Smart grid review: Reality in Colombia and expectations

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Abstract. Colombia has a hydroelectric power generation capacity of over 60% and thermal generation just above 30%. Smart Grids have as a common objective the reliability of the energy service and the economic growth using Information and Communication Technologies for the generation with minimum contributions of energy supply sources derived from fossil fuels. Therefore, some strategies are proposed for the implementation of components such as renewable energies, controlled loads, energy storage systems, electric vehicles which are managed by an aggregator, besides considering the uncertainty in the Colombian environment that includes climatic conditions, the prediction of user load and market prices. Smart Grids requires flexible management of loads in collaboration with users, it depends on their habits and control of charges (smart households). Energy storage is a tactic to control user loads and generation with non-conventional renewable energy. As energy storage methods are presented adapted to regional conditions.

1. Introduction

Future needs effect of SG is related to the reduction of environmental impact. Because there are different definitions of SGs depending on local needs and specific applications, some important characteristics of traditional power grids and SGs are presented. Traditional power grids 1) centralize the sources of power generation, 2) the flow of energy is unidirectional from sources to customers, 3) participation is passive on the part of clients (limited monthly knowledge in most cases), 4) real-time monitoring and control generation and transmission, and only some utilities are extended to distribution systems, 5) System not flexible some difficulties in the alternation of sources at any point of the electrical network \[1\].

SGs arise due to the need to reduce the production of CO\textsubscript{2}, generate a more flexible network to the growth of the demand. In Colombia, installed capacity grew by 6.4% in 2014 \[2\], the population growth demands new requirements, thus it is necessary to connect sources of power generation in different demographic points of the electrical network. In addition, the SGs are generated in order to minimize costs for users and encourage their active participation, the penetration of non-conventional renewable energy NCRE own of each region, energy storage by users and power generation, and use of vehicles electric. Due to the great challenges of the SGs that they initially proposed were cataloged as futuristic electrical networks. However, today the components have been studied, showing an approach to reality.

One of the disadvantages of SGs is that they usually operate at the distribution level, so that generated power variations occur which can cause instabilities during distribution \[3\]. The traditional
Colombian generation is based on mechanical systems, thermodynamic generation cycles and hydraulic energy [2]. These systems tend to have inertia which is beneficial in the case of blackouts or drastic changes in generation, because their inertial masses allow the generation of energy even without fuel or water resources. However, renewable energy systems such as solar and wind energy lack inertia or have no inertia, so controls with inertial imitation must be implemented [4,5].

The transformer is vital in PS power systems. The topologies of the PS are migrating to the intelligent network, so it is required that the parameters of the transformer model the phenomena of these electrical networks. These systems include smart meters, intelligent accessories, renewable energy resources that generate high frequency components in the network due to the electronic switching of DC/AC converters and energy efficiency resources [6,7]. The life of the transformer is given by the insulation, and variations in the frequency of the SG can affect the speed of deterioration of the insulation. Which are modeled from dissipation factor, temperature and frequency variations (use of inverters in renewable energy applications), according to an Arrhenius type law, the aging speed and transformer life factor is predicted [7-9].

In the SG vision for 2030 in Colombia, it is proposed to analyze generation components, including transmission and distribution, the electricity price market, ICT communications infrastructure and non-interconnected areas with low population density and difficult access. These strategies are guided by policies of member countries of the UN that are the habit of protecting the environment, becoming aware of climate change for the reduction of greenhouse gases, enhancing energy efficiency and increasing the share of renewable energies. The power generation capacity in Colombia varied between 2012 and 2014; the generation of hydroelectric power is greater than 60% (divided between large power plants and smaller hydraulic plants) and thermal generation just over 30%, with the participation of natural gas turbines, coal and cogeneration plants. However, the increase in CO2 emissions causes an increase with the years of thermal participation due to water scarcity. There are also small hydro, thermal and wind power plants that represent 4% and 1% is attributed to cogeneration plants that reuse excess heat for the generation of electric power, which improves the efficiency of the system [2,10].

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The article is organized in the following way. Section 2 presents the qualities of an SG in Colombia and its main components. In Section 3 are presented the management characteristics of the SG and the qualities of the optimization algorithms to apply artificial intelligence, and in section 4 are concluded.

2. Smart grid SG

The SGs (see Figure 1) are made up of 1) renewable energies that are specific to each region of Colombia, 2) energy management in homes that is essential for customers to participate actively, this is based on optimization algorithms whose function is to ensure economic security and comfort in homes, 3) energy storage systems are dependent on natural and regional resources, 4) electric vehicles connected to the V2G network that are more efficient however are more expensive for the same power compared to polluting vehicles, so V2Gs are economically competitive and need to be encouraged by government policies. With the objective that users improve energy consumption habits and that the user can improve their income and economic expenses, the intelligent measurement system allows to know expenses and income in real time. The SG is controlled from the energy dispatch and the energy price market in order to economically benefit generation companies and users. In addition, it provides other benefits such as flexibility and reliability in the network [1,11-13].

2.1. Energy security

The uninterrupted availability of energy sources at an accessible price is defined as energy security; nonetheless the use of variable renewable energies has direct implications. The distributed generation of the SGs has the advantage that it minimizes the electrical losses in transmission and distribution lines, because they are closer to the user. When there is a greater increase in the penetration of renewable energies the network are more vulnerable in hours or minutes to power cuts, the penetration of non-inertial loads caused by solar and wind energy change the behavior of the systems, although it
is not has established a percentage relationship between the degree of penetration of renewable energy and the stability of the network. However, the use of greater connections between networks ensures reliability and the capacity to deliver excesses to other networks will cover local demand [14].

Figure 1. Components of smart grids.

Figure 2. Levelized cost of energy [2].

Renewable energy sources such as biomass energy (organic origin) and geothermal energy (use of aquifers and heat sources) ensure that their exploitation is carried out in a sustainable manner, so as not to deplete resources over the years. The supply of energy with renewable has the advantage of staying stable unlike the prices of non-renewable energies. In addition, in the last 8 years the price of solar energy has decreased (see Figure 2), which makes it more accessible to users.

2.2. Smart households (controlled loads)

In Colombia traditionally the energy saving in homes has been achieved by modifying the consumption habits of the users, that is to say, the invitation is made to them to efficiently use their electro-domestic appliances, the electric shower, change their lighting by thrifty light bulbs; use directed lighting and design homes with high luminosity. The demand profile is analyzed based on the different types of electrical loads such as: the refrigerator, the lighting and the television with encoder with the purpose of giving a recommendation of good practices to users. In times of child phenomenon between 2015 and 2016, a massive invitation to rationalize energy consumption has been made [15]. However, the user's participation is limited by the information that may be received. For this reason, mass media in real time that include social networks must be studied.

Controlled loads, for example, smart households have artificial intelligence for the participation of response programs to demand, a control operates the connection of renewable energies such as wind and solar in homes, energy storage is also incorporated with electric heaters water, electric vehicles or batteries, in addition to including the electricity price market. This is done in cooperation with the user, depending on his needs he can adjust some parameters of the home controller. An optimization algorithm is proposed to reduce the cost of energy by 29.5% in a household [12].

The threshold of unregulated users must be reduced so that smart households are part of the unregulated market; in Figure 3 is presented the trend in the contracted prices of regulated and unregulated users. Prices for unregulated users are lower than for regulated users for the time interval between 2005 and 2015. Since the first seminar held in 2010 in Colombia, progress has been made to implement the SGs and afterward Law 1715 of 2014 was approved by the Colombian government to generate incentives for the development of SG [16,17]. Some policies have been implemented so that users can acquire smart meters and become aware of their consumption.
Figure 3. Contracted prices of regulated and non-regulated users [16].

At the global level, we speak of distributed generation so that users become prosumers, that is to say, the benefits obtained from the network as unregulated users also extends to demand management with the filling of valleys and displacement of loads in peak hours. This objective is fulfilled with a bidirectional communication between generation companies and users. Efforts are coordinated to obtain mutual economic and operational benefits (reduction in voltage spikes) [3,18].

2.3. Energy storage systems

In the SGs, users must participate actively by buying energy in the electric market from cheap prices in off-peak hours to use it during peak hours when it is more expensive. In addition, SGs to be flexible have a high dependence on storage systems, according to the region and available resources can be used thermal, electrical, mechanical and chemical storage.

2.3.1. Thermal storage. The thermal energy can be acquired by the sun or another source of heat and work in a hybrid form for example with solar energy [19]. Phase change materials (PCM) can be suitable to produce almost constant temperature.

2.3.2. Electrical storage. The storage using electrical energy is done with supercapacitors and magnetic superconductors. The supercapacitors do not depend on an electrochemical reaction for their operation; therefore, they have a higher number of charges and discharges compared to batteries [20]. The stored energy is equal \( 0.5 \times C \times V^2 \), where \( C \) is the value of the capacitance and \( V \) the value of the voltage.

The superconductors operate when the direct current flows in a coil, which is made with a superconductor and this stores the current. For the material to have these properties it must be refrigerated at very low temperatures [20]. The stored energy is equal \( 0.5 \times L \times I^2 \), where \( L \) is the value of the inductance and \( I \) is the value of the current.

2.3.3. Mechanical storage. Two methods are presented by means of compressed air and hydraulic pumping. The compressed air method consists of storing the energy in porous deposits or aquifers. During low demand air is compressed and during peak hours the air expands to generate energy in a turbine. The hydraulic pumping system consists of pumping water to a higher tank when it is required to store energy and use a power plant to generate energy [20].

2.3.4. Chemical storage. These batteries use the electrochemical process to recharge themselves with electrical energy. There are several types of lead-acid batteries, nickel-cadmium, and lithium polymer among others. They have improved their development and lowered their prices thanks to the...
development of cell batteries. They usually consist of a battery bank with a control system and an electronic inverter to carry power to the grid [20].

2.4. Electric vehicles

In Colombia the use of electric vehicles extends to few users, mostly vehicles operate with petroleum derivatives, to reduce the levels of CO$_2$ generation have been studied to improve the efficiency of combustion and use filters at the exit that trap the greenhouse gases.

Electric vehicles are more efficient than combustion vehicles. An example is the hybrid vehicle designed to operate on gasoline with an electrical storage system, despite charging more in weight (mainly due to batteries) than a normal vehicle, has a saving of gasoline [21]. This is explained because to vary the power of electric vehicles with AC generators it is enough to change their frequency and in DC with changes in the PWM bandwidth module [22], while mechanical vehicles require gearboxes, which means losing time between changes. In addition, these have technology based magnetic brakes that have two advantages: 1) they minimize the wear of their components due to the brake, 2) They store energy during the brake.

Hybrid vehicles combine the best of the advantages of electrical and mechanical technology, so they pollute in lower percentages, while electric vehicles connected to the V2G network operate only with electric power, these are non-polluting. To close the cycle and lower CO$_2$ levels, the energy with which electric vehicles operate must be supplied by non-renewable energies, however even when the energy comes from non-renewable energy sources there is a decrease in carbon dioxide due to its efficiency [14]. Figure 5 shows the percentage of CO$_2$ originated by transportation in Colombia.

In Figure 4 is evident that the production of CO$_2$ for Colombia in terms of electricity production is favorable, since it has remained fluctuating in the last 50 years. The global environment the generation of CO$_2$ due to the production of electricity was 28.56% and gradually increased to 49.04% by 2014. It also shows that most of the CO$_2$ generation is due to transport and not to the production of electricity.

![Figure 4. Percentage CO$_2$ emissions from transport in Colombia [23].](image1)

![Figure 5. Percentage CO$_2$ emissions from electricity and heat production in Colombia [23].](image2)

3. Management of SG

To manage the SG is used artificial intelligence, one of the components that are integrated are the intelligent measurement systems that have characteristics such as:

1. Digital telecommunications with security protocols.
2. Visualization of statistics and consumption forecast.
3. Economic calculation in real time.
4. Access to the electricity price market.
5. Integration of distributed renewable sources.
6. Data storage to integrate models of the network [2].

Artificial intelligence is achieved using heuristic algorithms designed to manage SG and smart homes, which have the following characteristics:
1. Información de frecuencia utilizando el aumento de inercia
2. Operar la red sin obtener beneficios para su administración.
3. Incrementar el ingreso de las empresas generadoras y reducir los costos para el usuario.
4. Operar la red en tiempo real con fenómenos de incertidumbre con respecto al pronóstico de carga, generación de renovables, planeación de viajes con vehículos eléctricos y el mercado de precios.

Artificial intelligence is achieved with heuristic algorithms, they allow the energy dispatch to make the best decisions; the characteristics of the winning VNS-DEEPSO algorithm of the competition "Evolutionary Computation in Uncertain Environments: A Smart Grid Application" of the world congress were presented on IEEE WCCI 2018 computational intelligence [11,13].

1. Buscar soluciones mejores para el SG. Basado en el mejor local optima que global optima, este cambio mejora la solución global.
2. Mejora el valor óptimo de funciones no-lineales y no-diferenciables, en caso de que exista no inercia en el SG.
3. Reducción del intervalo de incertidumbre para los casos de pronóstico de carga, penetración de renovable, variación de precios y planificación de viajes con vehículos eléctricos del SG.
4. Tiene poder adaptativo, inspirado en la evolución biológica como en reproducción, mutación, recombinación y selección, permite tomar la mejor opción en el SG.
5. Capacidad de explorar nuevos escenarios del SG.
6. Probabilidad de comunicarse entre un gran número de partículas para seleccionar el mejor escenario.
7. Número restringido de evaluaciones para que la decisión pueda ser tomada en un plazo breve (en tiempo real).

4. Conclusión

Traditional networks are migrating to smart electricity grids, Colombia, as a country with water wealth, has a favorable outlook for the reduction of environmental pollution. Transportation generates more pollution than the production of electricity; in addition, its percentage of participation has a growing trend over the years, so it is proposed the use of electric vehicles to mitigate these emissions. However, in order to obtain the expected impact, the renewable energy participation matrix must be increased. The SGs are proposed in the Colombian panorama with the purpose of improving the reliability during the provision of the service, favoring the end user with lower prices and encouraging generation with renewable energies. All this is integrated using the communications infrastructure in Colombia. The SG looks for competitive prices, so it incorporates consumption profile of users by habits and in a controlled manner, the electricity prices market and energy storage systems, this facilitates the flexibility of the energy dispatch to buy and sell electricity, to maximize network revenues and lower user costs. In addition, some essential components are analyzed, such as intelligent measurement systems, intelligent transformers and heuristic algorithms for the management of the SG.

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