Renewable and Sustainable Energy Reviews 26 (2013) 60–95

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

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

Review of grid-tie micro-generation systems without energy storage: Towards a new approach to sustainable hybrid energy systems linked to energy efficiency

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ARTICLE INFO

Article history:
Received 14 April 2012
Received in revised form
3 May 2013
Accepted 7 May 2013
Available online 16 June 2013

Keywords:
Homeostatic control
Sustainable hybrid energy systems
Rural communities
Energy efficiency

ABSTRACT

This paper reviews the literature on the subject albeit approaching hybrid micro-generation power systems from a systems thinking (ST) and cybernetics standpoint, viewing them as dynamically complex adaptive systems (CAS) coupled with and supplying to a set of homes termed a sustainable block in a rural setting. Here homeostatic regulation (HR) and control play a vital role in reaching efficient equilibrium towards reconciling power supply and demand response management. Unlike most of the work reviewed in the literature, the focus here is on supervisory control of grid-connected micro-generation systems without energy storage, aiming towards building energy efficiency, thriftiness and sustainability in energy consumption. Building on homeostatic control (HC) principles first introduced by F.C. Schweppe in 1979, the paper explores the concepts of sustainability and sustainable hybrid energy systems (SHES) applied to micro-generation, focusing on operational aspects rather than on socio-economic, environmental or regulatory ones. A concrete theoretical model for building a SHES is presented for a proposed grid-connected renewable microgrid. The model seeks to reconcile power supply and demand towards efficient equilibrium (homeostasis) proposing reward-based criteria for controlling renewable electricity supply and consumption in rural communities in Chile. Discussion and recommendations are also offered stating that energy sustainability (ES) is essentially a systems issue, and one where ES is first and foremost a structural, organizational and operational property which is in the very nature of the system itself – it is built into it – rather than explained by exogenous factors.

Contents

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http://dx.doi.org/10.1016/j.rser.2013.05.002

1. Introduction

The potential for using hybrid renewable energy systems (HRES) based on non-conventional renewable energies (NCRE) for electricity generation in rural and remote communities is big and growing and Chile is a perfect candidate for such initiatives being rich in renewable energy sources (RES) throughout its long territory. For this purpose drivers for implementing distributed generation (DG) systems using NCRE are to be identified in each case, but in general, these are the geographic potentials for production, the technology available and the social, economic and political support garnered along with the active involvement of the local community and authorities, respectively [1–33]. Therefore, to meet the energy requirements of remote and rural communities, HRES for DG of electricity and heat – working in a variety of smart microgrid configurations – can be a viable and convenient solution, especially in those places where there is still no electrical energy distribution network available as it is presently the case in many locations of Latin America. However the cost of hybrid energy systems based on renewable energy technologies (RET) is generally high and there is also the problem of reliability associated with the RET due to the intermittent nature of RES [1–8]. Thus there arises the need to design and develop small, modular, smarter hybrid micro-generation systems (HMS) that are efficient, cost-effective and economically profitable as an investment notwithstanding their small size and power generation ranges, which usually operate in the kW range. They are employed for residential or small commercial/industrial purposes and also for small size power back-up applications, rather than in the mega watt (MW) range for power utility size applications. These can be comprised of mature technologies such as small wind turbines, photovoltaic (PV) panels and microturbines or generators, for example, operating on diesel or with liquefied petroleum gas (LPG), in rural/remote locations which can also incorporate different options of energy storage systems (ESS) [9,10] but only when these are economically feasible for the project's users, are deemed appropriate and necessary for the particular configuration and sizing chosen for specific needs, and are not thwarted by the location's ordinances, environmental or budget restrictions, many of which exist today in several locations of Chile as well as in the rest of the world. With respect to this, the examination of past energy technology practices at other well known sites with uniquely fragile environment [6–8,12–33,129] can provide valuable lessons for new HRES designs that integrate centralized power generation and distribution infrastructure with local RES, matching distributed energy demand with local power supply effectively [1–8]. Likewise NCRE have significant potential for contributing to the economic, social and environmental sustainability of these rural and remote communities, which are so abundant in number in South America. They also reduce emissions of local and global pollutants and may create local socioeconomic development opportunities as well [1–33]. On the other hand, sustainable hybrid energy systems (SHES) are those that can overcome perturbations and chaos, enduring adverse and changing conditions in spite of how complex the environment in which they are immersed turns out to be. Chaos theory studies the behavior of complex, dynamical systems that are capable of adapting and are highly sensitive to initial conditions [226,227] just like HRES are. Such systems face unpredictable conditions and situations continuously, throughout their operation, due to a myriad of factors, such as the weather, sudden and abrupt changes in peak power demand and harmonics, for example. Maintaining voltage and frequency stability is also a concern – especially when operating in tandem and parallel with the grid – indeed a complex ongoing task for such systems [93–108]. Small differences in initial conditions or in operating parameters which directly determine their generating capacity and the quality of their power supply at any point in time can yield widely diverging outcomes in HRES. This is particularly true for HRES connected to the grid and operating without energy storage systems (ESS). Up until now, much work has been published on stand-alone and grid-connected HRES with energy storage [1–183,187–208], yet upon an extensive review of the relevant literature on the subject, it is found that there is a void in this area in particular, with practically no research work published on grid-connected HRES without energy storage. Therefore there is a clear need to address such systems configuration and device new and innovative supervisory control strategies [30–34] from an alternative viewpoint that can aid more effectively and efficiently in the coordination and control of such systems operation, equipping them with the means to overcome these challenges. Moreover, these new and innovative supervisory control strategies for MGS – especially for those tied to the grid – must be addressed and resolved but with customers (loads) being active players in such strategies, not passive ones as seen in several other more traditional approaches to the subject, which focus rather on components, technology choices and in energy management devices that totally exclude or bypass the energy user interaction and choice. For this task several approaches were reviewed in the literature, where the hybrid micro-generation plant generally has some type of device incorporated in its control system which decides when, how and how much to adjust the power supply and manage energy demand response in order to carry out load shedding, in an effort to keep the system's stability in regards to power supply and demand side management (DSM) requirements. This is particularly complex with respect to reconciling power supply and energy demand management in grid-connected micro-generation power systems operating without energy storage, where the price of electricity supplied by the local grid can be very high at certain times of day and during seasons of high energy demand like in several touristic locations throughout Chile, particularly so in the south and north of the country and in places like Easter Island or the large island of Chiloe, located at the far south tip of Chile. Therefore it is in this particular case where there is a need – addressed in this paper –