BRAZILIAN SMART GRID ROADMAP - AN INNOVATIVE METHODOLOGY FOR PROPOSITION AND EVALUATION OF SMART GRID FUNCTIONALITIES FOR HIGHLY HETEROGENEOUS DISTRIBUTION GRIDS

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ABSTRACT

The Smart Grid concept has been calling attention worldwide, being appointed by experts as a possible paradigm rupture in the power electricity sector.
Smart Grids bring a number of functionalities and new forms of integration and relationships between the various players, who need clear and objective conceptualization as well as methodologies for analysis of costs and benefits.
Thus, it is essential to analyze all aspects from the perspective of all those involved in order to establish optimal deployment policies, so as to maximize the associated social benefits.
In this context, this paper presents a methodology that allows the functionalities evaluation deployed along time, enabling the proposition of roadmaps according to the current characteristics of the utilities and based on social benefits. Furthermore, it is presented the main results of the Brazilian Roadmap, obtained under a R&D project approved by the Brazilian Energy Agency and the Brazilian Association of Distribution Companies.

INTRODUCTION

The Smart Grids concept brings the implementation of an advanced number of features. These features impact both in distribution system management processes and in planning procedures, operations and engineering. Furthermore they allow the greater consumer management over their energy consumption, and they may even take up the producer's role.
In this scenario, it is essential to analyze all aspects from the perspective of all stakeholders in to establish optimal policies for Smart Grid features, seeking to maximize the social benefit provided by this.
It is important to note that the interests of various agents in the evolution of the electrical system do not always coincide. It is necessary to define appropriate ways in order to guarantee adequate supply of consumer energy distribution, including consideration of new technological developments and the new possibilities enabled by these, as well as ensure the sector's attractiveness and the economic sustainability of the companies responsible for providing this service.
During the year 2011 was developed R & D project on Smart Grids, which aimed to guide a National Plan for the technological migration of the current Brazilian electric sector stage for the full adoption of Smart Grids concept throughout the country.
Every study that involves the definition of a "roadmap" must answer four key issues in order to optimize costs and benefits from the desired deployments:
1) Where are we? (Diagnosis)
2) Where we want to go? (Target)
3) How to get there?
4) When you get?
This paper is about the methodology used to answer such questions, and present the results of its application in the development of the Brazilian Plan for Smart Grids.

DIAGNOSIS

As part of strategic R & D project on Smart Grids (SG), a study was developed in order to define the current state of the Brazilian Electric Distribution.
This diagnosis contemplates a search of the SG current situation in Brazil, stratified by type of functionality, implemented features, Distribution System segments, equipment technologies and IT infrastructure and communications.
For this, the following activities were performed:

- Searches, from reports, documents and technical articles in national and international events;

- Questionnaire to the Brazilians Electricity Distribution Companies. It characterizes the distributors, diagnoses the functionality, telecommunication and IT for Automation and collects data of pilot projects already developed, in developing and future plans.
- Research via QuestionPro, with 16-Companies participation. Subsequently, analysis and synthesis were summarized as results.
- Questionnaire to equipment and system manufacturers for SG automation.
- Meetings with manufacturers to clarify issues related to the questionnaire, as well as experiences exchange. Additionally, it was demonstrated the key features available in their equipment and systems for SG.

The survey was referred to a set of 37 associated companies. Of these, 16 answers were obtained from the South, Southeast and Northeast companies, totalling about two-thirds of the Brazilian market in terms of consumers and consumption.

In addition to the physical characterization of who was consulted, the questionnaire covers grids physical aspects, operational procedures and practices used in distribution automation.

Therefore, the follow main conclusions were obtained:

