Analysis of the Inclusion of Smart Grids Technology in the Colombian Electric Power System

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Abstract **– The incorporation of Smart Grid technologies into the national electric power system involves the updating and modification of operating characteristics, legislation and regulations, among others. This article initially presents an overview of the concept of Smart Grids and its relationship with Micro-grids Then, an analysis of the available potential energy for the implementation of renewable energy systems in the country is provided, and finally of the current policies related to Smart Grids and how they promote or inhibit the consolidation and development of these technologies are discussed. Additionally, a compilation of the most important projects related to the promotion and research of these technologies in others countries and Colombia is presented as well.**

Keywords – Energy policies, Micro-grids, Renewable energies, Smart grids, Colombian Electric Power System.

I. Introduction

THE steady increase in electricity use in Colombia, mainly due to the growth of cities, is a major challenge for the national electricity system, which requires the implementation of new projects of generation, transmission and distribution to meet the required demand [1]. A key strategy to meet this challenge is the development of Smart Grids (SGs), which are in the process of rapid global consolidation.

The SGs are intended to manage generation and consumption facilities for specific applications in order to supply energy maximizing available resources and integrating distributed energy resources (DER) from conventional and non-conventional generation systems [1].

Several research centers around the world have conducted numerous projects related to the development of the Smart Grid [2–14] as an initiative to address the problem of future energy shortage, particularly, because they promote the use of renewable energy, which also guarantees a reduction in the |environmental impact.

Given the strategic importance for a country like Colombia, the technological appropriation of this solution is necessary and can be undertaken by promoting specific applications that facilitate a process of learning, adaptation and implementation of Smart Grids.

However, significant barriers have been identified in changing the architecture of the grid and upgrading the correspondent legal and regulatory framework.

In order to provide an analysis that favors the identification of the key factors to achieve the stated objective, the following topics are presented in this paper: general concept of Smart Grids and Microgrids, availability of renewable generation in the country and existing barriers for penetration, a diagnosis of the correspondent current policies, a general review of Smart Grids projects at global and national levels, and finally, conclusions of the analysis.

II. Introduction To The Concepts Of Smart Grids And Microgrids

In this section the concept of Smart Grids and Microgrids are exposed. These concepts are closely related because the latter is a particular case of the first one, since the microgrids allow developing smart distribution systems that can be interconnected to form a much larger distribution entity. Thus, Microgrids are the heart of the Smart Grid providing the most added value in terms of efficiency and reliability. A Microgrid is also the part of the electric system where customers will interact with the Smart Grid [15].

A) Smart Grids

A Smart Grid is defined as "an electricity network which intelligently integrates the actions of generators and consumers connected to it in order to efficiently deliver sustainable, economic and secure electricity supplies" [5].

Also, the term 'Smart Grid' refers to the modernization of the electricity delivery system, from the central and distributed generator through the distribution system and high-voltage network . The development of the Smart Grid will involve numerous technologies, devices, and systems that will be deployed throughout the electric system to make the grid 'smart'. The automation of the transmission and distribution (T&D) systems will be critical for full smart grid deployment [15].

An operation scheme for incorporating these systems should be composed of small power systems that interconnects across the country [16]. These would change the current configuration of the grid and promote the emergence of new agents such as: combined consumers/producers and providers of smart-services [17], [18].

B) Microgrids

A micro-grid is defined as a power system of interconnected DER, storage systems, loads and other systems, that can operate connected or disconnected to the

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grid, to supply energy demand (electrical or thermal) with the least impact on the loads of local grid [19], [20].

These grids are composed of various types of DERs, generally based in renewable energy systems, such as photovoltaic generators, solar-thermal, wind, geothermal, biomass, tidal, micro-turbines and cogeneration systems, among others, whose implementation greatly depends on the energy availability on site.

A micro-grid also has a central control system that optimally manages the energy locally generated and consumed by the loads [21]. These grids also have an advanced metering infrastructure (AMI), based on information and communication technology (ICT), to measure power consumption in real time and to facilitate external control and monitoring of the behavior of loads [22]. The data collected by the AMI allow creating load profiles that underlie the design of demand response programs and contribute to fault management and power quality monitoring [23], [24].

