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A decision support system for planning and coordination of hybrid renewable energy systems

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ABSTRACT

Due to the growing concern about climate change and environmental sustainability, hybrid renewable energy system (HRES), which refers to a system that combines several renewable power sources and a conventional power generator to cover the power shortage when the renewable power is insufficient, has gained more and more popularity over the decades. While the HRES is very attractive due to the minimal environmental and health impact compared to fossil fuels, the planning and coordination of HRES so as to supply stable power in a cost effective way are very challenging. This is mainly due to the unknown power demand, the highly volatile amount of renewable power supply and the complex topology of power network. In this paper, we model the planning and coordination of HRES in uncertain environments and develop an efficient heuristic to solve the model. A decision support system(DSS) integrating the proposed model and the heuristic is developed as an efficient decision tool to enable effective and efficient energy management of HRES. The visualized outputs of DSS allow decision makers to gain better understanding about the management of HRES, facilitating the decision making process.

1. Introduction

With the United Nations predicting the world population growth from 6.6 billions in 2007 to 8.2 billions by 2030, demand for energy is expected to grow in an increasing speed over that period. According to [28], renewable energy sources, such as hydropower, solar and wind energies, only account for 19% of the total world energy demand in 2013. Renewable energies are green and clean resources. They are non-depletable, non-polluting and have minimal environmental and health impacts compared to fossil fuels. It has been long recognized that excessive fossil fuel consumption can lead to significant adverse impact on the environment through superfluous carbon emissions, and in turn cause global climate change. While renewable energies are gaining more popularity over the decades, many countries are still resistant to increase the usage of the renewable energy, especially for the developing countries that are in dire need of power to sustain their economic growth. This is mainly due to the undesirable characteristics of renewable energies—their power supply is highly volatile and unpredictable; heavily relying on renewable energies is likely to result in instable power supply and could harm the economy.

Many countries are thus looking for other alternatives. Hybrid renewable energy system (HRES), which refers to a combination of at least one renewable energy source and a conventional power generator, is one viable and attractive choice that allows for the advantages of the renewable energies, while eliminating their disadvantages [7]. The HRES essentially utilizes renewable energies to fulfill the power demand and, if the power supply from the renewable energy sources is not sufficient, the conventional power generator is used to cover the power shortage, in turn ensuring that all power demand can be satisfied. In fact, HRES has received a great deal of attention over the decade, not only because it is more environmental friendly, but also because it provides an excellent solution for electrification of remote rural areas, where the grid extension is either difficult or uneconomical.

Although HRES is attractive in many aspects, the planning and coordination of HRES so as to fulfill the power demand are very challenging. This is attributable to the unknown power demand of each area distributed in a wide region, the highly volatile renewable power supply over time, and the complex topology of power network that connects all power stations and demand areas. In addition, there are many other factors that are also linked to the effectiveness of HRES, such as properties of resources, efficiencies of technologies, transmission loss, and site-specific characteristics of locations. The interaction of these factors, which is complex, nonlinear and unknown, further presents major challenges for the energy management of HRES. There is a need to develop an effective decision tool that can aid in the decision making when the HRES is intended to be implemented.

In this paper, as shown in Fig. 1, we consider a region that includes several demand areas and multiple power stations to supply all demand areas with power. There is an electricity grid that connects all power stations and demand areas to allow for power transmission, either between stations or from stations to areas, with uncertain power transmission loss to satisfy the power demand of each area. We assume that each power station includes two kinds of renewable energy sources—the solar and wind power generators, and a conventional power generator

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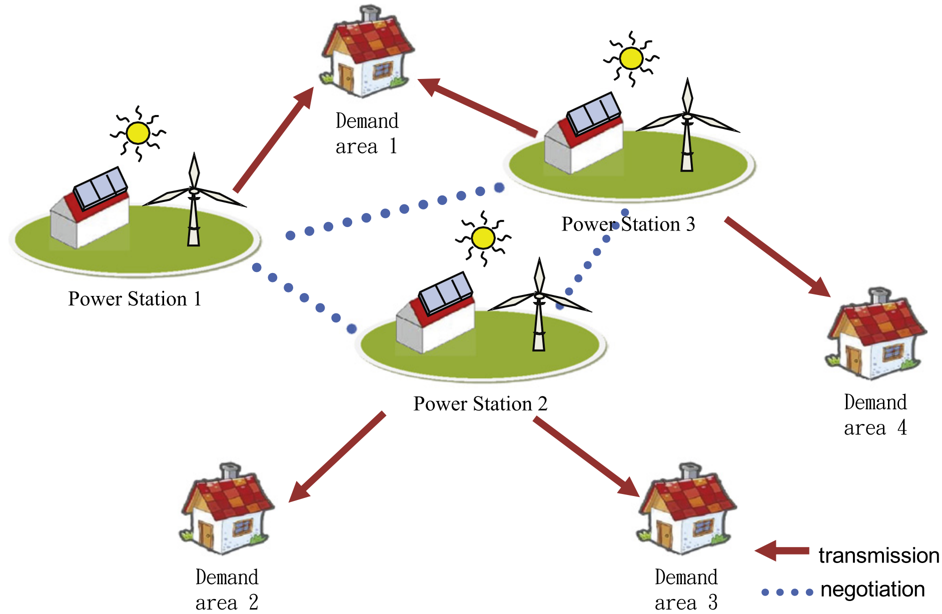

