A Robust Optimization Model for Optimal Design of Hybrid Renewable Energy Systems

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Abstract

As the public has gradually realized the adverse impact brought by the effects of global warming, a hybrid renewable energy system (HRES), which refers to a system that combines several renewable energy sources, one type of conventional power generator and energy storage systems, has become increasingly popular because it can reduce dependence on fossil fuel by utilizing wind power and solar radiations, while ensuring the stability of energy supply. While the HRES is attractive in many aspects, the stochastic nature of renewable energies makes the determination of the proper sizing of HRES a very challenging task. In this paper, we propose a risk-control decision support framework that encompasses a decision model and a solution method to enable the generation of optimal sizing of HRES with controlled risk. The objective of the proposed model is to seek the minimization of quantile total cost, which contrasts with the existing models that are largely focused on the minimization of expected total cost. A solution method consisting of effective quantile estimation techniques and a simulation optimization method is developed to enable the solving of the proposed model. Finally, a decision support system that integrates the decision model and the solution method is developed to facilitate the sizing decision of HRES in the real world.

Key words: Hybrid renewable energy system, Monte Carlo simulation, Quantile estimation, Nelder-Mead simplex method
JEL Classification: C02, C44, C46
1. Introduction

Energy is a vital issue for social and economic development of any country. Nowadays 80% of worldwide energy demand is supplied by conventional energy sources like coal, natural gas, crude oil, etc. However, the conventional energy sources are well known to be finite and fast depleting and it is expectable that future energy demand and supply will not be balanced. Furthermore, the conventional energy sources produce a great deal of greenhouse gas emissions that cause global warming. Over the last decade, the public has realized the urgent need to cut back on the use of conventional energy sources in order to reduce the global warming effect. For this reason, renewable energies, such as solar and wind energy have attracted much attention because they are non-depletable, non-polluting and environmentally friendly. As shown in Figure 1, a hybrid renewable energy system (HRES) includes two or more renewable energy sources, one type of conventional energy generator (e.g., diesel generators) and energy storage systems (e.g., battery bank or fuel cells) to cover an electric load, commonly an AC load; however, it may also supply a DC load or both at the same time. Typically, HRES would first use renewable energies to fulfill the energy demand and, when there is a deficit of energy supply; HRES utilizes diesel generators to meet the peak load demand during short periods, thus maintaining the balance of energy demand and supply. One advantage of HRES is that the weakness of some energy sources is complemented by strengths of the other sources in a centralized way, thereby ensuring the reliability and feasibility of the whole system.

In the literature, probabilistic methods is considered one of the simplest sizing methodologies, though results obtained by these methods are not the most suitable to generate the best solution (Luna-Rubio et al., 2012). In order to size each component of HRES, the probabilistic methods optimize one or two system performance indices, e.g., Bagul et al. (1996); Protogeropoulos et al. (1997); Karaki et al. (1999); Yang et al. (2003); Celik (2003); Tina and Gagliano (35). Usually, these methods first develop the appropriate models for generation and/or load, followed by a combination of these models to create a risk model. A fairly general methodology is presented in (Protogeropoulos et al., 1997) for the sizing and optimization of renewable power supply systems such as those with PV and wind generators. The technical and economic optimum configurations are obtained by considering the periods over which the average resource (e.g. wind/solar) is least or the average load demand is greatest. In Yang et al. (2003), a probabilistic approach is proposed and it is reported that a suitable meteorological year should be studied and utilized in order to obtain an accurate assessment of performance in a hybrid PV-wind energy system.
In this research, we propose a risk-control decision support framework that consists of a decision model, effective quantile estimation techniques, and a simulation optimization solution method to derive the optimal sizing of HRES in uncertain environments. As far as the problem is concerned, we consider a region that consists of several demand areas and several power stations; all the power stations and demand areas are connected by electricity grids. The power stations jointly supply power for all demand areas. We assume each power station has two types of renewable energies (PV and wind turbines), one type of conventional generator (diesel generators), and energy storage systems. The proposed decision model aims to seek the optimal size of PV, wind, and diesel generators, as well as the optimal size of the energy storage systems so as to achieve minimum \( \alpha \)-quantile total cost, while satisfying the power demand of each area.

3. Methodology

The proposed risk-control decision support framework is shown in Figure 2. Specifically, the framework starts with problem definition, which entails a clear description about the problem, specifically the objective function, the constraints and the decision variables of the problem under investigation. Then, a total cost model is developed where all factors that affect the total cost associated with HRES are taken into consideration. Next, the parameters in the total cost model that are uncertain are identified as random variables and their distributions are approximated by real data. To control the risk, the decision makers are required to specify the \( \alpha \) value. The selection of larger \( \alpha \) values implies that decision makers are more averse to the risk. Finally, a Monte Carlo simulation method, coupled with a
simulation optimization solution method, are applied to generate the optimal sizing of HRES. This process is continued until a termination criterion is satisfied. It is remarkable that, while a total cost model is developed in Section 3, it can be replaced by any other existing models in the literature without affecting the applicability of the proposed framework.

Figure 2: The proposed risk-control decision support framework

4. Decision Support Systems

In this section, we develop a decision support system (DSS) that integrates the proposed model and the solution methodology to produce the optimal sizing of HRES with controlled risk. This DSS is an improved version of that given in Chang (2014). Specifically, decision makers are allowed to choose the performance measure from a drop-down list that includes expected values and quantiles. The development of DSS is in collaboration with the Institute for Information Industry (III) in Taiwan. In brief, III, a Non-Governmental Organization (NGO), was established in 1979 through the joint efforts of public and private sections; its aim is to support the development/applications of the information industry as well as the information society in Taiwan. Figure 4 is the main interface of the DSS that includes four components consisting of “Input Parameters”, “Output Results”, “Sensitivity Analysis”, and “Power Generation, Allocation and Transmission”. Specifically, the existence of “Input Parameters” is to allow
users to provide the parameters needed in the model. As soon as the decision model is solved, the results are shown in “Output Results.” After the HRES is implemented and is in use, the power transmission model allows generating the information about how much power is needed from the diesel generator, how to allocate power to each power station and how to transmit power from each power station to demand areas. The results are shown in the “Power Generation, Allocation and Transmission.”

Figure 3: Interface of the Decision support system

5. Conclusions

In this paper, we study the optimal sizing problem of HRES in uncertain environments and propose a risk-control decision support framework to generate the optimal decision. Compared to the existing models that are largely focused on the minimization of expected total cost, the proposed decision model seeks the minimization of quantile total cost, allowing the risk to be controlled. This is complementary to the existing models. Further, we propose effective quantile estimation techniques and a simulation optimization solution method to enable the solving of the proposed decision model, producing the optimal sizing of HRES in the real world. Finally, a decision support system that integrates the decision model and the solution method is developed to facilitate the sizing decision of HRES in the real world.

References