One of the main advantages of using micro-grids is the increase of reliability and power quality because of its infrastructure allowing variable control of voltage and frequency, and storage of the energy generated by DERs.[25]. The energy excess can be sold to the grid, this represents a financial advantage in an appropriate legislative framework [17].

The current trend in the development of micro-grids focuses on the use of renewable energy generation, with the goal that between 80% and 90% of the energy consumed should be generated from these systems, leaving conventional generation for exceptional situations [19].

The micro-grids represent a possible solution to: (1) rural electrification, thus allowing the improvement of quality of life and economic development of millions of people [20], [26], (2) reduction in consumption peaks, (3) increasing energy efficiency in transmission and distribution systems and (4) integration of renewable energy, which results in reduced carbon emissions [11].

C) The grid of the future

Because national T&D networks were conceived in the sixties, they are rigid systems which lack of flexibility in their different stages making thus difficult to integrate distributed generation systems. Moreover, limitations in areas such as transmission facilities with bidirectional power flow capabilities and compatibility with new equipment also refrain the development of smart grids and micro-grids in the country [27], [28] .

The national distribution grid should allow in the future functionalities like: bidirectional power flow, instantaneous response to the failures before they affect the service, access to real-time information to the customers, communications that incorporate diagnostics and feedback to the system in order to prevent instabilities, disruptions and disturbances, integration of renewable energies and a safe and reliable service [29–31]. The challenge is then to design an intelligent, digital, sustainable and flexible grid [32].

This process of adaptation could be complex because it requires high investment to afford the system modernization and the adaptation and compatibility with the infrastructure still not modernized. In the future, the transmission and distribution grids must move from a passive and centralized system to a system composed by several sub-grids with active and controlled participation. [27].

The final consumer participation should become an integral part of the distribution systems. Using interactive tools, like interactive customer interfaces (ICI), allows the user to make decisions about their energy consumption according to the cost and demand at certain times, which reduces the distribution systems overload and generates cost and power consumption savings [6], [33], [34].

III. Availability Of Renewable Energy Resources In Colombia

Colombia is one of the countries with the highest energy potential in South America, due to its geographical and climatic diversity throughout its territory [35], [36].

This availability of energy resources could facilitate the incorporation of renewable energy generation market, diversifying the energy matrix [37], reducing the high dependence of the generation on fossil fuels, in addition to playing an important role in the energy supply in the non-interconnected zones [38].

In 2008 the country had an installed capacity of 13 540 MW, with 192 MW corresponding to non-conventional grid generation (PCHs, biomass and wind generation) [39]. In 2012, the country's installed capacity grew to 14 361 MW with a 2.07% increase in PCHs generation [40]. In Table I, a summary of the renewable generation technologies most used in the country is presented.

TABLE I
Most used technologies in the country [39], [41].

Renewable Energy Source	Installed Capacity	Transformation Technology
Solar Energy	9 MW*	Photovoltaic Solar
		Thermal solar Energy
Eolic Energy	19.5 MW	Aero-generation
Hydroelectric Energy	591** MW	PCH water-edge
		PCH with Dam
Biomass	26.9 MW	Anaerobic Digestion
		Gasification
		Combustion
Geothermal	0 MW**	Hydrothermal fluids
		Hot Rock and magmas
Ocean Energy	0 MW	Wave Energy
		Tide Energy

* Non-connected to the NIS ** in 2012

According to [42], the PV generation is estimated to be 9 MW, which corresponds to isolated applications for rural electrification and communications antennas. There is no report of large-scale photovoltaic generation connected to the network in the country.

This capacity is minimal compared with the generation potential in the north of the country, which could meet the energy demand of the country, according to [43]. The estimated generation could be over 21 GW.

An important opportunity to develop renewable energy in Colombia corresponds to non-interconnected zones (ZNI), which are not financially viable for transmission and marketing companies because of the large distances and low demand [44].

These areas are generally rich in renewable energy resources usable for local generation [45]. Currently, there are identified areas which provide the greatest potential for generating according to each type of technology, as it is shown in Table II.

