Renewable and Sustainable Energy Reviews 91 (2018) 1121–1147

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review on the utilization of hybrid renewable energy

Shaopeng Guo[a,c], Qibin Liu[a,b,*], Jie Sun[d,**], Hongguang Jin[a,b]

[a] Institute of Engineering Thermophysics, Chinese Academy of Sciences, 100190 Beijing, China
[b] University of Chinese Academy of Sciences, 100049 Beijing, China
[c] School of Energy and Environment, Inner Mongolia University of Science and Technology, 014010 Baotou, China
[d] School of Chemical Engineering and Technology, Xi'an Jiaotong University, 710049 Xi'an, China

ARTICLE INFO

Keywords:
Hybrid renewable energy utilization
Solar energy
Biomass energy
Wind energy
Geothermal energy

ABSTRACT

The utilization of renewable energy is significantly important for the world because global energy consumption is increasing, while conventional energy sources are no longer sufficient to meet the energy demand, triggering energy crises. However, variation in solar radiation and wind speed caused by climate and weather conditions restricts the stable operation of renewable energy systems, therefore, causing the output to fluctuate. A hybrid renewable energy (HRE) system can be highly efficient by combining multiple renewable energy sources and is regarded as a promising solution to the above issue. In this review, a comprehensive summary and discussion of the uses of HRE in terms of space heating, cooling, hot water usage, power generation, hydrogen production, drying and multi-generation are conducted. Hybrid system configurations, specific devices, application procedures, and performance are reviewed. Moreover, the challenges and outlook for HRE utilization are discussed, including the following points: proper use of the local sources in view of disperse and regional distribution of renewable energy; development of hybrid storage subsystems for HRE to improve the stability of the energy supply; further optimization of the operation strategy and system size to minimize the cost in order to promote the application; and, clear identification of the supporting local policies of renewable energy, especially considering HRE. Furthermore, the research potential is described for HRE utilization integrating direct CO_2 reduction.

1. Introduction

The increasing demand for energy and the urgent need for environmental protection calls for efficient and environmentally friendly energy systems. The utilization of renewable energy is widely considered as a promising alternative to conventional fossil fuel system and therefore draws more and more attention [1–5]. Currently, energy production from renewable energy sources increases every year, and most countries aim to achieve greater than 15% renewable energy production by 2020 [6]. However, compared with conventional energy sources, most renewable energy, for instance solar and wind energy, is usually unstable and intermittent. Solar irradiance and wind speed can vary greatly over hours or days. In addition, low energy density is also regarded as a main drawback for renewable energy. It is apparent that a single renewable energy source is insufficient to support a continuous energy supply system. To overcome the disadvantages described above, the integration of various renewable energy sources has been proposed [7,8].

Originally, the focus on the utilization of hybrid renewable energy (HRE) was mainly concentrated for power generation in remote areas [7]. The feasibility of integrating wind-powered generator and photovoltaic (PV) array was discussed earlier by Castle et al. [9] in 1981. To cover the shortage of renewable energy such as intermittence, a diesel generator is introduced in HRE system as a backup source by Losie et al. [10]. Afterwards, many researches on hybrid wind and PV system have been carried out in terms of system modeling, control strategy, size optimization, efficiency evaluation, economic assessment and etc. McGowan et al. [11] developed the models of a hybrid wind-PV-diesel system using the method of HYBRID2 and SOMES respectively. They compared the simulation results of two models and found that both HYBRID2 and SOMES gave similar results. The main differences were in energy flows due to the different modeling method and strategy of subcomponents. Arul et al. [12] discussed the control strategies for the hybrid wind-PV power system. Results indicated that the appropriate interfacing power conversion methods and corresponding devices were crucial for the hybrid system. To make the system economically attractive while providing a reliable energy supply, the size optimization is crucial in the design of a HRE system. Al-Falahi et al. [13] categorized

* Corresponding author at: Institute of Engineering Thermophysics, Chinese Academy of Sciences, 100190 Beijing, China.
** Corresponding author.
E-mail addresses: qibinliu@mail.etp.ac.cn (Q. Liu), sunjie@xjtu.edu.cn (J. Sun).

https://doi.org/10.1016/j.rser.2018.04.105
Received 26 December 2017; Received in revised form 6 March 2018; Accepted 21 April 2018
1364-0321/

the methodologies of size optimization as classical algorithms, modern techniques and software tools. They found that the modern techniques were more popular than classical algorithms when solving complex optimization problems. In addition, there has been a clear trend to use hybrid algorithms over signal algorithms in recent years. Balleh et al. [14] compared the efficiency of energy production from solar PV, wind turbine and hybrid system. They also analyzed the production quantity and the profitability of the above energy supply systems. Hiendro et al. [15] investigated the potential use of solar energy and wind energy for a hybrid wind-PV system in an onshore/remote location. They used software HOMER to analyze the techno-economic feasibility of the hybrid system. Furthermore, the integration of biomass energy and geothermal energy is also concerned. For those agriculturally developed or forested regions, there are usually sufficient sunlight and biomass feed stocks. Thus, the hybrid solar and biomass energy system was paid more attention in those regions [16,17]. Similarly, the introduction of geothermal energy is implemented for the regions rich in geothermal energy [18–20].

