Low Cost Self-Healing Applied to Distribution Grid Supplying Brazilian Municipalities

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Abstract— **Companies distributing electricity in the world have sought to enhance the operation of their networks in order to minimize the impact of supply disruptions. Nowadays, with the rise of the Smart Grid concept, the insertion of sophisticated features in the distribution of electric energy has become a reality. This article aims to describe the current situation of the implementation of smart grids by distribution companies in Brazil and the challenges especially regarding the economic viability of this technology for practical deployment. For this sake, this paper proposes the development of a low cost methodology that provides improvements in supplying power to municipalities of a Brazilian electricity company (CEMIG D), building the smart grid through the application of the concept of self-healing.**

Index Terms -- **Smart Grids, automation, self-healing, distribution system, power quality, reliability.**

I. Introduction

THE Smart Grid concept has as an integrated power distribution and communications infrastructure which can process quickly and accurately all the power demands and information necessary for operation. The connection of all users is safely and intelligently managed. Therefore, it enables the utilities to supply the energy in a more efficient, economical and sustainable way. Numerous innovative technologies already available can contribute to meet the demands of a power grid of the future, either by increasing the reliability of transmission and distribution systems or by seeking energy efficiency, reducing electricity costs and losses in the grid [1].

The automation of power distribution is essential to the concept of a self-healing grid. Distribution automation applications improve the efficiency of the electrical distribution system, reconfigure the system after disturbances, improve both reliability and power quality, and identify operational problems [2]. The concept of DA (Distribution Automation), along with DG (Distributed Generation) and smart metering are integral parts of the concept of smart grid applied to the distribution system [3]. In the distribution automation (DA) segment, the development and deployment of advanced distribution automation (ADA) functions may play an important role. The concept of self-healing is important in this context, since it may embrace automatic restoration through FLISR (Fault Location, Isolation and Supply Restoration) functions, also known as FDIR (Fault Detection, Isolation and Restoration).

The control system used in voltage and reactive power (Volt/VAr), also called IVVC (Integrated Volt/VAr control) is also worthy of mention. This system may be used in networks that can adapt automatically to constant variations of voltage/VAr in the distribution system topology.

The FLISR system aims to improve the reliability of the distribution network, using the detection and location of faults in certain sections of the circuit by remote measurements, derived from several existing microprocessor devices on the network (reclosers, switchgear, voltage regulators, capacitor banks, etc.), or by specific location of equipment for signaling faults (FD - Fault detectors).

After the fault location calculation, the reconfiguration of areas not affected by the fault is done. This is accomplished by employing the switches available that can isolate the faulted section. Along with this analysis, load flow analysis is executed, so the power capacity of the remaining branches is checked, enabling one to check if the power quality indicators have been violated. In the case of Brazil, the limits are set by ANEEL through the PRODIST – Module 8 [4].

The IVVC system aims to improve the efficiency of the distribution network by optimizing the load flow and reducing the losses. The IVVC uses advanced optimization algorithms for the coordinated control of all equipment involved in the Volt/VAr network control (capacitor banks and voltage regulators). Similar to FLISR system, the IVVC system also has a state estimation function that adds to the decision-making functionality.

This work was supported in part by ANEEL (throughout R&D projects), FAPEMIG, CAPES and CNPq - Brazil.

978-1-4673-6605-2/15/$31.00 ©2015 IEEE

II. Current Status of Implementation of Smart Grids in Brazilian Utilities

The scenario of the implementation of Smart Grids is not the same in all countries. Some countries are very advanced, for example, Japan and some European countries. Other countries have some investments mainly on demonstration projects, as in the case of Brazil, which, with its continental dimension, has the need for extensive power transmission lines with large capacity and operating flexibility. In fact, Brazil's priority is building a grid able to host enough capacity for the rising demand for electricity. Brazil, similar to the United States and Europe, is currently challenged with an ageing infrastructure (grid modernization). However, Brazil is also facing a vast increase in energy consumption, which was expected to growth by 60% between 2007 and 2017. The utilities are the connecting link between all stakeholders and are key elements for the development of smart grids, mainly through various smart grids pilot projects, usually with R&D (Research and Development) resources.

