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A conceptual model for prioritizing dam sites for tidal energy sources

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ABSTRACT

Ocean energy is abundant in China, and the utilization of ocean energy could improve current energy structure and contribute to energy security. If tidal power is harnessed efficiently, it could help China reach its renewable energy goals. A suitable model for solving the multi-criteria decision-making problem is proposed in this paper. The model incorporates the fuzzy analytic network process (FANP) and the fuzzy goal programming (FGP). The FANP can consider various factors, the interrelationships among the factors, and the impreciseness and vagueness of the problem more thoroughly based on expert opinions. The FGP can help select dam sites to maximize the satisfaction of the system when resources are limited. A case study in an east-coast province in China is presented to demonstrate the practicality of the proposed model.

1. Introduction

As evidenced by China's commitment to the Copenhagen Accord (United Nations, Copenhagen Accord, 2009), the Chinese government has plans to increase the proportion of non-fossil fuels in Chinese energy production. With the dilemma between the urgent need to be environmental and the demand to increase energy generation for maintaining economic development, the government needs to face the challenges of achieving the divergent targets.

Ocean energy offers a promising contribution to the current mix of renewable energy. The average ocean power impinging on China's coastlines has been estimated as 1000 GW (Wang et al., 2011). The theoretical generating capacity of tidal power in China can be up to 1.1×10^8 kW, and 242 potential tidal energy dam sites are available with installed capacity from 200 to 1000 kW with total capacity of 12.3×10^4 kW and annual energy output of 3.05×10^8 kWh (Wang and Lu, 2009; Wang et al., 2011). Therefore, the utilization of ocean energy can contribute to energy production in China. There are many forms of ocean energy. The current ranking of ocean energy types in China according to relative abundance is: wave energy, ocean thermal energy, tidal current energy and tidal energy (Wang et al., 2011). While the technologies and devices for other ocean energy are still in the stage of research and pilot test, those for tidal energy are comparatively mature (Wang et al., 2011; Zhang et al., 2012). China's tidal power resource has been estimated at 190 GW, and 38.5 GW of which is available for development (Elliott, Renewables, 2013). This paper will focus on the utilization of tidal energy in China.

Dam site selection for tidal energy is important. Due to low energy density, high construction costs and low energy generation, the cost of tidal energy is much higher than that of a conventional energy source. However, if tidal energy production is successful, tidal energy may contribute to sustainable energy resources (Liu et al., 2007). Therefore, selection and prioritization of suitable dam sites is an important task.

In this paper, a multi-criteria decision-making (MCDM) model that considers multiple critical characteristics of tidal energy sources is proposed for prioritize dam sites. The proposed model is then applied to a case study in an east-coast province in China. The rest of the paper is organized as follows. The critical decision-making factors to prioritize strategic dam sites for tidal energy are discussed in Section 2. Fuzzy analytic network process (FANP) and fuzzy goal programming (FGP) are introduced in Section 3. The strategic planning of renewable energy sources is introduced in Section 4. A suitable model for solving this MCDM problem is proposed in Section 5, and a real case study is analyzed by the proposed model in Section 6. Finally, the feasibility of the proposed model is summarized in Section 7.

2. Critical characteristics of tidal energy sources

A good energy source can generate more electricity at times of peak demand and less energy at times of lower demand, and it should be consistent and predictable. Tidal energy is generated by flood and ebb tide, and its operations are similar to that of hydroelectric generation. Thus, a high power density may be feasible if a high utilization can be obtained through engineering solutions (Leijon et al., 2006). There are

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three popular generating methods for tidal power: in-stream devices, tidal barrages and tidal lagoons (Baker, 2006). In-stream devices, like wind turbines, make use of the kinetic energy of water over the blades to generate a lifting force (Baker, 2006). Tidal barrages, or tidal energy dams, make use of the potential energy in the difference in height between high and low tides (Baker, 2006). Tidal lagoons are similar to barrages, but they can be constructed as self-contained structures with turbines to capture the potential energy of tides (Baker, 2006). Among various marine renewable energies, China has the most mature technology for utilizing tidal energy (Zhang et al., 2014). The Chinese government has evaluated 426 potential sites for utilizing tidal energy, and 242 sites were found suitable for tidal energy dams which could provide installed capacities from 200 to 1000 kW (Shi et al., 2011). Therefore, this study focuses on the selection of dam sites for tidal energy.

The costs for the construction and maintenance of dam sites must be considered in dam site selection. Ocean energy devices are often located in a hostile environment, and their lifetime has great uncertainty and may affect their economic performance. Manufacturing cost includes the type and the volume of materials required for the device of tidal energy conversion. Total costs incurred from operational and maintenance activities are uncertain and critical since different dam sites may have different characteristics and thus require different operations and maintenance costs. Day et al. (2015) reviewed some important issues in the physical and numerical modelling of marine renewable energy systems, such as wave energy devices, current turbines, and offshore wind turbines.

