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Impact of differentiated local subsidy policies on the development of distributed energy system

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ABSTRACT

Distributed energy system (DES) has always been taken as one of the key strategies for optimizing the energy structure in developed counties. Over recent years, the contradiction in energy structure has become prominent in the process of China's economic development; in face of severe air pollution, Chinese government has started facilitating the DES projects. Distributed natural gas projects for combined cooling, heating, and power generation (CCHP) attract the most attention from investors, but they are not well developed mainly due to the input–output and the policy orientation. The objective of this work is to analyze the factors that have major influences on the investment in distributed natural gas projects based on its development mode in China; besides, for a more feasible subsidy policy beneficial to the DES development, the cases of two developed cities are presented to compare the effects of their subsidy policies on the investment in such project.

1. Introduction

The DES works either independently or grid-connected to supply the energy at the place of user; with the operation method and capacity determined in the manner of maximizing the resource and environmental benefits, it integrates and optimizes the variety of energy needs and resource allocation, and realizes the decentralized energy supply with its demand-responsive design and modular configuration. Under development in China, it is defined differently, particularly this first representative one is a system that is able to independently output the cooling, heating and power energy by directly installing the cooling/heating/power system at the user in a small scale, low-capacity, modularize and decentralized way, where they have variety styles such as solar energy, wind energy, fuel cell and CCHP; and the second representative description is an energy system installed at the place of user where the primary energy utilized includes the gas fuel, supplemented by the renewable energy, and the secondary energy is mainly the combined cooling, heating and power energy, complemented by other energy. It combines the power, thermal, refrigeration and storage technology to directly meet the needs of the user, realize the energy cascade use and maximize the resource utilization through the support and assistance from public energy supply system.

From the energies currently used, whether wind energy or solar energy are known as natural resources, which are highly dependent on the environment, and a vast land area is required for the construction of either wind energy projects or solar energy projects, so such projects are not suitable for cities; while with abundant reserve of natural gas in China and transportation via underground pipe network, distributed natural gas projects could be built under the ground, making the best use of space. In this respect, the vigorous development of distributed natural gas project remains the mainstream in future energy structure adjustment of China, for it has great development potential, in particular with the commercial production of coalbed methane and shale gas.

Throughout the past studies on the DES, three aspects had been focused on macroscopic analysis, the operation of DES on specific environments and the optimization model in the operating process. Li [1] studies the analysis of the great challenges faced by China's energy industry in the development of low carbon economy, it is advisable that China increase the proportion of natural gas (NG) in primary energy as the main strategy of energy conservation and CO2 reduction in the advancement of industrialization and urbanization. This research mainly analyzed the energy structure in China at the macro level, and then put forward the important significance and suggestions for the development of DES.

On the aspect of the operation of DES on specific environments, in Mago's [2] study, CCHP systems operated following the electric load (FEL) and the thermal load (FTL) strategies are evaluated and optimized based on: primary energy consumption (PEC), operation

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cost, and carbon dioxide emissions (CDE). Results show that CCHP systems operating using any of the optimization criteria have better performance than CCHP systems operating without any optimization criteria. Fumo [3] focuses on considerations for CCHP systems design at altitude. The analysis covers the processes affected by altitude and their specific application on how to assess the performance of the individual components of CCHP systems when operating at altitude. Virulkar [4] studies an improved integrated battery energy storage system (BESS) controller for distributed energy system. The test results of a prototype system are presented, which validates the proposed controller strategy of BESS in a distributed power system network. Ebrahimi [5] presents climate impact on the prime mover size and design of a CCHP system for the residential building. Mago [6] explores the use of carbon credits to show how the reduction in carbon dioxide emissions that is possible from the CCHP system could translate into economic benefits.

