Methodology for defining the Functionality of Advanced Measurement Infraestructure in Colombia

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***Abstract*— Smart Metering systems, in addition to the function of energy consumption metering, can support a wide variety of additional features by optional devices or programming. These functionalities allow the implementation of key elements of Smart Grids (SG) such as distributed generation, new market models, advanced tariff schemes, among others. The Colombian's Smart Grid Roadmap identifies the implementation of smart metering through an Advanced Metering Infrastructure (AMI) as one of the first activities to be carried out to implement the SG in Colombia. This activity must be carefully planned to gradually activate all the AMI functionalities required by the regulation and the market in a period of time without changing the meters; this will ensure a good return of investment of the adoption of this technology throughout its useful life. This paper presents the agreed methodology for the process of defining the minimal functionality required for AMI in Colombia and the expected benefits for the Colombian electric sector.**

***Index Terms*—Smart Metering, Advanced Metering Infrastructure (AMI), Regulatory Framework, Functionalities, Benefits.**

I. Introduction

The electrical sector worldwide is in an evolution process as the result of the integration of new technologies complementing the conventional power system elements. This has led to the development of new markets and services in the supply chain meeting the current and future needs of the system with additional benefits for all actors [1], [2].

Several countries have started with the transformation of the traditional power system with the aim of increasing the efficiency, reducing CO_2 emissions, integrating new technologies into the network, etc.; looking for the implementation of a concept of electrical network, called Smart Grid [3]. Colombia has developed in recent years' various pilot projects and initiatives, both governmental and private, focused on the formulation and implementation of SGs in the national electrical network.

One of the most relevant experiences is a project developed by the Ministry of Mines and Energy of Colombia in conjunction with the Ministry of Information and Telecommunications supported by the Inter-American Development Bank (IDB). The objective was to establish the strategies, standards and regulatory changes necessary to ensure an effective implementation of SGs in the Colombian territory. In order to meet this objective, a benchmarking process of SG technologies that have been successfully implemented in selected countries were studied and the strategies used in those cases were adapted to the particularities of the Colombian case.

As a result of the study, the document "Smart Grids Colombia Visión 2030 - Roadmap" was published [4]. It defines four technologies considered appropriate for the Colombian case. It also establishes the actions to be followed and the necessary regulatory adjustments for their implementation. The technologies defined in the Roadmap were: Advanced Metering Infrastructure (AMI), Advanced Distribution Automation (ADA), Distributed Energy Resources (DER) and Electric Vehicles (EV). The study determined that a fundamental part for the development of SG is AMI; therefore, the most immediate actions have to be carried out in this area because this technology allows the integration of all the others into the conventional network.

Based on this result and with the aim of promoting the development of AMIs, the *Mining and Energy Planning Unit* (UPME) and *Universidad Nacional de Colombia* (UNAL) decided to develop a project to define the set of minimal functionalities of the Smart Meters (SM) to be used in Colombia, in order to meet the current and future needs of the electricity sector. This study, in addition to defining the set of minimal functionalities, aims to establish the bases for the construction of a regulatory framework that promotes the development and massive implementation of AMI and other technologies associated with SGs in Colombia.

This paper describes the project methodology developed by UPME and Universidad Nacional. It includes a general conceptual framework associated with AMI, the analysis of some relevant international and national experiences, the methodology used and the most relevant benefits associated with the use of advanced metering for all the electricity sector.

II. Advanced Metering Infrastructure (AMI)

AMI creates a smart connection between system operators (Traders, utilities, operators, etc.) and end users providing functions that support the integration of all actors by means of the information that everyone needs to make decisions [5]. AMI integrates hardware and software elements in an infrastructure that allows the exchange of bi-directional information related to energy use and rates, remote management of metering devices, while implementing cybersecurity measures protecting the transmitted information [6], [7]. All elements of the infrastructure must interact with each other in a reliable, flexible

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and efficient way to allow interactions between the end user and the operators [8].

