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Sustainable Hybrid Energy Systems: An Energy and Exergy Management Approach with Homeostatic Control of Microgrids

Fernando F. Yanine*,[a], Felisa M. Córdova[b], L. Valenzuela[a]

[a]Dpto. de Industrias, Dpto. Ing. Comercial, Universidad Técnica Federico Santa María, Av. Santa María 6400, Vitacura, Santiago, Chile
[b]Dpto. Ingeniería Industrial, Universidad de Santiago de Chile, Av. Ecuador 3769, Estación Central, Santiago, Chile

Abstract

Sustainable hybrid energy systems (SHES) are not only possible but can also be affordable for both rural and urban communities. SHES can also replace to a great extent the high cost of utility grids' installed power capacity which, in counties like Chile, is outrageously expensive. A new theoretical approach for developing grid-connected SHES is proposed here based on exergy and energy management, cybernetics and homeostatic control (HC), with special emphasis on exergy optimality. The measure of exergy is directly linked to the micro
grid system's sustainability index, when understanding that exergy expresses the capacity of the meta-system to do useful work. This capacity is enhanced and augmented whenever energy efficiency (EE) and thriftiness are incorporated into the equation. Thus when consumers behavior becomes an energy source in and of itself, and this is potentiated by the appropriate HC and energy management mechanisms, with appropriate economic incentives for the entire community, the result is that there is much more energy available in the system. Therefore, given a certain amount of energy employed by the overall meta-system, supplied by the SHES and the grid, it is possible to maximize consumers benefits and EE as a whole when supported by individual and collective efforts to ensure the system's overall sustainability.

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1. Introduction

The is hardly any doubt by now that the sustainable energy systems of the future will encompass today's large electrical networks (transmission and distribution), and a variety of distributed generation (DG) systems

* Tel.: +56223531238, Fax.: +56223531267.
E-mail address: fernando.yanine@usm.cl

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like the intelligent micro grid [1-9], which will fully coordinate, support and work with the future smart grid everywhere. Especially in the small and medium-size industrial/commercial and residential sectors, it is expected that micro grids will play a protagonist role in helping to secure greater grid reliability, electric supply service quality and flexibility, but also in ensuring electric power supply under a variety of conditions. Energy independence and lower energy costs are also a major issue going forward, and in countries like Chile where the electric power generation and distribution is very concentrated and expensive albeit with regulated tariffs, it will be even more so. Thus far only the US military has been working heavily on this for military applications like the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) projects [10-11] but there are also several initiatives, some of which have already successfully materialized, for remote and rural areas [12-15] and for urban environments too [15-17], introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. The section headings are arranged by numbers, bold and 10 pt. Here follows further instructions for authors.

In Chile for example there is interest today in micro grids that can be both affordable and sustainable for the commercial/industrial, government, health care, education, and residential sectors. North America in particular has large planned capacity growth through 2020 and beyond while the rest of the world, especially developing countries like Chile, cannot fall behind. As of today, Chile stands as a country where the need for new energy projects is so great and dire that DG solutions will have to move in sooner than expected, given the brisk new legislation that the current administration is passing. However one must make no mistake in foreseeing various hurdles and regulatory obstacles ahead as well coming from the incumbents. Thus DG will finally win and enter the market as a main player, not just as an extravaganza like today, and will do so to provide new solutions and compete with the large electrical distribution networks in a smart way. Chile is a country of approximately 17 million people where both industry and residential energy consumption are quite high at present and where the price of electricity is the highest in Latin America. Both sectors are expected to continue growing steadily through 2025 at the same pace of Chile’s economic growth, as it is typically seen in developing countries which are in their last stages of integrated socioeconomic development to access the develop world club. Moreover, Chile is a nation where both rural/remote and urban DG applications of various kinds and sizes are expected to thrive out of sheer necessity given the electric power generation projects’ deficit at present; and the Chilean market and development model for many industries is seen as the example for the region in economic growth and in pioneering new technologies. It is also acknowledged that Chile is a good test beds for new technologies- notably among them the intelligent micro grid- wherein energy is envisaged as one of the strongest long-term market and an enabler for many other businesses.

