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Homeostatic control, smart metering and efficient energy supply and consumption criteria: A means to building more sustainable hybrid micro-generation systems

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ABSTRACT

This paper presents an innovative approach for the understanding and control of grid-connected hybrid micro-generation systems (HMS) without energy storage, to supply electricity to a group of homes designated as 'Sustainable block'. The initiative is based on an effort to integrate non-conventional renewable energies (NCRE) through distributed generation (DG) projects intended for remote and rural communities in Chile and South America, where electricity supply is both expensive and often times unreliable. This may be due to equipment malfunction, line faults and/or harsh climatic conditions or other natural phenomena like earthquakes, all of which can undermine the electric power distribution networks. Here a systems thinking (ST) and cybernetics approach is employed which looks at grid-connected microgrids supplying power to local loads as intrinsically dynamic, complex adaptive systems (CAS). Moreover, such systems can be viewed and approached as a complex sociotechnical system, wherein the energy users ought to play a crucial role as 'active loads' within the sustainable block to which the grid-tie microgrid is coupled. Building upon this theoretical framework, a set of coordination and supervisory control strategies for renewable microgrids is presented based on homeostatic control (HC) principles introduced by Schweppe et al. Homeostatic control of power systems. In: Fourth energy monitoring and control system conference. Norfolk, VA: November; 1979. The approach is intended to study and eventually develop new forms of sustainable renewable energy technologies (RETs) for DG of electricity and heat, working in parallel with the grid and offering new choices and benefits to energy users everywhere. A concrete theoretical model is proposed and the algorithms depicting the strategies are explained and compared through simulation analysis.

Unlike what is available in the literature on sustainability, and looking at what is missing in regards to HMS as sustainable energy systems (SES), this paper offers an entirely new and significant perspective in terms of design and operation of such systems. First the concepts of sustainability and SES applied to HMS are explored, finding that the large majority of the mainstream analysis reviewed on the subject is focused on socio-economic, environmental, and regulatory issues rather than on the systemic, technical and operational aspects of such systems, as this paper does, and how HC, energy efficiency (EE), and a novel approach to energy supply and consumption equilibrium based on homeostasis can help build more sustainable HMS. Results are presented which confirm the hypotheses underlying the strategies employed and the model predictability, showing that SES are indeed possible and feasible. Discussion and recommendations are also offered stressing the fact that sustainability is essentially a systemic property and operational in nature, rather than explained by exogenous factors.

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1. Introduction

Homeostatic control is a term first introduced by Schweppe and his group of collaborators at MIT back in 1979 and in early 1980s [1–6] which stems from their highly visionary work and insight regarding both, flexibility and stability in electric power systems (EPS) linked to homeostasis, understood as reaching and maintaining an efficient equilibrium state between energy supply and demand, considering the diverse nature and operation dynamics of the wide variety of industrial and commercial loads [1–6]. Their approach advocated homeostatic control (HC) of energy supply and demand in an effort to make utilities power supply more efficient, particularly when supplying large industrial and commercial customers. Indeed Schweppe and his group were much ahead of their time, having had a true insight for what was to come in the years ahead, anticipating also the need for new control technologies and energy management systems to adequately manage the intermittent supply of RETs (mostly wind back then) and how to best fit these RETs in the current electric power infrastructure [7–11]. Something that we are still dealing with today. HC is based on the idea that homeostatic regulation (HR) and control mechanisms apply in EPS management when viewed as dynamically complex adaptive systems [12,13]. In fact a grid-connected microgrid supplying energy to a group of residential consumers somewhere, where the energy users have access to all the relevant information regarding the microgrid's supply, the grid's provision of electricity and their energy usage dynamics, constitute indeed a complex, dynamic sociotechnical system in itself [14]. Such sociotechnical system is a CAS in transition to a new order in terms of its energy management and efficient equilibrium between energy intake and expenditure [8–10,12–14].

On the other hand sustainability is the capacity of a living system to endure and survive in spite of changes within or outside of the system. It is inherent to all living systems – just like homeostasis is – whether they are open or closed. Understanding this concept is basic for the effective development of sustainable energy system (SES) and important for building more robust and efficient EPS in the future [7–11]. Unlike most of the work done up to the present on the subject of sustainability and sustainable energy systems – which largely pertains to economic, environmental, social and regulatory issues – this paper focuses rather on the concept of built-in sustainability in hybrid energy systems (HES). Hence, departing from the main stream analysis of sustainability in micro-generation power systems in particular, the paper explores the technical and operational aspects of such systems and how homeostatic control (HC) principles, energy efficiency (EE) and a novel approach to managing energy supply and consumption towards efficient equilibrium can help build more sustainable hybrid micro-generation systems (HMS).

Upon reviewing the subject one finds that most of the literature dealing with sustainability and SES addresses the classical issues on sustainability in regards to energy systems design and management, somehow overlooking the more systemic, technical and operational aspects of SES linked to HR mechanisms and HC (see Fig. 5 on [9]), somehow lacking an in-depth analysis of the participating systems interaction from a systemic and cybernetics viewpoint [15]. Thus one finds that much of the work done up to the present on the subject matter focuses on economic, environmental, social and regulatory issues, somehow overlooking key operational and technical aspects of SES. This becomes particularly relevant when it comes to micro-generation power systems and their inherent sustainability. Such classical views of SES look rather at the sources of energy, making economical and environmental considerations the pivotal factors in the decision making process, and favoring the use of energy derived from renewable energy sources (RES) 100% whenever possible. This is particularly evident when reviewing the literature on such topics as communitarian cooperativism in HMS implementation and sustainability indicators in rural electrification [16,17], or reducing energy demand using demand side management (DSM) programs in targeted areas through all kinds of action plans, policies and regulations as it is being done in highly populated regions like India [18]. Yet using 100% renewables is not always possible or even convenient. Thus a proper combination of RES-based technologies and conventional energy sources is used in such cases [7], along with an adequate design and configuration of the grid-connected HMS where RES and the grid supply play a crucial role [7–11,19–26]. This should be accompanied by a proper system design, dimensioning and management of the loads (demand for energy and how it is expended), EE considerations in such designs, and the use of feedback [19–33] in a way that the entire system is made as efficient, productive and sustainable as possible in terms of energy supply and demand considering various factors and constraints [33–36]. Such views even go as far as suggesting that “there is a need of an energy ethics: a moral obligation to deal with the energy problems at the center of that decision making process” [37] and also introduce all kinds of social, economic and environmental