Among the various pilot projects undertaken by Brazilian utilities, are [6]:

A. Coelce – Fortaleza-CE

R&D project to implement a pilot smart grid for electric system automation: development of a smart grid pilot project in Aquiraz, 30 km far from Fortaleza, through the implementation of a system for automatic supply (SRA) for medium voltage of 13.8 kV network, with an intelligent system for automatic switching protection system adjustment (SIAP).

B. CELPE – Island of Fernando de Noronha-PE

Development and implementation of concepts of smart grids in a pilot project location with high environmental restrictions: the project objective is to develop and implement concepts of smart grids on the island of Fernando de Noronha, using technological resources for automation networks, telecommunications, metering and distributed microgeneration, as well as evaluating the feasibility of its application in the aspects of sustainability, quality of electricity, supply of electric vehicles, the study of applying different electricity rates and work safety.

C. Ampla Energia e Serviços S.A – Búzios-RJ

The smart city project is located in Buzios streets, with the goal of innovation, technology and sustainability. The project aims to contribute to the energy goals of Brazil and demonstrate the applicability of key concepts of smart grids technologies, such as smart meters, network automation, integration of renewable energies, electric mobility and efficient public lighting.

D. LIGHT Electricity Services S.A. – Rio de Janeiro-RJ

Smart grid project with the goal of deploying AMI (Advanced Metering Infrastructure) for 400,000 consumers, integrated with remote Connection/Disconnection of Customers; automation of 1,700 Transformers Chambers in underground distribution network and 1,200 reclosers in aerial distribution network. Testing on GPRS (General Packet Radio Services) Communication, RF and PLC systems and MDC/MDM with Data Storage, integration with Commercial System (Metering/Billing, Billing/Disconnection and remote Connection systems).

E. AES Eletropaulo – Barueri and other places. São Paulo-SP

Smart Grid Program - Eletropaulo Digital Project: the project aims to implement technological infrastructures, applications and features appropriate to the Smart Grid network, the market and the priority strategic and operational challenges of AES Eletropaulo. It aims to create a replicable model of deployment throughout the concession area of AES Eletropaulo - Technological and Strategic Roadmap.

F. EDP Bandeirantes – Aparecida-SP

Deployment of the InovCity project: the project goal is to develop a smart grid pilot project in São Paulo that includes electric mobility, distributed generation, efficient lighting, energy efficiency, automation and smart metering grid.

G. COPEL Distribution – Curitiba-PR

Parana smart grid program: the project is an initiative that proposes to carry out elements of smart grid applications. The power distribution, with the establishment of a pilot project in an area with high load density and high visibility through demonstration of the systems currently in deployment and testing advance concepts for future applications.

H. CEMIG Distribution – Sete Lagoas-MG

The project "Cities of the Future" is one of the most comprehensive programs of the Brazilian architecture deployment of Smart Grids, considering the diversity and amplitude of the geographical area and classes of consumers, the infrastructure deployed and its systemic integrations. The scope of this program is extremely challenging and is not limited to technological or functional assessments.

The goal of the project is to establish a functional reference model to support future decisions on large-scale deployment, regulatory, socio-economic, financial and customer perception aspects under evaluation. Methodologically, the project also evaluates the impacts on business processes of CEMIG in the smart grid value chain and the necessary training efforts to professionals who will deal with the new technologies.

Therefore, currently in Brazil there is still no clear definition of the feasibility of large-scale deployment of technologies in smart grids, although there are many pilot project under development. This might be mainly due to the Brazilian regulatory model, which has a greater focus on electricity price/rate than on the quality of energy.

A study by Abradee (Brazilian Association of Electricity Distributors) [7] pointed out that, currently, it is not worth investing in smart grid, except in specific cases, because such investments would bring negative Net Present Value (NPV), which represents injury to companies´ shareholders.

However, some authors instead of using the concept of smart grid are moving to a new concept, called a smarter grid [8]. The concept of smart grid requires the existence of a "dumb" grid that need to be smart. The concept of a smarter grid, assumes that the existing network can migrate to a smarter grid, so when resources are available for investment in this grid.