However, when we talk about state-of-the-art, real time intelligent micro grids solutions [15-17] for a variety of civilian services at affordable prices, we find that there is a void; especially when we talk about the residential sector and the society at large. This even takes new meaning when the affordability and customer choice go hand in hand with dependability and sophisticated, customized solutions that are both reliable and affordable. The average residential consumer does not have the wallet that the US Navy or the US Army have. Even wealthy communities in North America are far off the mark when it comes to the kind of budgets and magnitude that the US Military smart micro grid projects and some Ivy League universities have done. Therefore there is a niche yet untapped when it comes to building economically feasible, highly reliable, flexible and affordable grid-interactive micro grids. This is the difference between the rest of the Industry and our new approach to Micro grids.

2. The difference between the rest of the Industry and our new approach to Micro grids.

All While much has been discussed and written already about the potential for micro grids for the various sectors of society, and how they can help control utility costs to consumers while ensuring energy supply to residential, commercial/industrial and public services during planned or unplanned grid power outages, and during other natural events, very little if anything has been said about affordability and choice of energy usage. Especially for residential consumers and small commercial/industrial customers, micro grids may have a tremendous impact on boosting EE and enabling energy demand and consumption initiatives to curtail peak power demand. This will be possible with new ways of generating and using energy which will change modern society forever [18-24]. However cost still remains a big hurdle when it comes to micro grids development and integration to the grid. Albeit power electronics provides a wide range of solutions in terms of smart inverters and other smart systems for grid interconnection and for various energy sources management and control, no real and concrete solution has yet emerged for improving power supply reliability across the different segments of society with a focus on affordability and collective effort management among the different elements which comprise the socio technical system we call micro grid; particularly so when the micro grid is tied to the grid. While actual working examples of large micro grids exist in the world that are located in rural and urban areas with poor reliability and which have had numerous experiences with both manual and automatic islanding from the external grid, none has thus far addressed the concepts of high service quality, customer differentiation and choice, and most importantly, affordability all in one package.

Among the several factors that push the price up, there are the control strategies, the energy management options and most of all, the engineering and integration of the micro grid's components that today's limited number of suppliers charge to their customers. In spite of the fact that there are power electronics and supervisory control systems that are very cost effective and affordable out there today, and that energy management is not something that has to be reinvented for the micro grid either, most of the time what we see are prohibitive prices on micro grids as a finished product. In fact what goes into the engineering alone can elevate the price to the million dollar range and well over that too, disguising the hefty price under the term "smart micro grid", as if it were something that required genius engineering to accomplish. Not true! A good micro grid solution can be simple yet highly effective and reliable, and can be relatively inexpensive even in the MW range as it is shown in [1-18-24]. It should operate efficiently and effectively with limited investment in hardware and software given the technology that is available today. Control strategies based on homeostatic control, cybernetics [18-24] and data acquisition systems, with a variety of automated energy management options and remote monitoring, all of which are possible and feasible at reasonable prices.

Chile in particular, being a model in Latin America in many fields, is still far behind in terms of incorporating advanced renewable energy systems to the national energy matrix and has been trailing on the traditional electric power infrastructure path for many years now. Change as we all know is slow in coming but the situation has turned worse in the last few years due to severe drought that has been diminishing the hydroelectric power generation component of Chile's centrally interconnected electric power generation system (SIC). With its dire need for energy supply at present and its large and spread residential sector in the different segments of society, Chile is a good example of why new and innovative solutions that can come at reasonable civilian price ranges are so necessary. It is right there and then when technological innovation comes in with the advanced micro grid solutions concept being proposed here. The solution is reached through real time, autonomous mission control implemented in a SCADA-like system, wherein Homeostatic control (HC) is also a part of the intelligent control and energy management system of the micro grid. Under such unique control scheme the system is able to provide a wide range of homeostatic control solutions for micro grids with state-of-the-art SW and control technologies originally designed for other industry sectors like Mining automation. Thus the technology is capable of handling whichever micro grid configuration choice and size the customer desires within a certain constraints, in order to keep the design affordable and feasible. Even if the project calls for a cluster of different interconnected micro grids whether this is in system design, size and/or specific configuration choice, the approach proposed here can handle it. With this technology it is possible to offer intelligent micro grid solutions at an affordable price that may be designed and configured according to customer choice of energy sources, interconnection systems, integration and communication solutions with a wide range of off-the-shelf renewable energy technologies (RETs) and communication systems currently available in the civilian market.

