Linking Exergy and Homeostatic Control to develop Sustainable Grid-connected Microgrids.

Franco Fernando Yanine

Graduate researcher

Department of Industrial & Systems Engineering

Pontificia Universidad Catolica de Chile, PUC

fyanine@uc.cl

Enzo E. Sauma, PhD

Associate Professor

Department of Industrial & Systems Engineering

Pontificia Universidad Catolica de Chile, PUC

INTRODUCTION

- Supervisory control strategies for integrating mini and micro-generation hybrid energy systems to the utility grid are proposed in a way that has not been done before:

- Linking exergy and homeostatic control (HC) to develop sustainable grid-tie hybrid microgrids.

- The approach presented here seeks to reconcile power supply and energy demand response management(EDRM) upon achieving efficient equilibrium (homeostasis) between the two.

- Control scheme sought to provide electricity and heating to small, rural communities. Based on this premise, an exergy and HC approach is proposed to develop such systems for rural and remote areas in Chile and South America.

Homeostatic control of grid-tie microgrids with and without energy storage

- Homeostatic control (HC) is a term introduced by F. C. Schweppe and his group of collaborators at MIT back in 1979 and early 1980s and stems from the highly visionary work done by them. It is ***"an overall concept which tries to maintain an internal equilibrium between supply and demand."*** **F.C Schweppe (1979,1980)** and it attempts to do so by informing the customer of the time-varying prices of electricity, whereby the customer can make his/her own consumption decisions independently, as opposed to having conditions being imposed on him/her

- We build on this concept and take a new approach, focusing on HES for residential electricity supply, where renewable power—being a scarce, limited resource that must be managed efficiently—is supplied only to homes which comply with a specific criterion in an effort to curtail demand to ensure energy efficiency (EE) and sustainability overtime.

- Micro-generation systems have demands up to ~10kWh/day load (3 to 4 kW peak load) whose technologies are easily available in today's market. We simulate for 8760 hrs run a wind, solar-PV, batteries and grid-connection inverter microgrid supplying close to 80% of the homes average daily electricity needs.

- Simulation shows that indeed certain criteria produce much better results than others in incentivizing efficient electricity consumption. Surprisingly however, including an energy storage device proves revealing showing contrary to what common sense would predict, that it operates as an enabler making a positive difference in the overall strategy aimed at eliciting a thrifty,

The general concept of Homeostatic Control for Electric Power Systems

•One can make the parallel between what happens in nature with different living organisms, and what may occur with socio-technical systems such as the grid-connected microgrid coupled to a sustainable block operating with and without energy storage.

•Rural and remote communities are a concern in Chile when it comes to energy supply and consumption as it is the case in other regions of the world. This is also the case with water supply given the menacing drought that has plagued Chile in recent years. The microgrid modeled in this paper supplies electricity and heat to a group of homes in a rural or remote community.

•Indeed the microgrid when coupled with a group of residential consumers and with the local grid somewhere is a perfect example of a sociotechnical system in and of itself. As such the microgrid— by its very nature—is also a complex adaptive system (CAS) and therefore will seek to change and adapt to changing conditions and to a variety of circumstances to preserve system sustainability.

•Here the key enablers are communication and control signals built into the supervisory control system which are sent (upon reaching a certain set-point) to the different components which comprise the entire system including smart-metering displays in people's homes. The approach is systemic, focused on EE, thriftiness in energy consumption and customer-driven as postulated by F.C. Schweppe's HC approach.

The general concept of Homeostatic Control for Electric Power Systems

• Energy efficiency (EE) being such an important concept has received little attention if anything when it comes to sustainable microgrids. Thus this paper attempts to link both EE and exergy to HC in electric power systems and—more importantly—to look at exergy as a means to enhance EE in the grid-tie microgrid system in terms of its energy supply and demand management.

• Here the key to a sustainable, exergetically efficient solution to the microgrid's power supply vs. energy demand management lies in the interaction among the three systems involved: the residential block comprising a number of homes, the microgrid with or without energy storage and the grid and how they strive to reach a sustainable, efficient equilibrium—the type of equilibrium homeostasis regulation (HR) in living systems is all about when it comes to energy supply and consumption management.

