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General indicator for techno-economic assessment of renewable energy resources

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ABSTRACT

Renewable energy is considered as a solution for mitigating energy crisis and environmental pollution. However, there are two main issues in techno-economic assessment of renewable energy resource: difficult to quantify assessment indicators and lack of a general indicator for multi-criteria evaluation. This study aims to develop a calculation methodology to quantify the techno-economic indicators including power generation, economic costs, incomes, and carbon emissions, through simulating the long-term implementation of solar, wind and biomass energy based renewable power systems. Moreover, by using normalization, weighting methods and Radar plot, all the indicators mentioned above are combined into a general evaluation indicator, which is able to provide a numerical result of multi-criteria quality evaluation of renewable energy resources. Hunan Province located in subtropical China where abundant of solar, wind and biomass energy resources, is studied as a case to present the evaluation methodology and its application. Through collecting the resource data of solar, wind and biomass energy and their facility costs data as the inputs, the long-term implementation of renewable power generation systems located in fourteen cities of Hunan Province are simulated; and then the numerical values of the general indicator are compared among different types of renewable energy resource. The general indicator evaluation results show that southern region including Yongzhou city have higher feasibility for wind power, while the eastern and northern areas including Loudi city have better feasibility of solar energy; for biomass energy resource assessment, the Huaihua system has the best feasibility while the Xiangtan system has the lowest among all the cities in Hunan province. The developed evaluation model and general indicator are able to provide a reference for investment decision making and subsidy policy optimizing.

1. Introduction

In many countries, there are a number of financial incentives for installing distributed solar PV, wind and biomass power plant to replace off fossil fuel power plant [1]. Before the terms of energy planning, system design, decision making and operation, it is necessary to quantificationally assess the techno-economic feasibility of renewable energy resources' exploitation [2].

Renewable energy resources assessment have been highlighted in a number of research projects, based on the techno-economic analysis [3–5] or on the more fundamental energy system simulation models and experimental studies [6,7]. Overall, these studies all proved that for different climatic and economic conditions. A renewable energy system is able to bring advantages of costs saving, energy resources saving and emissions reduction, but the range of financial benefits would vary depending on different climatic conditions. Because different prices of different power generator facilities are dependents on different manufacturing materials and technologies, these variations do have a significant influence on the techno-economic performances of renewable energy system. Therefore, it is lack of a reliable assessment tool to predict the system incomes and costs when using those renewable energy resources.

While most of current research concentrates on individual indicator assessment of renewable energy systems, there appears to be a few studies on comprehensive assessment of systems. Despite the feasibility analysis have been studied based on various technical or economic indicators [8–11] and energy systems have been optimized to meet the demand of energy saving [12], few studies presented quantified information on the comprehensively evaluation of a renewable energy system. Limited information has hindered seriously the application of renewable energy for users and decision makers. This requires a general assessment indicator which combine all the techno-economic evaluation indicators [13].

As there are difficulties in quantifying assessment indicators and

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lacking of a general indicator for multi-criteria evaluation, this paper aims to develop a general indicator to quantify the resources evaluation of solar PV, wind and biomass energy. Through developing computer simulation model for these three energy power system, the extent of changed electricity generation and carbon dioxide emission mitigation imposed by external conditions, such as solar irradiation, wind speed and biomass prices, and the change is analyzed. These results provide resident occupants and energy consultants with information on what extent of energy saving, return of investment and emission reduction bought by PV system under the current and future climate. Then, a multi-objective evaluation indicator is developed to combine the above techno-economic indicators for all the renewable energy resources. Hunan, as a subtropical province of China, there are abundant solar irradiation, wind resource, and biofuel; however the techno-economic feasibility have not been quantified in previous reported researches. The fourteen cities of Hunan are analyzed as a case study in this article to present the evaluation model and the general indicator. In this method, few techno-economic indicators are combined into a general evaluation indicator, which may be used as a tool to make the best application strategies of renewable energy by electrical sector, users and industry. It is believed that the methodology and results from this research will form a basis for the formulation of government incentives policies and renewable energy subsidies regulation.

2. Research methodology

In this reported research, three power generation systems based on three types of renewable energy resources mentioned above have been modeled by computer-based renewable energy simulation tool. By defining collected weather data as energy resources inputs, the configuration model and the long term operation of the systems are simulated to predict the systems' techno-economic performances. The simulation objectives and simulation processes of these renewable energy systems are introduced in this section. In addition, multi-objective evaluation index, constructed according to the multiple index evaluation method, is also developed to comprehensively assess the sustainable feasibility of the systems.

