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Techno-economic evaluation of a community-based hybrid renewable energy system considering site-specific nature

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ABSTRACT

In order to mitigate the environmental pollution and ease the energy consumption intensity, the integration of renewable energy sources (RES) and combined heating and power (CHP) system is expected to be widely applied throughout the world. This paper proposes a hybrid distributed energy resources (DER) system integrating CHP, photovoltaic (PV) and wind power, to handle the electrical and thermal load for residential buildings. The system economic, technical and environmental performance is analyzed in seven typical Chinese cities based on various evaluation indicators. Moreover, a non-renewable grid-connected energy system is assessed as a reference system. It is found that the optimized DER system not only meets load supplying, but also effectively minimizes emissions and system lifetime costs. DER systems are of great advantages over reference systems in almost all optimal evaluations, especially in Beijing, Wuhan, Shanghai and Nanjing. Sensitivity analysis indicates that the economic performance of DER system will become better with increase feed-in tariff, decrease local grid tariff and natural gas price. The impacts of subsidy coefficient and loan ratio on return on investment are more significant than other factors.

1. Introduction

Residential building sector is a high energy consumption sector in all countries, whose energy demand leads the world energy demand growth, predicted to rise by a total 48% from 2012 to 2040 [1]. Increasing concerns on climate change and energy security have pushed residential power system towards lower emission and higher efficiency of energy use [2]. Renewable energy system is viewed as a promising alternative due to its advantages of less air pollution and ability to broaden the energy sources [3]. However, renewable energy sources (RES) are of great fluctuation and intermittent [4,5], so they cannot reliably satisfy the load demand. Since the feed-in tariffs of photovoltaic (PV) and wind energy have decreased, besides, the economic benefit of renewable projects has risen. Therefore, it is urgent to improve and evaluate renewable energy systems in an effective manner.

Although connecting with public grid and coupling more than one RES are common methods to ensure the reliability of energy supply [6–8], these systems will either result in heavy dependency on grid or only slightly mitigate the effects of intermittent. In this context, many researchers have developed a distinct type of hybrid energy system integrating conventional renewable energy systems and natural-gas-based combined heating and power (CHP) system, considering the low-emission and continuable supply of natural gas, as well as available thermal by-product. For instance, the RES-fuel-cell coupled energy systems recently have attracted many research interests around the world, such as wind turbine/proton exchange membrane fuel cell based hybrid energy system [9], and photovoltaic/wind turbine/proton exchange membrane fuel cell integrated energy system [10,11]. These fuel cell based hybrid energy systems are of great innovativeness in energy efficiency improvement, but the relevant technology of fuel cell is not mature enough and the investment cost is relative high [12,13]. So, the combustion based CHP systems involving internal combustion engines (ICEs) or micro gas turbines (MGTs) are still good choices during a period of time in the future. In this view, such hybrid systems (in the following called RES-CHP hybrid system) are considered here.

RES-CHP hybrid energy systems have mainly two different applications. First application is common that the hybrid energy systems are used to cover the loads in building level [14,15]. Other application is the use as a micro-grid in building clusters, and relevant studies in residential cluster are quite limited [16]. Thus, techno-economic analysis of this application is in the focus of this paper using residential communities in China as case study. In addition, techno-economic analyses of RES-CHP systems have been conducted while taking resource conditions of one specific place into account in many previous studies using various methods. Amiri et al. analyzed a biofuel-CHP hybrid system to supply district energy in the city of Kisa, Sweden using

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Nomenclature

AC	alternating current
C_{gas}	cost of natural gas consumption
C_n	total cost of year n
$C_{o\&m}$	operation and maintenance cost
C_r	replacement cost
CHP	combined heating and power
CI	initial cost
CNY	Chinese Renminbi Yuan
COE	cost of energy
CRF	capital recovery factor
DC	direct current
DER	distributed energy resources
E_{MG}	electricity supplied by microturbine generator
E_n	electricity consumption of year n
E_p	energy purchased from the grid
E_{PV}	electricity supplied by PV
E_s	energy sold back to the grid
E_{WT}	electricity supplied by wind turbine
EP	electricity production
GDP	gross domestic product
i	types of components
ICE	internal combustion engine
ISO	International Standardization Organization
j	the years in which system runs
MGT	micro gas turbine
n	the number of years
N_c	capacity of each system component
NPC	net present cost
NREL	National Renewable Energy Laboratory
O&M	operation and maintenance
P_f	feed-in price
P_g	grid tariff price
PBP	payback period
PT	peak time
PV	photovoltaic
r	interest rate
R_{ev}	total revenue of investment
RES	renewable energy resources
ROI	return on investment
T	time that system works
T_B	thermal supplied by boiler
T_{MG}	thermal supplied by microturbine
TAC	total annual cost
TP	thermal production
VT	valley time