- Monitoring and border control bar with National Interconnected System (NIS): most border points with the NIS (about 63%) are monitored by SCADA, and very few with control functions (about 90 points of the 1600 sample).
- Monitoring and control of distribution substations: Most (about 80%) of the substations are monitored and controlled by SCADA, but still many under local automation.
- Monitoring and control of distribution grids: Much feeders are monitored and controlled (71%) on outgoing bays of Substations. Some have automatic switches and reclosers. Of total reclosers, 23% operate remotely. The capacitor banks operate locally and without communication in 52% of feeders and voltage regulators in 21%.
- Metering: Almost all customers in HV have remote metering systems. The main functions implemented are: Periodic and upon request reading, meter maintenance and integration with commercial systems.
- Grid faults: The blackout reporting is, generally, held by consumers, but substation and grid automation become increasingly used. The fault location, isolation and restoring downstream blocks are, in most part, carried out by teams, but it has increased the use of fault indicating devices and remote control.
- Load management: it was noted the presence of a few companies with automatic resources and centralized load cut, especially in consumer HV.
- Voltage control and reactive: voltage and reactive flow levels are monitored and controlled mainly in substations, and of this, about 50% is locally and about 80% is remotely. Most monitoring and control features of the feeder are local (70%) and very few feeders (17%) show remote control.
- Preventive maintenance: About 70% of the companies surveyed have features for monitoring electrical, thermodynamic and physicochemical quantities in their facilities and equipment as guidance in predictive maintenance actions.
- Interaction with the transmission in load shedding situations: The surveyed companies have, in response to “Regional Load Relief Scheme”, an automatic selective cutting system, mainly operating in High Voltage Lines (sub transmission) (46%), in distribution substations (77%), MV Feeders (69%) and consumers (HV-15%, MV-8% and LV-8%).
- Commercial losses: In the surveyed companies, commercial losses are typically identified by periodic measurements only (17%), by energy balance in transformer (17%) and combinations of both (42%).
- Power Quality: Specific meters monitor the quality of the product, mainly in Substations (including the bays feeders).
- Of the companies surveyed, eight reported that 100% of their Substations are automated, providing a very high rate. However, these automations are relatively old, reflecting on the applied communication technologies, focusing on Digital Radios, Private Lines, satellite, and optic fibber (in more modern facilities).
- Communication protocols: the protocols used in substations and distribution grids are basically the DNP3. In Substation, on a smaller scale, it is used the IEC 61850 and 60870 protocols.
- IT Resources: All companies have SCADA (supervisory control) and almost all have GIS (Geographical Information System). The event management systems are deployed in 87% of the companies surveyed. However, the solutions used are very old suggesting difficulties in SG deployment. About 50% of the companies have or plan to deploy a Distribution Management System but there is still a lack of standardization of this type of system.
- Interoperability: The majority still maintains integration and interoperation processes based on specific interfaces. Which represent the major obstacle to the implementation of necessary platform interoperability for SG.
- Smart grids: still notice a small presence of pilot

projects on smart grids. However, it is observed concern in performing some specific designs. In this sense, 13% of companies have had some pilot project, 26% have ongoing projects and 20% plan to do some.
- Distributed resources: regarding the pilot projects using distributed resources, 20% already conducted a project in DG, 26% in electric vehicles and 13% in energy storage.

METHODOLOGY

The methodology is basically composed of five main steps (Figure 1).

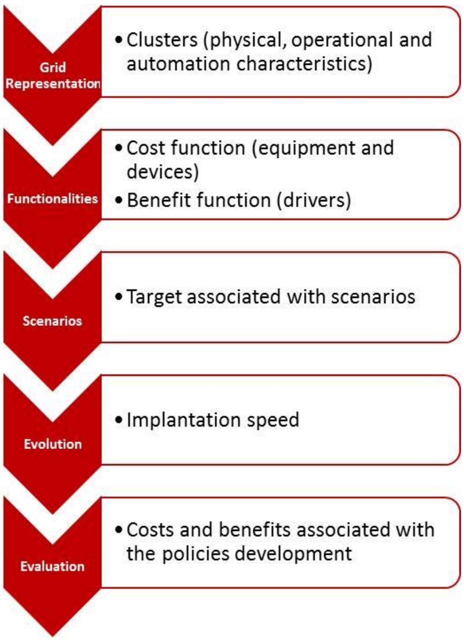

Figure 1. Methodology

SYSTEM REPRESENTATION AND FEATURE MODELING

The major challenge of the proposed methodology lies in the system representation, considering that it should be able to capture the Brazilian. It has, also, to express relevant physical, operational and market features for the evaluation of the SG implementation.
The solution adopted was a clustering methodology, where each electrical assembly, composed of a substation with their feeders, is now represented by attributes, totaling more than 2,000 sets for Brazil.
Through this process, these sets became 30 representative clusters, according to the same concept that the regulatory agency (ANEEL) used for quality regulation.
As this attributes are not sufficient to characterize the system, it has been proposed additional attributes.
Additional attributes were: load growth rate, commercial losses and ENS cost. In addition to these attributes were incorporated SAIDI (System Average Interruption Duration Index) and the penetration level of SG features.
In the studies, it was reported significant dispersion between the SAIDI values calculated in the same cluster. As this attribute is very important for the reability gain evaluation by grid automation features, it was chosen to subdivide clusters from 30 to 60 for automation solutions.
For the last attribute (SG), it is necessary to define the SG features considered in the study. In a total, it was designed 20 features, divided by application segment and groups, according to costs and benefits sharing. The 20 features are presented in table 1.
Each functional group has been modeled by: functional specification, with each logical operation as well as the required IT and telecommunications elements; cost and objective functions, using as inputs the cluster attributes.
The cost function basically involves the need to purchase equipment and devices (IEDs), telecommunications and IT infrastructure. The benefits were measured as a function of the main drivers of SG in Brazil, namely:

- Improved service quality (reduction of energy not supplied - ENS);
- Increased operational efficiency (including reduction of technical losses);
- Better assets management;
- Reduction of commercial losses

For the definition of the equations, it was adopted a typical model of distribution substation and medium voltage feeder. The first is composed of two power transformer and eight medium voltage feeders. On the other hand, the second model assumes in the feeders are installed three automatic equipment in series (maximum), with two transfer points to adjacent feeders.
These models are shown in Figures 2 and 3, respectively.