Among the main elements of AMI are the Smart Meter (SM), the data concentrator, the communication network and the information management system [6]. Fig. 1 shows a schematic of the components of the infrastructure.

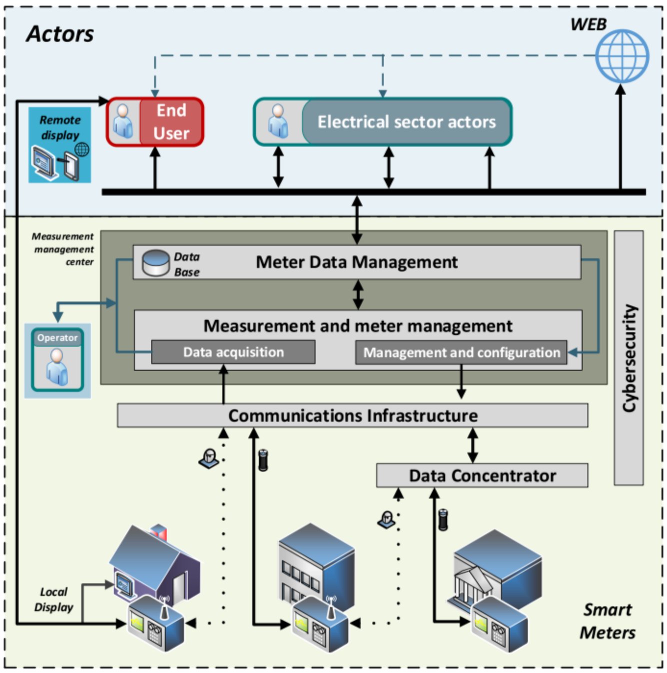

Figure 1. Basic scheme of an AMI

The operation of AMI starts from the SM which acquires and transmits, through the communication infrastructure, information on energy use and associated tariffs. The exchanged information travels directly or through data concentrators towards the management center where it is processed, stored and distributed among the different actors involved to make decisions after its analysis. The decisions can produce control centers' orders as control and configuration signals which are transmitted from the control center to the SMs by means of a management center.

III. Methodology

Fig. 2 shows the methodology proposed for the definition of the minimum AMI functionalities in Colombia. Based on international experience, the project seeks to define an initial set of functionalities supported by AMI, identifying its benefits and costs in order to define the minimum functionalities supported by AMI. The technological and communications implications have also to be evaluated in laboratory in order to take into account the practical aspects of the implementation and deployment of this type of new technology for the electric sector of a country.

IV. AMI Implementation and Standardization Projects

For more than a decade, countries in Europe and North America have led the implementation of AMIs demand control, reduction of CO2 emissions, loss reduction purposes among others [9]. In most cases, this implementation has been accompanied by the definition of a regulatory framework that promotes the deployment of this technology as part of the development of a SG package.