TABLE II
AREAS OF THE COUNTRY WITH THE GREATEST ENERGY POTENTIAL [36].

Type of Energy	Area of the Country with Better Advantages
Solar Energy	Magdalena, La Guajira, San Andrés and Providencia
Wind Energy	La Guajira and San Andrés Island
Biomass Energy	The states of Santander and North Santander, the Eastern Plains and the Atlantic Coast
Hydropower	In order to generate this energy, dams should be built. This may include diversion of the course of rivers, flooding of arable land and displacement of people.
Ocean Energy	Colombia has an estimate potential of 30 GW in the 3000 km of coast
Geothermal Energy	The Chiles Volcanoes, the Azufral volcano, the Snowy Mountains National Park and the geothermal area of Paipa, Boyacá.

In the following, it is presented a description of the estimated energy resource available in the country for different generation systems:

A) Solar

In 1996, it was conducted the first study on characterization and main applications of solar energy in Colombia [46]. As a first approximation, the development of PV systems was characterized in the country, determining that most applications were isolated.

Currently, solar potential assessment in Colombia has been done mainly using information from weather stations, installed all over the country by the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) [37]. The most recent study corresponds to the Solar Radiation Atlas of Colombia, made in 2010, which includes an estimate of the radiation values for different cities [47].

However, there is a deficiency in the quality of information available, because of the density of stations in the Andean region is higher than in the North region, where the greatest potential is, so that the interpolation of radiation values is less reliable [37], [48].

Radiation available in the country varies depending on the region, on the Atlantic coast there is a potential of 5.5 kWh/m^2 per day , the country's largest, reducing gradually to the Pacific coast, where is about 3.0 kWh/m^2 [49].

Colombia is the country in the region with the best solar potential, averaging to 4.5 kWh/m^2 of daily radiation [35], [41]. In addition, it has been identified that in 87% of the 32 capitals, radiation varies between 4.5 kWh/m^2 and 5.5 kWh/m^2, so that the resource available is sufficient to implement photovoltaic generation in all the cities [50].

When comparing the average radiation of the country with the average global maximum, located in Saudi Arabia with a value of 6.8 kWh/m^2, it is observed that this varies between 84% in La Guajira and 54% in the Pacific Coast [47], [50]. Table III presents a summary of average radiation for some regions and departments in the country.

Since investment in PV systems decreases with the increasing average radiation in Colombian cities, it is more cost effective to install systems with these characteristics in the cities in the north than in the center regions [50]

TABLE III
AVERAGE RADIATION FOR REGIONS AND DEPARTMENTS IN COLOMBIA [38].

Region	Average Insolation [kWh/m^2/year]
Peninsula La Guajira	2 190
Atlantic Coast	1 825
Orinoquía	1 643
Amazonas	1 551
Andean	1 643
Pacific Coast	1 278

B) Wind

Wind energy is the source that could penetrate more easily in the Colombian electric system, because it has great wind potential, especially in the north of the country [51]. Estimates show a generating capacity close to 20 GW [52].

Furthermore, in the *Cabo de la Vela* and San Andres Island there is a power density estimated between 344 W/m^2 and 397 W/m^2, so that from the technical point of view, these areas are the most attractive for implementing wind projects [41].

La Guajira provides constant wind speeds and extreme winds infrequently near 18 m/s at 10 m height [53]. Comparing this wind resource with the one available in countries like Germany, which have winds of 8 m/s at a height of 80 m, it is concluded that the potential for implementation is higher in the country because if the height of the wind turbine tower is reduced, the financial viability is then increased [54].

Moreover, in these zones winds are complementary with the drought seasons presented in the country [51]. It has been observed by meteorological records made by the IDEAM, that during times of drought the average wind speeds are higher, thereby increasing the potential for generating [54]. This phenomenon would ensure the required energy demand in times of drought, taking into account that the highest percentage of generation in the country, that is 61%, is generated by hydropower energy [55].

C) Tides and oceans

Water mills are an alternative technology which has the advantage of improved energy density, because the water is over 800 times denser than the air [56].

