Characterization Model of Smart Grid in Colombia

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Abstract— **Electric energy has been gaining importance for its role in the competitiveness, productivity and economic development of modern society; consequently better and more complex energy systems are required. Additionally, new industry requirements have to be met with limited energy resources. These challenges promote the development of smart grid projects towards guaranteeing quality, reliability, sustainability, security and efficiency of power supply, while reducing environmental impacts.**

Colombia is currently evolving its electricity sector modernization through a substantial number of initiatives. However, there is neither an inventory that shows the current state of the practice of smart grids in the country, nor a strategic framework or a roadmap to visualize where the country should be heading. To resolve these uncertainties, it is necessary to have tools and methodologies that give complete and reliable information about smart grid projects. These tools should provide a framework based on the Colombian context and useful reports to define technological strategies for implementing smart grids at an enterprise, regional and national level.

Under these premises, an analysis model is proposed to identify the stage of implementation of smart grid projects in Colombia. The main feature is the integration of a reference model applied to technologies and another model, which is an adaptation of the Smart Grid Maturity Model of Carnegie Mellon University modifying it from the corporate point of view to a focus on projects

The application of this model is expected to result in a baseline that helps with gap identification and the development of roadmaps that would outline a vision for transition to a smarter electricity system in Colombia.

***Index Terms*— Smart Grid, Maturity Models, Analysis Model**

I. Introduction

The growth of global population is a phenomenon that affects multiple aspects of every nation's development and its consequences could be catastrophic. Particularly in the electric sector, population growth, hand in hand with industrial growth, have resulted in projections that predict a continuing increase in energy demand [1]. This becomes critical when it is faced with a shortage of non-renewable natural resources, which calls for alternative and sustainable energy sources, in addition to the constant pursuit of energy efficiency in all stages of the electricity value chain. In this sense, the modernization of the electric power system is imperative to obtain better systems and processes, from electricity producers to end users, that would make it possible to take advantage of available resources more efficiently, to have real time management of power flows, provide bi-directional metering and offer consumers more energy options [2], towards to optimize generation, transmission and distribution systems and additionally, introduce the consumer as an active user.

Smart grid is one response that has emerged to solve the problem of modernizing power systems. Currently, many countries have joined a revolution in the production and management of electrical energy, developing smart grid initiatives with different objectives, expectations and results, to contribute to the modernization of power systems. Technological developments in this sector have resulted in an increased number of smart grid projects, which are progressively more complex and ambitious.

The need to identify the current maturity stage of smart grid in Colombia becomes evident. Therefore, this paper proposes an analytical model to characterize the smart grid in Colombia.

The first part of this paper presents a framework that introduces the concept of smart grids from a systemic perspective and it facilitates the visualization of the topics needed to characterize the degree of implementation of smart grids within a regional context by exploring academic trends and specific studies from different regions.

The second part consists in the Analysis Model. The Model is focused on projects and it requires project specific information, which is collected through a structured survey. After the information is collected, it is processed and analyzed, and then, it presents the results. This facilitates the interpretation of data and drawing up conclusions, and helps identify significant technological strategies for any given region.

Finally, the paper presents the conclusions and areas that are beyond the scope of this study and could be covered in future work.

II. Framework

First, to characterize the smart grid status in Colombia it is necessary to know about state of smart grids in the world: the leading countries, their proposals, investigations and

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publications. All of those could be a base reference to study smart grids in Colombia.

A. *State of the Art of Smart Grids*

An analysis of the state of art of smart grid was made using a data mining software which considers 639 journal publications from Scopus data base. Articles published up to September 4th, 2012, where considered on this search. Figure 1 shows that the USA's leadership with 211 smart grid related publications, which is 33% of the 639 searched articles. USA has two times more articles than the next country in the list, China, which has 16% of the publications. Colombia has three articles which place it 28th out of 57 countries and second in Latin-America after Brazil.

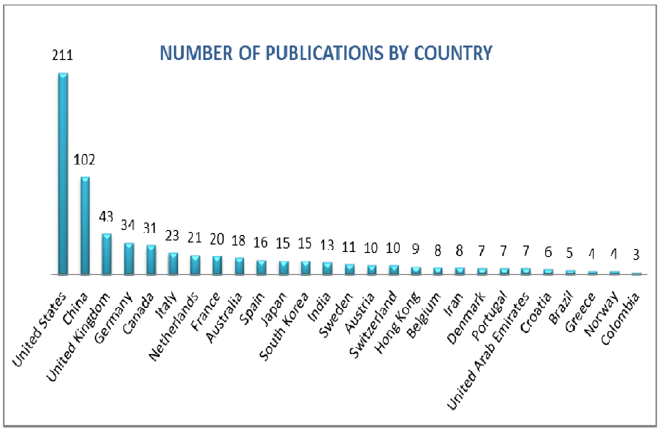

Figure 1. Countries leadership in smart grid.