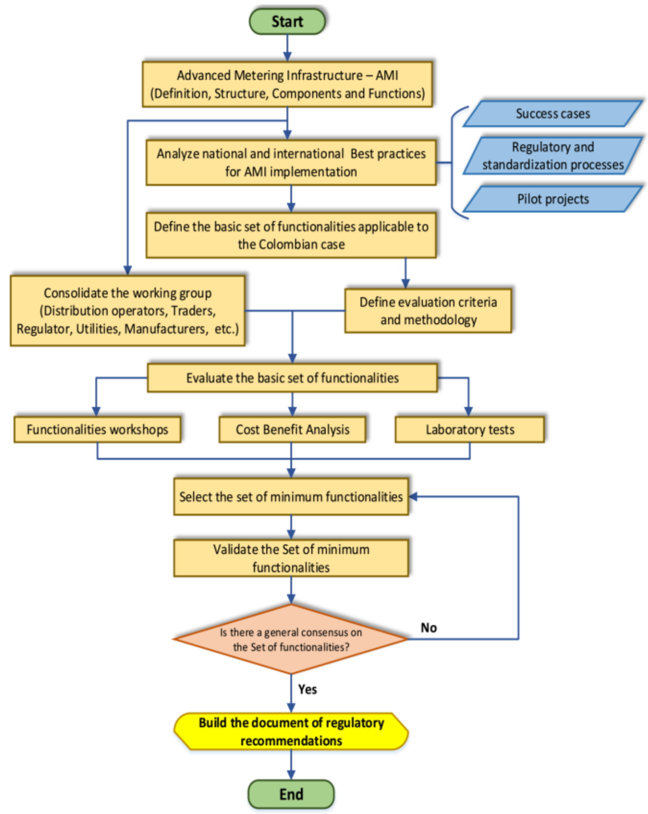

Figure 2 Methodology of the project

In Europe a project for the definition of the minimal set of functionalities of AMI was developed with the aim of defining a sound implementation of SGs avoiding the early obsolescence of meters.

A. Analysed International Experiences

Countries such as Spain [10], [11], France [12], Italy [13], the United States [14] and Brazil [15] currently have functional deployments of AMIs and also regulatory frameworks that can be considered a reference and practical experience for the Colombian case.

1) France: in 2012, the French Parliament incorporated, under Article L.341-4 of the French Energy Code, the provisions defined by the European Community in Directive 2009/72/EC [16]. This Article establishes that distribution network operators must implement systems that allow suppliers to offer their customers prices that vary with time of year or day; they must also implement metering devices that allow users to access their production or consumption data [17]. Subsequently, the Decree issued on January 4, 2012 established the basic requirements for all users' SMs with power lower than 36 kVA [18].

Among the most outstanding projects for the French case is the *Linky Program*, which plans to implement 35 million SMs for users with contracted power less than or equal to 36 kVA by 2021. This replacement will have no cost to the end user and the total investment will be borne by the company EDRF [19].

2) Spain: in 2007, the Spanish government established the Unified Regulation of Measurement Points of the Electricity System, approved by Royal Decree 1110/2007. It sets the requirements that all metering devices must meet. At the end of the same year, the Ministry published the Meter Replacement Plan under the First Additional Provision of Order ITC/3860/2007. This establishes that before December 31, 2018 all meters with a contracted power less than or equal to 15 kW must be replaced by new equipment that allows time differentiation and remote management [202].

One of the most outstanding projects for the Spanish case is the Star project, developed by Iberdola; it plans to replace more than ten million meters by 2018 and implement a system of remote management and automation of the grid. It comprises meters with contracted power up to 15 kVA [21].

3) Italy: in 2007, the Authority for Electricity and Gas published Resolution 292/2006, ordering, according to a gradual schedule, the installation of SMs at all low-voltage points in the national territory [22]. Annex A thereof establishes the minimal functional requirements for single-phase and three-phase electronic meters used at the power extraction points in the low-voltage network.

Among the most outstanding projects for the Italian case is the Telegestore project, which began in 1999 and replaced 32 million electromechanical meters in its first stage with smart electronic meters with bi-directional communication as well as data concentrators through the low-voltage network. The second stage started in 2016; its objective is the installation of 21 million second-generation SMs [23].

4) Brazil: the National Electric Energy Agency of Brazil (ANEEL) conducted a study to define a regulatory framework that would establish the minimal technical and functional requirements for metering devices. As a result of the study, Resolution RN 502/12 was issued, regulating the implementation of AMIs in Brazil [24].

Among the most outstanding projects for the Brazilian case is the Eletropaulo Digital Project, developed by AES Brasil, which aims to implement an infrastructure that meets the needs of the network, market and users and that addresses the strategic and operational challenges of the company. By 2017, it plans to install 62,000 SMs, 2,100 of them for the normalization of low-income communities [25].

The analysis of international cases shows that it is essential to have a regulatory process prior to the implementation of AMI infrastructures in order to achieve an optimal development of this technology; this framework should establish the minimal conditions that this technology must meet to ensure its proper functioning and avoid future inconveniences such as early obsolescence of equipment, lack of interoperability, etc. This is evidenced in cases of countries where an initial technology implemented was replaced by another in relatively short time periods with higher costs and with the consequent impact especially for the end user [12].