In Colombia, the most promising ocean currents are the ones induced by tides. These currents are generated by the movement of the tidal wave, this means that in bays with narrow mouth, high speeds occur that can be exploited [57].

Different estimates has resulted in 45 possible bays in the Pacific Coast with an energy potential estimated at 120 MW with speeds estimated at 2.56 m/s, compared to the Atlantic coast, where the speed is estimated at 1.2 m/s, because most bays are of greater amplitude [56], [57].

D) Geothermal

Due to his geographical position, located exactly on circum-Pacific belt, Colombia is one of the most attractive countries for the exploitation of geothermal resources, however, high exploration costs make this technology financially unviable at the moment in the country [41].

The Institute of Planning and Promotion of Energy Solutions for ZNI and the Latin American Energy Organization identified three areas for the development of geothermal energy projects in the country. These areas have temperatures between 220 ° C and 230 ° C at a depth from 5 km to 10 km. However, there is not a study to estimate the potential for generation of these already identified areas [39].

E) Biomass

The biomass generation projects can be classified, according to the nature of the waste, in animal or vegetable, also, according to the generation process, in anaerobic digestion, gasification and combustion, the most developed in the country [41].

The Mining and Energy Planning Unit – UPME in 2003 identified a potential of 16 266 MWh/year of primary energy with 658 MWh/year of fuel oil, 2 640 MWh/year of fuel alcohol, 11 828 MWh/year of crop residues and agro-industrial, 442 MWh/year of waste from planted forests, and 698 MWh/year of natural forest residues [39].

Recently, it has been developed, in conjunction with the Universidad Industrial de Santander, the first Atlas of Biomass Waste of the country, as a first attempt to identify this potential and encourage its development in the country [58].

IV. Penetration Barriers Of The Renewable Energies Generation Sources

The generation of renewable energy in urban environments is a trend in countries with intense development in micro-grids, mainly of small PV systems (<5kW). In Colombia this practice is almost inexistent, indicating a precarious development of micro-grids.

This is paradoxical because, as [59] exposes, Colombia has a significant energy potential of non-conventional energy.

Such situation is mainly due to two barriers, the lack of financial competitiveness and the still incipient regulatory framework. These barriers can keep reduced the penetration of renewable energies in the country in the long term [36], [55].

In Colombia, the renewable generation projects are characterized by high investment [60], which ranges from USD$ 1,5 to USD$ 7,0 per Watt installed, according to the used technology; also, the variability of generation due to the climatic dependence increases the investors´ risk perception [37], [43].

On the other hand, the lack of regulatory provisions is evidenced by the absence of financial incentives and studies about bidirectional flow regulation and recognition of potential customers as small generators (special case of generation distributed), among others.

A special issue that can limit the government support for promoting major projects is the potential reduction of costs of energy generation by coal based in processes friendlier to the environment, this would give a privileged position to this technology in a country with high coal production [59].

A strong constraint on the development of distributed generation projects corresponds to the reliability charge, which is the compensation paid to a generator for the availability of its assets; that warranties the fulfillment of the obligation of firm energy (maximum electrical energy that is capable of delivering a power plant continuously in unfavorable conditions for one year) [61].

As wind and PV plants reduce their generation during certain periods, this parameter implies that the income would be negligible in the remuneration of the plant [42].

The circumstances mentioned do not yet allow the diversification of energy matrix of Colombia [55], [42]. However, there is an opportunity for theses energy systems in non-interconnected zones. These efforts are led by the Institute of Planning and Promotion of Energy Solutions for non-interconnected areas [60].

V. Current Policies Related To Renewable Systems

In Colombia, the legal and regulatory framework for the rational use of energy is based on the Law 697 of 2001, which declares it as matter of social and public interest. It is promoted by the Program of Rational Use of Energy and other forms of non-conventional energy [62], [63].

This law states that the Ministry of Mines and Energy should develop polices, strategies and instruments for the promotion of the use of non-conventional source with priority in non-interconnected areas. Though such guideline does not yet achieve to produce a large scale impact, it is seen from 2010 a progressive advance in this field [42].