The technological innovation being proposed here is indeed unique in terms of its powerful combination of two control architectures: advanced homeostatic control and intelligent, autonomous mission control for micro grids. It is unique in the sense that it combines effectiveness, reliability and affordability by providing fast, real time intelligent mission control responsiveness with ultra efficient HC; and this approach as such has no similar in the market to date. It encompass a set of distinctively designed, customer-specific set of 'power supply control criteria' to condition hybrid power supply from the micro grid to specific energy demand profiles of residential consumers (the loads). This will impel and foster energy sustainability (ES), EE and thriftiness in the community. It does so by eliciting change on the energy consumer side and rewarding it for a sustainable energy consumption which benefits the entire residential or small industrial/commercial community. The HC criteria especially designed and tailored for the customers' energy consumption dynamics, accomplish these goals by making energy consumers work together as a collective and benefit from such action by obtaining both economic and non-economic rewards. These may come as a lower energy bill for their monthly use of electricity and heating and also for contributing to use more green power, thus reducing the local community's fossil fuel and carbon foot-print. The key to understand this unique solution is to view the intelligent microgrid being coupled to a sustainable block™ as a dynamically complex adaptive system -a socio-technical system in and of itself [25-26], when the micro grid is connected to the local utility grid. This proprietary control engineering scheme allows reaching efficient sustainable energy equilibrium (homeostasis) between the grid-connected micro grid's energy supply and the customer's demand side management strategy. While a dynamic system may reach equilibrium at some point, this may not be efficient and sustainable overtime. Therefore the HC strategies are designed and tailored to achieve just that: to enable the grid-tied micro grid system coupled to a sustainable block™ to reach and maintain an efficient equilibrium state under different and changing conditions and circumstances [18-24]. Thus the adaptability capacity of the smart micro grid in this case comes from the unique control system solutions which fuse autonomous real-time mission control with homeostatic control and communication networks.

3. Sustainable micro-generation power systems by means of cybernetics, homeostatic control and exergy management

Micro grids are also a form of energy provider that can supply power in a crisis situation like natural disasters and fires by rapidly relocating and acting on site to supply much needed power. While they are connected to the grid, they also have the ability to disconnect and act as islands in autonomous fashion. Meanwhile, much of our dispersed generation uses fossil fuels like backup diesel-powered generators, so they are vulnerable to interruptions in the fuel supply, especially when long distances and a rough geographic landscape like Chile has is involved. Micro grids on the other hand use clean energy forms for the most part whenever possible, and even when micro turbines are involved, they are flexible, transportable and can operate with various fuels like butane or propane, sync gas and natural gas as well. Finally, in order to be able to supply a constant and stable power flow to consumers, DG solutions should be integrated to the grid, operate ideally in a cluster of micro grids and should be coupled with energy storage to reduce the need for grid backup power at any time as much as possible. Figure 1 shows the HC control logic proposed, where energy and exergy management system is a key enabler for grid-connected sustainable micro-generation power systems.

Thus not only can the intelligent micro grid cluster prevent and defend customers from the effects of blackouts, especially if the size of energy storage is significant, by reducing the micro grid's reliance on grid-supplied power as backup, but can also provide substantial savings to consumers too; especially so in the case of Chile where electricity is very expensive and not always reliable, even more so in remote and rural areas.