B. Colombian experiences

The following are some of the pilot projects developed by energy distribution and trading companies:

1) Empresas Públicas de Medellín (EPM): in 2010, it formed a strategic alliance for the development, production and marketing of prepaid energy meters. Initially, the program was conceived as a pilot project to connect 35,000 families in 5 years, but the goals were achieved in only 3 years; the project was extended to the entire market inclusive its subsidiaries. Currently, more than 90 thousand people in the department of Antioquia have prepaid meters; about 87 thousand are located in low-income sectors.

2) Empresas Municipales de Cali (EMCALI): in 2010 within the loss reduction program, EMCALI implemented an AMI system on the TWACS communication platform, with three main objectives: to reduce energy losses, to support the prepaid billing scheme and to automate the reading, the suspension and the reconnection processes. There are currently more than 20 thousand meters of this type installed. The previous pilot has been complemented with meters that use other technologies and communications.

3) Empresa de Energía del Pacífico (EPSA): EPSA has installed centralized metering, which allows users to know the energy consumption by consulting a display installed in each home, thus monitoring the daily consumption. The prepaid information management software is integrated with the commercial system to transmit the KW/h values acquired from the bank collectors to the meters. The system allows the company to perform telemetry and remote management of customers; remote suspension, cut and reconnection; remote meter management; demand management; demand control response; and loss management.

4) CODENSA: currently, Codensa, as a member of ENEL Group, is implementing the first phase of the Smart Metering program in Bogotá, which includes 40,000 customers. The consumption metering equipment and its technology were developed by the ENEL Group.

In addition, several advances have been made in Colombia on vision, policy and regulation as follows:

1) *Mapa de Ruta Smart Grid Colombia Visión 2030 [4]*: it aims to identify, prioritize and plan actions to ensure the development and deployment of SG technologies and the necessary ICT infrastructure in Colombia, considering the "Visión 2030" scenario for sustainable economic, technological and social development that can be cost-effective and adapted to the particular needs of the country.

*2) Standard NTC 6079 [26]:*it establishes the minimal requirements that AMI systems must meet for their operation and management.

3) Decree 348 of the Ministry of Mines and Energy (*March 1, 2017) [27]*: it establishes public policy guidelines on efficient energy management and delivery of surpluses of small-scale self-generation. It establishes that bi-directional metering is necessary for the connection of self-generators; this implies the need for SMs in this type of connections.

V. Definition of the Basic Set of Functionalities of AMIs for Colombia

A. Identification of the basic set of functionalities applicable for the Colombian case

Table I shows the result of the application of the methodology proposed for the study. This set was divided into two categories depending on the function fulfilled by each one within the AMI. The categories were the following:

- **Inherent to the meter**: characteristics of the meter necessary for its operation as a part of AMI. They allow the operation of the meter, but do not provide information to the external actors.
- **Supported by the meter**: provide the actors with the information they require. Each supported functionality is assigned to an actor, as appropriate. The meter, in interaction within the AMI system and the conditions of each actor, must ensure the supported functionalities.

As shown in Table I, the basic set includes several functionalities that allow extended benefits of the implementation of this technology, since it is not limited only to the measurement of energy. However, it is necessary to define the minimum functionalities of the SM, considering the incremental costs of this technology for each additional function and the corresponding benefits for every user. Table I lists each function with an acronym that identifies it throughout the study.