An effort to promote non-conventional generation sources corresponds to the Law 788 of 2002, which exempt of taxes to the investors during 15 years for sales of electrical energy obtained from biomass, wind and agricultural wastes, whenever they meet with the certificates of reduction of emissions by the Kioto Protocol, and the half of the incomes is invested in social benefit projects, such as in the Jepirachi Wind Park [64]. However, this law does not include PV systems, this being regressive given the popularity of this technology and the solar potential in the country.

In order to facilitate the development of generation projects, in 2003 it was created the Intersectoral Commission for the Rational Use of Energy and Conventional Energy Sources. This organization is headed by the technical committee of the UPME, this is supported on the Energy Regulatory Commission and Gas – CREG [42], [65].

Now, within the current regulatory framework for urban environments (residential, commercials and/or industrials), there is a set of decrees and resolutions ([65–75]) that exposes guidelines on the promotion and use of renewable energies; nevertheless regulative provisions are not still evident. Currently, the UPME develops technical studies for the CREG whit the purpose of establishing the regulation to facilitate the distributed generation based on PV and cogeneration systems [59].

While these regulatory advances are given, in [59] is mentioned that it is necessary to develop demonstrative projects in order to leverage the technological settlement.

VI. Current Smart Grids Projects in others Countries

For more than a decade different types of projects related to the development of Smart Grids have been conducted worldwide. These projects have been funded and implemented by government agencies, universities, research centers, utilities, system operators, and all stakeholders related to these technologies. Below it is presented a summary of some projects by country.

A) Australia

The government of Australia has invested over US$100 million in research projects. Energy Australia was selected to lead a Smart Grid study that included the construction of five of these grids in New South Wales with partners like IBM, Grid Net, GE Energy and an USA Based energy software company [2].

B) Brazil

Since December 2012 to August 2013, Brazil will develop a project between Swedish and Brazil stakeholders to explore opportunities for development of sustainable urban smart grids in Brazil.

The consortium is formed to: (1) Identify potential technological and institutional solutions aiming to the development of smart grids for urban areas in Brazil, (2) Identify a concrete pilot area that serves for developing an implementation project, and (3) Increase the understanding about conditions for development of smart grids and smart grid-based products and services aimed to the Brazilian market.

The initial partners are: The Royal Institute of Technology (KTH), Volvo IT, Swedish Aerospace and Defense Company (SAAB), Federal University of Minas Gerais (UFMG), São Paulo University (USP), The Swedish Governmental Agency for Innovation Systems (VINNOVA) and others [3].

C) Canada

The government of Ontario in 2010, through The Energy Conservation Responsibility Act, ordered the installation of Smart Meters in all Ontario businesses and households [2]. Other important policies in the province of Ontario that have transformed the power sector are: The Green Energy and Green Economy Act (GEGEA) in 2009, which commits on conservation and demand management (CDM), renewable generation, and the comprehensive development of a Smart Grid and Ontario policies to shut down coal plants by 2014 and achieve 1 in 20 passenger vehicles to be electric by year 2020 [4].

D) China

As part of a five-years master plan, China built a Wide Area Monitoring System (WAMS) and implemented Phasor Measurement Units Sensors (PMUS) in all the 300 MW and above generators , and all 500 kV substations[2].

In 2008, Shanghai Municipal Electric Power Company launched the research of intelligent distribution network focused on aspects like: smart metering, real-time data management and visualization technology, Energy Storage technology and application and integration of large-scale renewable energy power and DERs [5].

E) Finland

The Tampere University of Technology through the Technical Research Centre of Finland (VTT) and different electricity companies has initiated a Project aiming to identify and demonstrate the concept, function and technological solutions of the Interactive Customer Interfaces (ICI).

Simulations and demonstrations are developed to verify the benefits of the ICIs from the network management and electricity market point of view [6]. The Green Campus Smart Grid project (GCSG) implements the Smart Grid concept into an existing low voltage customer network in Lappeenranta University of Technology. The Smart Grid consists of DG-units, energy storages and controllable loads [7].

