Journal of Information Technology Management

Print ISSN: 2008-5893

Online ISSN: 2423-5059

# Green Energy Generation in Buildings: Grid-Tied Distributed Generation Systems (DGS) With Energy Storage Applications to Sustain the Smart Grid Transformation

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## Abstract

The challenge of electricity distribution's upgrade to incorporate new technologies is big, and electric utilities are mandated to work diligently on this agenda, thus making investments to ensure that current networks maintain their electricity supply commitments secure and reliable in face of disruptions and adverse environmental conditions from a variety of sources. The paper presents a new model based on energy homeostasis for power control and energy management using tariffs differentiation as incentive, considered by ENEL, the largest electric utility in Chile. The model optimizes grid-tied distributed generation (DG) systems with energy storage, in line with the utility's green energy program, part of its Smart Grid Transformation, aimed at installing grid-tied DG systems with solar generation and energy storage in Santiago, Chile. Results present different tariff options, system's capacity and energy storage alternatives, in order to compare proposed strategies with the actual case, where no green energy is present. The results show the advantage of the proposed tariffs scheme and power-energy management model based on different scenarios, providing a good and safe option for installing DG solutions to the grid.

**Keywords:** Electric tariffs, Energy homeostasis, Distributed generation, Electric utility, Green energy, Power and energy management.

DOI: 10.22059/jitm.2020.75798

# Introduction

## Understanding Electric Utilities' Perspective

Nowadays, electric utilities everywhere are facing a series of challenges, from legislation changes to urban crowding and radical changes in the electric power system landscape, largely justified by current market policies, plus a variety of other issues dealing with the reliability and manageability of the grid (Parejo et al. 2019; Yanine et al. 2017). For example, market policies are currently being influenced by the concept of "unbundling". This principle establishes that generation, transmission, and distribution services must be managed by independent organizations, or even by regulated entities, as it is the case with the transmission systems in Europe (Van Koten & Ortmann, 2008). Of course, the implementation of this idea requires new forms of operation in terms of large-size bundles of information sharing amongst market agents of the power system sector and its efficient and timely management. Notwithstanding important technological advances in the last 20 years to improve power systems design and overall infrastructure, much remain yet to be done when looking at the overwhelming costs of catastrophic natural disasters suffered by the US in recent years (Minnaar, 2016; de Faria Jr. et al. 2017; Hanna et al. 2017). For example, extreme weather phenomena like torrential rains right out of the blue or sudden heavy snow fall, earthquakes and huge fires in some regions where these type of destructive occurrences did not normally occur. All of this, points to the necessity to advance in more flexible, resilient, and dependable electric power systems that can prevent in some cases and diminish in others, the effects of those natural disasters. Due to this situation, United States of America considered that it was necessary to take measures about these problems. As an example, in 2014 the US Senate passed a bill (Wood, 2016) where they showed their support to distributed energy system connected to the power grid (like microgrids) to reduce the effects of the described natural and climate disasters, making the electric power distribution more resilient and proactive towards the unexpected and destructive climatic events. This support stimulated the developing of multiple technological and legislative initiatives in the field of microgrids and distributed generation systems (DGS) in general. In this sense, another significant decision made (from the point of view of legislation) was the Energy Policy Modernization Act of 2015 (Ungar, 2015) promoted by the US Senate on September 2015, with the objective of promoting the US Grid improvement.

## Study Aim

This study aims to analyse and project the impact of green energy generation in buildings by ENEL Distribucion in Chile by means of grid-tied distributed generation systems (DGS) with energy storage applications to advance the smart grid transformation in Chile.

The work presented in this article is based on a theoretical framework developed for ENEL by the authors and the projections for growth of green energy generation to be undertaken by ENEL and by other electric utilities in Chile as expected. The chief aim behind the study undertaken is to foresee and project the role and operation of grid-tied microgrids in the electricity distribution sector of the country as well as its management by the utilities.

## Materials and Methods

### Research Design

The research study was conducted using mostly qualitative and partially quantitative methodological approach based on the variables identified and projections given by ENEL in Chile and by the electric authority of the country regarding projection of electricity tariffs with strong green (renewable) energy penetration in the distribution sector. The study was carried out in Universidad Tecnica Federico Santa Maria's San Joaquin Campus where the research team has a grid-tied microgrid that simulates green energy generation in a residential building,

The model presented optimizes grid-tied distributed generation (DG) systems with energy storage, in line with the utility's green energy program, part of its Smart Grid Transformation, aimed at installing grid-tied DG systems with solar generation and energy storage in Santiago, Chile. Results present different tariff options, system's capacity and energy storage alternatives, in order to compare proposed strategies with the actual case, where no green energy is present. The results show the advantage of the proposed tariffs scheme and power-energy management model based on different scenarios, providing a good and safe option for installing DG solutions to the grid.

