Electricity market strategies applied to microgrid development

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ABSTRACT

Over the last decade, the liberalization of the electricity market has been sought. In order to fight the environmental impact caused by the use of fossil fuels, it is aimed to change the current system of centralized generation and achieve a more distributed one; distributed resources can use renewable or non-renewable resources as main source of energy, one way to implement these distributed systems is through micro electrical grids, since these allow improving energy efficiency. The way to efficiently implement this type of network is an important point to be solved in future research and even more if the way of conducting an electricity market for different communities is unknown. That is why this text presents the characteristics of microgrids, the management of microgrids, and the wide and promising panorama of future opportunities for a great development of this type of grid.

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1. INTRODUCTION

There is still no clear indication of strategies pointing towards a decrease in electricity consumption in the coming years, as observed in the evolution and projection of energy consumption from 1850 to 2050 [1] energy demand is expected to double in 2050 [2]. Excessive consumption has led to an increase in the generation of electricity with a large number of energy sources, which depend mainly on the energy resources available to each country [3].

Fossil fuels are the main source of energy in most of the planet [4], and the dependence on their electrical system is very high, these currently satisfy 80 % of the demand [5], [6]. The bigger problem is that fossil fuels have a not infinite reserve, which means that at some point they will end. In addition, the way in which these fuels are distributed on the planet is not homogeneous at all, which implies the emergence of political conflicts between countries [7], [8], [9]. and as if that were not enough, the way they can be used to produce energy is highly polluting as it promotes the emission of toxic gases that deteriorate the atmosphere [10].

However, there are still alternative ways that can be used to produce energy sustainably; one of these routes is the use of renewable energy sources, due to their wide availability in the world, even greater than conventional energy sources [11]. It is of great importance to increase the use of energy resources based on renewable energies that mitigate the negative effects the excessive increase in electricity consumption can bring to the world.

It is important to highlight that renewable resources do not imply that there is a sustainable energy system, hence the need to move to new energy sources, such as mechanical energy through combustion engine, thermal energy that becomes mechanical thanks to the steam engine, the use of natural gas, and more recently, electric power [10]. These ethical energy transitions did not arrive together all over the world but were given as they became necessary in each geographical location [12].

Nuclear fission energy is a good alternative for the supply of large amounts of electrical energy; it is based on the use of uranium as the main material to produce it, but currently the use of this element is very high, so it is estimated that reserves will not last more than 180 years and its constant increase in production costs [13], [14] must be taken into account, bearing in mind that uranium contributes an approximate amount of 2.6 % to world energy, this figure becomes negligible [5], [15]. An additional, more promising alternative is nuclear fusion, with higher probabilities of continuous use, but this way of producing energy is very complex for carrying it out and can only be done in second-generation reactors, which is a serious problem, since their construction is not viable in the future, considering that not even those of the first generation are being marketed [16], [17].

On the other hand, in relation to renewable energy sources, its main component as an energy resource is not a limitation. For example, if we refer to solar energy, its annual flow over our planet is 10 times greater than the total of finite resource reserves and a thousand times greater than the amount of energy that can be consumed annually [2]. It is important to note that the distribution of solar energy on Earth would not cause problems among nations and is environmentally friendly. Over the years, the cost of renewable energy generation has decreased noticeably due to the effort made for its technological development [5], [18], [19], [20]. This indicates that this is a promising energy resource for the future, as long as the enthusiasm to continue investigating ways to reduce its costs in terms of production and storage is maintained.

Therefore, the best current alternative, technologically viable and sustainable, is given by renewable energies. The way to take advantage of renewable energy sources is presented as a necessity that cannot be postponed for the sustainable energy development of the world and as a priority solution to the growing global demand for electricity, the instability of oil and other fuel prices fossils, the decrease of their natural reserves and the ecological threat that the current global energy scheme represents to exceed the limits of the planet's capacity to assimilate the environmental impacts it causes.

The impetus for the use of renewable energy sources is a strategic element for the economic development of the country, which allows a distributed generation of electrical energy and makes it possible to reduce the loss of energy through transmission. The interest of the consumption of renewable energy sources is due to the social, economic and environmental impacts derived from its implementation; these have been used since the last millennium to meet energy needs in isolated communities, and so on.

Currently and in the coming years, renewable energies will not replace traditional energy sources altogether, but it is expected that the new installations made will be mainly renewable energy [21], [22], [23]. For 2014 they accounted for 58.4 % of the installed power capacity in the world [5], therefore, the amount of former sources will decrease in comparison to the total installed sources as expected in any transition [4]. It is precisely the way to manage a new energy production system that is constantly increasing, the main subject addressed in this document.

Each region must adapt to the change of energy system towards renewable energies in the easier way for them. In this way, it is believed that the largest amount of electricity produced will be of renewable origin [23]. It will be useful for transport, heating, and even for air conditioning, being able to be produced from biological origin fuels or from renewable resources [5]. As for renewable fuels, it is expected that there will be a technological transition in the way of producing them [24], but the ways of managing and using it will be very similar, if not the same as those used today [24]. The problem in the shift towards renewable energy sources for the generation of electric power is not in the form of doing it, nor in its use, but in its management [25].

Currently, the way to manage the generation of electricity is by controlling the speed of large synchronized generators set in motion through turbines with a common axis. If there is a difference between the amount of energy generated and the consumption in the electricity grid, it is resolved by working on machines speed, until a stable control is achieved due to the inertia present in them. A fault present and that has spread in renewable energy generators is the lack of inertia and manageability, so that a large number of the installations of these systems causes problems in the network in terms of stability due to the distributed and intermittent form of both the wind - in the case of the wind power source - and the irradiance of the sun [26], [27]. To solve this problem, ways to store energy have to be created, but the current cost of equipment fulfillying this function is high [28] and not easily accessible. Thus, new network management alternatives are needed in order to achieve a greater impact of renewable energies on the current electrical system without the need for large-scale accumulation systems [29], [30].

So far, the installations of wind and solar sources were being carried out connected generally to main networks, based fundamentally on generation of manageable conventional regime [31], [32], in this way, the power can be transmitted without control. However, renewable energy sources begin to be important in the energy field in many nations, having to be disconnected at certain times for reasons beyond the system [5], [33].

From any point of view, the transition to renewable energy sources is technically feasible [34]. It is projected that a large part of the way to generate renewable energy is In situ and micro, to reduce losses in transport and distribution networks, to make the system more efficient and to support the formation of a more flexible, quality and reliable electrical system [35].

Distributed or In situ energy is installed at points close to consumption, depends on management skills and is connected at a single point to the main network; in this way the so-called microgrids are created [36]. Microgrids function as the main unit of a decentralized energy system. These could be connected to small industries, homes, buildings, urban areas or offices; through energy storage systems, they control the power exchanged with the network [37].

2. MICROGRIDS

The implementation of intelligent electrical systems, capable of providing the necessary power to a given charge through the interconnection of several distributed generation systems, generally based on renewable energies, has allowed the development of the microgrid concept [38].

The unidirectional architecture of the current electricity network, vertical in its generation, distribution and consumption operation, is now requiring drastic changes due to advances in new technologies in generation [39], also the needs of dynamic characteristics and speed in the transfer of information and communications [40]. Smart energy grids allow to solve reliability problems and implement systems based on renewable energies, with all the positive characteristics they have shown [41].

From this concept, microgrid arises defined as a part of the electric power system, composed of distributed generation sources and controllable loads, which operate individually and autonomously, in parallel or isolated from the existing network [36]. A microgrid must be intentionally planned [42]. For an electrical system to be considered as a microgrid, it must meet certain technical specifications [43].

Smart microgrids form electrical networks that integrate the behavior of consumers and generators to provide a more economical, sustainable electricity supply that works efficiently and provides security [41]. Unlike the concept of Smart grid, the microgrid can work both connected to the main electrical system and disconnected from it, in case of electrical disturbances or if the energy demand allows it [44]. In the definition of microgrid no voltages are specified nor are power limits set [44]. This has a great dependence on the application of the microgrid, on the charges to which energy is supplied and on the availability of energy resources near its location [44], [45].

Microgrids can be applied in different technological ways [46]; they can be used for rural, commercial, residential or industrial clients in civil or military installations [47]. The country that has more megawatts installed in micro grids is the United States [46], [47]; however, the microgrids installed in rural areas in many underdeveloped countries represent a larger number of individualized projects [47]. Even more important is the constant growth of facilities in these urban areas, as revealed by several studies [37].

The main advantages of the distributed electrical system are: production systems for a longer time thanks to the integrated energy demand profiles that have greater regularity [48]. A smaller investment per unit of power thanks to the scale factor in the market of cogeneration units and absorption system, which favors the installation of more powerful systems [48]. It is because of these advantages that microgrid marketing aims to develop methodologies and the main bases to guarantee energy efficiency so that a sustainable energy system environmentally friendly and economically accessible can be obtained [48]. Finally, microgrid technologies are fundamental for intelligent energy consumption in both industry and homes, that is, adjustment and load balancing, leveling of consumption peaks, motivated by time-use rates [48].

In countries with high technology, microgrids are presented as an opportunity to produce electricity in a friendly way to nature and sustainable through local resources [49]. Projects are carried out to provide greater independence in the energy sector while guaranteeing the continuous supply of electricity to their charges [37]. Microgrids must be able to self-supply and isolate themselves in the event of a network failure, providing greater confidence in the supply [49].

On the other hand, in underdeveloped countries, rural areas in which there is no access to sources of electricity nor are there any approaches that imply doing so. This is because there are many technical difficulties for the projects to be carried out and also costs are very high, leaving more than 1.2 billion people without electricity [49].For these situations, microgrids are presented as a viable solution to provide electrical service to these areas, improve the well-being of its inhabitants, public health and the local economy [49].

These diverse scenarios present a very large diversity of ways to configure microgrids, as well as their network design and even the objectives to be achieved, such as determining the best performance of each element composing the microgrid, the power maximum that the batteries can deliver, the maximum power consumption of the charges, and the exchange of power with the connected network. Identifying each of these characteristics allows designing a good management strategy that would be applicable to each electrical installation and achieve greater efficiency of resources. Thus, two forms of microgrid implementation are taken into account: isolated and directly connected to the network, each one with its advantages and disadvantages.

A microgrid isolated from the main grid must have non-manageable sources and control in a limited way the power of the generators to always remain in operation if there is excess energy [50], [51]. Demand management techniques are also necessary if there is an energy deficit. In case there are manageable generators, the main objective is to reduce operating costs through optimal programming of the units [47].

When microgrids are connected directly to the network, the case is very different from the previous one, since the excess power can be sent to the network [52], [53]. In these cases it is important to consider the value of electricity in the market, if the objective is to reduce the operation cost [54]. Figures 2 and 3 show an example of a microgrid with various types of generation and storage.

2.1. Advantages and disadvantages of the microgrid

Among the many advantages of microgrids are [55]:

a. **Energy efficiency.** With proper planning and operation of the generation and storage systems of the microgrid, electrical and thermal generation can be combined to increase energy efficiency [56], [57].
b. **Increase in the use of renewable energy.** Microgrids facilitate the penetration of generation systems based on renewable energy, since renewable energy resources available are used through a system conditioned to handle these technologies [56].
c. **Energy cost reduction.** A microgrid can participate in the electricity market and sell the excess energy generated, which reduces the generation price of the energy resource [56], [57].
d. **Safer** energy **supply**. Currently, electrical grids offer an adequate level of security for the operation of electrical charges. However, in the case of disturbances in the distribution system, the microgrid can be disconnected from the system and operate autonomously until proper maintenance is performed [56].
e. **Minimization of electrical losses.** In microgrids, the sources of generation are located near the centers of consumption, so that losses of power by distribution and transport are reduced, which can decrease the cost of energy by a significant percentage [56].

It is important to mention that, just as microgrid can bring advantages such as those mentioned above, they can also generate additional problems [58]. It all depends on the location, dimensioning and parameters such as grid imbalance, both low and medium voltage [1]. There are also economic disadvantages such as the high cost of the initial investment and the regulation gaps that impede the growth of such generation [10]. An issue of crucial importance in the operation of microgrids is energy storage, since it allows compensating for imbalances between generation and consumption, enabling an adequate supply quality [58]. However, there is no perfect storage technology and they all have their limitations in terms of power/energy density, response time/autonomy time, economic cost and life cycle [56], [58].

Hybrid storage systems allow to cover the entire spectrum of applications. Storage offers the opportunity to decide the optimal operation of the microgrid, whether it works in island mode or in the network connection mode, in which case the optimal moments to exchange energy with the external network can be managed [59]. The possibility of having a hybrid system with various technologies is of great interest [49].

2.2. Topology of microgrids

There are three ways of classifying microgrids according to their topology [55], [60]:

a. **AC**. Where systems are connected through an AC connection system, in which the energy exchange takes place. The distribution of energy within the microgrids is in AC. Some implemented with this system are [59]: voltage transformation, circuit breaker protection [61].
b. **DC**. The energy is distributed within the microgrid in DC. The energy exchange is done through a DC connection system connected to the network through a DC / AC inverter. The inverters also feed the AC charges [59]. Some implemented with this system are [62]: incorporation of renewable energy resources, greater reliability.

c. **Mixed**. In this case, the DC connection system and the AC system coexist, and it can be the same grid. Each element is connected to the corresponding connection system according to its nature [59]. Some implemented with this system are [59]: integration, synchronization, voltage transformation.

2.3. Elements of a microgrid

The microgrid provides benefits to users in quality and safety in the service, as well as to the electrification company, in solving overload problems [1]. The main core of a microgrid is composed of a control system; this system allows the electrical network to be managed as a single entity based on an advanced measurement system for the management of the generation and internal consumption of the network [63].

The energy flow is bidirectional: the smart grid brings the electrical energy from the generators to the users, thanks to the digital technology that allows to control the needs of the consumers and contributes to energy saving, cost reduction, efficient and rational energy use and the reduction of greenhouse gas emissions [57], [64].

In addition to the main control system, the microgrid is composed of distributed power generation systems, which use renewable energy [65]. Generation sources for microgrids of special interest are those of lower generation (100kW) with electronic interfaces [63]. These systems are generally micro-turbines [66], solar panels [67], wind turbines [68], fuel cells [69], and they are located near consumption sites [44].

A microgrid is basically formed from hybrid systems, with a configuration that considers several renewable energy sources, and a conventional one, with storage for isolated places with control and regulation systems [70]. The structure of the microgrid also contains DC accumulators or batteries, charge regulators, voltage inverters for the conversion of DC voltage into AC, a power transfer system and the necessary protections to provide security to the electricity network before any disturbance or unexpected variation of weather conditions, short circuit or equipment failures [70].

The following describes important elements that make up microgrids [71]:

a. **Distributed generation systems:** a group of energy sources that can be connected to the main network or that can operate autonomously. Generally, renewable energy sources such as solar, wind, micro turbines, fuel cells and cogeneration schemes. The installation and implementation of each of these systems will depend on the climate and the geographical location of the microgrid [71].
b. **Charge regulators:** The microgrid requires a system to be installed for regulating the charge between solar panels and batteries; this is the regulator whose function is to prolong the life of the batteries, preventing their charge and over discharge. The regulator participates in both processes, and guarantees both sufficient battery charge and no overload situations. It also ensures the necessary supply and avoids situations of excessive battery discharge.
c. **Accumulators or batteries:** To store the charge generated in solar panels, wind turbines and other sources dependent on varying conditions, accumulators or batteries are commonly used. With these you can build small size systems. Generally, the use of special batteries that make it possible to reduce the charge by up to 60 % without damage is preferred. Its lifespan is 5 to 7 years depending on the manufacturer and the operation of the system [72]. The configuration of batteries is designed so that the operating voltage can be maintained while providing the power necessary for the operation of the charge, without exceeding the minimum storage limits of batteries, according to the characteristics defined by the manufacturers. The total number of batteries will depend on the average consumption in amperes-hour and the number of days of autonomy considered convenient [72].
d. **Inverters:** They are used to convert the direct current (DC) generated by wind turbines, solar panels or batteries in alternating current (AC), for its use either in the electricity network or in isolated electrical installations. In isolated systems, the sine wave inverter is used, capable of producing alternating current of sine wave similar to that of the network. Another type of inverters are auto-switch, which use their internal circuit to produce electricity compatible with that of the network. Auto-switch inverters are used in microgrids due to this ability to produce an electrical signal compatible with that of the grid. Thus, when necessary, the main power grid can be disconnected and the inverter can provide the power required by the charge, without stopping the supply. Another important feature in the operation of an inverter is its ability to continue operating in isolation. Grid-tied inverters generate a sine wave matching voltage, phase and frequency with the grid signal .To operate they need this signal as input. Grid-tied inverters cease to operate once an electric network failure occurs. These inverters are used in applications isolated from the network or where the entire system stops its operation if the voltage coming from the network shows any failure. Grid-off inverters generate a pure sinusoidal signal; they have internal control circuitry to maintain the voltage and frequency ranges within the parameters considered standard and permissible by the network. This type of inverter operates without need of the

power grid, so it can be used to operate in isolation, because it is expected that this is one of the operating characteristics of the microgrid [59].

e. **Charge transfer systems:** Power transfer or charge transfer systems (CTS) are the equipment responsible for coordinating power injection to the charge. They are the central axis of the microgrid, because their function goes beyond coordinating the power delivery. This equipment must have the necessary technology and infrastructure to transfer the power of a critical charge to any of the generation systems (or the electrical network) that make up the microgrid and guarantee the constant and stable supply in phase, voltage and frequency. Current charge transfer devices have the ability to expand the number of sources of distributed generation systems they are connected to. This, because it is possible to make a configuration with more similar equipment to guarantee the power required by the charges. This equipment must guarantee the complete separation of the generation systems, so that if a fault in the network or any of the distributed generation systems is detected, it is isolated from the microgrid and the operation continues normally. The CTS has internal equipment for measuring the parameters and quality variables of the electrical energy supplied, control software and communications protocols such as RS232, RS485 and remote monitoring capability via Ethernet [59].
f. **Smart regulators:** The advanced metering infrastructure, or AMI, is composed of solid-state digital meters with two-way communication, capable of providing parameter values characterizing the microgrid. Parameters such as voltage, current, frequency, phase and power consumed by the charges, allow to know the changing behavior of the energy produced by the local generation systems, and how this energy is distributed within the system.
g. **Protections:** The protections used for the connections derived from inverters in alternating current, are the ones commonly used in electrical installations. To protect against overvoltage, devices known as voltage arresters or high energy varistors are placed near the generation systems. The function of this device is to detect surges in a given space-time and to derive them to earth. For solar panel protections it is recommended to use thermal magneto protections or disconnecting switches. The protections must respond to the two basic structures that make up the microgrid; electricity network and distributed generation systems. If the fault is in the electrical network, the desired response of the system is that it isolates the micro network from the main network, as quickly as necessary to protect the system loads. If the fault is within the microgrid, the coordinating system must isolate as little as possible of the micro network to eliminate the possible failure. Conventional protection systems start from measuring the short-circuit current of the system. The coordination of protections is therefore a design component of great importance. For this, it should be borne in mind that currently distribution systems are designed based on a feeder from which the phases and system loads are branched; being a static system, it is relatively easy to size the estimated currents and powers, as well as the different types of fault currents. In a microgrid, the complexity of this coordination may increase as there are possibilities for reconfigurations, which implies different scenarios. The coordination, therefore, should provide for this type of possibilities, through proper planning of the microgrid.
h. **Control and management of the microgrid:** Controlling the microgrid is in charge of the charge transfer system or CTS, because this equipment fulfills the function of central axis of power transfer from distributed generation systems or the public service network. The CTS, due to the internal meters it has, is able to perform an analysis of the different operating parameters of the two redundant sources, and of the operating conditions of the load, in order to decide whether the priority source provides the better operating conditions for the correct operation of the load or it is necessary to transfer to the backup source. However, to strengthen control of all connection and energy transfer nodes, micro grids use smart regulators. These regulators are capable of providing, through different communication protocols, the real-time values of the operating conditions of each of the generation systems .All this integration, between measurement and communication systems, allows the structuring of a grid capable of operating autonomously and with high efficiency, in order to guarantee the flow of power towards the load, but having as priority the use of energy produced through the installed renewable energy systems.

2.4. Microgrid control methods

There are mainly two types of control methods in microgrids: One that requires communication between generators or a centralized control, and the other that needs to establish the necessary active and reactive power autonomously [73].

a. **Microgrid Central Controler:** Generation control, dispatch, charge disconnection and auxiliary services management are performed through a central controller. Media need to be placed between sources through wired or wireless. This control scheme is more aligned with the concept of microgrids.

b. **Microgrid with Autonomous Control:** Under this control scheme, the demand is shared between generators in proportion to their respective "drops" of active and reactive power, as in a traditional power system.

2.5. Microgrid communications system

The communication system of a microgrid is made up of the deployment of ICT (Information and Communication Technologies) devices and tools in the fundamental electrical context for the achievement of all the expected functionality of a microgrid [73], [74].

In a generic way, the communication system of a microgrid can be defined in the form of layers or subnets, among which three stand out [75]:

- User environment, can be home grids or Home Area Network (HAN), building grids or Building Area Network (BAN), industrial networks or Industrial Area Network (IAN) [74].
- Environment of a set of users, and within this, neighborhood networks or Neighborhood Area Networks (NAN), or wide area networks or Field Area Network (FAN). Local Area Network (LAN) can also be considered here [74].
- Environment beyond the neighborhood, wide area networks (WAN) [74].

The main requirement that a microgrid in relation to ICTs is self-configuration, that is, it must be able to automatically manage the address, the description of the network devices as well as their registration and location [74].

2.6. Examples of microgrids

Microgrids are subject of constant study and testing around the world under the standard that determines the operation and integration of isolated distributed resources. Listed below are some examples found in the literature [6].

There are two in Canada: BC Hydro Canada - Boston Bar [59]. Where a microgrid is interconnected to a 69 kV feeder through a 69/25 kV substation composed of three radial feeders. It was built as a solution against continuous blackouts. This microgrid has two hydroelectric generators of 8.75 MVA each and the connected peak load is 3 MW. It depends on the demand and the water level of reservoirs. This system does not have storage devices. Hydro Quebec - Boralex planned islanding is another microgrid built to power 3000 consumers. The substation is connected to 120 kV with a 40 km transmission line. The generator of this MG is a steam generator. The peak demand is 7 MW and this MG does not have a telecommunications system, nor storage [76].

Near Columbus, Ohio, a microgrid called CERTS Test Bed was built [59]. It consists of generators or sources based on static converters (inverters) of 60 kW powered by natural gas. It has a large telecommunications system with a network operator, which allows the dispatch of the generating units in the microgrid when the system is disconnected from the distribution network. At the University of Wisconsin - Madison there is the microgrid called UW microgrid, implemented to investigate the modeling and control of diesel-based distributed generators; it also includes a source based on static converters (inverters) and has the possibility of using them as a storage system [77].

In the Netherlands, there is the Bronsbergen Holiday Park microgrid [59], which is one of the largest projects in the European Union. The microgrid feeds 208 homes, and the energy comes from 108 solar panels with a peak generation of 315 kW. This microgrid is connected to the 10kV network thanks to a 400 kVA transformer. The system has a storage center consisting of two battery banks. The system includes central control to handle the data sent to the dispatch, measurement and monitoring center of all system variables, and an automation system for operation of the microgrid independent of or connected to the network [78].

Microgrids in rural areas offer benefits by replacing low quality energy sources as they are used with fuels and technologies that offer the same energy services as communities have access to higher quality energy, and enable new services on the whole. Benefits include improving health, safety, productivity and education. Electric light is a vital replacement for lighting based on kerosene in and, when supplemented with other enabled services, it can improve productivity on the local scale and help increase well-being. On a national scale, the electricity service is highly correlated with improvements in the human development index, which show strong marginal decreasing benefits. In other words, only a few kWh can greatly improve the national electricity service [79].

The harmful effects on health of using kerosene include structural fires and severe burns, respiratory diseases, possible links to tuberculosis and cataracts, and childhood poisoning due to the involuntary ingestion of kerosene. The low levels of light, due to the lighting caused by kerosene, which medical professionals face, create a series of challenges, such as risks in childbirth in rural areas and infections caused by difficulty of maintaining sanitation. The supply of electric light alone dramatically reduces these negative effects on health and safety [60].

There are also unexpected benefits of electricity beyond these cases. In rural areas in India, for example, there are venomous snake bites and deadly clashes with tigers, with the introduction of domestic and public electric light, villagers were able to see poisonous snakes in their bedrooms or avoid stepping on one on a dark road; together with refrigeration for anti-poisons and other medications, microgrid operators on these islands claim that the injuries and deaths caused by these threats decreased dramatically after the introduction of electric light [60].

Studies have shown a variety of social benefits and income generation opportunities associated with microgrids in these areas. A detailed case study in a rural town in Kenya reveals significant improvements in worker productivity, income and sales prices in small micro-businesses, such as coffee shops, carpentry workshops and sewing companies. The same study reveals improvements in education services by reducing the time spent in collecting water in schools through water pumping and home improvement. In Bhutan, rural micro hydroelectric networks allow households to cook with electric rice cookers, save time and avoid expenses and the use of oil, coal and wood for cooking [60].

A study by Rangarajan and Guggenberger explores the profitability of using microgrids based on renewable energy for power generation in rural environments [80]. The study involves the feasibility analysis of wind, photovoltaics and biomass as renewable sources to generate energy on farms in Missouri, Ohio and Nebraska and provides decision strategies to achieve sustainable energy management solutions.

3. MICROGRID MANAGEMENT

The environmental and economic benefits of microgrids and, consequently, their acceptability and degree of distribution in the electric power industry, are mainly determined by their controller capabilities and operational characteristics [81].

The control and operation strategies of a microgrid may be significantly different from those of conventional energy systems, depending on the type and depth of insertion of distributed energy resource units, charge characteristics, energy quality restrictions, and market participation strategies [81]. The main reasons are the following:

- The characteristics of stationary and dynamic states of distributed energy resource units, in particular electronically coupled units, are different from those of large conventional generating turbines.
- A microgrid is inherently subject to a significant degree of imbalance due to the presence of single-phase loads and / or distributed energy resource units.
- A notable part of the offer within a microgrid can be from "uncontrollable" sources; for example, wind-based units (wind energy).
- The short and long term energy storage units can play an important role in the control and operation of a microgrid.
- The economy often dictates that a microgrid must easily accommodate the connection and disconnection of units and loads of distributed energy resources while maintaining its operation.
- A microgrid may be required to provide pre-specified energy quality levels or preferential services to some charges [81].
- In addition to electrical energy, a microgrid is often responsible for generating and supplying heat to all or part of its charges [81].

For the concept of microgrid, the coordinated operation and control of the energy resources sources distributed with storage devices is essential; for example, capacitors and energy batteries, and controllable charges [59]. A microenterprise can operate autonomously, if disconnected from the main network, in case of external breakdowns, or can be interconnected to the main distribution network. This is how a microgrid can be considered as a controlled entity within the electrical system that can function as a single aggregate load [79] and, given an attractive remuneration, as a small source of energy or auxiliary services that support the network. From the user's perspective, microgrids similar to traditional distribution networks provide their thermal and electrical needs, but also improve local reliability, reduce emissions, improve energy quality through voltage support and reduce falls of voltage, and potentially produce lower energy supply costs [41].

A small energy market can operate within the microgrid. The producer units and at what level are regulated, and this is the result of an optimization procedure that aims to maximize the value of the microgrid [82].

3.1. Energy markets

The lack of manageability, as well as the penalty for deviations in the matching market, hinders the economic competitiveness of renewable energies in the energy market [82]. Energy storage systems are a technological solution to the controllability of renewable energies by allowing their introduction into the daily energy market through microgrids [82]. With the implementation of microgrid, a different dynamic of the energy market should be considered [82]. Among the special characteristics changing the dynamics of the market in microgrids, it is that the proximity between demand and generation can contribute to the reduction of loss, resulting in an improvement in reliability and security in supply when it is connected to the network or when a physical island is presented [42].

Complementary services can be provided with precision, agility and remuneration since the operation changes market dynamics and allows new agents to provide these support services to the network [83]. Additionally, the agents participating in the energy market increase and it is possible to reduce the market supremacy of the large generating agents [36].

As for the investment in network expansion, it should be borne in mind that the power system operating in microgrid would postpone large investments in generation and transmission. In each microgrid there must be a central control that allows it to operate both technically and economically. When talking about microgrids, distributed generation can be considered as another source of generation, moving away from subsidy schemes that in many countries are part of the rate of end users [28].

It is important to note that, regardless of its possibilities, the definition of a microgrid has not become general and has been limited to remote regions in which the current electricity service is not accessible for years. It is known that there are no technical problems for the implementation of microgrids, but regulatory, legislative and economic difficulties [84].

That is why current laws prohibit the economic accessibility of renewable energy generation devices to consume it, or store it [84]. In addition, there are no systems the user can connect or disconnect from the main network according to their interests. Hence the need to solve these problems and adapt legislation to the concept of microgrid. According to qualified opinions, the definition of a standard for the specific regulation of the interconnection to the public network of different sources of generation of renewable energy has been pending for years [84].

On the other hand, and recognizing the technical feasibility of microgrids, it is a fact that they can be perfected. This would involve the introduction of modifications in three main areas: in the current system of meter boxes, protections, land and communications [35], in achieving the balance of generation and consumption at the local level, and in the incorporation of energy sources that favor access to electricity market transactions and facilitate the provision of complementary services [35].

The microgrid market is evolving rapidly, with orders executed throughout the world in diverse application segments [26]. Microgrids are leaving behind the pilot demonstration projects of technology, replaced by commercial projects driven by sound economic analysis [26]. A recent Navigant Research report has identified more than 400 microgrid projects in operation or in development worldwide [26]. In this study, the annual global capacity of microgrids is expected to increase from 685 MW in 2013 to 4,000 MW in 2020. North America will continue to lead the micro-grid market and the Asia Pacific region will probably emerge in 2020 as another area of growth because of the enormous need to supply power to growing populations, unserved by traditional network infrastructure [26].

3.2. Demand management

Economic growth is accompanied by the increase in energy demand, but it is important to consider that this increase entails a depletion of natural resources and an environmental impact, so demand management aims, among other things, to decouple this premise through energy saving and efficiency actions [6], [79].

Demand management is the planning and implementation of different measures that influence demand behavior. These measures are aimed at reducing consumption through the promotion of efficiency and energy savings, by reducing consumption during peak hours, hourly discrimination and the response to market prices and storage technologies entering participate in an active demand market [33].

Demand management programs are designed to encourage consumers to modify their electricity demand and consumption pattern, in order to respond to economic and reliability signals. This management is not related to the changes in demand derived from the normal operations that occur in the networks. It seeks to help solve demand fluctuations and so that the generation supply has greater competition [36].

In the future, demand may play a more dynamic role in electricity markets based on policies and new technologies that allow them to interact with the network operator. The decrease in demand derived from the implementation of management programs can lead to a significant decrease in marginal costs for power generation [36].

Among the advantages of active demand management are [1]:

- Reduction in price volatility.
- Market power reduction.
- Increase in network reliability.

- Increase in availability and transfer capacity in transmission networks, which translates into an optimization of the existing infrastructure.

In order for good demand management to exist, it is necessary to have advanced measuring devices together with automation and control so that energy management can become efficient management.

3.3. Micro markets

A micro market is the union of local generators and demands of a community that allows to resolve the restrictions of the grid locally. In addition, a micro market can boost the purchase and sale of energy in the wholesale market considering network restrictions.

The matching procedures for these markets could be: cooperative, cost-based, or competitive, based on the buy-sell offer. The advantage of cost-based procedures is that the micro-market manager (aggregator) could easily determine the minimum operating configuration, but with the disadvantage that if there are several generating owners, the system can be easily manipulated if any of the generators declare costs different from the real ones.

On the other hand, the advantage of a competitive system is that each generator would not need to declare costs and the point of operation would be determined based on purchase, sale and network connection point offers, if the restrictions of the net are considered. The disadvantage of a competitive system is that there is a generator with great market share conditioning the participation of the rest of the participants.

In summary, cooperation systems seem to be more appropriate for systems with single owners and competitive systems would be more suitable for systems with several owners with sufficient participation to avoid predominant positions.

The structure of micro markets has the advantage of allowing the integration of different owners with total privacy, unlike centralized control systems.

Likewise, the benefits of micro markets in distribution systems are [59]:

- Implementation of optimal load flows to reduce costs and losses.
- Storage units can be operated optimally considering economic and technical constraints.
- They have greater resilience, being able to easily adapt to unexpected situations.
- The quality of supply can be increased with local controls.

The characteristics of the micro markets are:

They stimulate competition and are not discriminatory. The system can participate in wholesale market through a virtual market agent. The objectives of buyers and sellers are strictly economic.

The general auction that must be sent to the wholesale market may include market restrictions in order to ensure a feasible point of appeal. The demand response can be implemented in the micro market and market agents can send offers to the micro markets.

Micro markets depend on:

- The configuration of local power systems. The objective of the shareholders involved. The features of participating markets.
- The factors to consider for the design of the micro markets are:
- Degree of competitiveness: a large participant can control the price of energy without taking into account the rest of the participants.
- Trading horizon: the daily market requires great precision in forecasts, on the other hand, real-time markets, on a minute scale, are a balancing mechanism.
- Transfer intervals: short transfer intervals reduce deviations from expected energy.
- Cost of the structure for the participants.
- The generation and coordinated consumption can be carried out oriented to achieve different objectives, such as: Tension level support. Frequency control. Provision of active power reserve. Complementary services.

3.4. Microgrid economy

This section addresses some of the economic issues related to microgrids. The economy, or the commercial case of the microgrids, determines its configuration and operation. The issues of the economics of microgrids can be divided into three categories [85]:

a. The first concerns the basic economy of optimal investment and the operation of the technologies available for micro grids [86]. These are problems that, at least on the scale of the distribution system, have received intense academic scrutiny. As a result, there are established and reliable tools to guide operations and should be effective, with some adaptation to the specificities of microgrids [85]. In other words, much of our accumulated knowledge about the operation of network scale systems can be applied to these systems.

b. The second refers to some of the unique aspects of microgrids that will require innovation [87]. In general, these are areas where microgrids differ significantly from distribution systems, for example, the possibility of providing heterogeneous levels of reliability to various end uses and the central critical importance of some operational limitations, which are relatively insignificant for the economy of the bulk energy provider [87].
c. The third refers to the relationship of the microgrids with the distribution system [88]. In many ways, these problems are related to the interface between clients and public services, for example, the need to provide a real-time price signal to the microgrids so that the optimal use of resources both by the micro network and by the network can be achieved simultaneously. There are also other problems, newer and more challenging [86]; for example, the ability of microgrids to participate in auxiliary services markets at the network level will most likely be limited by voltage and losses, but these could provide some local services, such as voltage support [89]. Creating a market for localized voltage support, or even putting significant value on it, seems unlikely at the present time [89].

A microgrid is designed, installed and operated by a client or group of clients mainly for its economic benefit [85]. The first issue refers to, although participants may be concerned about the environmental effects of their energy supply system, as well as noise and other similar considerations, the most important benefit that participants seek is a lower total energy bill. The microgrid may be able to operate some or all of its end uses at a lower cost than the network.

The cost of energy supplied by the traditional system includes losses, customer services, congestion and other costs that together typically exceed the cost of generation alone [90]. The microgrid will probably have smaller losses, as well as other advantages that will reduce its costs in relation to the costs of the distribution system.

The direct application of the principles of engineering and economics can help determine which technologies may be attractive to microgrids and how these technologies will be implemented and operated [91]. In many ways, the economy is similar to that of network scale systems. For example, the economic dispatch rules apply to both, and minimizing costs for both types of systems requires that the combination of resources of the lowest possible cost operates at all times, to the extent allowed by the characteristics of the equipment.

The purchase and sale of electricity is possible for both systems, and both activities can occur at different times [91]. The variety of work cycles required implies that the optimal combination of resources chosen by the microgrid will be technologically diverse, such as the combinations used in utilities.

In this context, technologically diverse resources include those used to meet a range of demands: basic duty cycle needs, maximum demand and other degrees of demand between these two extremes. Different types of generators will be more efficient to meet different types of demand. The classic solution in grid systems is that high cost and low variable cost technologies are suitable for base charge, and generators with the opposite qualities are suitable for maximum demand. This principle could be equally true for microgrids.

Although there are many similarities between the microgrids and the current network economy, some aspects of the traditional microgrid economy are new and will require rethinking or extending familiar tools. Two notable examples are the joint optimization of heat and energy supply and the joint optimization of loads and supply.

The joint optimization of demand and supply is a key area in which a certain extension of the traditional economy of the energy system for microgrids is required [58]. In scale systems, load control is usually addressed during analysis and planning such as demand side management, load control or load reduction and interruptible tariffs or contracts [59].

Microgrids are different in several key aspects. First and most importantly, the marginal cost of self-generation at any time is well known and really self-paid. In other words, for the energy generated, the vagaries of the recovery of investment costs, cross subsidies and inaccurate measurement and tariffs are avoided. This does not mean that costs will be well represented in tariffs, environmental standards, etc. The registration to date on the tariff reform to improve the cost signals to customers is unfortunate and the appearance of microgrid will not change this balance, but the generator and the consumer are one and the same decision maker and the struggle to coordinate investment and operating decisions on what was formally thought of as opposite sides of the meter is eliminated.

You can easily know its marginal cost of energy supply at any time and the costs of investments for greater efficiency; likewise, it is possible to analyze and establish its cost of reduction and then easily compensate them. This simple reality elevates charge control to a new level of importance and requires an extension of current thinking.

The second group of related economic issues covers some unique characteristics that require innovation in the traditional economy of the electrical system. In general, these are areas where microgrids differ significantly from current systems, for example, the possibility of providing heterogeneous levels of reliability to various end uses, and the central importance of some operational restrictions, such as noise, which are relatively insignificant for the network economy.

Energy systems have been traditionally designed and operated around the concept of "universal service", which argues that the quality and reliability of the energy delivered to all customers must meet approximately the same standard. In practice, there are significant deviations from this universal standard, partly due to the problems of serving vast and diverse geographical areas, but the goal remains to adhere to a universal standard.

A key motivation is the desire to bring control over the reliability and quality of the energy to the place of final use based on optimizing them for the specific charges served. Simple economics tells us that to adapt energy reliability to end uses served may provide benefits simply because, in times of energy deficit, energy can be moved from lower value end uses to higher values.

In addition, since it can be assumed that the supply of higher quality and reliability entails some cost, savings will be obtained if higher quality power is not provided to end uses for which it is not required.

The traditional economy of electricity system has paid considerable attention to some aspects of energy quality and reliability assessment, in particular to estimate the cost of general interruptions and priority pricing schemes that would allow customers to make their choice in their level of reliability. However, the notion that systems could be built around the quality of the heterogeneous service is quite new.

Another related issue is the optimum level of quality of the universal service provided by the network. If generalized microgrids effectively serve sensitive charges with locally controlled generation, backup and storage, the bulk energy system benefits because it is no longer limited to establishing its reliability requirements to meet the needs of sensitive local end uses.

The third set of economic issues covers the relationship of microgrids with the network. A fundamental principle of the paradigm is that they must present themselves as a good citizen; that is, strictly adhere to the rules that apply to all connected devices. They must behave as a legitimate customer or generator or both, and can improve those traditional economic roles.

The delivery of real price signals over time and space poses some important problems, because a new generation is incorporated into the existing radial distribution system, system updates, which would otherwise be necessary to meet the increasing charge, can be postponed or avoided altogether.