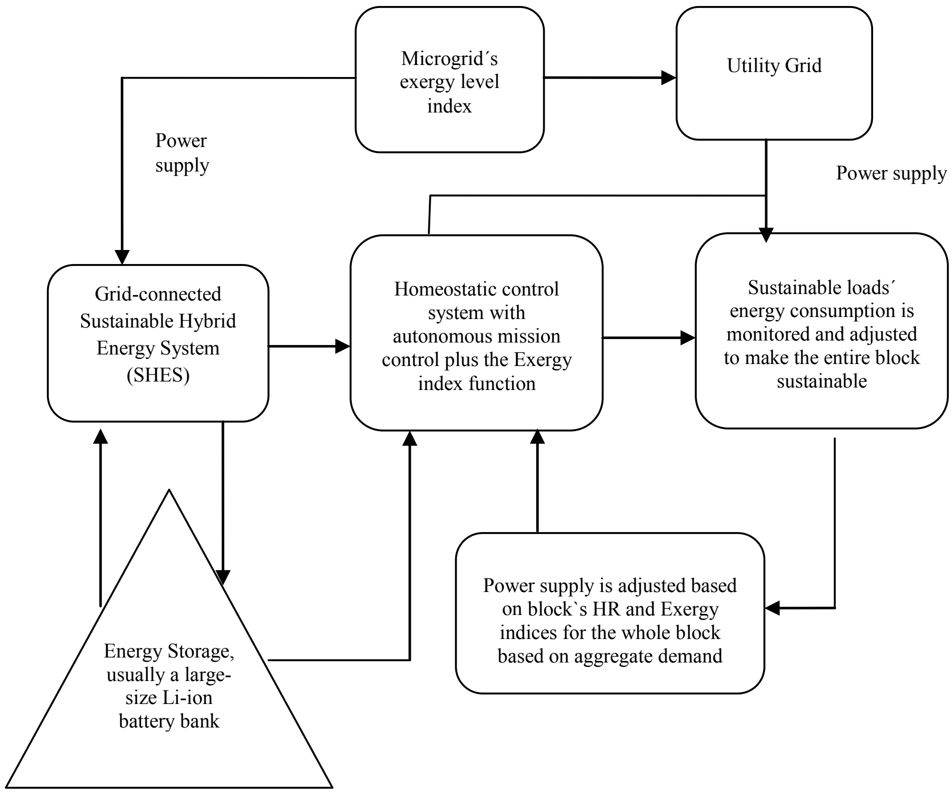

Fig.1 Above is the HC control logic proposed, where energy and exergy management system is a key enabler for grid-connected sustainable micro-generation power systems.

The natural monopoly of electric power utilities both in the generation and distribution sectors that characterizes the industry still to this day in most regions of the world is a perfect example of a good idea gone wrong. In Chile in particular there is fierce opposition by lobbyist groups to pressure lawmakers and regulation authorities to fend off or stall legislation that could make possible for DG to be introduced on a massive basis. An example of this lobbying is the delayed and widely discussed net metering and net billing law which is still under the magnifying glass of the Chilean congress and regulatory agencies. What once seemed an efficient, reliable and high-quality electricity service industry that was customer-oriented and a fair deal industry has turned into a profit hungry white shark that will devour anything that comes its way in the form of alternative energy systems and DG solutions like the micro grid itself. Thus government regulated oligopolies in the generation sector and natural monopolies in the distribution of electricity have turned the deal sour and inefficient, as well as highly unreliable and expensive for customers in many parts of the world. In the early days of the industry they set about to convince the governments and the public at large that regulation was not only necessary but also a much better deal for everyone, arguing that competition in such an industry would drive players to do anything for a piece of the business (for a price) producing unreliable and unsafe services to consumers. There was also the argument of preventing over capacity, avoiding uneven and unsafe infrastructure standards for electric power transmission and distribution systems, a flawed argument being employed even today in the imminent integration of DG; and of course never absent benefit of acquiring economies of scale. All of these issues and several others led government authorities everywhere and industry people in general to believe that allowing regulated oligopolies and monopolies in the electric power generation and distribution sectors was necessary for providing a safe, efficient and reliable electricity supply service while keeping costs reasonably low. But that is no longer the case given the current state of events, especially with the rapid climate change and the dangers that treasonous and unpredictable natural events and emergencies like fires and earthquakes can poise to the electric power infrastructure. Today there are new, revolutionary technologies in the DG sector, small-scale and medium-size hybrid renewable energy systems of great capacity, flexibility, effectiveness, and with high energy efficiency standards. Thus, when employing reliable state-of-the-art intelligent control and energy management systems everything is possible [20-22-27-34]. Key to making micro-generation systems sustainable and responsive, especially those connected to the grid, is their capacity to maximize energy production and supply under changing conditions, coupled with some form of energy balance or equilibrium between supply and demand, plus an energy efficiency strategy that can ensure system sustainability. For this the HC model proposed has both an exergy index based on how much energy is available in the micro grid system at any given time.