Figure 2 shows how smart grid is a recent concept and it shows how fast the number of studies are growing. There are 64.5% more articles in 2010 than the year before. 2011 had the greatest number of smart grid publications with 236 out of 639, which is 37% of the articles in all years. During 2012 (up to September), 125 articles were published, 53% of the 2011 publications.

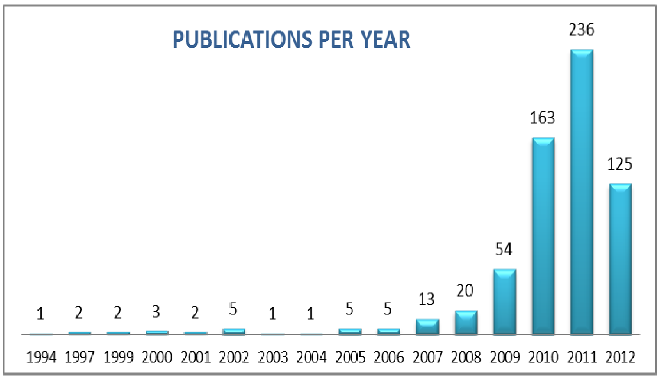

Figure 2. Smart grid publications across time

Because smart grids are gaining importance worldwide and currently Colombia is one of the leading countries in the Latin American electrical sector it is important to keep encouraging the research and applications of the new electric system.

B. *Smart Grids in the European Union*

The European Union (EU) is composed of first world countries and as a region it is one of the leaders in implementing smart grid projects. EU has defined objectives, research topics and activities needed to have a smart electric system by 2035 [3].

The EU strategy starts by tracking the smart grids regional perspective through an inventory of projects, investments and budgets in different smart grid categories. This allows for evaluating the maturity of the projects and classifying them in investigation, pilot and implemented stages. Using project tracking methodologies it's possible to identify the direction that the smart grid development is taking; and the people and the utilities that are researching and investing in the subject.

The methodology used was to conduct a survey [4]. It was distributed to organization and companies and more than 300 projects responded [5]. The responses were filtered and 219 projects were used to make a database that shows the current state of smart grid development in Europe. The description of each project and its details are shown on a EU map [6].

The EU program is an example of the global trend towards smart grids, which is led by the largest economies in the world. The EU survey demonstrates the importance of understanding the current Colombian smart grid projects status as it will be required to , propose guidelines, technology roadmaps and to direct future researches and investments.

III. Maturity Models

Institutions and consulting organizations have developed models such as General Electric's "Proficy Grid Manager"[7] [7], the Siemens "Smart Grid Compass" [8], the Smart Grid Maturity Model [9] and " A Reference Model for the Electrical Energy System Based on Smart Grids" [10]. These models are designed to provide solutions to different business objectives through strategic implementation of smart grid, implementation diagnostics and evaluation of existing systems and thereby determine the best alternative technology for system modernizations.

An analysis of the mentioned models was conducted in the article: "Modelos para Medir el Grado de Madurez de las Redes Inteligentes" [11], in which SGMM was identified as a complete and detailed model that involves and describes a large number of features. Therefore SGMM was chosen as the base for developing a project oriented model to evaluate the state of smart grid in a region.

A. *Smart Grid Development Model*

This model is a tool that provides a framework for determining, based on the approach and vision of projects, a diagnosis of smart grids development. The model application provides analysis, projections and alternative perspectives if required. It also offers a context for determining future strategies and work plans for smart grids.

Smart Grid Development Model (SGDM) is project oriented and it is a capability model because it is not necessary to implement the characteristics of the levels in their strict order

[12]. SGDM was created based on SGMM which is a maturity model and it is tailored for utilities.
The Smart Grid Development Model contains seven areas, which cover smart grids extensively, and five stages of development, which define progress toward a smart grid system.
The stages of development represent a state of progress toward full implementation of a smart grid system. Area stages are completely independent from the rest. A project can be focused on one or several areas, and it could be at different stages of development in each of the areas.
Each area is normalized in three main features; each feature is independent of the other. The characteristics together form the description of a specific area in each stage of development. The model is then defined, for a total of 105 features, which cover the subjects of smart grid systems.
The stages and areas of the model are described ahead.