F) France

Integration and Optimization of Distributed Generation, Demand Side Management and Renewable Energy Resources, PREMIO, is a three-year demonstration project on Smart Grids in France co-funded by the Region Provence-Alpes-Côte d'Azur (PACA) and launched in 2008 with the principal objective of demonstrating an innovate, open and replicable architecture of a Virtual Power Plant (VPP) to optimize the integration of Distributed Generation (DG), storage and Demand Response (DR) and energy efficiency strategies to relieve stress on the local electrical power grid by providing peak shaving, load leveling and to reduce CO2 emissions [8].

G) Greece

The National Technical University of Athens installed a Microgrid in the Power System Laboratory which includes a modular system, PV generators, a battery bank, interfaced to the AC system via bi-directional PWM voltage converter, and a connection to the local LV grid. This Microgrid is employed to research about function scenarios and multiagent system (MAS) for the control of this kind of grids [21].

H) India

North Delhi Power Limited (NDPL) is a Joint Venture created between Tata Power Company and the government of Delhi, which has announced the development with GE Smart Grid Technologies of the first distribution utility in India aiming to research in an advanced Outage Management System (OMS) [2].

The City Electricity Distribution Automation System (CEDAS) has funded more than US$150 million and have been linked utilities as The Bangalore Electricity Supply Company (BESCOM) and Andhra Pradesh State Electricity Board (APSEB) [9].

I) South Korea

The government of South Korea launched a pilot plan of US$65 million, which included major players in the industry, with the aims of integrating a Smart Grid for 6000 households, wind farms and four distribution lines [2]. In 2006, Korea Electric Power Corporation (KEPCO) had determined to cluster a total of 190 branch offices for establishing a center based large scale direct operation system and an advanced distribution operation environment [10].

J) Spain

The Catalonia Institute for Energy Research (IREC) installed a low voltage 200 kW Micro-Grid composed of emulated systems (wind power, battery, load, PV and nonlinear loads emulator), real systems (Urban windmill, PV generator, lithium-ion battery storage, ultra-capacitors storage), semi-emulated systems and other systems (power grid emulator, fast disturbance emulator and compensation system) [11].

K) Portugal

InovGrid is a project of The Portuguese Distribution System Operator which has three pillars: (1) Smart Metering, designed to implement system-wide Automation Meter Management (AMM) capabilities; (2) Smart Grids, aimed at improving the efficiency and reliability of the grid through the introduction of a new level of intelligence on its management systems; and

(3) Micro generation, consisting on the adaptation of the grid to the growing demand for the connection of DERs [12] .

L) United Kingdom

AuRA-NMS (Autonomous Regional Active Network Management System) was a three years research and development program that involves seven UK universities, two distribution network operators and a major manufacturer with the aim of developing and demonstrating a "smart" active network management system [13].

M) United States

Since the emergence of the Energy Independence and Security Act of 2007, support for Smart Grid research projects from 2008 to 2012 has received funding of over US$100 million. The law also establishes a matching program to states, utilities and consumers, in order to build Smart Grid infrastructure and create a Grid Modernization Commission to assess progress and funded projects and to recommend needed standards [2].

Through the American Recovery and Reinvestment Act, the U.S. Department of Energy (DOE) and other funding agenices have initiated 99 Smart Grid Investment Grants and 41 Smart Grid demonstration Projects [14].

VII. Current Smart Grids Projects in Colombia

Several studies have focused on the development and the implementation of the Smart-Grids in the country, Table IV shows a short description of them.

TABLE IV
PROJECTS THAT STUDIED THE IMPLEMENTATIONS OF SMART-GRID IN COLOMBIA.