As an example, CEMIG is providing the installation of 4,000 reclosers. However, these acquisitions do not include yet all telecommunications infrastructure and inherent systems to enable the full implementation of FLISR and IVVC functions, mainly due to economic uncertainties feasibility [7]-[8].

Nevertheless, this utility has invested in low cost solutions with respect to the need for telecommunication between the equipment and the distribution operation center (COD) solutions. A very used low cost solution is the GPRS communication (General Packet Radio Services), because it allows multiple users to share the same resources and thus increases the capacity of the network, and also has a large coverage, which is the case of distribution network, the largest one in Brazil and Latin America.

Unlike other more advanced utilities with self-healing solutions of other countries, Brazilian utilities are still in an early stage of implementation of automatic restoration systems in their distribution networks, except for the case of the pilot projects mentioned previously. Among the possible solutions there is the deployment of autonomous self-healing (decentralized), through the coordination of protection functions (relay undervoltage and overvoltage) and internal logic in their respective relays. As examples, one can mention the solution implemented by AES-Eletropaulo [9], and also a similar model, used in 64 circuits, totalizing 144 reclosers by ELEKTRO [10]. The self-healing examples mentioned, although they have been made without the need for communication between devices, do not become viable for the future, because they require local parameterization, and are therefore very costly, since they have no remote supervision and is difficult to maintain their settings.

In [11] it is mentioned that the main challenge faced by utilities is the structure, in broad aspects, of ADA capability, since the need for distribution network in the cities evolve, towards increasing levels of intelligence to be implemented. In this book is mentioned that there are two steps to Self-healing for implementation: Level I (local automation) and Level II (central automation).

For local topology automation, communication becomes necessary between the devices, making the speed of decision-making to be much faster and more robust. However, it is still expensive, because its implantation requires local parameterization and still needs to have remote supervision by SCADA.

III. Example of Application of Low Cost Self Healing System Used by CEMIG – D

The information processing application architecture concerning Advanced Distribution Automation functions can be classified as:

- Centralized (through the SCADA (Supervisory Control and Data Acquisition) / DMS (Distribution Management System) located at the distribution control center).
- Centralized in substation.
- Decentralized (distributed in the distribution network).

The centralized architecture has the advantage of using all automatic features installed in the SCADA system for the management of information. On the other hand it has the problem that latency for transporting data will be higher and this makes necessary the availability of high performance data channels, which still has a high cost.

It is currently being used to integrate the operation support functions through the implementation of DMS applications. The DMS extends the functions of traditional SCADA systems offering a geographical view of the entire distribution network and support functions to the operating team. DMS is a collection of applications designed to monitor and control all distribution network in an efficient and reliable way. It acts as a decision support system to help the COD in the operation of the electricity distribution system, which enables the use of the following features, among others:

- State Estimation (SE)
- Load Flow Aplication (LFA)
- Volt-VAr Control (VVC)
- FLISR (Fault Location, Isolation and Service Restoration).

Despite the great benefits of a DMS system, up to 2014 there was not any full DMS system installed in any Brazilian utility. However, the DMS system is a key element for deployment of advanced ADA functions, and it is estimated that its implementation after 2015 will be increasingly used by utilities.

In distribution systems, there is the insertion of remotely controlled recloser due to the flexibility provided to loads dispatch, contingency service and personnel cost savings. This reclosers´ remote control process is being made possible by the cited benefits as well as the significant decrease in costs of these reclosers combined with low cost communication channels, for example the GPRS systems.

Recloser´s installation in CEMIG's network has the function to increase reliability and reduce operating costs through remote control by SCADA at the COD (Distribution Operation Center) using GPRS low-cost communication.

The communication through GPRS enables packet data transmission, allowing speeds of around 40 Kbps, but the pricing is performed based on the amount of transmitted data. This feature is the limitation of the GPRS system used by the utility, because in order to implement 4,000 telecontrol equipment, monthly data rate must be very low (around 10 MB per month), in order to have viable costs.

The methodology applied for the limitation of data is the use of telecontrol at regular time intervals (3 minutes), thus the system is not operated in real time. However, due to the characteristics of the used communication protocol (DNP3 - Distributed Network Protocol version 3.0) the system keeps characteristic of the remote real-time.

