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Feasibility and economic analysis of a renewable energy powered special town in China

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ABSTRACT

The Jiuquan Satellite Launch Center (JSLC) is a relatively isolated special zone in the northwest region of China. The potential risk to the energy supply security and the pressure of national greenhouse gas emissions reduction clearly indicates the JSLC's need to lower its dependency on imported fossil fuels and electricity. This article presents a feasibility analysis on the available hybrid energy system based on the renewable energy availability and local electricity demand estimation in 2020 through HOMER model. The simulation results indicate that cost of energy (*COE*) of the three proposed options are 0.127, 0.033 and 0.123 $/kWh, respectively. It also shows that the proposed hybrid renewable energy systems can reduce carbon emissions by 40–70% compared to electricity from the existing power grid. A sensitivity analysis reveals that the *COE* has a significant positive relationship with carbon price and discount rate, whereas carbon price shows a significantly distinct impact on the *COE* for different options considered. The optimization results also show that a grid-connected renewable power system comprised of wind power and natural gas power plant is the most economic and environment-friendly energy supply option for JSLC. However, a hybrid RE system with a local energy storage facility can better guarantee the energy supply safety considering the special function and security needs of the JSLC. This study verified that constructing new coal fired power plants is not a suitable choice from both the cost effectiveness and environmental protection perspectives.

1. Introduction

China is facing increasingly severe pressure from the international community to curb carbon emissions (Wang et al., 2015a,b). Developing renewable energy (RE) has become an important part of China's energy strategy. The central government of China issued a series of policies and measures to promote renewable energy utilization (Jiang et al., 2013). As a result, the wind and solar energy power capacity installed has increased rapidly since 2009. However, as a result of the power transmission limitation, the discarded renewable electricity also grows rapidly. As the discarded electricity from RE generation has become increasingly large in the last few years, the Chinese government has gradually realized that a distributed power generation system can lower the possibility of discarding RE electricity and promote RE exploration. Therefore, the central government of China announced several regulations to encourage the penetration of distributed energy systems (DES) since 2013 (Zhou et al., 2013a,b). One of the most important applications of DES technologies is the utilization of hybrid RE micro grid, especially using at an isolated area where the fuel transport or electricity transmission cost is high. This study attempts to determine whether local RE resources can meet the energy demands of an isolated special zone in Chinese northwest desert and at the same time reduce carbon emissions from the power generation process.

2. Literature review

To design a power system for a given area, a series of decisions must be made, for example, what is the best configuration of power system components for the target area? What size and number of

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Nomenclature

BS	battery storage
BYD	name of a Chinese battery company
COE	cost of energy
CEQ	carbon emission quantity
DG	diesel generator
DSM	demand side management
DES	distributed energy systems
EV	electric vehicle
HOMER	hybrid optimization model for multiple energy resources
O&M	operation & management
PV	photovoltaic
PSPS	pumped storage power station
RE	renewable energy
NPC	net present cost
JSLC	Jiuquan Satellite Launch Center

each kinds of component should be involved in the hybrid energy system? Many technical choices, divergence on the cost of each technology and the energy resources availability make it difficult to design the power system. Previous works related to the planning of a hybrid energy system from their research objectives, research methods, and energy storage methods are reviewed in this section.

