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Economic assessment of a distributed energy system in a new residential area with existing grid coverage in China

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ABSTRACT

A distributed energy system refers to an energy system where energy production is close to end use, typically relying on various small-scale energy generation, conversion and storage technologies. The Chinese government has recently expressed interest in promoting this type of energy system. The paper 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. The economic implications of adopting different grid connection regimes are also assessed.

Results show that compared to the more conventional approach of relying entirely on the grid for electricity supplies, a distributed energy system is cheaper when a connection to the power grid can still be used to draw some electricity during periods of peak demand. Additionally, the economic benefits of electricity buy-back provisions for the distributed energy system are found to be minimal.

1. Introduction

A distributed energy system refers to an energy system where energy production is close to end use, typically relying on various small-scale energy generation, conversion and storage technologies. When considering a localized energy demand source, an appropriately designed distributed energy system can have a number of advantages compared to the more conventional approaches of solely relying on connection to the power grid to meet electricity demand. For instance, the on-site production of electricity can minimize energy losses linked to transmission and distribution processes. Distributed energy systems may also reduce the need for grid expansion and added centralized generation capacity, thereby avoiding often difficult planning and construction processes associated with large plants and long distance transmission. In the case of grid failures, distributed energy systems continuously provide electricity to customers thereby enhancing energy security. Various renewable energy resources can also be integrated into distributed systems, including solar energy, wind power, biomass, or geothermal energy, thereby adding potential benefits of reduced air pollution and greenhouse gas emissions.

The Chinese government has expressed interest in promoting distributed energy systems in China. Regulations have been issued to encourage the penetration of this type of system in the near future. For example, In October 2011, the National Energy Administration (NEA) issued a regulation entitled "the Guidance on the Development of Natural Gas Distributed Energy Systems". It suggests installing up to one thousand distributed natural gas energy stations, *i.e.*, combined heating cooling and power (CCHP), during the period of the 12th five-year plan, and the total capacity of CCHP is expected to reach 50,000 mW by 2020.

Distributed energy system is a relatively new concept in China and experience with the design and operation of such systems is still lacking. Distributed energy systems can have many different applications each with specific attributes. In this paper, we are specifically interested in the case of new residential building constructions within the existing coverage of the electricity grid. We mainly focus on two key issues: the economic viability of adopting a distributed energy system compared to the more conventional approach of straight grid connection, and the impact of different grid connection configuration for such a distributed system. Specifically we investigate the economic implications of the following three different grid connection regimes:

- Grid connection without electricity buy back provisions: in addition to its own energy generation capacity, the distributed system has the possibility of buying electricity from the grid.
- Grid connection with electricity buy-back provisions: in addition to its own energy generation capacity, the distributed system has the possibility of buying electricity from the grid as well as selling back electricity generated by the distributed system.
- No grid connection: the distributed system can only use its own energy generation capacity.

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The connection regimes are emphasized in our study for two reasons. First, the optimal techno-economic configuration of a distributed energy system differs under the three different connection regimes. Accordingly, the connection regime becomes an important factor in determining the economic viability of a distributed energy system. Second, there may be some institutional barriers associated to the connection regime adopted. By adopting a regime of grid connection without electricity buy-back provisions the distributed system simply acts as a new demand source for the grid, which is the more traditional model of grid-connection services. In contrast, if developers of distributed energy systems want to adopt a regime of grid connection with electricity buy-back, this may create new load balancing challenges for the grid operators, in addition to a need for extra investment on facilities like inverters. The regime of grid connection with electricity buy-back may therefore require important institutional adjustments, which may limit the scope of distributed energy systems.

This paper is organized as follows. Section 2 introduces a general optimization methodology for the design and operation of distributed energy systems. Sections 3 and 4 present a detailed description of the mathematical formulation of the optimization model. In Section 5, a case study of a new residential community in Beijing, China, is described as an illustrative example to assess the feasibility of a distributed energy system in a residential area with existing power grid coverage. The energetic, economic and environmental performance under different connection regimes are analyzed and discussed in Section 6, before concluding in Section 7.

2. Superstructure representation of the optimization model

In this section, we introduce an optimization methodology for the design and operation of distributed energy systems based on the superstructure approach (Biegler, Grossmann, & Westerberg, 1997).