In principle, the remote system does not have these reclosers availability and speed requirements to implement advanced functions of self-healing. However, through the profile settings of the reclosers and the settings of GPRS modems, it can be used functions of DNP3 protocol.

The DNP3 protocol defines a set of procedures for the implementation of SCADA communication link between master stations and Remote Terminal Units (RTUs) or Intelligent Electronics Devices (IEDs). The RTUs are microprocessors equipment installed in the distribution networks, such as the reclosers, voltage regulators, capacitor banks, etc. The DNP3 protocol has three layers of networks (Physical, Data Link and Application), as defined by the EPA (Enhanced Performance Architecture) standard.

The application layer provides prioritization of events by assigning classes, and it is possible to use it for sending messages through priority-by-exception Report [12]. This function allows that some priority information (for example, opening statement and closing of the recloser) are practically in real time.

These settings do not increase the amount of monthly data, so the system is still low-cost. Although the DNP3 has no attributes necessary for a full function of the smart grid, the configuration above enables low-cost connection, but with sending priority information, which although not in real time, still allow for implementation of automatic restoration function.

To use this methodology, CEMIG has created a homologation methodology for a recloser that will be remotely controlled, so that all profiles DNP3 of the equipment to be configured allow the optimization of the traffic of data.

A. Proposed Methodology

The concept of municipal headquarter (normally are small cities) refers to cities not fed directly by substations, but supplied through long feeders, which often reach up distances of up to 100 km or more.

The proposed methodology will allow the power restoration of these municipal headquarters within less than 90 seconds. It will enhance the overall benefits through a project called double energy, providing the expansion of distribution networks that still do not allow double feeding in several municipal headquarters.

Moreover, the project in question has already become operational in municipal headquarters with double feeding, and not having power restrictions.

The automation to be implemented was made through automation functions in SCADA. This tool allows automatic real-time conditioning the default settings of triggering and restriction.

At first, two different topologies will be provided as follows:

a. One normally closed (NC) recloser and one normally open (NO) recloser, installed in the inputs feeding the small city, as illustrated in Fig. 1:

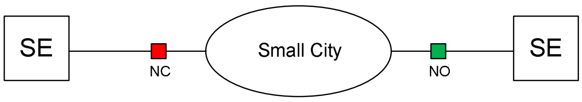

Figure 1. Topology with one NC recloser and one NO recloser.

b. Two normally closed (NC) reclosers and one normally open (NO) recloser. Two NCs reclosers are installed in the inputs feeding the municipal headquarter. One NO recloser is installed within the small city, as illustrated in Fig. 2:

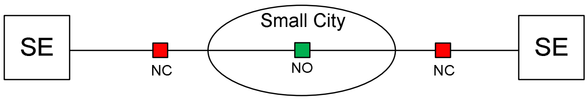

Figure 2. Topology with two NCs reclosers and one NO recloser.

B. Application Example

For this example, the basic operation of the automatic control algorithm as shown in Fig.3, with the topology 1 NO + 1NC reclosers was used to supply the city of São Bento do Abade-MG through the recloser R100788 (NC) and R22683 (NO), as illustrated in Fig. 4:

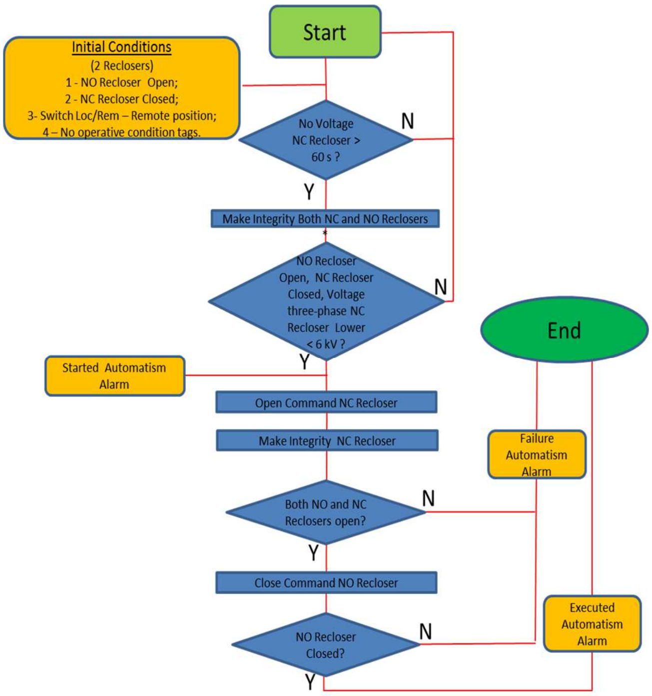

Figure 3. Algorithm for automation in self restoration of municipal headquarters used by Cemig-D.