Fig. 1. An illustration for the power transmission network.

that produces power whenever the renewable power is insufficient to meet the demand. Further each power station has a power storage for storing surplus power when the power supply is greater than the power demand. The research problem is to decide on the appropriate number of solar and wind power generators of each power station so as to achieve the minimum expected total cost, while satisfying the power demand of each area.

We propose a stochastic optimization model to characterize the decision problem. In particular, the model emulates the power generation, allocation and transmission within the HRES, taking into account the uncertainty that could affect the HRES, including the power demand, the renewable power supply, and the power transmission loss occurred when transmitting power within the HRES. The objective function is defined as the minimum expected total cost, where the expectation is taken with respect to all uncertainty mentioned above. One challenge about the proposed model, however, is to locate its optimal solution due to that the objective function is not analytically available, which is mainly because it involves many factors, profound uncertainty and their complex interactions. To overcome the difficulty, we propose a Monte Carlo simulation model, along with a sample size scheme, to obtain estimates of the objective function. Then, based on the developed simulation model, we propose a simulation optimization method, called metamodel-based simulated annealing method (MSA), to enable the efficient derivation of the optimal solution. Finally, we integrate the proposed model and the solution methodology into a decision support system (DSS) as an efficient decision tool for analyzing and visualizing impacts of different designs of HRES, and facilitating the decision making process. More details about the proposed methodology and the DSS will be introduced in later sections.

The remainder of this article is organized as follows. In Section 2, we review the existing literature related to this research. In Section 3, we present the mathematical model that characterizes the planning and coordination of HRES. In Section 4, we introduce the analysis methodology, MSA, developed to solve the proposed model. In Section 5, we compare the performance of MSA and other two existing algorithms based on a variety of simulated problems. In Section 6, we develop a decision support system (DSS) that integrates the proposed model and the heuristic to allow decision makers to obtain better understanding about the energy management of HRES. We conclude with future research in Section 7.

2. Literature review

In this section, we review the previous work related to the planning of HRES. In the literature, the feasibility and performance studies about the HRES in various forms have been extensively conducted, e.g., [7,16,12,14]. In particular, Gorgopoulou et al. [18] proposed a multicriteria decision aid method to examine a particular case study in a Greek island and pointed out some aspects that are crucial in reaching a compromise in regional energy planning problems. Nehrir et al. [27] developed a computer-based approach for evaluating the general performance of stand-alone PV/wind generating systems. Giraud and Salameh [16] discussed the steady-state performance of a grid-connected rooftop hybrid wind–solar power system with battery storage. The system reliability, power quality, loss of supply, and effects of the randomness of the wind and the solar radiation on system design are also discussed. Alarcon-Rodriguez et al. [2] provided a timely review of the state-of-the-art in multi-objective distributed energy resources planning, and discussed in detail the challenges, trends and latest developments in this field. Hunt et al. [19] presented a new integrated tool and a decision support framework to handle complex decision making problems in the UK energy sector.

Some analysis is also presented for hybrid renewable energy systems. For example, Elhadidy [12] presented a techno-economic study to design a hybrid solar photo-voltaic–wind domestic power generating system for one site of the western coast of India. It was shown that the optimum system would be able to supply 84.16% of the annual electrical energy requirement of the site. Celik [10] proposed a technique to analyze the performance of the autonomous small-scale PV and wind hybrid energy systems. Kolhe et al. [22] provided an analysis of the performance of a photovoltaic array that complements the power output of a wind turbine generator in a stand-alone renewable energy system based on hydrogen production for long-term energy storage. Elhadidy and Shaahid [14] presented an analysis of the performance of hybrid PV/wind energy system with hydrogen energy storage for long-term utilization. The impact of variation of battery storage capacity on hybrid power generation is also explored. Rentizelas et al. [28] investigated the effect of various scenarios for emission allowance price and provided directions on which technologies are most probable to dominate the market in the future. Xydis [33] studied the wind potential of Kythira Island and provided a techno-economic analysis aiming at identifying