2.1. System modelling

Three sampled renewable energy power generation systems, as shown in Fig. 1, are all grid-connected systems which separately have a DC (Direct Current) PV panel, a DC wind turbine or a DC biogas generator as the energy generator, a DC battery as electricity storage system, as well as a converter converting electricity between DC and AC (Alternating Current).

PV array is a device to convert solar irradiation energy into DC electricity. Eqs. (1) and (2) are used to calculate the output of the PV array in considering or ignoring the effect of temperature on the PV array [14]:

$$P_{PV} = f_{PV}\,Y_{PV}\left(\frac{\overline{G}_T}{\overline{G}_{T,STC}}\right)[1 + \alpha_P(T_c - T_{c,STC})] \tag{1}$$

$$P_{PV} = f_{PV}\,Y_{PV}\left(\frac{\overline{G}_T}{\overline{G}_{T,STC}}\right) \tag{2}$$

where Y_{PV} is the rated capacity of the PV array (the power output under standard test conditions), kW; f_{PV} is the PV derating factor, %; $\overline{G}_T$ is the solar radiation incident on the PV array in the current time step, kW/m^2; $\overline{G}_{T,STC}$ is the incident radiation at standard test conditions, kW/m^2; α_p is the temperature coefficient of power, %/°C; T_c is the PV cell temperature in the current time step, °C; $T_{c,STC}$ is the PV cell temperature under standard test conditions, 25 °C.

Wind turbine converts wind energy into DC electricity. According to Standard Power Curve Method, power generation of wind turbine is calculated by Eq. (3) [14]:

$$P_{wind} = \frac{1}{2}\rho A V^3 \tag{3}$$

where P_{wind} is the energy output of the wind turbine, kW; ρ is the air density, kg/m^3; A is the swept area of wind turbine blades, m^2; V is the wind speed, m/s.

In this study, a wind turbine of FL250 kW produced by fuhrlaender AG is chosen as the wind turbine generator model. As the power curve of the wind turbine shown in Fig. 2, the power output increases with the wind speed varying from 0 m/s to 25 m/s.

Biogas generator consumes biogas to produce electricity, and the biogas is created by the biomass materials fed into a gasifier. In this process, the power generation of biogas generator could be calculated by Eq. (4) [14,15]:

$$P_{biogas} = \frac{BQ_{LHV}\,\eta\eta_{biogas}}{3600} \tag{4}$$

where B is the biomass materials consumed, kg; Q_{LHV} is the low calorific value of the biogas, kJ/m^3; η is the biogas generator efficiency, and η_{biogas} is the gasification efficiency of the gasifier. η and η_{biogas} are

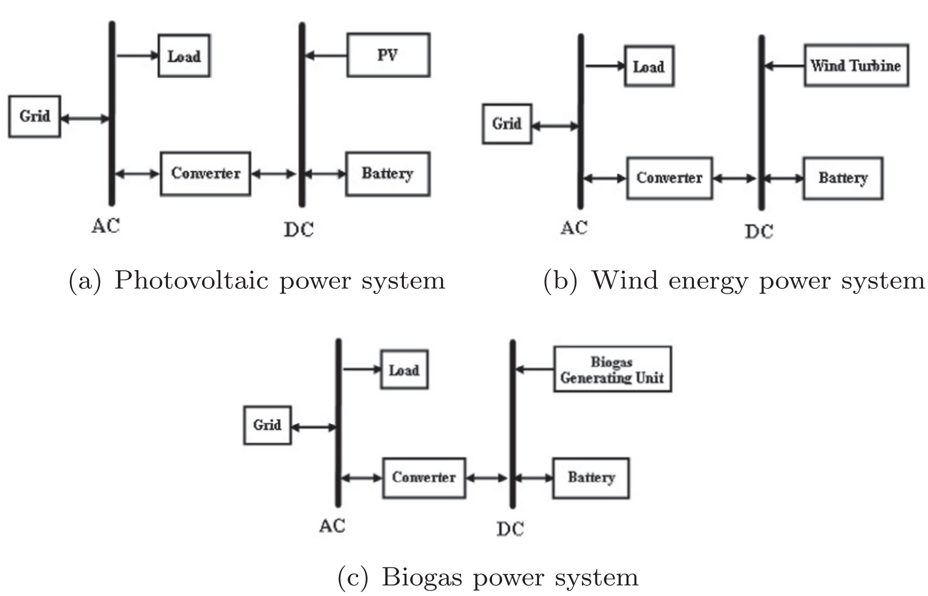

Fig. 1. Sustainable energy system configuration.