A number of optimization models for the planning and operation of distributed energy systems exist. For example, the National Renewable Energy Laboratory (NREL) developed an optimization model for distributed power (NREL, 2005), while the Lawrence Berkeley National Laboratory (LBNL) developed an economic model for the design of micro grids (LBNL, 2011). In the literature, Mago and Hueffed (2010) modeled a distributed natural gas combined cooling heating and power (CCHP) system for a large office building considering both primary energy consumption and carbon emissions; Arcuri, Florio, and Fragiacomo (2007) developed a mixed-integer programming model for a distributed natural gas CCHP system in a hospital complex; Cho, Mago, Luck, and Chamra (2009) developed an optimal energy dispatch algorithm for the evaluation of distributed natural gas CCHP system from the view points of operational cost, primary energy consumption and carbon dioxide emissions; Liu, Pistikopoulos, and Li (2010) developed a multi-objective mixed-integer programming model for energy system design in supermarkets in England; Ren and Gao (2010) developed a multi-objective mixed-integer programming model for the distributed energy system in a commercial area in Japan.

A shared deficiency of the models mentioned above is that many important distributed technologies are not included in these models. Most are just focused on the distributed natural gas CCHP system. As a result, a general optimization methodology for distributed energy systems with various distributed energy technologies is not yet available. In this study, the optimization model for distributed energy systems is based on a superstructure modeling approach. The framework of the optimization model is shown in Fig. 1. It consists of an energy generation section, a secondary carrier and energy storage section, and an energy conversion section. In the energy generation section, various energy production technologies are adopted to generate heat and electricity from different

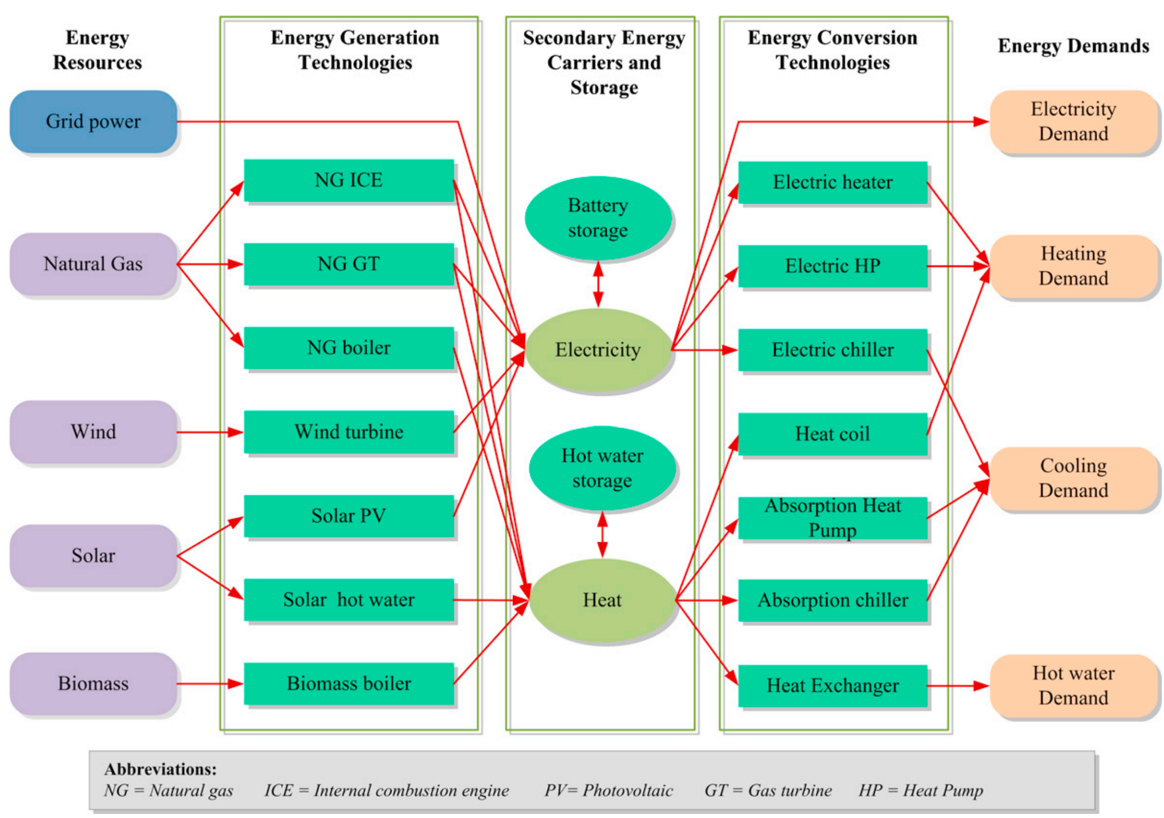

Fig. 1. The superstructure representation of the optimization model for distributed energy systems.