Over the past decades, the hybridization of different renewable energy sources has been extensively concerned. The HRE systems are summarized in consideration of system modeling, control and sizing methodologies and optimization [21]. However, the previous reviews mostly address the above issues based on the discussion of power generation or grid design. Other factors of HRE utilization should also be comprehensively outlined to provide more insightful prospects on the utilization of renewable energy. Moreover, the HRE systems with more than two inputs and outputs were not widely discussed in the previous reviews. However, it is becoming a trend to integrate various renewable energy sources and supply various outputs simultaneously [22,23]. In this paper, we focus on the utilization of HRE. The combination of two or more renewable energy sources are discussed. The paper begins with a literature review of HRE utilization in terms of space heating, cooling, hot water usage, power generation, hydrogen production, drying and multi-generation. The corresponding system configuration, specific device, operation procedure and performance are reviewed. Afterwards, the challenges and outlooks of HRE utilization are presented. The objective of this paper is to help the readership obtain an incisive overall understanding of HRE utilization, which is conducive to the promotion of HRE technology. The route toward HRE utilization with multiple inputs and outputs is demonstrated in Fig. 1.

2. Literature review of hybrid renewable energy utilization

In this section, the utilization of HRE is summarized based on the literature review. The discussion is carried out according to the categories including space heating, cooling, hot water usage, power generation, hydrogen production, drying and multi-generation.

2.1. Space heating, cooling and hot water usage

At present, the energy consumption for space heating, cooling and hot water usage is a key component of the total energy consumption for most countries [24]. To reduce energy consumption and greenhouse gas emissions to achieve the goal of controlling the increase in the global average temperature, i.e., below 2 K, alternative energy resources in addition to conventional fossil fuels have been seriously considered. As the most widely available renewable energy source, solar energy can be easily collected and used for space heating, cooling and hot water usage [25,26]. However, because of the fluctuation of solar irradiance, the systems combining solar energy and the other renewable sources like biomass or geothermal energy were proposed. The road map toward HRE utilization for space heating, cooling and hot water usage is shown in Fig. 2.

2.1.1. Space heating and hot water usage

As shown in Fig. 2, there are mainly two combinations designed for space heating and hot water usage. Hereinto, the approach combining solar and biomass energy was proposed in regions rich in both solar and biomass resources.

The medium temperature of space heating and hot water is usually below 353 K, which can be decreased to approximately 323 K when using under-floor pipes [27]. For low-temperature solar energy applications, the flat plate collector dominates the market due to its advantages of convenience and low cost. Considering the instability of solar energy, flat plate collectors and biomass boilers should be connected to the heating system simultaneously. Heat from the combustion

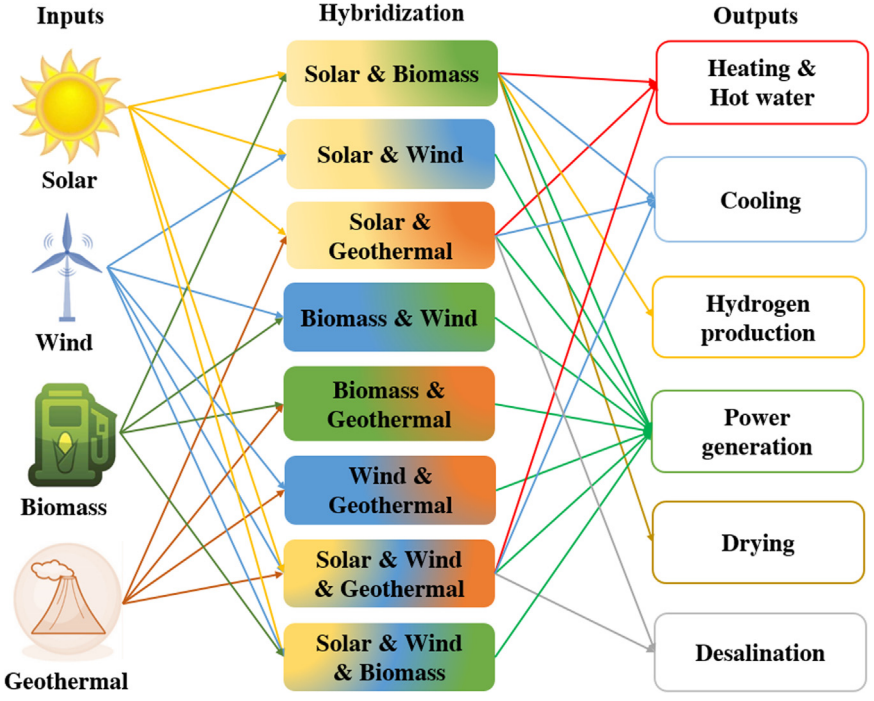

Fig. 1. Route toward HRE utilization.