• Exergy expresses the quality of a particular energy source and also quantifies the useful work done by a certain amount of energy employed in any given process where there is energy intake and expenditure. Exergy is also defined as a measure of the actual potential of a system to do work.

• The exergy content required for satisfying the electricity and heating demand of a small community is very low when their energy needs are very manageable and aligned with the conditions imposed upon them by the systems which provide such energy. It is a more exergetically efficient and sustainable system in and of itself.

GENERAL APPROACH AND METHODOLOGY

• The microgrid delivers power supply to a small-size community of 15 homes which is coupled, via a parallel network, with a generic solar PV-wind grid-connected hybrid micro-generation system typical of distributed generation (DG) projects everywhere and from which consumers may satisfy if not all at least a good part of their electricity consumption needs.

• We introduce a set of merit-based control strategies for the coordination and control of such systems' power supply (the mains and the grid-tie microgrid) based on particular criteria to enhance homeostatic regulation (HR).

• Insight is drawn from earlier work on the subject and, especially in the microgrid´s context, looks at exergy as both a driver and an enabler of EE and energy sustainability (ES) linking these important concepts to add further insight and perspective to the ES model and approach presented on earlier work by the authors.

How the coordination and control strategies work

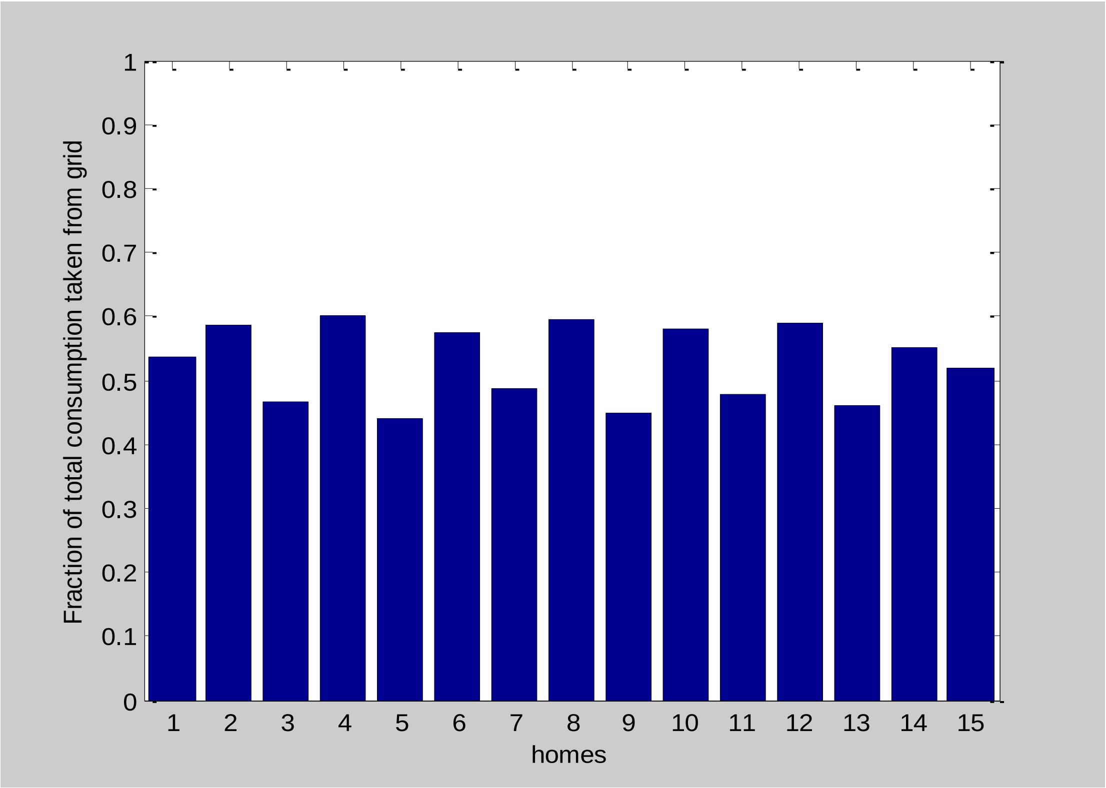
• Each criterion has a predefined set of rules and conditions upon which the control system will decide on whether a home is eligible or not to receive renewable power supply from the microgrid. Based on the specific criterion employed, renewable power is supplied only to those homes which comply with the set criterion in an effort to influence and condition the block's electricity consumption in a way that ensures that the meta-system is sufficiently efficient and sustainable overtime.