### Grid-Tied Microgrids with Energy Storage for Green Energy Penetration in The Distribution Grid

As a way of advancing green energy and power systems decentralization, microgrids have come to be seriously considered by electric utilities like ENEL Distribucion in Chile and in other parts of the world (Wood, 2014), as a means to supplement and support electric power distribution decentralization, providing the grid with much needed back up, while advancing green energy penetration. It can also operate as a local solution to service small and medium size communities, as in condos, buildings or a cluster of buildings where district heating can also be implemented (Farhangi, 2016).

Figure 1 shows a general structure of the control system model, where energy management system (EMS) and power management system (PMS) are designed following particular homeostatic control (HC) strategies. The EMS/PMS, receives as input, the electric power generation predictions, based on predictive homeostasis data carried out by the HC system's assessment of internal and external variables (Yanine et al. 2018). This is done taking into account the photovoltaic generation plant capacity, climatic conditions and the electricity consumption ranges of the community in terms of demand side projections, so as to decide on the magnitude and the energy flow composition. Electric utility sets the tariffs and green energy has as expected a lower tariff thus being favoured by consumers, who can save money by adjusting their energy and power consumption in such a way as to make the green energy supply and availability last as much as possible. In addition, energy storage status of the batteries must be monitored at all times. Thus, and pursuing the objective of minimizing operating costs (i.e. minimize price paid monthly for energy consumed per household), the homeostatic controller will have the following attributions:

- ***Battery management***

Defines when and how much energy to charge/discharge. The control system will charge the batteries when the demand is low and will draw energy form the batteries when the tariff of electricity is more expensive, depending on the electric tariff that is being implemented.

- ***Active control of the energy demand***

It is determined by how much energy is consumed by each client of the microgrid as recorded by the smart meters of each household. The aim here is very distinct: to maximize the use of green energy with the microgrid's available generation and supply capacity. Customers who are not "solidary" and efficient in their consumption, or choose not to align with the needs of the rest of the community, will be notified through an interface and/or alarm, and their loads exhibiting constantly high electric power consumption (e.g. washing machine, heating, ventilation, air conditioning or HVAC) will be disconnected from the microgrid by smart switches (Smart plug), leaving them with the grid-only option, paying quite higher tariffs for electricity Yanine et al. (2019 a,b).

- ***B. Payment based on Power and Energy consumption management***

This control unit is responsible for prorating payments between users and the electric company. Customers exhibiting low consumption from the microgrid supply (those that exhibit a thrifty consumption behaviour), have the right to receive economic compensation as a reward. Since overconsumption will be penalized, such reward is made possible by those who have a higher consumption of electrical energy, particularly those that use power consumption more often. This arrangement is being considered by ENEL Distribución as a means to entice a sustainable and more manageable energy consumption in light of constraints imposed by DG plants, operated by the electric utility, as a way of favouring renewable or green energies penetration. The utility's aim is to reinforce a thrifty electricity consumption behaviour and, at the same time, an easier stabilization of the system if it were needed.

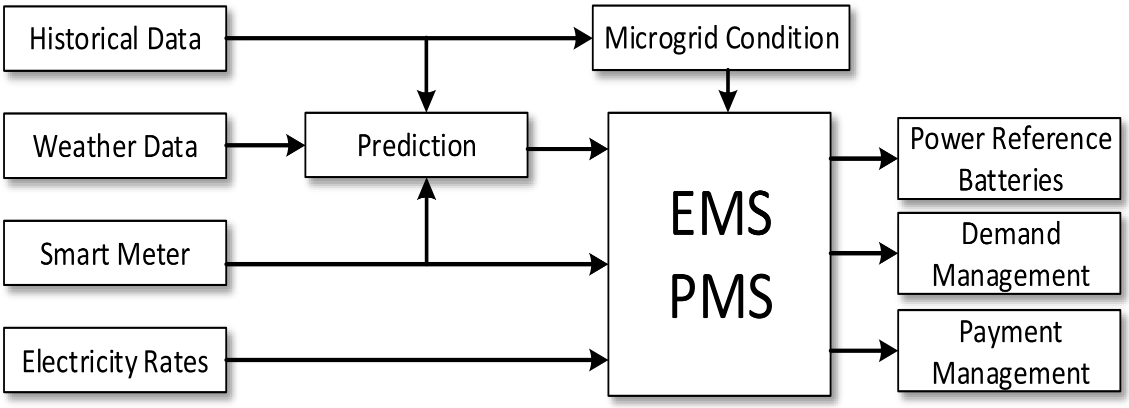


**Fig.1.** Homeostatic control model based on power management systems and energy management systems for the sustainable block™ with energy storage