Project	Characteristics
Model of Application of Distributed Generation in Colombian Rural Zones [38].	This works analyzes the impact produced by the incorporation of renewable energiy generation in a hybrid model in rural residential areas in the country.
Evaluation of methodologies for remunerating wind power's reliability in Colombia [43].	This work analyzes three methodologies currently used in energy markets around the world to calculate firm wind energy capacity.
Large Scale Integration of Wind Energy in Colombia: Electrical Analysis-Part I [51].	This work analyzes the technical and economic implications of the penetration of wind power in the Colombian Interconnected system (SIN).
Large Scale Integration of Wind Energy in Colombia: Electrical Analysis-Part II [52].	In this second part, the same group of wind farms was employed, while dynamic models were fit to ensure the proper operation of controls against the contingences.
The assessment of wind energy projects in Colombia under the real options approach [76].	This work concluded than wind projects would not be considered viable through traditional valuation methods.
Optimal Operation of Microgrids in the Colombian Energy Market [77].	This work investigates the optimal operation of a microgrid in the Colombian energy market.

These projects have analyzed various technical requirements, which must be updated for the introduction of the new systems in the national grid, as well as the modification of the regulation, among others.

Recently, in 2010, and with the same purpose, it was conducted the first Workshop in Medellin, Colombia related to the implementation of the Smart-grid in the country. This event studied five specific areas: transmission, generation, distribution, consumption and support areas (regulations and standards, communications systems and human resources).

Following similar international experiences, this event structured a proposal for the roadmap for the development of this technology in the country, identifying implementation challenges, and developing the initiative Colombia Intelligent (CI) [78].

The main objective of such a proposal is that Colombia achieves high efficiency in the implementation of best practices in the use of energy efficient solutions. It was also conceived the National Smart Grids Program, which supports the development of projects in the framework of the CI [79].

With respect to wind generation, as shown in studies [51] and [52], some technical challenges to interconnect the various wind farms planned to be built in the north would have to be overcome, especially in terms of the stability of the connection, for proper operation. These studies are consequences of putting into operation the only wind farm in the country, the park Jepirachi, which has an installed capacity of 19.5 MW, generating 50 GW annually [43].

In terms of PV generation, the first prototype with grid connection of a PV system was installed at the *Universidad Nacional* de Colombia in 2004. This application uses virtual instrumentation to acquire and explore the system performance data in order to monitor the behavior of the generation system [80].

Another important PV generation system is located on the campus of the *Universidad Autónoma de Occidente* in Cali [44]. The acquisition of this equipment is part of the research carried out in this university to support new technologies for power generation in Colombia.

Similarly, the Universidad Industrial de Santander presents the design of two micro-grids connected to the grid that will reduce its consumption [81]. These micro-grids are composed of a photovoltaic system installed on the main campus located in Bucaramanga [82]. Moreover, the Energy Integration Laboratory, which will be the basis for the study of the integration of micro-grids with low voltage grid, is now projected by the *Grupo de Investigación de Sistemas de Energía Eléctrica*, GISEL [83].

Other notable projects are the AMI project developed by Emcali, Electricaribe, EPSA and EPM; and the workshop Technology Smart Grid Implementation in the Colombian electricity sector [84].

The project: "Towards a smart city: the design of a smart micro-grid pilot phase III", which aims to design a smart grid pilot in a circuit from CODENSA or on the campus of the *Universidad Nacional*, includes distributed generation applications, storage, energy efficiency, advanced metering, demand response and electric vehicle technology support tools like control, telecommunications, information and data management is being jointly developed by: The Universidad de los Andes, the *Universidad Nacional*, the *Pontificia Universidad Javeriana*, the *Universidad Industrial de Santander*, the CIDET in association with CODENSA and COLCIENCIAS.

VIII. Conclusions

Colombia has a great potential for generation from renewable energy sources that could supply much of the energy demand. This would diversify its energy matrix and allow addressing changes in prices and availability of energy from conventional sources. For now, these resources are not significantly utilized, partially due to the lack of a promoting legislative framework.

Based on the consulted international experiences, it is established that the consolidation of technological applications such as Smart Grids and Micro Grids requires a legislative framework to ensure its development; guidelines from the joint participation of universities, utilities, private companies and stake-holders related to the electricity sector; and also provisions to actively integrate these technologies into the national electricity system.

Currently, there are not commercial projects to implement technologies related to Smart Grids and Microgrids in the country. The projects are developed under initiatives from universities in order to support and encourage their development in the Colombian electricity system. It is expected that these pilot projects to stimulate investment.

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