More researches on the optimization model in the operating process of DES had been followed with interest. Jing [7] establishes an evaluation model which integrates fuzzy theory with multi-criteria decision making process to assess the comprehensive benefits of CCHP systems from technology, economic, society and environment criterions. Aaron Smith presents an analysis of a CCHP system model under different operating strategies with input and model data uncertainty. Zhou [8,9] develops an optimization model to evaluate the economic feasibility of adopting a distributed energy system in a new residential community in Beijing, where grid coverage is already well developed and accessible. Meanwhile, they present two mathematical models for the optimal design and operation of CCHP systems with the target of minimizing the total annual cost. One model is formulated using the constant efficiency assumption. In the other model, off design characteristics of all equipments are considered. Tichi [10] examines the effects of current and future energy price policies on optimal configuration of combined heat and power (CHP) and combined cooling, heating, and power (CCHP) systems in Iran, under the conditions of selling and not-selling electricity to utility. Most of them adopt a constant efficiency assumption, whilst others take equipment off-design characteristics into account. Gu [11] investigates the performances of typical CCHP systems for a high-rise residential building, which is experiencing rapid expansion in China. Based on the building's energy consumption, four types of CCHP technologies have been assumed following three design and management modes, namely, heat tracking mode, electricity tracking mode and energy island mode. In Wu's [12] study, a comprehensive micro-CCHP system is built, basing on gas engine and adsorption chiller. Auxiliary devices, such as gas boiler, heat pump and electric chiller, are also considered in the study of operational optimization. Ebrahimi [13] proposes a multi-criteria sizing function (MCSF) for designing the optimum size and operating strategy of the prime mover of a residential micro-combined cooling heating and power (CCHP) system. Díaz [14] utilizes a general model for complex CCHP systems which is based on the general theory of exergy cost and structural coefficients of internal links. Smith [15] presents an analysis of a CCHP system model under different operating strategies with input and model data uncertainty. However, the uncertainties that underlie the variation in input parameters such as the thermal load, natural gas prices and electricity prices are not readily available. Additionally, engine performance uncertainty can be difficult to characterize because of the nonlinearity of engine efficiency curves. This paper presents practical and novel approaches to estimating the uncertainty in these and other input parameters.

From the above literature review, it is known that large numbers of literatures studying the distributed natural gas project in China have been published, however, these literatures only focused on the optimization and balance of combined cooling, heating and power energy generation system after the system is put into production, for the purpose of balancing the economic and environmental benefits. The energy management has long been policy oriented with the factors decisive to the investment and operation of the distributed natural gas project determined by government departments through assessment, such as the natural gas price, the pipe construction and occupation fees and the electricity price; this situation cannot be changed in short term, so subsidies have to be accordingly provided by the government which is committed to promote the distributed natural gas project. For this purpose, this study different from previous studies on the distributed natural gas project in China makes following contributions:

(1) First introduction to two prevailing modes of distributed natural gas projects in China, which are empirical compared with theoretical modes in previous literatures;
(2) First analysis of the reason why such policies decisively impact the distributed natural gas projects;
(3) Verification of above analysis results via comparing two most developed cities with respect to the subsidies to reveal the difficulties in developing such projects in China at present;
(4) Suggestions on promoting the development of distributed natural gas projects from the prospective of future energy structure adjustment.

In terms of the composition of this paper, two modes of distributed natural gas projects are discussed in Section 2; the factors affecting such projects are analyzed in Section 3; the impacts on such projects are compared by citing different local subsidy policies and reasonable subsidy policies are obtained by the sensitivity analysis of key factors in Section 4; and the conclusions are drawn in the final section.

2. Analysis of modes

Several core points need to be considered as below based on the definition of distributed energy system: first, the location nearby the place of the user and direct transmission of energy; second, the energy cascade use to improve the efficiency; third, optimal allocation of energy network and combination of the distributed energy network with the backbone energy network for support to each other. None of above features exists in any of current distributed natural gas projects in China, which generally operate in the modes referred to hereinafter.

2.1. Power plant mode

First we justify the operation process in this mode in brief. CCHP have three operation lines: one line is generating electricity from natural gas and deliver to the customers; one line is to use the waste heat continuing to generate electricity and heating the boiler, providing the heat and hot water to the customers; another line is to use the waste heat producing the cool air and replace the air conditioning. The characteristics of this mode is that more electricity must be delivered to other customers and too much waste heat may be exhausted.

Power plant mode [16] based on the energy structure adjustment of traditional power plants realizes the energy cascade use, but it relies on traditional grid connection mode for power supply, which increases the cost of users and wastes heating energy. Fig. 1 shows a typical case of this mode, i.e., the distributed energy system project at Higher Education Mega Center in Guangzhou invested by China Huadian Corporation in 2006.

The differences between this mode and typical DES projects lie in that: