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# Homeostatic Control of Sustainable Energy Grid Applied to Natural Disasters

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**Abstract:**
According to seismologists Chile has yet to face another big earthquake in the very near future, yet the country remains largely unprepared against massive electric power systems brake-down. The problem lies in the centralized electric power systems and the lack of adequate technologies and back-up/emergency power systems for disaster recovery. The flaws that are built into the very fabric of the presently centralized power systems were on full display in the February 27th earthquake in Chile. Nowhere it becomes more evident that hugely centralized power generation and distribution systems are extremely vulnerable and ineffective to disruptions from natural disasters, human error or other calamities. The large power networks that once proved very efficient and secure, are now at the center of discussion fueling the need for decentralization and the rapid growth of distributed generation (DG). Highly decentralized, diversified and DG-oriented energy matrix is notoriously much better suited to withstand these disasters. In centralized electric power grids, servicing large metropolitan areas, albeit with some but limited differentiation in service, can only be on or off, so either everyone gets power or no one does. This makes recovering power service in an emergency situation a much more difficult task. On the other hand, decentralized power systems (DPS) reduce the obstacles to disaster preparation and recovery by allowing the focus to shift first to critical infrastructure and then to flow outward to less integrated outlets. A DG-based model for a smart micro-grid based on hybrid electric power systems (HEPS) using both renewable energy technologies (RET) and conventional power generation units is presented. The hybrid energy system may be portable or fixed in one place, highly reliable, easy to assemble, modular, flexible and cost-effective solution, that is ready-to-run and go to where it is needed to supply power in natural disaster.
**Keywords:** natural disasters, energy sustainability, smart micro-grid, hybrid electric power systems, sustainable blocks, sustainable energy strategy.

# 1 Introduction

The days of huge, highly centralized electric power networks paradigm may be numbered based on the current trends in the electric power generation and distribution industries worldwide (see [1], [2], [3], [4], [5], [6], [7], [8] and [9]). In the last 20 years, DG and the decentralization of electric power systems in general has gained substantial ground, especially with the rapid advancement in renewable energy technologies (RET), power electronics for system interfacing, and the continuous efforts and great strides, especially in developed countries, to integrate NCRE/alternative energies into their power generation matrices. Yet the problem is not trivial when we think that current electric power grids that span hundreds of miles and supply power to very large regions which comprise several metropolitan areas, were not built thinking that one day DG plants would require access to these electric distribution networks in order to supply power to local communities of different sizes as part of worldwide efforts towards decentralization in the electric power generation and distribution industry ensue. However, the explanation for this rapid shift to DG and further decentralization in the industry worldwide may not lie only in an effort to cut on fossil fuel consumption, green house gas (GHG) emissions and reduce the strong dependence on foreign oil imports, both in developed and developing countries.

Yet, despite the profound vulnerability that such situations entail, right along with the dire need to reduce high energy costs and become more efficient in offering electrical energy and heating services to their populations, especially to remote, rural and isolated communities; that as we mentioned earlier, may not be the most pressing issue, at least not anymore. For some time now the authorities around the world have been worried and lately overly concerned about the rapid and drastic changes in the weather (one of the greatest concerns cited by The Millennium Project 2011 State of the Future Report [31]), along with the frequency and magnitude of natural catastrophes like large earthquakes, rising sea-levels and solar storms, among other threats to world populations in urban and rural areas, and how to deal with such situations, considering the severity of the disasters and chaos that they may bring to modern mankind (see [30] and [31]).

## 2 Building the case for decentralized power systems (DPS) and the Penetration of DG

Natural disasters, like earthquakes, volcano eruptions, wide-spread fires and violent weather phenomena like prolonged periods of intense rain and snow, strong winds and hurricanes are not new to humanity but the difference is that in today's 21st century world much of our fragile living systems and economic sustainability depend on modern infrastructure of which roads, electric power transmission and distribution networks, and telecommunications are a most vital part, yet increasingly vulnerable when faced with these calamities. Since the huge earthquakes and resulting tsunamis in 2010, the first which hit Chile with a giant earthquake and the second, which hit Japan creating a devastating tsunami, more and more people have come to realize the vulnerability of modern world infrastructure and way of life.

Although of great concern for millions of people, particularly for those countries where the technology is currently being used, and a grave threat of disastrous implications to humanity should an accident or negligent act were to occur again (like the disasters as a result of the Fukushima nuclear accident in Japan and the Chernobyl nuclear power plant meltdown in the old Soviet Union), the nuclear power issue and its future standing in today's world energy matrix is a case of profound implications on its own right, and would require an entire paper to discuss it so we will leave it out. Yet if we are to focus too much on power generation technologies like nuclear, fossil fuels or hydroelectricity generation, we may be ignoring a larger concern or at least not giving it its proper place in the scale of concern it deserves. Centralized electric power systems, and their still huge concentration on fossil, non-renewable fuels and large hydroelectric projects which require building large dams and the inundation of vast extensions of fertile land are a big problem.

Another drawback of largely centralized power systems is their inability to differentiate among different end users. A health care facility like a hospital, or a school with small children, or traffic lights across an entire city should be serviced differently than just a regular home, machine shop or convenience store in a neighborhood. In a disaster situation, favoring the power supply to the most critical customers becomes very difficult because the systems are made to provide equal power quality and stability to everyone, even during disaster situations. In a centralized electric power grid servicing a large metropolitan area, albeit with some but limited differentiation in service, can only be on or off, so either everyone gets power or no one does, as simple as that. This makes recovering in an emergency situation a much more difficult task, sometimes virtually insurmountable. On the other hand, DPS reduce the obstacles to disaster recovery by allowing the focus to shift first to critical infrastructure and then to flow outward to less integral outlets [30].

## 3 Main benefits and advantages of DPS and DG

Just like in decentralized communication networks, where if one of the stations breaks down, it does not bring the whole network down with it, when faced with a disaster like a hurricane or an earthquake, DPS can eliminate the threat of the entire power grid collapsing by creating a series of redundancies in the power system itself. With several decentralized power generation plants and distribution networks, a smart micro grid, powered for example by several combined heat and power (CHP) units (see [10] and [11]) can disconnect from a grid experiencing a power outage and continue to operate free of disruption until the main power grid is back on-line. The US has learned its lesson from major disasters over the past decade, especially in areas of recurrent phenomena like in the Midwest and in the states of Florida and Texas, and when making choices on how to rebuild critical pieces of infrastructure, there has been a marked increase in the number of vital facilities like healthcare , schools, industrial parks, airports, large manufacturing plants, military outposts and administrative office buildings developing CHP generation systems (see [10] and [11]). These, along with other changes like introducing adequate pieces of legislation and giving tax incentives to small businesses and large size community investments in RET and mini and micro-grid technology may represent the beginning of much needed change which we may see more forthcoming in the following two decades.

Thus the potential for building a stronger and more resilient energy matrix lies in our hands. We need to have less vulnerable, more flexible and resilient electric power systems, as the next disaster will come for sure, but when? Nobody knows. But what we do know is that we ought to be ready and well prepared for it, otherwise we will continue to suffer at the expense of the capriciousness of nature and the unpredictability and absurdity of human error, especially in our most critical systems. Notwithstanding this general consensus by experts and authorities in general that something has to be done fast, change, as we all know is slow in coming. If the power grid were to collapse in the immediate future, the only facilities with any power at all will be those equipped with microgrid power plants based on DG technologies, most likely utilizing a combination of both, diesel fueled generators and grid-connected HES employing conventional and unconventional generating technologies like RET (using one or more NCRE), and able to work as a stand-alone system as well, to generate their own electric power, just like we see diesel fueled alternators in the basement of just about every apartment building in Santiago today. In this regard, those facilities which for example, are equipped with their own CHP-based microgrid stand the best chance of maintaining their full power supply regardless of the calamities and climatic menaces that may be lurking in the horizon (see [19] and [26]).

## 4 Energy storage systems

It is common to find that during off-peak times, when there is excess power due to high amounts of renewable energy being generated in the system by the different components, a certain amount of excess energy must be dumped if energy storage systems (ESS) are not available, to avoid over voltages and damage to equipment. Wasted energy that otherwise could very well be used at a later time.

In [27] three stand-alone solar PV (photovoltaic) power systems, using different energy storage technologies, are modelled and optimized both technically and economically. The proposed modelling of components in [27] facilitates the assessment of the ESS capacity and also allows for better computation of system's overall efficiency. Key components including PV modules, fuel cells, electrolyzers, compressors, hydrogen tanks and batteries are modelled in a clear way so as to facilitate the evaluation of the hybrid power system. Using energy storage technology, a method of ascertaining minimal system configuration is designed to perform the sizing optimization and reveal the correlations between the system cost and the system efficiency.

The three hybrid power systems, i.e., photovoltaic/battery (PV/Battery) system, photovoltaic/fuel cell (PV/FC) system, and photovoltaic/ fuel cell/battery (PV/FC/Battery) system, are optimized, analysed and compared (see [27], [28] and [29]). The optimal solution comes as a trade-off to the problem as expected, where the proposed PV/FC/Battery hybrid power system is found to be the configuration with lower cost, higher efficiency and less PV modules as compared with either single storage system (see [27], [28] and [29]). For homes in general we believe the battery bank as part of the HES is the most convenient choice given the cost and modularity provided by this ESS. Particularly relevant when it comes to ESS technology review are (see [12], [13], [14], [15], [16], [17] and [18]) all presenting important contributions to the subject.

Likewise it is important to mention the need to carry out a very thorough pre-feasibility study of non-conventional renewable energy (NCRE) sources potential present at site, particularly solar and wind, studying load characteristics carefully to identify distinct consumer patterns in power demand, and to do a correct mapping of the electricity distribution network. Once the project is decided upon, there comes the need to deal with system sizing, optimization of different system components and of the system as a whole, including energy system design, optimal control of HES. By choosing the right components and the appropriate system configuration, their costs can be minimized through proper equipment sizing and load matching (see [12], [13], [14], [15], [16], [17] and [18]). The bottom line is to make the most efficient use of NCRE sources and the HEPS configuration chosen throughout the lifetime of the system.

## 5 Smart, flexible and modular micro generation systems as means to supply electricity to homes in case of natural disasters

Smart micro generation systems belong in general to the type of applications called smart microgrids. Smart microgrids are understood as the enabling technology, integrating hybrid energy systems and energy storage, which allows for the development and integration of alternative energy sources (see [19], [20], [21], [22], [23], [24], [25] and [26]). It is en essence a micro generation system that uses **bidirectional communication systems**. The concept of smart microgrid for a group of homes can be utilized to define a diverse group of applications, which fosters the ability to monitor and control an electricity network (US Department of Energy, 2010) (see [19], [20], [21], [22], [23], [24], [25] and [26]). There is however not one but several definitions of smart grid, even though it is easily distinguished from a conventional power grid. However, one can easily recognize that just about any definition on the subject points to an entirely different system, much more capable, robust and resilient than the traditional electric power systems we grew up with. In general, conventional power generation plants, transmission and distribution networks have a limited capability of monitoring and control.

This way, it is common to see control centres far away from power generation communicate with generation centres, power substations and large consumers; control functions are often operated manually (see [19], [20], [21], [22], [23], [24], [25] and [26]). In contrast, a smart grid is characterized by a two-way flow of electricity and information and is capable of monitoring everything from power plants to customer preferences to individual appliances. It delivers real-time information and enables a near-instantaneous balance of supply and demand at the device level. It can operate at different scales as long as it is located near the source of energy and near the areas of delivery, ideally used to produce and consume energy locally. It involves changes not only in the technology, but also in the elements such as users' practices, regulations, industrial networks, infrastructure and symbolic meaning (see [19], [20], [21], [22], [23], [24], [25] and [26]). The distinctive feature of an appropriately designed network control is that it admits local and changing communication networks, is robust with respect to intermittency and latency of its feedbacks, and also tolerates connection and disconnection of network components [32]. However, a small DG has some significant problems of frequency and voltage variation when it is operated in stand-alone mode. Therefore, a small DG should be interconnected with the power system in order to maintain the frequency and the voltage " [32].

For a microgrid it is essential that the energy management system (EMS) employed delivers active and reactive power generation by means of set-points for the generation sources, including the battery bank used in this particular case, and sends information to consumers about changes in energy supply and consumption. The paper "Grid-Connected Hybrid PV/Wind Power Generation System with Improved DC Bus Voltage Regulation Strategy" [33], authors point out that among the various types of renewable energy sources available, the solar and wind energies are by far the most utilized; because of the inherent complementary nature of the solar and wind energies, the hybrid PV/wind power system has higher reliability to deliver continuous power than either individual source [33]. Also aiding this trend is the rapid growth of the power electronics techniques, the photovoltaic (PV) and wind power generations systems have increased rapidly (see [21], [22], and [23]).For a microgrid it is essential that the energy management system (EMS) employed delivers active and reactive power generation by means of set-points for the generation sources, including the battery bank used in this particular case, and sends information to consumers about changes in energy supply and consumption. The paper "Grid-Connected Hybrid PV/Wind Power Generation System with Improved DC Bus Voltage Regulation Strategy" [33], authors point out that among the various types of renewable energy sources available, the solar and wind energies are by far the most utilized; because of the inherent complementary nature of the solar and wind energies, the hybrid PV/wind power system has higher reliability to deliver continuous power than either individual source [33]. Also aiding this trend is the rapid growth of the power electronics techniques, the photovoltaic (PV) and wind power generations systems have increased rapidly (see [21], [22], and [23]).

In the hybrid energy system configuration which is part of the microgrid proposed here, a battery bank must be used to draw maximum power output and to safeguard the electricity supply to the homes in case of a power outage. Different circuit topologies for the grid-connected hybrid PV/Wind power system are shown in the paper. Since the output voltage of the PV array is different from the one of the wind turbine and the maximum power point tracking (MPPT) feature is demanded, a DC/DC converter and a DC/AC inverter are both needed for the PV/Wind power system [33]. As this paper shows, a good configuration option is to have an AC-shunted grid-connected hybrid PV/Wind power system using two individual DC/DC/AC converters. Each one of them is capable of delivering maximum power produced by the PV array and/or the wind turbine. In general, the use of wind energy is cheaper than that of solar energy. In areas where there is a limited wind source, a wind system has to be over-dimensioned in order to produce the required power resulting in higher plant costs [34]. It is emphasized the importance of the grid-connected PV system regarding the intermittent nature of renewable generation, and the characterization of PV generation with regard to grid code compliance. To meet technical requirements in this case, the DG units in the microgrid must have protection, control and communication components to have safe operation.

The local electric utility grid, which is connected to the homes (AC loads) through the smart microgrid, is the key player within the system. Once the key player is out of the game, the rest of the players, namely the advanced sensing, data measuring and communication systems, the advanced hybrid control system, the advanced human-machine interfacing and decision support systems and the energy storage systems (ESS) must all figure out a way to continue to work and coordinate adequately to supply power to the homes in case of a power outage caused by a natural disaster or another adverse condition.

Figure 1 below shows the schematic diagram of the proposed PV-Wind hybrid energy system (HES) with energy storage for power supply to a group of homes in case of a power outage caused by natural disasters. We envision a smart microgrid configuration comprised of one or more HES with the following simple but effective configuration.

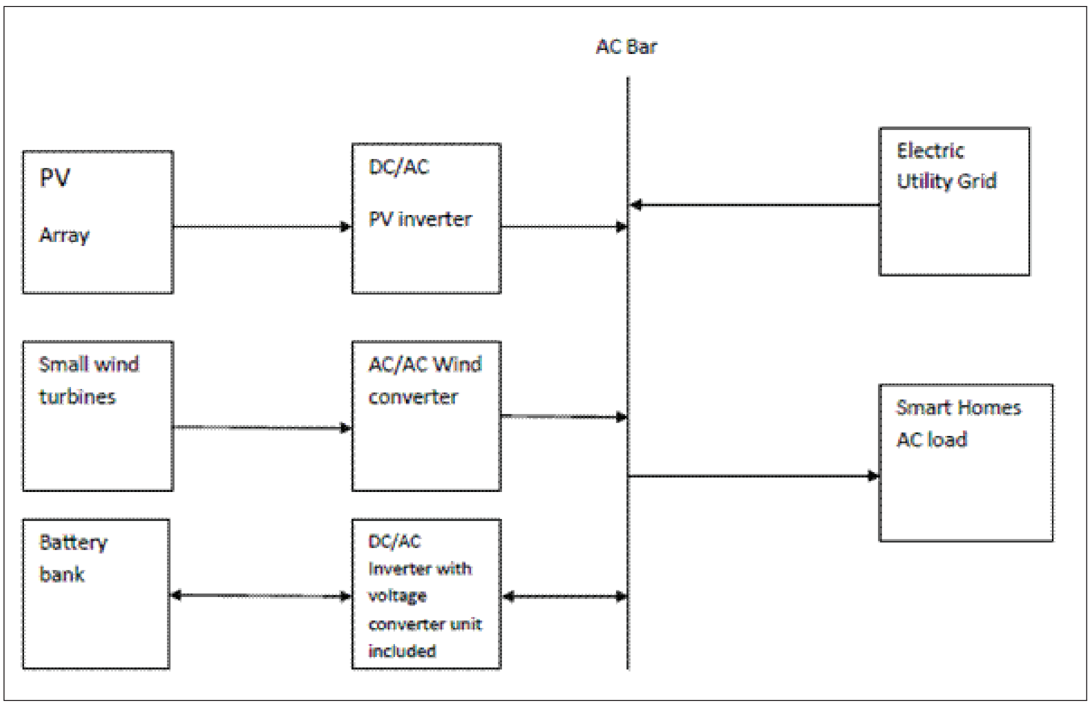


Figure 1: Schematic diagram of grid-connected solar PV-Wind hybrid energy system (HES) with a battery bank as energy storage to supply electricity to a group of homes for disaster readiness.

Double pointed arrows on the battery bank connected to the AC bar indicate bi-directional electrical energy flow. The main utility power grid is always connected to the battery bank and recharges the energy storage system (ESS) whenever this is needed. Likewise, when there is a need to draw electricity from the ESS, as it is the case when there is an power outage and no electricity is available from the main grid and in addition, the electric power being drawn from the wind turbines and the solar PV panels may not be enough or may unstable the Meta-controller sends the signal to start the flow of electricity from the battery bank.

The micro grid system shown in Fig. 2 will operate connected to the local electric utility grid, and will have communications linkage among the different systems, namely the HES control system, the utility grid control operator, and the people in their homes whom are being provided electricity both by the microgrid system and by the local electric utility grid. The aim here is for everyone that is part of the system being proposed to have the necessary and relevant information on the status and operating conditions of the microgrid and its electricity generation capability throughout the day. Ideally the different loads in the homes to which the microgrid supplies power for their operation will have sensing devices, in order for the microgrid controller to sense the power consumption of the loads throughout the time it remains in operation and will also be sensing the data provided by the utility grid status.

The task of the HES homeostatic regulator function in the hybrid controller is to regulate the electrical energy flow to and from the microgrid to the homes including the battery bank and also the electrical energy flow from the utility grid once the electric power supply is restored. It is part of the microprocessor-based control set-points, and its response is triggered by signals being sensed by the system (power consumption demand in Watts) which tells the system that its capabilities to produce enough power to meet demand are either within the range of its generating capacity or out of range.

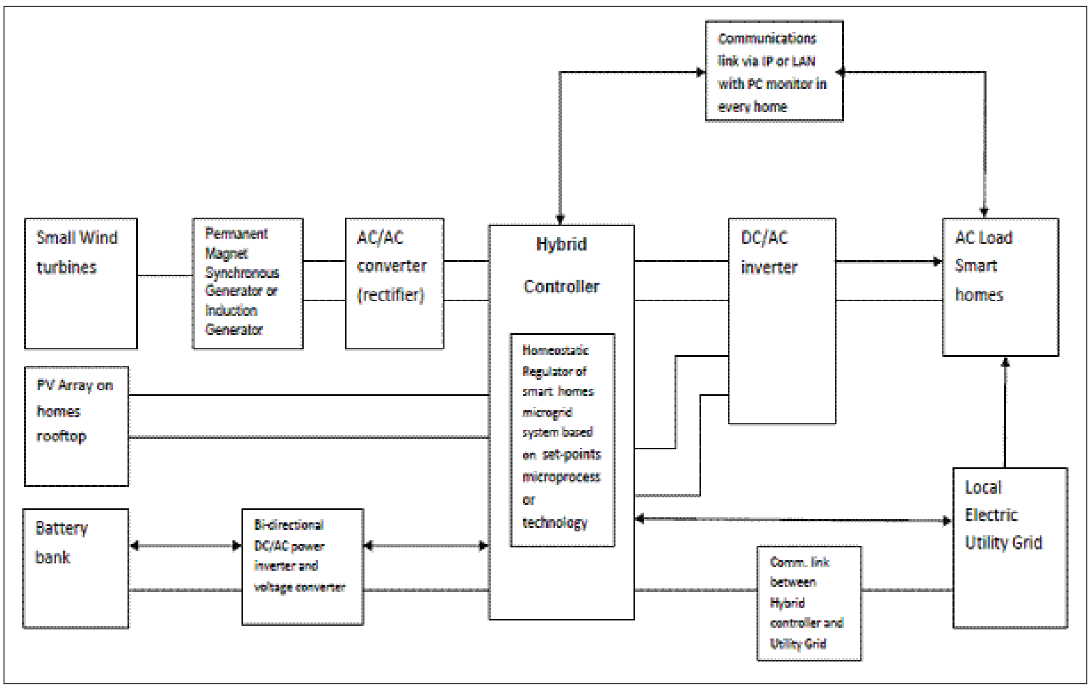


Figure 2: Model diagram of grid-connected hybrid energy systems (HES) comprising a small micro grid with energy storage system to supply a group of homes in case of a electric power outage.

