Renewable and Sustainable Energy Reviews 82 (2018) 126–155

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

A review of energy management strategies for renewable hybrid energy systems with hydrogen backup

F.J. Vivas*, A. De las Heras, F. Segura, J.M. Andújar

Grupo de Investigación de Control y Robótica TEP-192, Departamento de Ingeniería Electrónica, de Sistemas Informáticos y Automática, Escuela Técnica Superior de Ingeniería, Universidad de Huelva, Spain

ARTICLE INFO

Keywords:
State of art revision
Energy management strategy
Hybrid renewable power systems
Hydrogen backup

ABSTRACT

Hybrid systems are presented as a viable, safe and effective solution to minimize the associated problems of the dependence on renewable energies with the environmental resources. In this way different renewable systems such as photovoltaic, wind, hydrogen and so on, can work together to configure hybrid renewable systems. However, to make them work properly in a holistic way by creating synergies among them is not an easy task. Recently hydrogen technology has appeared as a promising technology to hybridize renewable energy systems, since it allows the generation (by electrolyzers) and storage of hydrogen when there is a surplus of energy in the system, and at a later time (e.g. when there are insufficient renewable resources available) using the stored hydrogen to generate electrical energy by fuel cells. The choice of a correct energy management strategy should guarantee an optimum performance of the whole hybrid renewable system; therefore, it is necessary to know the most important criteria in order to define a management strategy that ensures the best solution from a technical and economic point of view. This paper presents a critical review and analysis of different energy management strategies for hybrid renewable systems based on hydrogen backup. In the same way, a review is also presented of the most important technical and economic optimization criteria, as well as problems and solutions studied in the scientific literature.

1. Introduction

With the advancement of civilization and evolution of technology, energy demand has become a basic issue for the development of a society today. The usual ways to address this demand today are based mostly on resources such as fossil or nuclear fuels [1–3], which have a negative impact on the environment, either contributing with greenhouse gases, or by production of radioactive or inert solid waste. For this reason, every day the need to migrate to more environmentally responsible energy production models becomes more evident.

Together with the above, due to the high-energy requirement, it is necessary to look for generation models to ensure maximum system performance, minimizing the use of resources, cost and thus the environmental impact. In recent decades, the use of distributed generation has emerged as a viable and safe solution to increase electrical system performance, reducing the distance between generation and demand [4,5].

The incorporation of renewable energies is a non-polluting solution for a distributed generation, allowing different generation points in the geography of a country, region or even district, as well as providing a viable alternative from a technical and economic point of view for isolated generation applications [6–9]. Among the main renewable energy sources for distributed generation, we can find photovoltaic panels, small and medium wind turbines, micro-hydro turbines, biomass and biogas [27]. The electricity production by hydropower, biomass and biogas need a constant supply of fuel and resources, which would imply a major economic commitment to such a sector and there are a lot of pollutant emissions in the case of the last two technologies; so they would not be suitable for small outlets in homes, small business systems etc. By contrast, wind and solar sources can be more suitable and they are nonpolluting [27]. This is why most applications choose these sources to implement hybrid systems based on renewable energies. The wind resource, despite being available throughout the day, has a high randomness and large variations in the short term, so it is not a reliable source for supplying a load [8]. On the other hand, although the solar resource is more predictable and suffers less pronounced variations, there can be no solar production during the night or at dawn or nightfall, so production is minimized due to the reduced amount of incident radiation, resulting in an energy deficit [28].

Despite the benefits of renewable energy, there are associated problems with each technology, such as dependence on environmental resources, high cost, etc. To minimize the negative impact of these

* Corresponding author.

http://dx.doi.org/10.1016/j.rser.2017.09.014
Received 26 April 2016; Received in revised form 20 August 2017; Accepted 2 September 2017
Available online 17 September 2017
1364-0321/

Nomenclature

BAT	Battery
CHP	Combined Heat and Power (cogeneration)
DOD	Depth Of Discharge
ELEC	Electrolyzer
FC	Fuel Cell
LPSP	Loss of Power Supply Probability
MH	Metal Hydride
MPPT	Maximum Power Point Tracker
MT	Micro Turbine
PV	Photovoltaic source
SC	Supercapacitor
SOC	State Of Charge
UC	Ultracapacitor
WT	Wind Turbine

disadvantages, hybrid systems are presented as a viable, safe and effective solution [10–16].