the linear program MODEST [17], while Sartor et al. used a self-built validated model to simulate a biofuel-CHP system available in the University campus in Lige, Belgium [18]. Such studies dealing with similar problem also include a feasibility analysis of an RE integrated CHP hybrid system for local demand uses in Rafsanjan, Iran [19], a wind-hydrogen based CHP system evaluation for electricity and heat generation in Khvaf, Iran [20], as well as an investigation into an islanded microgrid consisting of PV-wind-biomass-battery system in rural area using HOMER software[21], etc. However, due to the site-specific nature of RES, the design and operation of RES-CHP hybrid system are greatly dependent upon local features, such as information about resources, climate, market prices and incentive policies. The economic, technical and environmental feasibility is needed to be assessed to satisfy different situations under different regional conditions. Ren et al. provided optimal options of an RES hybrid system under 5 different Chinese cities [22], while Moghadam et al. studied the implementation of a solar dish micro-CHP system in five different cities in Iran [23]. More recently, Martinez et al. sized and compared performances of a micro-CHP system based on RES for five different Iranian locations [24]. However, techno-economic indicators of these studies are not comprehensive and systematic enough to reveal the performances and superiority of the examined system. Based on the above consideration, this paper further improves the evaluation method. In general, this paper chose HOMER as the simulation tool because it is a strong and widely-used software and has been used into countless studies on city and building levels. Under the support of effective data, simulation and evaluation method of this study can also be applied to other regions more widely.

This paper offers comprehensive assessment from an integrative viewpoint, which combines PV-wind energy and CHP as a regional integrated distributed energy resources (DER) system (in the following called DER system for simplicity). This system aims to serve thermal and electrical load reliably and effectively in the long term to residential buildings located in seven typical cities under different local features in China. Optimal design options, economic, technical and environmental performance are presented considering the comparison between DER system and conventional non-renewable system. Moreover, sensitivity analyses are executed as well to reveal the impacts of local tariffs, subsidy coefficient and loan ratio on economic performance of DER system. Results of this work would provide valuable insights to system designers to realize the utilization potentiality of the examined system, providing example for designing more economical and environmental systems. This work also provide theoretical basis and guidance about the local price setting for policymaking of both the government and the market.

The rest of the paper is organized as follows. Section 2 describes the structure of the hybrid DER system and the reference system. System components information and data collection are also included. Section

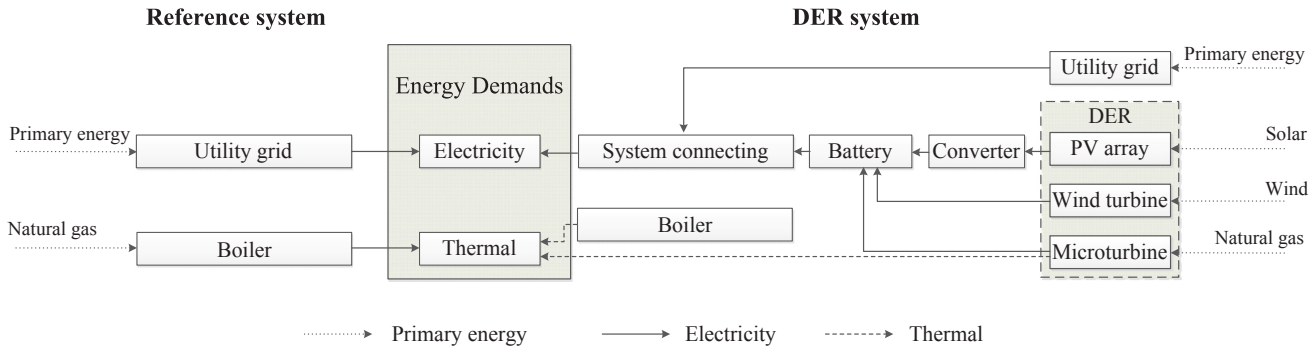

Fig. 1. Schematic illustration and energy flux of the DER system and reference system.