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Multi-objective energy planning for regional natural gas distributed energy: A case study

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ABSTRACT

Energy planning for sustainable development plays an important role in guiding the future of local, regional and national energy systems. This paper presents a multi-objective energy planning methodology for regional distributed energy site selection based on natural gas (NG) CCHP systems in a high-tech industrial park in China. The energy planning developed in this paper includes four hierarchies: the planning objective; pretreatment, including load calculation and available resource estimation; site selection and configuration; and implementation. The treatment procedures in each hierarchy are described. Particularly for site selection and the configuration of CCHP schemes, multi-objective optimization is used to configure the capacities of the CCHP systems, and the multi-criteria decision making (MCDM) method is employed to evaluate their integrated performance, including energy generation, and impact on the environment, economy and society. The analysis results indicate that this methodology is at supporting the decision maker with regards to energy planning and site selection.

1. Background

Energy planning is the process of developing long-term policies to help guide the future of local, regional, or national energy systems and plays an important role in creating the framework for regulations in the energy sector (Brandoni and Polonara, 2012). Traditionally, energy planning has been guided only by technical and economic criteria. However, as concerns grow regarding the environmental impacts of energy consumption, energy planning is not only considered from quantitative (technical, economic) but also from qualitative (environmental, social) criteria (Alarcon-Rodriguez et al., 2010; Mourmouris and Potolias, 2013).

A distributed energy system (DES) refers to "an electric power source connected directly to the distribution network or on the customer site of the meter" (Ackermann et al., 2001). DES technologies include combined heat and power (CHP) systems, combined cooling heating and power (CCHP) systems, gas turbines (GT), internal-combustion engines (ICE), fuel cells, solar photovoltaic (PV) generators and micro hybrid schemes (Akorede et al., 2010). Natural gas (NG) CHP/CCHP has been forecasted to be the most important mean of meeting the increasing energy demand and reduce carbon dioxide (CO_2) emission in China in the next 20 years (Li and Xia, 2013).

The development of DES technologies mainly depends on resource security, related technologies and economic efficiency. The supply of China's NG mainly comes from domestic gas fields, pipeline NG and LNG from abroad. In 2013, the annual NG consumption growth was approximately 10.8% (Ahmadi et al., 2014) and would account for approximately 11% of primary energy by 2020 if growth continued at this rate (Li and Xia, 2013). Meanwhile, related technologies have matured as well. Although the economic efficiency of gas power is less than that of coal power, its construction and operation costs will decrease gradually with the development of NG CCHPs (Li and Xia, 2013). In the documentary "The Development Plan of Natural Gas in the Twelfth Five Year (2011–2015)" promulgated by the National Development and Reform Commission in China, it is clearly proposed that 1000 NG DES projects and 10 regions will be built as demonstrative projects.

The purpose of this paper is to present a multi-objective energy planning methodology to select the most suitable regions for NG DESs. Section 2 presents the multi-objective energy planning methodology for DES; Section 3 shows a case study of a high-tech industrial park in China to describe the multi-objective energy planning; and Section 4 summarizes the conclusions.

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Nomenclature

AC	absorption chiller
CCHP	combined cooling heating and power
CHP	combined heating and power
COP	coefficient of performance
CO_2	carbon dioxide
CO2ERR	CO_2 emission reduction ratio
DES	distributed energy system
GT	gas turbine
ICE	internal-combustion engine
MCDM	multi-criteria decision making
NG	natural gas
PESR	primary energy saving ratio
PV	photovoltaic

2. Methodology

2.1. Problem

The purpose of this paper is to propose a multi-objective energy planning approach that accounts for regional energy situations. After using the multi-objective energy planning methodology, the following questions can be answered:

(1) What area is suitable for a NG CCHP system in the studied region?
(2) How should the CCHP systems be configured to maximize the integrated benefit, including the energy generated and economic, environmental and societal impacts?