4. Energy storage systems (ESS) as an energy buffer: How homeostatic control plus energy and exergy management can determine a more efficient consumption behavior.

Expectations and anticipatory behavior can explain also why homeostatic control responses are more active and quite stronger when we expect a particular situation to last long, as opposed to anticipating shorter time durations. People certainly react differently and become much more prone to change, exercising control in their behavior more effectively and efficiently as complex living organisms do out of sheer need, adapting sooner and more willingly when they know they are to expect a particular situation to occur or a particular scenario to last a long time, instead of one that is expected to last a rather short time span. In the latter case they find it much more difficult to accommodate and adapt to changes and strive or fight hard to maintain our equilibrium clinched to their original and familiar state or scenario, in spite of the changes that the new environment has brought in. Just as self-regulating processes in biological or mechanical systems via negative feedback seek to maintain stability while adjusting to changing conditions, systems in dynamic equilibrium as simulation results show [20-24], reach a balance in which internal change in the sustainable block of 15 homes continuously compensates for external change -namely change in power supply availability- in a feedback control process to keep conditions relatively uniform [20-24].

5. Conclusions

Renewable energies play an increasingly important role in our society due to the greater awareness of the damage that is caused to the environment by the anthropogenic activity and because it is expected that by 2020 there will be a serious restriction of energy from fossil fuels [4-20-23]. In this context, the developed countries and some developing countries like Chile have sought to give answer to this problem by assuming certain goals as the 20/20, this is that 20% of the energy supply will be coming from renewable in the year 2025 as is expected to significantly increase the share of renewable energies in the electricity generation process. In Chile there isn't a very significant share of renewable energy sources in the energy matrix, currently reaching only 3% of the total. So, Chile wants to make a significant leap in the coming years that leads it to technological leadership in Latin America employing more sustainable energy systems SES [18-23]. However, there are still obstacles to making this big leap in electric power technology modernization towards a greener energy matrix. A micro grid is a distributed micro-generation system employing different energy sources some of them renewable and some of them conventional that may also provide early warning to consumers from natural events like changing climatic conditions and hazards like fires. It can also warn customers from internal changes in operation modes and grid-related issues like maintenance and outages. Also data sharing and synchronization among customers and among several micro grids will allow the overall micro grid community to be enhanced, to produce new forms of operation and coordination that will benefit both the consumers and the micro grid cluster as a whole whether it is integrated with the utility networks or is islanded. It may also modify the micro grids operation dynamics and their integration with or islanding from the grid under various conditions or circumstances whenever there is a cluster of such systems in operation. This may occur in order to maintain stability and reliability among the clustered micro grids or to enhance stability conditions at a specific unit within the cluster, and also for the whole group or part of it to provide ancillary services to the grid. What is important to consider here is not only what the cluster of micro grids can do under a particular configuration and structure but also what the customers (the loads) can do to augment the collective effort in order to maximize the work potential of the entire cluster. This is where the unique approach being presented in this paper as part of the intelligent hybrid control system for the micro grid already discussed makes a substantial difference from the rest of the industry. The approach is based on energy and exergy management concept [27-32] where energy is shared equitably. It is designed to provide new solutions that can shed light and remove the clutter from the murky issue of whether modern society is to pursue DG as part of the electric power infrastructure or not. An issue which is eternally being discussed still today in Chile, in spite of the technology and the advancement in price competitiveness of the kWh of renewable energy.

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