In Figure 2 we have the model diagram showing a solar PV array and a set of small wind generators as renewable energy sources (RES) comprising the hybrid system for electricity supply to a group of homes. The generator will most likely be an induction generator (because of its convenient cost and simpler technology) coupled to the set of small wind turbines. The induction generator is then connected to a voltage rectifier and this in turn to the AC load (the homes). Everything is connected to the microgrid controller. The solar PV array is connected to a PV Energy Conversion System or DC/AC Power Converter and this to the load AC bus and to the AC utility grid as well. Likewise the battery bank is connected to a bi-directional DC/AC power inverter and an integrated voltage converter unit to make sure that the voltage signal going in and out of the ESS is adequate.

As it is said earlier, everything is connected to and controlled by the System controller. The controller coordinates and controls the entire system in a distributive manner, and incorporates an innovation element called a HES homeostatic regulator, which acts much like the homoeostatic regulation that takes place in the metabolic system of living organisms like humans and animals.

This microgrid system is thus able to adapt to abrupt changes in climate conditions and/or changes in the consumption patterns of the homes or changes in the electricity supplied by the utility grid to which it is connected. Thus the system is capable of reacting and at the same time communicating to other systems, namely the people in their homes and the power utility grid control operator the conditions of the system. The HES homeostatic regulator is a vital part of the hybrid controller, and constitutes the means to regulate energy flow from the smart microgrid to the homes and also the electric energy flow from the local utility grid to the homes, an important parameter which is fed into the microgrid controller in real time on a permanent basis. It is in essence an intelligent component based on data set-points enabled by a microprocessor that allows the control system of the smart microgrid to manage the energy flow among systems and also makes the controller ”aware” of what's happening in the system in regards to its sustainability.

The homes can be connected to the utility grid control operator and to the micro grid's controller through a communications link via IP or LAN. The controller coordinates and controls actuating on the different individual controllers and providing status and other vital systems information to users and to the utility grid control center operator. The electric power (in Watts) being supplied by the local utility grid, the watts being consumed by the AC loads (homes) and the energy flow within and throughout the small microgrid being drawn from the HES' operation will all be shown on a PC monitor in each home and in the monitor of the utility grid's control operator remotely located. Ideally voltage and frequency will also be shown to the electric utility control operator since voltage for some given frequency varies as a function of time, and thus both are important parameters of the quality of power that the homes are getting from the microgrid system. Hence it is important for those monitoring the microgrid operation at a distance to learn of the quality of the voltage being supplied (looking for possible voltage drops or sagging) and that this is maintained within standards.

The system controller will be able to act and respond to disruptions being provoked by internal or external phenomena that may occur during operation, adapting the HES operation to these changes. For example, should the DC/AC inverter fail/break-down, the controller will continue operating with the wind turbines and the battery bank as back-up; or else, should the wind turbines coupled to a generator and this to an AC/AC power converter break-down at any point, preventing the flow of electrical energy to continue operating properly, the controller will continue operating by means of the solar PV panels and the battery bank.

## 6 Conclusions

The potential for building a stronger and more resilient energy matrix lies in our hands. We need to have less vulnerable, more flexible and resilient electric power systems, as the next disaster will come for sure, but when? Nobody knows. But what we do know is that we ought to be ready and well prepared for it, otherwise we will continue to suffer at the expense of the capriciousness of nature and the unpredictability and absurdity of human error, especially in our most critical systems. Notwithstanding this general consensus by experts and authorities in general that something has to be done fast, change, as we all know is slow in coming. If the power grid were to collapse in the immediate future, the only facilities with any power at all will be those equipped with microgrid power plants based on DG technologies, most likely utilizing a combination of both, diesel fueled generators and grid-connected HES employing conventional and unconventional generating technologies like RET (using one or more NCRE), and able to work as a stand-alone system as well, to generate their own electric power, just like we see diesel fueled alternators in the basement of just about every apartment building in Santiago today. In this regard, those facilities which are equipped with their own microgrid stand the best chance of maintaining their full power supply regardless of the calamities and climatic menaces that may be lurking in the horizon (see [19], [20], [21], [22], [23], [24], [25] and [26]).

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