Stages of Development

Features and capabilities expected of the projects in each stage of development in each area of smart grids. The characteristics of each stage of development are summarized in Table 1 shown below.

STAGE	DESCRIPTION
Stage 1: Initiation	Smart grid initiatives deployment in any area. Stage one is achieved in an area when it has taken the first steps towards grid modernization.
Stage 2: Implementation	Implementation of projects that achieve and maintain certain grid modernization.
Stage 3: Integration	Smart network projects and processes that are integrated into regional development.
Stage 4: Optimization	Projects integrated into the grid looking to improve processes, expand coverage and increase profits.
Stage 5: Leadership	Innovation projects, new technologies, methodologies and processes. Leadership programs in the state of practice of smart grids.

Table 1. Stages of development

Areas

Groups of features and capabilities related to smart grid systems, which could define the state of a progress from conventional grid to smart grid. The areas of the model are described in Table 2, with an overview of the capabilities that encompasses each one and its expected features, which are standardized to just three for each stage of development.

AREA	DESCRIPTION
Strategy, Management and Regulation (SMR)	Vision and strategy to achieve a smart grid system. Management and regulation processes development, norms communications, and incentives promotion for the implementation of smart grid related topics.
Organization and Structure (OS)	Promotion of a smart grid culture, by training interdisciplinary staff and by knowledge management. Identification of opportunities in order to ensure a proper smart grid structure implementation is achieved. Links between strategies and results are made explicit.
Grid Operations (GO)	Skills required ensuring a reliable, secure and efficient system operation. An automated, flexible and adaptive grid operation is able to support the smart grid objectives.
Work and Asset Management (WAM)	Information technology uses for asset and work resources (personnel, equipment), location, monitoring and management.
Customer (CUST)	Customer active participation in the electric system, obtaining the benefits offered by the smart grids; visibility and load control; possibility to choose the energy provider according to the prices and market availability. Introduction of electric vehicles to the system.
Value Chain Integration (VCI)	Interaction among the electrical supply chain agents to achieve a functional and efficient smart grid system. Use of new technologies and processes in the whole value chain, to provide smart grid characteristics, development opportunities and competitiveness.
Society and Environment (SE)	Social and environmental objectives by achieving a reliable and secure system, integration of alternative and ecological energy sources and reduction of environmental impacts by infrastructure as well as consumption. Information supply for a better decision making process, promotion of renewable and distributed sources. Integration of regulatory entities, utilities and communities to promote benefits for all, better quality of life and reduced environmental impact.

Table 2. Description of the areas of Development Model

B. Reference Model [10]

The model proposes to evaluate technology associated with smart grids by an intelligence levels path to be followed by electrical networks to become self-sufficient. It features an emphasis on the development of architectures for efficiency, flexibility and sustainability over time.
Taking the OSI communications model as a reference, the grid would have seven layers described below in Table 3:

LAYER	DESCRIPTION
Physical Layer (P)	Physical elements of power system and analogic devices. E.g.: generators, power lines, transformer, protection equipment, common meters, transductors, etc.

Interface Layer (If)	Connection and data transference between physical elements and the higher layers. Analog/digital devices. E.g.: sensors to digitalize operational variables (voltage, current, etc.), PMU (Phasor Measurement Unit), IEDs (Intelligent Electronic Devices).
Communication Layer (C)	Components for data Exchange between smart grid elements and communication mechanisms, such as protocols. Support devices, such as routers, multiplexers. Optical fiber, wireless signals and power carrier line for digital data transmission.
System Layer (S)	Devices and applications for data sampling from the communication, interface and physical layers. Data storage and processing basic functions. Alerts, events and register generation. E.g.: SCADAs and MDM (Measurement Data Management).
Model Layer (M)	Abstract representation of the system, communication, interface and physical layers set; such representation is intended for later analysis and simulations. Modeling languages, like UML (Unified Modeling Language), are used for documentation. E.g.: CIM (Common Information Model) and the IEC61850 standard.
Analysis Layer (A)	Functions and applications to support the operator decision making processes. It uses the historical and real time data which are generated by the system layer. E.g.: a State Predictor uses data from a SCADA system to perform calculations and estimations and to help the network operator with consistent data bases. Such data supports the later processing done by the Contingency Analysis and Power Flow.
Intelligence Layer (I)	It is the higher level of the Smart Grid Reference Model. Advanced data processing applications, data mining, process automation with no human intervention. Data sampling from applications and complex systems, to transform such data into information and decisions. It supports the typical applications of smart grids: self-recovering, automated grid operations, advanced adaptive protection.