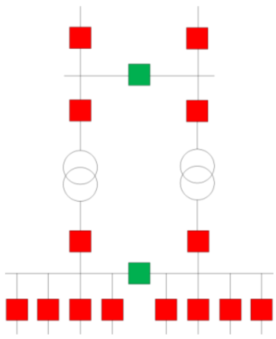

Figure 2. Substation Model

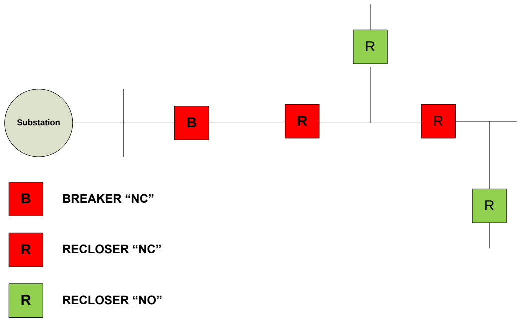

Figure 3. Medium Voltage Feeder Model

Application segment	Groups	Functionalities
		Load monitoring
		Equipment remote control
	1	Automatic transfer load between transformers
	2	Automatic load rejection
	3	Predictive maintenance focused on equipment condition
		Remote setting of protection devices
	4	Automatic analysis for diagnosis of outages
Substations	5	Logical schemes of protection and control
		Load monitoring along the feeder
		Equipment remote control
		Power quality monitoring
	1	Location of defects by switches and reclosers
	2	Predictive maintenance focused on equipment condition
	3	Location of defects by switches, reclosers, metering and fault locators monitored
	4	Automatic fault isolation and recovery (self-healing) - Local automation
		Automatic fault isolation and recovery (self-healing) - Central automation
	5	Automatic reconfiguration for managing the technical indices
MV grids	6	Volt-VAR control
	1	Load response
LV grids	2	Load shedding by low voltage

Table 1. Functionalities groups

For example, equation 1 expresses the quality improvement benefit (reduction ENS) for Group 1 features of Distribution Substations.

$$B_{CONF} = \frac{1}{2} \times (T_L + T_{MM}) \times (1 - P_{BLOQ}) \times \frac{E_T \times N_{TSEDEF/ANO} \times \Delta_{PEN} \times C_{END}}{8760 \times K_{EM}} \quad (1)$$

Where:

T_L	Displacement time to substation
T_{MM}	Open/close manually time of switch
ET	Total energy of representative cluster
$N_{TSEDEF/ANO}$	Defects number per year in substation transformers, in the cluster
Δ_{PEN}	Variation of functionality penetration from one year to another
P_{BLOQ}	Parcel of events where the transfer is blocked by capacity constraints
C_{END}	ENS cost
K_{EM}	Ratio of average consumption and consumption at the default time

Besides the mentioned features, it was also considered other more focused on smart metering, as cut/reconnects, remote metering, etc. Although these were not modeled as presented, they were also important to the benefits.
With this model, it was possible to evaluate the implementation impact of each feature per grid type.

DEFINITION OF SCENARIOS AND TECHNOLOGY MIGRATION POLICIES

The SG evolution is represented by the growing penetration of functionalities in clusters along the timeline. The studies are performed for three different scenarios, called: conservative, moderate and fast. They differ just on the definition of grid evolution parameters, as an increasing curve defined by four parameters:

- Pi - initial penetration of functionality
- Ti – inflection year for increasing rate
- Tf – inflection year for penetration stabilization
- Pf – Final penetration of functionality

In fact, the first parameter Pi is obtained from the diagnostic phase. Therefore, it only takes the other three parameters to define the penetration curve.
Since there is relative heterogeneity of physical, operational and market between clusters, it was defined three targets to Ti, Tf and Pf parameters. In this way, the most advanced clusters concerning to its operating performance and market have high functionalities penetration, and so on.

BRAZILLIAN DISTRIBUTION ROADMAP

It was held a methodology application in 3 scenarios.
As presented in the previous section, it was obtained the costs and benefits values per year per cluster. To transport these values to Brazil, it multiplied the costs and benefits by the sets number represented by each cluster.
The results obtained for the fast and conservative scenarios are shown in Figures 4 and 5.