• The control system assigns renewable electric power supply from the microgrid to a sustainable block of 15 homes only if the home is within a certain consumption range established in the particular criterion being utilized.

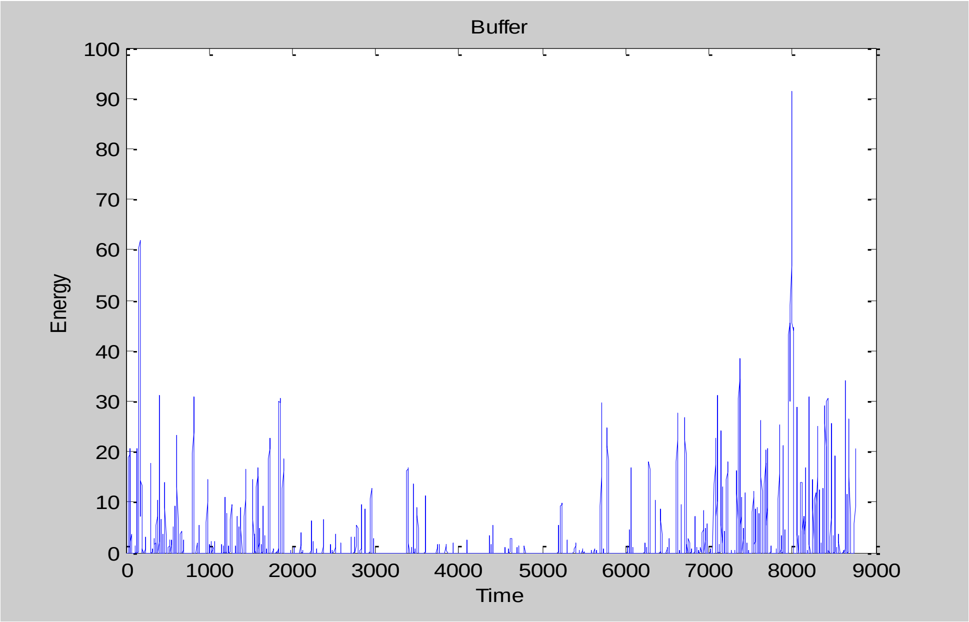
• Simulation provides a good fit for the real consumption data utilized, and the response of the system to changing supply in different scenarios was characterized by its consistency and by the logical framework supporting the model employed.

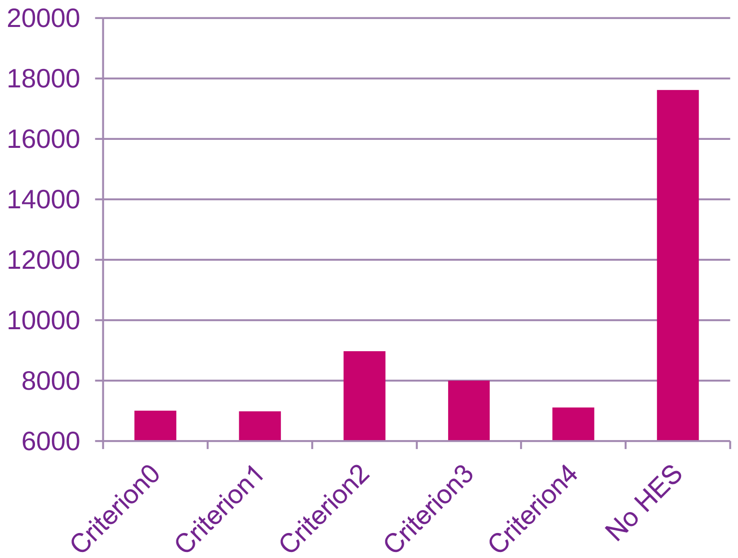
• Furthermore, results show how important HR concept is and the notorious difference that an energy storage system (which we call an energy buffer) makes, as well as the action of a compensatory function (the compensator role) toward a successful collective aim of both individual and communitarian efforts to ensure the system's overall sustainability.