Within the distribution system, in times of increasing congestion, the delivery of a price signal to the customer would stimulate the development of microgrids and the investment in generation and / or load control to mitigate congestion. But the execution of this does not seem easy, the design of distribution systems in areas of high population density is quite flexible so that any end-use load can be served by several alternative system configurations. Thus, the congestion costs seen would depend on a somewhat arbitrary configuration of the network that could change abruptly, thus disrupting the economy dependent on that configuration.

The participation of microgrids in the markets is possible and desirable, but there are some probable limits. Low voltages will inhibit their ability to supply energy efficiently beyond the substation, and the provision of auxiliary services will be similarly limited, however, it is a service that can easily provide an interruptible load, taking advantage of its generation In situ and control schemes to protect sensitive charges. This could be a valuable contribution to the general health of the electrical system, as market responses to charge changes become less and less feasible, when response times must be seconds or minutes.

4. PROMISING FUTURE OF MICROGRIDS

Today, the energy industry faces many problems, including rising energy cost, energy quality and stability, an aging infrastructure, mass electrification, climate dynamics and so on. Those problems can be overcome using low voltage distribution generation where all sources and loads are placed [92].

In the application market of microgrids in 2022, the majority of applications would be for micro-type campus [93]. Projected market growth and revenue growth by region are shown in [94] where North America has the largest share. Some important aspects to note are the following:

- Global microgrid installed capacity growth has increased dramatically since 2011 and is expected to reach a total installed capacity of more than 15GW by 2022 [95].
- The market has a potential of more than $ 5 million and is likely to reach more than $ 27 million in 2022, in terms of market value for distributors [95].
- Currently, micro-grid campuses are the largest by application and are expected to grow at a compound annual growth rate of 18.83 % from 2012-2022 [95].

- Military, defense-based and commercial microenterprises are expected to have a similar installed capacity in 2022 [96].
- There are still many research opportunities available before micro enterprises begin to play an important role in communities [97]. The following explains some aspects of great importance [98]:
- Investigation of stability problems for both the network-connected and island mode for various types of microgrids, in terms of voltage and frequency [99], [45].
- Full-scale development research and experimental evaluation of control methods according to various operation modes [99], [45].
- Determination of transition dynamics between network-linked modes based on the interactions between the generation of distribution and the high penetration of the distributed generation [100].
- Definition of intelligent and robust energy supply systems in the future providing significant safety and reliability benefits [100].

The future network system must be changed to a more efficient use of available energy. Then various characteristics of prospective networks are shown, [101], [102], [103]:

- Independent network microgrids, poorly integrated.
- Use of heat and energy.
- Allow response to demand.
- Avoid transmission losses.
- Integration of renewable energy sources.
- Resistance to domino failures.
- Empowering independent consumers and producers of energy to be proactive actors and stakeholders in energy transactions.
- Loading and generation forecast, introduction of several loads for inverters and converters.
- Introduction of distributed generation with central control output for numerous energy sources. Requirements to be able to give higher quality.

It is necessary to work at several points to introduce a microgrid as a commercial product. Politically, a microgrid may not work because the local utility does not have the benefit of eliminating the current network and replacing it [104]. It may take longer for microgrids to become primary agents of the power supply. In addition, utilities continue to own cables and transmission components, authorization permission is required to transfer power through the current network [105].

On the other hand, public service operators assume the microgrid as a competitor and have begun to invest in the improved reliability of the macro grid [90].

In addition, it is necessary to change existing codes to allow considering microgrids. Localized energy will help from the user 's point of view energy-environment, but politically, the utilities do not see it that way [90].

The state of the industry is going through a revolution and a meaningful evaluation until the relevant issues have been addressed and decisions have been taken [95]. Currently, public utility companies are slow to adopt new technologies, but unless they release ownership or control of the equipment, microenterprises will not be commercially viable [95]. Even so, more research is required to solve several critical problems, as well as to provide stimulation and support to the microgrids of providers to local and federal administrations.

5. CONCLUSIONS

The common approaches are focused on reducing the consequences that have to do with network performance and security of a relatively small number of individually interconnected micro-generators, which implies, for example, that security requires they are disconnected instantly in case of system interruption. On the contrary, microgrids would be designed to operate independently, usually operating connected to the network, but as an island of it, in a cost-effective way to maintain performance.

A microgrids is a semi - autonomous grouping of generating sources and sinks at the end placed and operated for the benefit of its customers. The supply sources can be driven by a diverse set of primary engines and / or storage devices.

The market acceptability of distributed energy resources technologies and the gradual and consistent increase in their depth of insertion have generated significant interest in their integration, controls and optimal operation, in the context of microgrids. Initially, microgrids were perceived as miniaturized versions of conventional energy systems, and intuitively their control / operation concepts were based on reduced and simplified versions of the control / operation concepts of large power systems.

The previous analysis shows that an adequate development of a microgrids can help the distributed generation not to be passively connected in the distribution networks if they can operate in an intelligent way that can increase the reliability of the supply and decrease operating costs.

The deployment of distributed energy resources and microgrids will improve the overall efficiency of the electrical system. In a liberalized environment, the price of electricity is established in markets, the development of micro markets can allow a greater participation of users, as well as facilitate the resolution of technical restrictions that arise as a result of centralized electricity markets.

The obvious advantages, from the environmental and social economic point of view, of the implementation of micro networks in Colombia, demonstrated throughout this study, are faced with interests and a legal framework that still does not respond to this necessity, even when the effort and progress in this regard are recognized.

In prospective, if we formulate an image of the future in the medium term of an environmentally sustainable, economically efficient, quality, inclusive in terms of rural and urban penetration and attention, and sufficient for the needs of national development electrical system, the strategy to move towards that desired future is through the determined impulse of microgrids.

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