Different techniques have been developed for evaluating energy projects. Most of previous economic studies on devices of ocean energy conversion employ the cost of energy (CoE) approach (Atkins Oil and Gas Engineering Ltd, 1992). In recent years, the levelised cost of energy (LCoE) approach by applying discounting techniques to the future costs and energy production has replaced the CoE approach (Allan et al., 2011). Neary et al. (2014) proposed methodology for design and economic analysis of marine energy conversion (MEC) technologies, and studied four MEC reference models with the consideration of the costs for designing, manufacturing, deploying, and operating commercial-scale MEC arrays. Astariz et al. (2015) evaluated and compared the levelized cost of tidal, wave, and offshore wind energy. The economic analysis was performed by considering the costs in the construction of offshore energy parks and operation and maintenance tasks during their lifetime. Jenne et al. (2015) presented a methodology to calculate the levelised cost of energy for marine and hydrokinetic reference models and performed an overall comparison of six reference-model designs. Yang and Haas (2015) applied the grid refinement technique to assess tidal current energy for particular sites due to its relatively low computational expense and high accuracy with the refined resolution. Soleimani et al. (2015) assessed the locations for tidal and wave energy conversion in Iranian seas. Based on relevant devices for marine energy extraction, the locations were evaluated using some important factors, such as wave heights, wave period, tidal velocity, water depth and shore condition. Laws and Epps (2016) performed a review of technology, research and outlook of hydrokinetic energy conversion, and generalized the major factors for site assessment as detailed flow characteristics, wave spectrum characterization, bathymetry and bed surface characteristics, and site access. Waters and Aggidis (2016) reviewed current tidal range energy production technologies and various tidal range turbines. The major aspects for evaluating tidal range turbines include environmental effects efficiency, initial costs and maintenance/running costs. Chen and Liu (2017) studied the influence of sea level rise on tidal power output and tidal energy dissipation, and an unstructured-grid, depth-averaged numerical model was proposed to simulate the hydrodynamics in the Taiwan Strait. The most suitable for constructing a tidal power plant could be selected as a result. Even though some works have been done for evaluating energy projects in recent years, very few have applied MCDM methods, which can consider multiple criteria with different importance. Therefore, a novel approach which incorporates the FANP and the FGP is proposed in this research.

Government support is crucial for energy projects. In order to attract the private investment to initiate large-scale ocean energy projects, higher levels of supports for ocean energy development have been proposed in many countries such as Ireland, Scotland and Germany. The supported policies include revenue support for feed-in tariffs, research and development grants, investment subsidy, national strategies and targets, tax reduction and exemptions, and free grid connection (Dalton and Gallachoir, 2012). In such a political and financial context, it is apparent that the investment decisions will be made on the integrated factors of technological, legal, environmental and social-economic considerations rather than on any single basis such as the performance of a device or a national capacity (Menanteau et al., 2003; Teillant et al., 2012). For example, Vazquez et al. (2015) assessed various kinds of marine renewable energy in Spain, including wave, tidal, and offshore wind energy, in terms of resource availability, government plans, policy regulations, and projects undertaken, and compared the situation in Spain with other European countries.

The Chinese government has provided supports for developing renewable energies. The Electricity Law and Energy Conservation Law went into effect in 1997 and 1998, respectively (NPC, 2009). Both laws clearly stated that China encouraged the development and utilization of new and renewable energy. The Renewable Energy Law of the Peoples' Republic of China, effective in 2006, aimed to secure the strategic position and future development of renewable energy. It was followed by several supporting laws and regulations, mainly including tariff reduction and exemption, value-added tax policy, tax shelter, soft loan, economic incitement and subsidy, etc. (Martinot and Junfeng, 2007). In order to exchange information and coordinate its members with those interested in tidal and wave energy, a Chinese Ocean Energy Association was founded in 2008 in Hangzhou (Zhang et al., 2009).

Some recent development in renewable energy policies and various types of renewable energy industry can be found in the works below. Jia et al. (2015) reviewed the development of renewable energy in China up to 2013 and introduced the relevant central government policies and some important ongoing demonstration projects. Shen and Luo (2015) performed an overall review of renewable energy subsidy policies in China, which include transfer payment, investment and development, tax deduction, price control, demand assurance and compulsory allocation. The authors analyzed the effects of these policies on the energy industry from 2005 to 2013, and recommended some possible policy improvement directions. Dent (2015) reviewed the renewable energy development in China from the perspectives of policy, industry and business, and concluded that the renewable energy business in China is an interaction among dynamic entrepreneurism, inter-sectoral connections, state-owned enterprises (SOEs) and private sector companies. He et al. (2016) presented the renewable energy development in China up to 2014 and the development outlook, and the current renewable energy regulation system in China is overviewed. The authors stated that the major problems for renewable energy development include institutional mechanisms and market factors.

Tidal energy may be a promising energy source in China. The utilization of tidal energy in China was popular from 1958 through 1970s. However, only three stations are still in service because of laggard technology, conflict purposes between irrigation and navigation, inconvenience in use and wrong selection of sites (Wang et al., 2011). Nevertheless, due to the continuous improvement in the technologies and operational methods, China has remarkable achievements in reliability of the generator sets, reducing sediments in reservoir, dispatching automation, safe operations, erosion protecting and optimal scheduling (Chen et al., 2008).

In this research, a conceptual model for prioritizing dam sites for tidal energy sources is developed. After extensive interviews and literature reviews, critical decision-making factors among different stakeholders in