## Results

### Experimental Results of On-Grid Distributed Generation System

The most interesting characteristic of this microgrid is that it is not composed only of power devices, but it also includes multiple temperature and humidity sensors deployed in and outside the building. This allows getting complete datasets that can be used for optimization of HVAC systems, taking into account how wall temperatures affect to the comfort of the rooms.

Batteries, particularly large-size batteries, will give extra flexibility to the EMS, but it could be also possible to design other types of controls without them, as can be seen in previous studies for an Easter Island's residential block (Caballero et al 2013). This is why buildings constitute a perfect environment for the application of an energy management system (EMS) and allow to analyse their electrical and thermal behaviour depending on weather conditions and forecasts. In this first probe of concept, the EMS monitors the external, internal and walls (of the microgrid room) temperature, while the whole thermal model of the building has been designed, using the real data of every room and materials that compose it. Using this model, it is possible to observe an approximation of the temperature profile during every day analysis using real weather data (temperature and solar irradiation).

Whether or not the microgrid has energy storage, in practice, the control system shall have a set of controllable loads which can be remotely disconnected, so the maximum demand can be maintained bellow a specified limit. In addition, customers will be notified automatically of their misaligned behavior with the community, and they will be penalized. Thus, the on-grid microgrid can be seen as a socio-technical complex system, in which consumers play an active role (Yanine et al. 2018; Yanine et al. 2014). This power limitation, despite being a convenient feature of the control system, will not be considered under the present paper for brevity.

Next it is shown in Fig. 2 how internal electric tariff for microgrid customers, based on the monomic energy cost, is employed with the aim of achieving an efficient energy consumption transferring the energy directly, almost at cost, to customers. It can be observed that the energy cost at peak hours is considerably higher than that of non-peak hours, so customers are expected to heed the homeostatic control strategy aim and adapt, moving part of their consumption to low demand hours, where the energy cost is lower, and exercise restraint in their power consumption habits. If, however, there is a shortage of green energy supply from the microgrid for whatever reason, the grid supply will automatically take over and supply for the deficit. For non-peak months in Chile (January, February, March, October, November and December), there is a flat tariff, where the price for energy is equal no matter what time it is consumed.

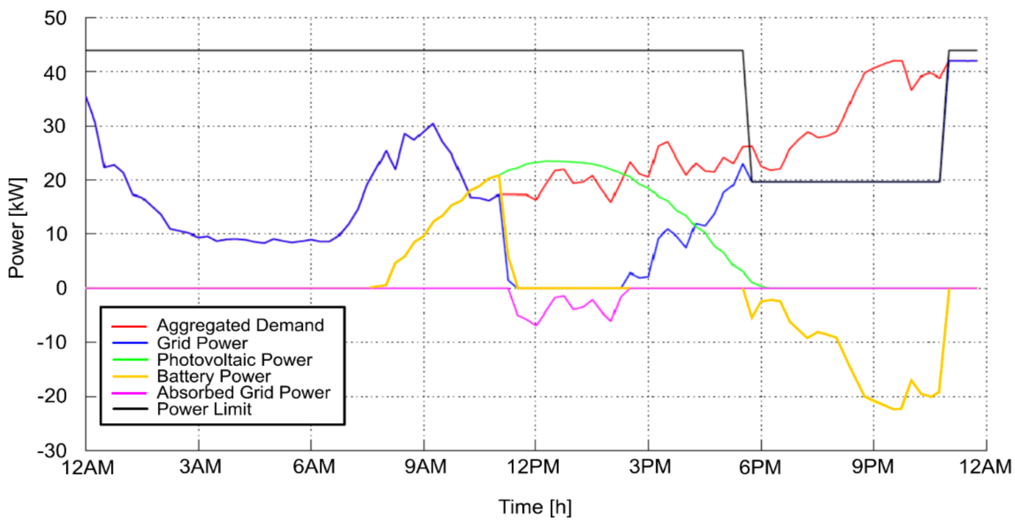


**Fig 2.** Sustainable Block's Power flow with energy storage and hourly tariff

## The microgrid's control block

The control block has a series of interfaces. Inputs correspond to measured variables and signals from the microgrid system which is interacting with the smart grid and with remote operators, while outputs correspond to "orders", that the system can accept. These are all listed in Table 1.

**Table 1.** Control block inputs/outputs

| Name | Type | Description |
|---|---|---|
| pow_limit | Input | Power consumption limit (from the utility grid) |
| pow_now | Input | Power consumption |
| soc_batBU | Input | State of battery group 1 |
| soc_batST | Input | State of battery group 2 |
| gridOK | Input | Indicates if the utility grid is available (no blackout) |
| Twalls | Input | Walls temperature |
| Text | Input | Outside temperature |
| Tint | Input | Internal temperature |
| contactOnGrid | Output | On/Off grid selector |
| ContactBat | Output | On/Off battery selector |
| ContactHVAC | Output | On/Off HVAC selector |

This control block executes intelligent algorithms based on energy homeostasis applied over selected variables. The result of such algorithms will be the control commands being sent to the power systems in order to generate the appropriate response under particular conditions and circumstances of operation throughout the day.

## Homeostatic control and energy homeostasis for grid-tied microgrids.

Homeostatic control system comprises both reactive and predictive homeostasis (Yanine et al. 2018; Yanine et al. 2014; Yanine et al. 2015; Yanine et al. 2014). Both aim at maintaining efficient optimal state of equilibrium between supply and demand favouring the consumption of green energy from the microgrid as much as possible. The reactive branch, which comprises the core of the control system, must keep the batteries with enough charge to maintain the microgrid running, even if a blackout occurs. Additionally, the storage capacity can be used when the utility advices that a higher energy price is to be charged (usually applied when a certain power or energy consumption value is reached), or in case of a demand response (DR) event which would require a high reduction in the consumption from the microgrid. This fact is reflected on the power limit managed by the DG system, which depends on the received information from the utility (or the distribution system’s operator). Hence, the power reduction can be reached disconnecting the microgrid from the power system, or also managing internal controllable loads (if such function is available). In both cases, the control system must ensure that the required reduction is to be achieved, whenever possible (Yanine & Córdova, 2013).

## Conclusions

The need to overcome the vulnerability of today's electric power distribution infrastructure is urgent and pressing, particularly in where seismic activity and harsh weather phenomena is recurrent. It is crucial that government authorities, industry regulators and main industry players like ENEL Distribución in Chile plan ahead and work on a Smart Grid Transformation Roadmap, as Chile is doing, in order to advance green energy by means of on-grid integrated distributed generators. There is much new technology and techniques in the market today to go that route safely (Paliwal et al. 2014). Decentralization of the power system using distributed generation (DG) solutions like the smart microgrid for buildings is a decisive step forward that countries like Chile and others are taking. Microgrids installed in buildings is part of this trend and they are to be managed and operated by utilities like ENEL Distribution (formerly Chilectra), employing both traditional and renewable power sources (like microturbines and solar/wind generation) all of which makes sense whenever there is an abundance of renewables. Furthermore, if these systems can be equipped with communication and advanced data processing interconnected systems that can operate together, making the power generation and distribution elements work in a collaborative way, it is possible to achieve greater systems efficiency and reliability. This structure can be managed by more flexible, less expensive, fast and reliable control system than other complex systems (e.g., multi-agent, or expert systems) that much of the current literature on smart grid and intelligent computing is proposing (Yanine & Córdova, 2013).

### Acknowledgments

We are very grateful to FONDECYT of Chile for the funding of the project FONDECYT POSTDOC # 3170399 and to the Dept. of Electrical Engineering of Universidad Federico Santa Maria, School of Engineering of Universidad Finis Terrae, both in Santiago, Chile and to the Escuela Politécnica Superior, University of Seville, Seville, Spain. Our sincere thanks go also to ENEL Distribucion for facilitating valuable data and support in this study.

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**Bibliographic information of this paper for citing:**

Sanchez-Squella, A., Yanine, F., Barrueto, A., & Parejo, A. (2020). Green Energy Generation in Buildings: Grid-Tied Distributed Generation Systems (DGS) With Energy Storage Applications to Sustain the Smart Grid Transformation. *Journal of Information Technology Management*, 12(2), 153-162.