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Building sustainable energy systems: Homeostatic control of grid-connected microgrids, as a means to reconcile power supply and energy demand response management

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ABSTRACT

The issue of worldwide over consumption and squandering of electrical energy has resulted in what one might call an energy obesity problem in terms of energy intake and its expenditure. It is indeed something that must change if modern society is to become sustainable someday. This is to be realized in conjunction with adequate government policies and innovative strategies aimed at effectively integrating non-conventional renewable energies (NCRE), with thriftiness and energy efficiency (EE) – the three pillars of energy sustainability (ES) – in today's electric power systems generation and distribution infrastructure. This ought to be done in a way that incorporates them jointly, as part of a comprehensive energy strategy to propitiate a wider penetration of distributed generation (DG) solutions. Departing from mainstream literature on the subject, this paper proposes such strategies for integrating hybrid micro-generation power systems to the grid through homeostatic control (HC), as a means to reconcile power supply and energy demand response management (EDRM). These strategies can be designed and implemented in the microgrid's supervisory control system for the purpose of eliciting EE and thriftiness in consumers to build ES in the system. The theoretical model behind the HC strategies is presented and a numerical example is provided, using real electricity consumption data of a small rural community in Chile. Upon examining a particular set of criteria designed to control renewable power (RP) supply from a grid-tie microgrid to residential consumers, simulation results show that the model proves effective when testing such criteria for different power supply scenarios. Particularly revealing is the role of the energy storage system (ESS) – the energy buffer – in the HC strategies being proposed and the difference that it makes in eliciting thrifty, efficient energy consumption as a result of individual and collective efforts to ensure energy sustainability of the system as a whole.

Contents

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1. Introduction

Today's society is at a crossroads and in the middle of a transition stage in terms of technologies, fuels and electric power systems (EPS) management that somehow must echo the energy crisis that many regions of the world live today. This goes right in front of the problem of high CO_2 emissions and green house gases (GHG) and the purported effects on climate change, air pollution and health risks [1]. Particularly dire is the situation of those regions of the world which – unlike Denmark – rely heavily on fossil fuels for their energy production, especially so when most of such fuels are imported. Chile in particular is a good example of this unfortunate case, with its unbound energy expenditure which parallels its economic growth in a way that clearly illustrates this energy obesity problem. With an economic growth which is still closely tied to a strong energy consumption, Chile is a country where the incorporation of renewables and EE measures [2,3] along with thriftiness in energy usage, even though as important and necessary as this initiative is, it has not yet been able to click in government authorities, the legislature and the population at large inserting it among their substantive priorities to make the change possible. In fact experts predict a grim outlook for Chile moving towards 2020, due to the lack of enough new energy projects approved in a timely manner and also due to the length of such projects, once they are approved. In light of such a worrisome outlook, it is urgent to shift course towards the adoption of DG in a larger scale with renewable energy sources (RES) and innovative technologies [4], along with the adoption of EE and thriftiness in energy consumption, and to push for these to be considered jointly in the national energy policy making of the country [5–11]. Indeed it is important to understand that the larger and more widespread the diffusion and integration of NCRE, along with thriftiness and EE, all deemed as one complete set of measures and incentives, comprise the three pillars of ES. This is to be expected someday in new DG projects incorporated into the country's energy matrix – the current EPS generation and distribution infrastructure – if more effective energy policies are to be achieved. Such concerted effort must work hand in hand with advancements in EPS technological innovations [4] and power management, as part of a national energy program that fosters and impels both of these towards a more sustainable economic development. For such purpose one must also develop new strategies aimed at finding new ways of implementing energy regulation (ER) and EE measures that may elicit thriftiness and ES in energy consumption of the population at large. To be effective, such measures should encompass economic reward-based mechanisms to elicit and instill the desired behavioral change being sought in return for such thriftiness and energy sustainability [5–11].

Conditioning human behavior to adjust to changing living conditions and circumstances, adapting to new environments with different resources under various degrees of availability and supply is nothing new. It has been done many times before. There are various strategies to influence and condition human behavior and socio-technical systems in general to adopt behavioral changes, adapting to diverse scenarios [5–10,12–19]. An example of this are the many strategies found in the vast organizational change and management literature, where a great number of strategies for a variety scenarios are presented. These are designed, planned and implemented in various ways to elicit changes in human behavior and to make organizations become more efficient, nimble, innovative, productive or resilient. Another example of successful conditioning of human behavior was the first experiment of its kind, Biosphere 1, and later Biosphere 2 [14–19]. Biosphere 2 is an earth systems science research facility currently owned and managed by the University of Arizona, whose mission is to serve as a center for research, outreach, teaching and lifelong learning about earth, its living systems and – most importantly – the possibility to condition humans to live in controlled environments under stringent conditions [14–19]. This in order to be able to adapt to new, more complex and changing scenarios such as the ones space colonies will most likely find upon achieving planetary colonization in the decades ahead. After spending prolonged periods in these locked controlled environments where they were subjected to special living conditions, adopting strict diets with rigorous low energy (low-calorie) diet and high

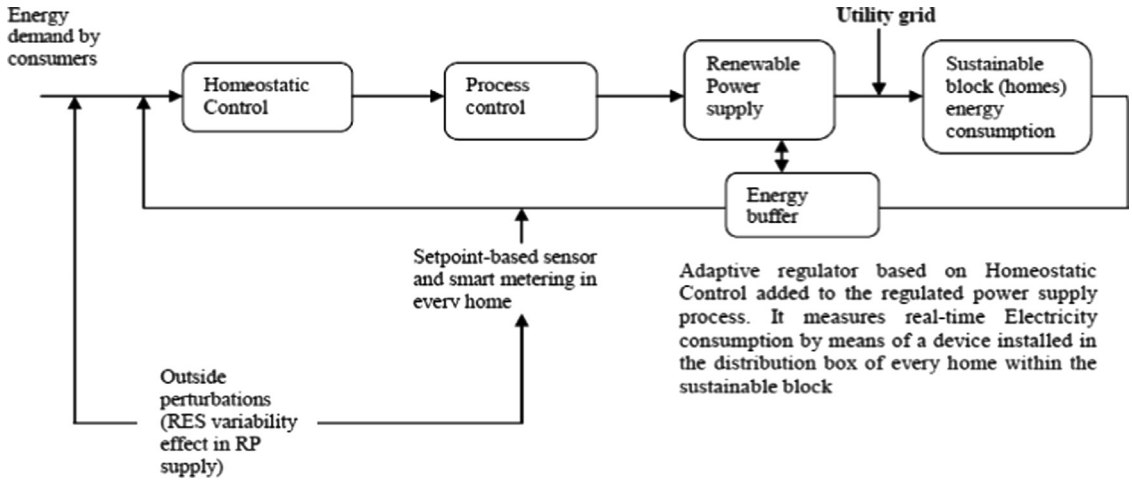

Fig. 1. A simple adaptive regulator model based on HC implemented through negative feedback for residential consumers with an energy buffer.