Table 3. Model reference layers

IV. Analysis Model for the Characterization of Smart Grids in Colombia

Analysis Model for the Characterization of Smart Grids in Colombia, aims to diagnose the current state of smart grids in Colombia with a project inventory. The methodology for making the model has three phases: general data collection of projects in smart grid subjects, information analysis using classifications and models, and finally, the results presentation in graphs, tables and maps.

The analysis of the obtained data is done through the integration of two models: Smart Grid Development Model and Reference Model, which complement each other. The first covers the areas that impact the implementation of smart grids, while the second focuses on intelligence, autonomy and automation technology related to smart grid.

A map of analysis model for the characterization of smart grids is shown in Figure 3. It gives an overview of the content of the analysis model, which will be deployed later.

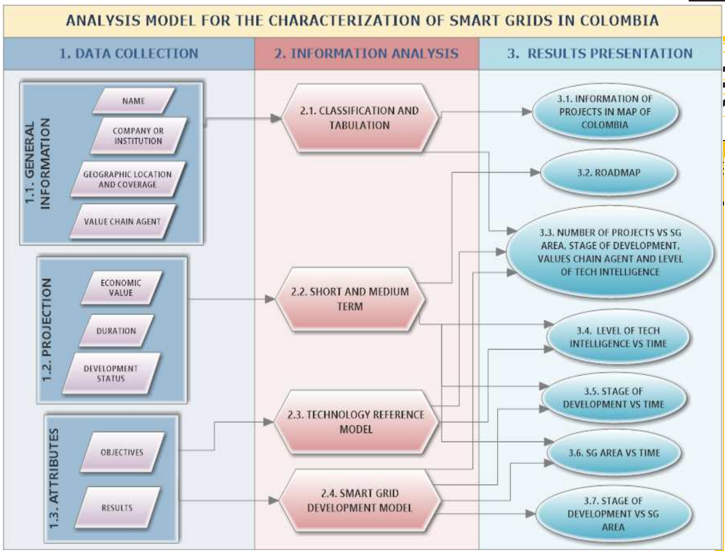

Figure 3. Analysis Model for the Characterization of Smart Grids in Colombia

1. Data collection

The first step in constructing the analysis model is the collection of primary information from implemented, being implemented or planned projects on different smart grid subjects in Colombia. Similar to the EU practice, a survey is proposed as a data collection tool.

The survey is focused on projects and filled out by those institutions or utilities in charge of projects. It covers three broad aspects: project general information, projection and attributes.

1.1 General Information

Collection of basic data for identifying projects, such as: name, utility or institution in charge, the location and the energy value chain agent in which they apply.

- Name: basic header to identify the projects.
- Company or institution: universities, organizations, institutions and utilities related to electrical sector or smart grids. These entities are classified according to their responsibility within the project:
  - Executor (s): organizations responsible for developing the project.
  - Beneficiary (s): entities that receive the benefits of the project.
  - Sponsor (s): organizations that subsidize the project.

A single entity can belong to multiple classifications at a time.

- Geographic location and coverage: location of the organization in charge of the project and where the project is developed.

- Value chain agent: spot the project subject within the stages of the electricity grid: generation, transmission, distribution, marketing, network operation and customer. A project may take one or several links at once.

1.2 Projection

The projection is constructed based on time and budget assignment for the project. Each project is classified according to cost, duration and development.

- Economic value: money resources assigned to the planning and execution of the project. This item provides information on the investment that is being made in the field nationwide. The amount is specified in three intervals: small value (0 to COP 100 million), medium value (COP 100 million to COP 500 million) and high value (COP 500 million and up).
- Duration: time estimate for project implementation. The projects are classified according to their duration short term (0-2 years) and medium term (2-5 years). For temporal analysis and to categorize the projects in short and medium term intervals, it is essential to know the stipulated start date and end date.
- Status: the implementation phase in which the project resides. Phase options are: project planning (with approved budget), execution or finished.

1.3 *Attributes*

The attributes of the projects such as the objective and results, characterize and provide information on the topics covered, the technology involved and the level of complexity to be developed.

- Objectives: description of the solution to the problem or situation that is to be covered. What is desired to be achieved with the project development and what is the methodology to be implemented: procedures, tools, technologies, etc. For projects that involve smart grid technology, the survey was expanded with seven questions that will give the base for the diagnosis of the technological intelligence level of each project.
- Results: project products such as documents, prototypes, programs, among others, which materialize the objectives and realize the scope.