Table I. Base set for the functionalities of SMs

Supported	UAM	User Access to Meter information
	RMR	Remote Meter Reading
	TSI	Advanced Tariff Schemes Implementation
	RCL	Remote Connection/disconnection, Limitation
	FPD	Theft Prevention and Detection
	EIX	Energy Import/export Reading
	PQR	Power Quality Data Reading
	YSI	Prepayment Schemes Implementation
	HAN	Home Area Network integration
Attached	MDS	Meter Data Storage
	BID	Different media Bidirectional Data communication
	SEC	Secure data communication
	TSY	Time Synchronization
	URC	Software Update and Remote meter Configuration

B. Selection process of the minimum function set

In order to carry out the selection process, the actors of the electric sector requiring the information of the smart meters for their operation were identified. Then, the processes responsibility of each actor was analyzed and those functionalities of the SM that support the optimization of each process were identified. The result is show in Table II.

Table II. Actors of the sector and associated functionalities

Agent	Associated functionalities
End user	a) User Access to Meter information b) Update frequency c) Bidirectional Data communication
Network operator	a) Remote Meter Reading b) Operation on the meter c) Theft Prevention and Detection d) Power Quality Data Reading e) Update frequency
Trader	a) Advanced Tariff Schemes Implementation b) Operation on the meter c) Remote Meter Reading d) Theft Prevention and Detection
Planning and control agencies	a) Remote Meter Reading b) Power Quality Data Reading

Based on these elements, Figure 3 was elaborated. It shows the flow of information between the different actors participating in the AMI, the functionalities associated with them and the processes that would be enhanced with the implementation of this technology.

C. Selection criteria for the definition of the minimum function set

In order to select the minimum function set for Colombia, the methodology makes an assessment process for each functionality by means of eight different criteria. The selected criteria are the following:

1) Costs: quantifiable incremental cost indicators for the cost-benefit assessment are analyzed. This criterion is considered to determine the economic viability in the implementation of an advanced metering system.

2) Benefits of the functionalities: an analysis of the benefits obtained with the implementation of each functionality of the AMI system.

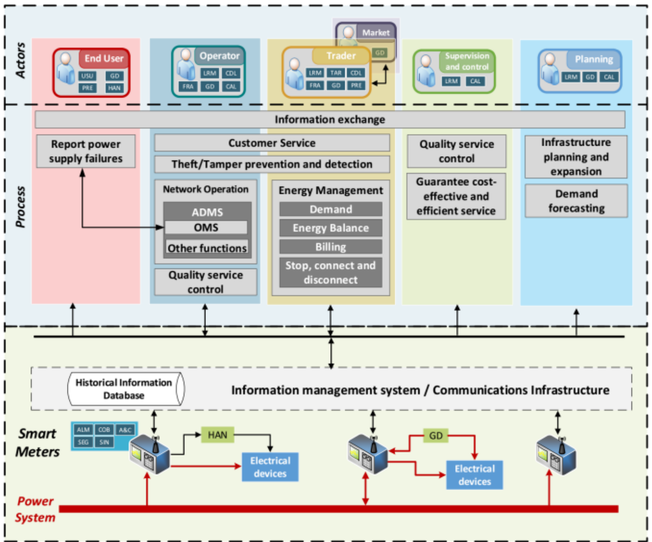

Figure 3 Scheme for the implementation of AMI in Colombia.

3) Regulatory criteria for the implementation CREG 038 - NTC 6079: it determinea the set of functionalities that have already been included in the current Colombian regulations.

4) Implementation level: it seeks to establish the operational limitations of the system implementation and the requirements for future maintenance. This was performed to estimate the operation costs and the feasibility of a gradual implementation of the technology.

5) Interoperability: the requirements for interoperability were analyzed with third-party devices for accessing the information available to customers and external users designated by the customers and the current technology available.

6) Communications with standard and open protocols: the reliability aspects of the communication system and its different components, schemes, architectures, among others, are assessed by means of tests on the available technology for the development of the project.

7) Security criteria: the verification of the security and protection of the transmitted information.

8) Use of the functionality by the system actors involved: determines the functionalities to be used by electrical system actors according to their particular needs.

The assessment of functionalities are discussed in group workshops and laboratory tests involving different actors of the electricity sector (network operators, traders, regulatory and control entities, manufacturers, National Government, etc.).