2.2. Multi-objective planning methodology for regional DES

The procedure of the proposed methodology mainly consists of the following four hierarchies:

HIERARCHY 1: Planning objective. Combined land-use planning with spot investigation, the site conditions including energy resources, municipal infrastructure and energy consumption are analyzed. Then, according to energy policies and standards, a comprehensive DES planning objective is proposed.

HIERARCHY 2: Pretreatment. This phase includes load prediction and available energy resource estimation. Through hourly electricity/heating/cooling load calculations, the load distribution in the studied region is obtained and then suitable areas or users for/of a CCHP system are found. The available energy resources are analysed, and the possible utilization methods are presented to integrate with the CCHP systems.

HIERARCHY 3: Site selection and configuration. Through comprehensive analysis of the energy demand and supply, DES locations are selected, their corresponding CCHP schemes are constructed and optimized, and then their integrated performance, including energy production and impacts to the economy, environment and society, are evaluated.

HIERARCHY 4: DES implementation. During this phase, the investment, management and construction schedules are incorporated. Management experiences and operational performance are obtained to guide the explanation of the near-term or the long-term project planning.

2.2.1. Planning objective

An objective associated with energy planning is the prerequisite to direct DES planning in a studied region. A reasonable and integrated planning objective incorporating technological, environmental, economic and societal factors stems from a comprehensive analysis of many factors, such as policies, standards, upper land-use planning, available resources, and so on. The planning objective hierarchy is shown in Fig. 1.

During the objective formulation, national and/or regional policies and standards must first be considered. In China, the governments, power plants, gas companies and some users are enthusiastic about the application of DES. The National Development and Reform Commission promulgated the official documents of “Guidance on Development of Natural Gas Distributed Energy” in October 2011 and “Interim Regulations on Distributed Generation” in July 2013 to encourage DES. In these documents, excess electricity from a DES is allowed to be sent back to the grid. However, grid companies are less enthusiastic because DES may reduce their power supply profits. Thus, the operation mode of a DES would be affected, which is considered during planning. The industry standard “Technical Specification for Gas-fired Combined Cooling, Heating and Power Engineering”, which is promulgated by the Ministry of Housing and Urban-Rural Development, stipulates that the integrated energy efficiency of a NG CCHP system is higher than 70%. In addition to these DES/CCHP regulations, other policies and standards, such as ecologically friendly park standards and renewable energy policies, are also considered.

Then, upper regional planning, including the land-use and construction sequence, is analysed, which determines the selection of DES locations. Moreover, the spot investigation, which includes resources, municipal infrastructure, building types and actual energy consumption, is vital to the subsequent pretreatment and DES planning.

Finally, according to the above comprehensive analysis, the planning objectives and rules are regulated. In this study, a multi-objective that includes technological, economic, environmental and societal criteria is constructed according to the DES characteristics and multi-criteria decision making (MCDM) for sustainable energy (Wang et al., 2009). The evaluation criteria in Table 1 are selected and employed to evaluate DES planning. The multi-objective can be expressed in the following optimization problem:

(1) To maximize the primary energy savings ratio (PESR) under the constraint that the integrated energy efficiency is higher than 70%;
(2) To minimize the payback period;
(3) To minimize CO_2 emissions or maximize the CO_2 emissions reduction ratio (CO2ERR); and
(4) To maximize social acceptability.

From the above analysis, it can be observed that DES planning is essentially a multi-objective optimization problem. All factors in the multi-objective problem have their internal impact reclassified to a common scale so that it is necessary to determine each criteria's relative impact. Weight is assigned to the criteria to indicate its relative importance. Different weights influence directly the results of energy systems' alternatives. Consequently, it is necessary to obtain the rationality and veracity of criteria weights. Generally, the equal weights and the rank-order weights are both applied in sustainable energy decision making (Wang et al., 2009). It is necessary to make a concrete analysis of each specific question, and we discussed the influences of different weights in the latter case study.