The use of hybrid systems with different generation sources is an acceptable solution to cover the deficiencies of the different elements, but a backup system is necessary for an optimal power supply [5,15]. Nowadays for small and medium scale, energy is stored mostly in batteries and, for specific applications, in supercapacitors. For larger scale storage, potential energy is used with hydro pumping in swamps. Because wind and solar resources have a stochastic behavior, and the supply of the load profile is the main objective of generation systems, the use of energy storage systems is necessary to ensure the demand is reached and the stability of the supply system [28]. In the short term, energy storage systems have the primary function of supporting excess/deficiency of energy, and guaranteeing system security and power supply when the load changes [1]. In contrast, in the long term, energy storage systems have the function of providing the demand for a long period when the generation is not sufficient to maintain the load [1].

Traditionally, batteries and more recently supercapacitors have been used as short-term energy storage systems. Supercapacitors have a better dynamic behavior than batteries, so they can respond to demand shocks and supply energy almost immediately [29]. Moreover, their lifetime is very high with a safe operation without emission of harmful gases [29]. Despite all these advantages, their low capacity restricts their use. In contrast, batteries are elements with worse dynamic response, and a limited lifetime based on the number of charge/discharge cycles. Additionally, batteries may suffer deterioration and during normal operation can produce harmful gases [30]. The fact that the batteries have gained greater prominence is mainly because of their high load capacity and the ability to support a higher density of discharge current in amplitude and time. These features ensure greater security in the system response, since batteries can withstand longer defects and deficiencies in generation and dynamic changes in demand.

The long-term energy storage systems have always been based on non-renewable energy sources, such as diesel generators. These generators require high maintenance cost and produce sound and environmental pollution.

Recently, the use of hydrogen technology is presented to have a future value [15,17]. The use of hydrogen as a fuel in fuel cells is showing its strengths compared to diesel systems. Fuel cells have higher performance, lower maintenance and no emissions. Because hydrogen is an energy vector and it can be produced renewably, it is ideal for use as renewable energy storage [18,19]. The use of hydrogen as an energy vector absorbs excess energy during generation and produce energy in stages of energy deficit [14]. This alternative decreases battery size and increases system performance by taking advantage of energy surplus. Despite the benefits of using hydrogen, it is true that greater control, security and associated equipment for proper operation is necessary [15].

The energy transformation based on electricity-hydrogen-electricity relation is a starting point for new models of energy storage for example: power to gas [20–27].

In order to ensure proper operation of hybrid systems based on renewable energy, guaranteeing the demand and increasing the system performance, it is necessary to use energy management strategies [6,28–30]. The goals of these strategies will determine the behavior of the system, so it is very important to define a proper management strategy. Therefore, this paper undertakes a review of different energy management systems on hybrid power systems based on renewable energies, with the use of hydrogen as an energy vector. Section 2 includes a review and a classification of the most common topologies studied in the scientific literature. In Section 3, a review of the main techno-economic criteria for designing energy management strategies is done. In Section 4 solutions adopted in the literature are presented. Section 5 reviews and analyses different strategies used in the scientific literature. Finally, Discussion and Conclusions are compiled in Sections 6 and 7 respectively.

2. Configuration of hybrid renewable systems

Hybrid systems can be classified in different ways; the most common are those which distinguish the different systems depending on their connection to the grid; as well as the method of integration of elements inside the system.

2.1. Classification according to grid connection

Hybrid generation equipment can be classified according to their stand-alone or grid connected operation. The use of one or another

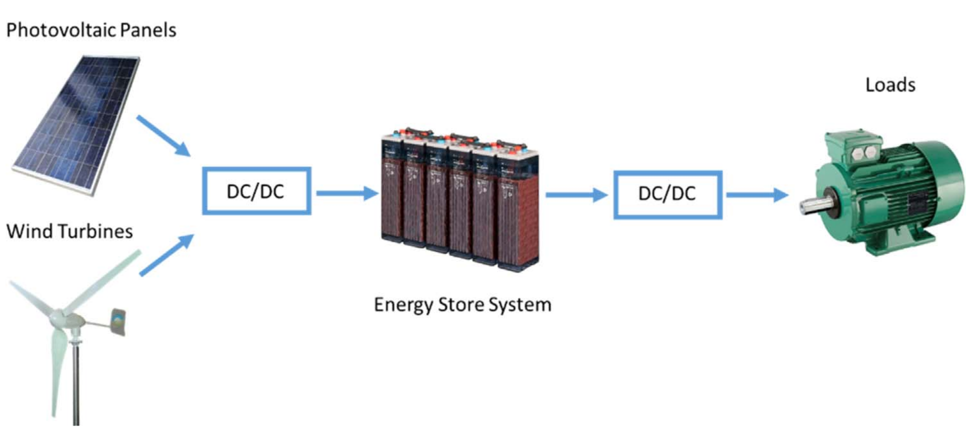

Fig. 1. Example of isolated topology.