  By interpreting the results, the areas of Development Model are identified in each project, which could be one or more. In the survey the seven previously defined areas are described.

2. Information analysis

The second phase of the model is the data processing. The information collected through the survey is stored, organized and classified in tables. Then it is analyzed and processed using two models, the Reference Model and the Smart Grid Development Model.

2.1 Classification and Tabulation

Project database which includes general information: name, affiliation, position in the value chain. Project information is organized and available for presentation purposes.

2.2 Short and Medium Term

Project is classified into short term and medium term depending on length and stage of the project. Assigning economic value to the respective ranking (small, medium and high value) in order to project investments in smart grids.

2.3 Reference Model

Application of Reference Model described above. Projects with smart grid technology are evaluated under this model, which assigns a level of intelligence between 1^{st} to 7^{th}. The seventh level is the highest with the technology independent and self-sufficient.

2.4 Smart Grid Development Model

This model was previously described in this paper. It is project oriented and it is focused on seven areas: strategy, management and regulation; organization and structure; grid operations; work and asset management; customer; integration value chain; and society and environment. Each of the areas is measured in five stages: initiation, implementation, integration, optimization and leadership, each of them with three items. The projects are located in one or more areas and at a stage of development corresponding to the area. One project could be in multiple areas and could be at different stages in each area.
The Model is proposed as a tool to identify the current and projected status of smart grids in Colombia, through the evaluation of projects in different areas described therein.

3. Results

Once the information is collected, stored, classified and analyzed, it proceeds to the presentation of the obtained results. The processed data are shown on maps, charts and graphics, which allow for conducting analysis and providing feedback to improve processes and find new opportunities.

3.1 Information of Projects on Map of Colombia

The smart grid projects are demonstrated on a map of Colombia, where one could view the general information of projects, in order to have a consolidation project database and an application with easy access and interaction.

3.2 Roadmap

A roadmap could provide information about the state of art of implemented smart grid projects. It's a projection of the future considering duration and stages of underway and planned projects.

3.3 Number of projects vs. smart grid area, stage of development, value chain agent and level of technology intelligence

Based on the data obtained by applying the Reference Model and Smart Grid Development Model, different graphics are made in order to present the state of the smart grid in

Colombia. The graphs show the number of projects that have been developed or are being implemented in a specific area of the smart grid and the link in the value chain. In addition, projects are consolidated regardless of the area or unit of the chain, and they are quantified by levels of intelligence and development to get an overview of the state of smart grids in Colombia.

3.4 Level of tech intelligence vs. time

The analysis of smart grid projects results in a temporal projection of technology intelligence level graph. It shows the evolution of the technology in Colombia over time.

3.5 Stage of Development vs. time

The construction of this graph aims to show the stages of the development behavior over time, to achieve a functional system in smart grids. The graph shows the diagnosis of smart grids condition through years: how it was, how it is today and how it is being projected.

3.6 Stages of development vs. smart grid area

This graph provides a complete visualization of the level of development of smart grids in Colombia in each of the areas. The graph is made with survey data that was previously collected and processed and it allows for analyzing improvement opportunities and tracing investment plans.

V. Conclusions

The presented model evaluates projects in all smart grid subjects, using the areas of Smart Grid Development Model and The Reference Model. The results obtained could be measured and represented in graphs to make projections and analysis. Hence, it is possible to show a perspective on investigated areas, developed topics and gaps that need further study.

This paper's results represent the first nationally structured proposal, to identify the current state of smart grids in Colombia holistically by evaluating projects, this provide the first step to improve the structure of implementation plans towards obtaining smart grids system.

The article presents a reliable method as it's based on a established maturity model recommended by power utilities worldwide. Also, the use of a project oriented survey methodology was applied by one of the leading regions in smart grid implementation, the European Union, to identify its current state of implementations.

The Smart Grid Development Model part, although is based on the SGMM, is conceptually designed in a different way. The Smart Grid Development Model's structure to evaluate and diagnose smart grids from projects, its characterization of the areas and stages, and the standardization in three capacities per stage in each area, make it an innovative initiative for the analysis of maturity in implementing the smart grid concept.

VI. Future works

The application of the analysis model which involves completing all phases: conducting survey, data processing and presentation of results are proposed for future work.

To ensure sustainability and flexibility in the application of the proposed analytical model, the need to design and implement an information platform system with smart grid projects in Colombia has been identified. This system should have an interactive survey; the application model results and it should be constantly updating and presenting the characteristics of smart grid projects.

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