Existing research for RE system optimization can be divided into the following categories based on their main research objectives. The first research type is related to climate change issues. The developed countries that are regulated by the Kyoto Protocol struggle to reduce carbon emissions by increasing the RE proportion in the existing energy structure, and result in the real demand of determining the optimal configurations of RE installed capacity based on local weather conditions (Olsson et al., 2015). Rozlan et al. (2011) and Maheri (2014) attempted to determine an optimal stand-alone RE configuration to satisfy the electric load demand and prevent global warming effects. Garcia et al. (2014) studied a grid-connected hybrid system that integrated RE. Second, existing research attempts to solve the electricity demand in remote or less developed areas (Shiroudi et al., 2012). Dalton conducted a feasibility study for a large-scale stand-alone tourist hotel located in Australia (Dalton et al., 2008). Rehman presented a pre-feasibility analysis of wind power resources penetration into an existing fossil fuel power system of an isolated small town in Saudi Arabia (Rehman et al., 2007). Third, the objective of existing research of this category is similar to the second class. However, the major difference between these two is that the third type focused more on environmental protection aspect, although cost is still important in these researches. In other words, the assessment criteria pay more attention on pollutant reduction. Several studies have confirmed that hybrid RE in off-grid applications is economically workable mainly in remote districts (Elhadidy and Shaahid, 2000). Adaramola et al. (2014) utilized a hybrid power system which consists of wind, solar and diesel power for a remote isolated village in southern Ghana. Bin et al. (2012) conducted a technological and economic analysis on a RE power system for a Chinese island. The modeling results demonstrated that RE can fulfill the energy demands of the island in the next 10 years and simultaneously reduce carbon emissions. Zhou et al. (2013a,b) developed a DES optimization model to evaluate its economic feasibility and applied the model in a Chinese new residential community. Ren et al. (2012) studied feasible DES resources in five different climate regions for Chinese typical buildings. Scherer et al. (2014) developed a DES model predictive scheme for energy management in buildings. The main research methods are mathematical programming, some studies use a MILP (mixed integer linear programming) model, whereas other studies use a non-linear optimization model (Muis et al., 2010). Mallikarjun and Lewis (2014) presented a multi-objective analysis framework to determine the best renewable energy technology allocation model (Mallikarjun and Lewis, 2014). Abdullah et al. (2014) developed a probability-based analytical method to evaluate the distributed energy resource network adequacy.

Energy storage is a critical issue in RE usage because it can ramp up fluctuating output from RE and ensure that the power produced by renewable sources can be released and dispatched reliably to better fit the demand. Therefore, the present study pays a special attention to energy storage methods. Pumped storage power station (PSPS) often plays the role of an energy storage facility in existing research. Ma et al. (2014) evaluate two types of energy storage technologies, which are “batteries” and PSPS for a renewable energy powered island in Hong Kong. The present study proposes to use EV batteries as RE storage devices and proves its feasibility through the HOMER model, developed by the NREL (National Renewable Energy Laboratory), USA.

The main purpose of this study can be summarized as follows:

(1) What is the best RE mix to meet the electricity demand of the JSLC based on its climatic conditions?
(2) If wind and solar power are added to JSLC’s existing power grid, how much economic and environmental benefit will gain? How large should the carbon reduction potential be with RE-based distributed power supply systems to address climate change?
(3) Considering the energy supply security of the quasi-military management of the JSLC, which types of energy storage mode are more appropriate in terms of economic and security aspects.

3. Methodology

This study considers three energy supply options for the JSLC in 2020. To figure out the optimal energy configuration, the HOMER model is used. It can model the economic features and physical behavior of a given power system and it also allows the modeler to assess different design options based on their technical, economic and environmental fitness. Furthermore, the HOMER software can perform sensitivity analysis to help modeler quantify the effects of uncertainty of input data on the final results (Lambert, 2006). HOMER software simplifies the task of hybrid power system design. To use HOMER, the modeler should collect data on resource availability, technology options and the components costs first. This study used 60 min as the simulation time step. For each time step of a year, HOMER simulates its actual operation of a power system through conducting energy balance calculations. It then determines if a configuration is feasible and assesses the initial investment of installing and the operating cost of the system during its lifetime of the project.

3.1. Brief description of JSLC

The Jiuquan Satellite Launch Center (JSLC) is the largest scientific satellite, carrier rocket, and manned space launch base in China. The JSLC has a special importance in the history of Chinese space research and exploration activities. Nowadays, the JSLC is confronted with the dual challenges of an energy supply shortage and restructuring.

The JSLC is located in the depths of the Badain Jaran Desert of Inner Mongolia Autonomous Region of China and covers an area of 2800 km^2. A 200 km radius of uninhabited area and 600 km of sparsely populated area surround the JSLC. The current power supply comes from an approximately 300 km transmission line and a thermal power plant in the JSLC. The base power supply experiences