Percentage of power drawn from the Grid by 15 homes in the Sustainable block.



The energy buffer function as thrifty consumption sets in





•The compensatory role of the energy buffer is as expected, showing that consumers tend to save RP to have sufficient energy stored so that less has to be purchased from the grid.

Fig. 1 on the right shows the general results with the five criteria compared plus the case with no HES. Total annual savings per home: US$ 912.98

The role of the Energy Buffer

- The concept of **energy buffer and its role as a compensator** is central to our model and is also a key part of the main control system strategy.

- We are referring to the role that the energy buffer plays in **the energy homeostasis regulation processes within the meta-system** (the sustainable block coupled to the grid-tied microgrid and to the mains), as a **key enabling technology of such important mechanisms.**

- It is critical to understand how HC plays a crucial role in realizing sustainable energy systems. HR mechanisms and system response can be influenced by expectations and anticipatory behavior of living organisms, depending on the degree of evolution of the organism itself, and this is never more evident than in the case of electricity consumers.

- Higher-order, more evolved living organisms have a more developed and effective HC mechanism than lower-order, less evolved ones. This is closely tied with energy efficiency (EE) and sustainability, and has societal and socio-technical implications

Results: The role of the energy buffer in building thriftiness and energy efficiency

• Based on simulation results we may conclude that the behavioral changes being sought in residential energy consumers **are intimately linked to and intertwined with the role of energy storage systems (ESS) in the microgrid and the energy buffer concept being used here**, which is at the very core of the strategy being proposed.

• As a matter of fact, and contrary to everything that has been said, and suggested in the literature until today, **the role of energy storage is far from passive.**

• **In fact, it is much less a supporting or back-up role only, as most people in the industry would have you believe, but a very different and much more important one; a very active and leading role indeed when it comes to eliciting and fostering energy regulation in living organisms and, in the context of this paper, for building sustainable energy systems.**

• At the same time**, it is ingrained in the very fabric of the HC-based strategy for hybrid renewable micro-generation systems (HRMS) proposed here, with regard to renewable power (RP) generation and supply, energy consumption and consumer demand response management**. As such, it must be thoroughly understood in order for this homeostatic control approach to be implemented successfully for the control of HRMS

Conclusions

- The ability to turn into a thriftier, greener and more energy-sustainable consumer depends greatly on the awareness of energy storage availability in the system and the crucial role that it plays in HR. Indeed, when it comes to really making a big leap forward in energy systems sustainability, it does matter whether there is or there is not an energy buffer in the microgrid system; and contrary to common credence, more so if the microgrid is grid-connected than if it is not, operating only as a stand-alone (island mode) system. Indeed something entirely not obvious and at odds with common beliefs in regards to ESS that are seen only as back-up systems.

- A battery bank is a fast-response energy storage technology (is readily dispatchable) and for the purpose described earlier, it can effectively act as an energy buffer in the HC strategic scheme we have already discussed. If we add to this a smart metering system to every home, we have effectively built energy sustainability in the meta-system, i.e. a sustainable energy system.

- As such the energy buffer, along with the different RP supply criteria prove to be key players in the overall strategy for implementing more sustainable micro-generation systems. The **optimal solution comes as a trade-off whereby higher efficiency and thriftiness is achieved by residential consumers exercising restraint and saving more energy to be stored in and available from the energy buffer** as needed when RP supply availability conditions change

- We think **EE being so important a part of success in such strategic energy policies should also be part of the equation and be tied to RP integration strategies and policies and not dissociated from them as it has been until now, especially in Chile.** Therefore we believe that coordination and control strategies that can aid in this transformation are important and should be embraced and implemented therein.