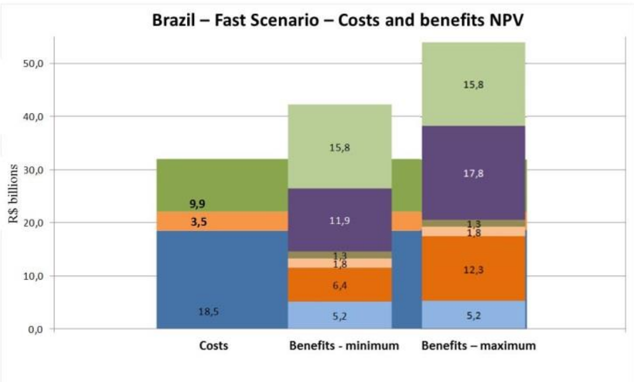

Figure 4. Fast Scenario – Brazilian results

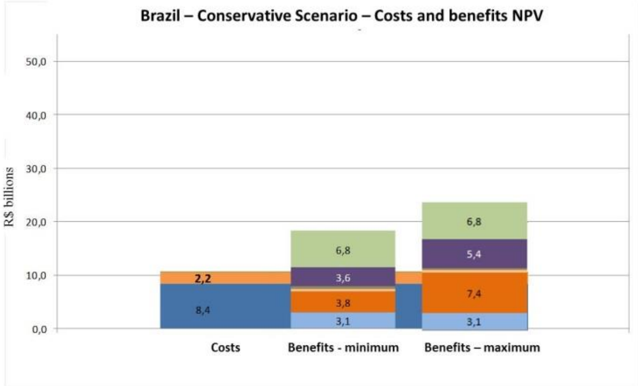

Figure 5. Conservative Scenario – Brazilian results

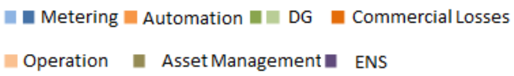

Figure 6. Graphics Legends

As can be seen from the graphs, there is a variation in the values benefits in reducing ENS and commercial losses. Due to the relevance of them and the difficulty in obtaining deterministic values for the variables that explain these, it was adopted a range of values, defining a minimum and maximum level of expected benefits.

Figures 7 and 8 show the distribution over time of the costs for 2 scenarios.

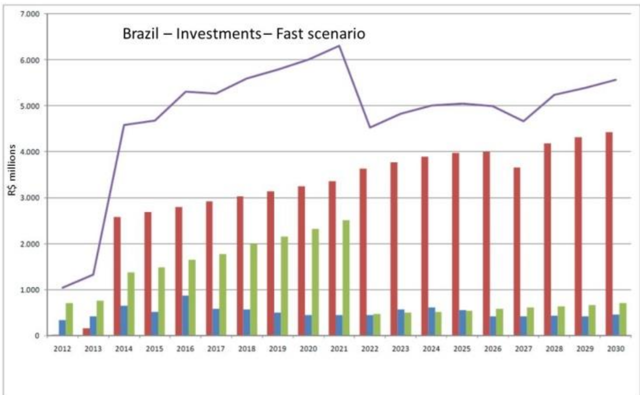

Figure 7. Fast Scenario - Investments

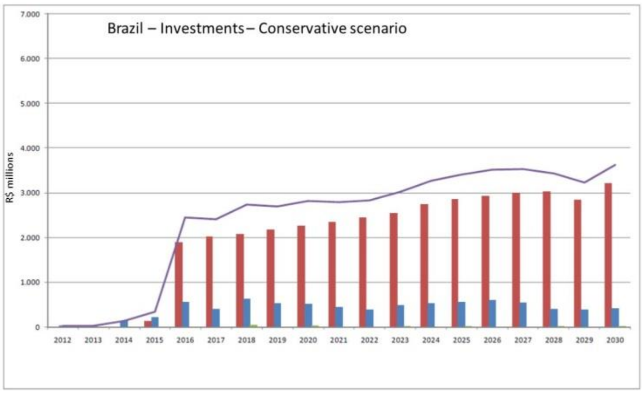

Figure 8. Conservative scenario - Investments

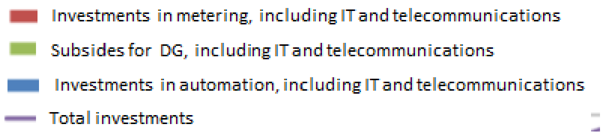

Figure 9. Graphics Legends

CONCLUSION

This work presents the developed methodology and the main results obtained in Research & Development project, developed under the Brazilian regulatory agency, which establish a National Plan for Smart Grids.

From the above in the previous items, it is inferred from them the following final comments:

- Only considering the quantified benefits, the implementation of SG is validated for Brazilian society in any of the scenarios considered
- This conclusion is limited to an overview of the set of all grids and should not be transplanted to all distributors or to all grids of each concession.
- A more detailed analysis in each particular case is necessary.
- The question posed is the correct and fair allocation of costs and benefits.
- The implementation of Smart Grids is not only an economic problem.
- Some challenges, technology choices and regulatory adjustments are still needed.

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