy station number and the control of start and stop of different energy stations, all the equipment can run around rated load with high efficiency. The number of energy station should consider the site selection and urban energy network, but these will be considered in the fourth stage and in this step we only consider the minimum number which can make all the equipment run around rated load, so it is also called as running level in our work. Take the CCHP number optimization as example, the problem is described as under the condition of electricity supply balance, high load of all CCHP such as 80% and as few as possible start and stop time, finding the minimum CCHP number. Figure 7 describes the operation of CCHP in different levels in a day. It can be seen that the load of each level only fluctuates slightly, avoiding low part-load efficiency.

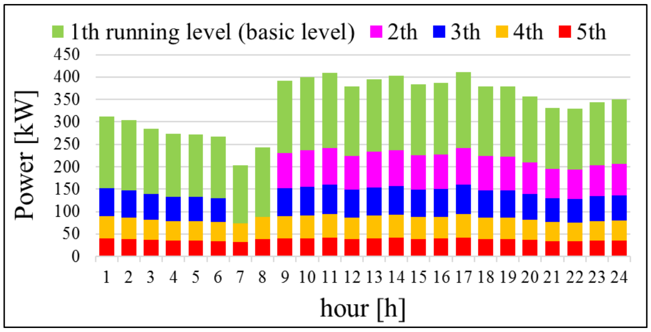


Figure 7. The operation of CCHP in different running levels in a typical day

3.4 *Site selection and network optimization*

Based on the above work and preliminary rough site selection, the specific site and network including whether increasing the number of energy station should be optimization in this step in our future work.

4. CONCLUSIONS

This study proposes an optimization process of planning and operation for low-carbon city energy system. The process is divided into four steps. In the first step, a simple method of evaluating heating, cooling and electricity load of the whole city approximately is adopted and shows reliability. Secondly, the technology selection and operation are successfully optimized by modifying building-level model. Then the minimum number of energy stations are optimized by our model to avoid low part-load efficiency. The specific site selection and network optimization will be completed in our future work. It is believed that this framework has contribution to low-carbon city energy system planning.

ACKNOWLEDGEMENT

The work was supported by National Key R&D Program of China (2018YFC0704700) and National Natural Science Foundation of China (51878441).

REFERENCE

[1]Kammen, D.M., Sunter, D.A.J.S. City-integrated renewable energy for urban sustainability. 2016;352, 922-928.

[2]Chauhan, A., Saini, R.P. A review on Integrated Renewable Energy System based power generation for stand-alone applications: Configurations, storage options, sizing methodologies and control. Renewable and Sustainable Energy Reviews 2014;38, 99-120.

[3]Alvarado, D.C., et al. A Technology Selection and Operation (TSO) optimisation model for distributed energy systems: Mathematical formulation and case study. 2016;180, 491-503.

[4]Ming, J., et al. MOD-DR: Microgrid optimal dispatch with demand response. Applied Energy 2017;187, 758-776.

[5]Wang, X., et al. Cascade energy optimization for waste heat recovery in distributed energy systems. Applied Energy 2018;230, 679-695.

[6]Zhang, Y., et al. Energy flexibility from the consumer: Integrating local electricity and heat supplies in a building. Applied Energy 2018;223, 430-442.

[7]Hou, J., et al. Implementation of expansion planning in existing district energy system: A case study in China. Applied Energy 2018;211, 269-281.

[8]Marquant, J.F., et al. A holarchic approach for multi-scale distributed energy system optimisation. Applied Energy 2017;208, 935-953.

[9]Xu, J., et al. Spatial-temporal load forecasting using AMI data, IEEE International Conference on Smart Grid Communications.2016