VI. Enabled Elements and Associated Benefits

The implementation of an AMI provides the electrical system with the necessary tools and means for the integration of new technologies and the adoption of new SG operational schemes. These elements facilitate the emergence of new markets, business schemes and operation strategies that result in benefits for all involved actors. Table III shows the most important aspects enabled with the implementation of the analyzed functionalities proposed for SMs in Colombia.

TABLE III. Elements enabled with the implementation of AMI

Funcionality	Element enabled					
	Distributed generation	Storage systems	Electric mobility	Demand management	HAN network	New markets
UAM	x		x	x	x	x
RMR	x	x	x	x	x	x
RCL	x	x		x	x	x
FPD						
EIX	x	x	x			x
YSI						x
BID	x	x	x	x	x	x
TSY	x	x	x	x	x	x

The benefits obtained with these new elements impact immediately aspects such as the visualization of information on consumption by the end user, or in the medium term, such as the construction of user profiles, operation optimization or loss reduction. Figure 4 shows the most relevant benefits identified for each actor of the sector.

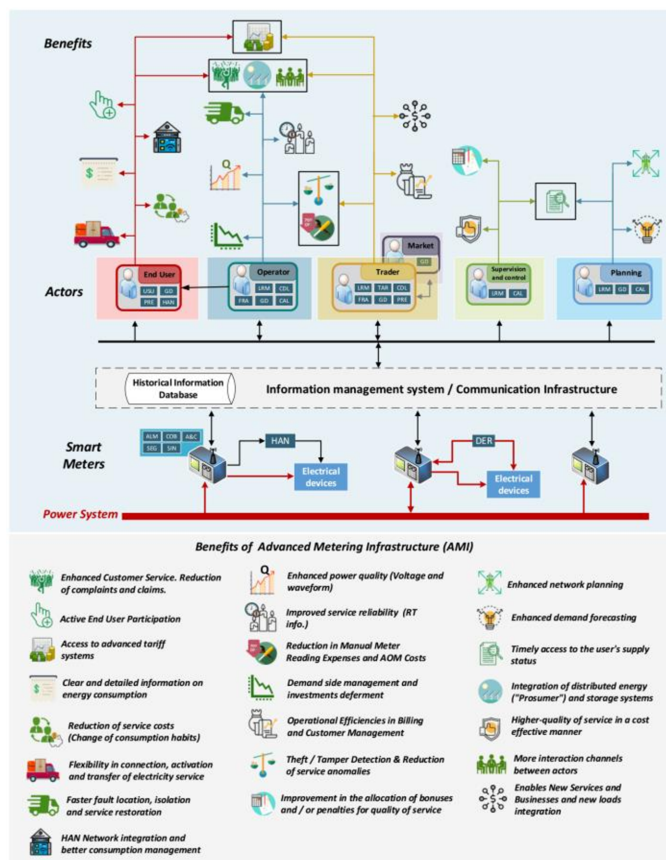

Figure 4 Benefits associated with advanced metering systems

VII. CONCLUSION

In order to ensure the success of Smart Grids implementation programs with the benefits associated with distributed generation, efficiency, demand response and other innovative aspects that bring new values to the electricity sector, it is important to promote AMI infrastructures. This requires policies that address these initiatives and a regulatory framework that promotes the development of new services with the respective associated technologies. Therefore, it is fundamental to define the functionalities associated with the AMI functions, according to the defined final use context.

The methodology presented to define the minimum functionalities could be customized with the local circumstances, in all countries that seek to implement SG, before the massive develop of technologies that require the AMI functionalities discussed in this paper. In this form, the functional standardization will be achieved and the interoperability of equipment can be discussed with more foundation in order to use smart meters from different suppliers, MDM software type from different suppliers, etc.

The massive use of AMI will put the cornerstone of an electric sector that includes the end user as a main actor, facilitating fluid intercommunication between all the actors involved, promoting new markets and services with benefits for all participants.

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VIII. BIOGRAPHIES

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