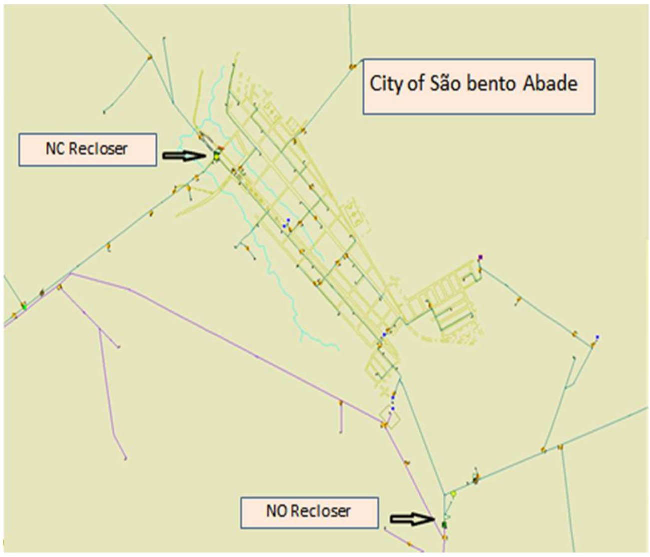

Figure 4. Topology with 1 NC recloser + 1 NO recloser, supplying the City of São Bento do Abade-MG.

C. Socio-economical Benefits

The proposal of CEMIG-D is to attend in the first stage 150 municipal headquarters, providing improvement in the supply of electricity to 320,000 customers, totalizing 1.2 million people.

The benefits of improved reliability and power quality with the decreasing interruption time and frequency will be evaluated through the continuity indicators DEC, FEC, DIC, FIC and DMIC [4] (equivalent to SAIDI – System Average Interruption Duration Index, SAIFI – System Average Interruption Frequency Index, Individual Customer Interruption Duration Index, Individual Customer Frequency Interruption Index, and Individual Customer Maximum Interruption Duration, respectively) .

In a second stage, the implementation will be extended to another 96 municipalities. Besides the above mentioned 246 municipal headquarters, there are still around 50 municipal headquarters that already have double feeding, totaling approximately 300 municipal headquarters, covering 500,000 consumers and 2 million people [13].

Regarding reliability and power quality indicators, it is expected an average reduction of 20% in the DEC (SAIDI – System Average Interruption Duration Index) of each municipal headquarter. In addition to the benefits arising from DEC reduction, it is also expected financial benefits through reduction of penalties and reimbursements due to power outages (DEC) and END (Energy Not Distributed). It takes into account also the reduction of operating costs (O & M), and the improvement of consumer satisfaction.

As an example of the expected benefits, one can cite the expected improvements in interruption indexes (DEC) in the 2 municipal headquarters within the Cemig-D concession area:

a) São Bento Abade-MG, expressed in Table I:

TABLE I. . IMPROVEMENT OF INTERRUPTION INDICATOR – DEC (SAIDI).

Year	Real DEC (SAIDI) [hours]	DEC Avoided [hours]	% DEC (SAIDI) improvement
2011	22.0	8.6	39%
2012	12.0	0.9	7%
2013	21.0	2.2	10%

b) São Tomé das Letras-MG, expressed in Table II:

TABLE II. . IMPROVEMENT OF INTERRUPTION INDICATOR – DEC (SAIDI).

Year	Real DEC (SAIDI) [hours]	DEC Avoided [hours]	% DEC (SAIDI) improvement
2011	26.8	10.6	39%
2012	35.4	7.7	22%
2013	21.4	5.0	23%

For the two cases mentioned before, the failures were listed considering the interruption of power in their municipalities (Avoided DEC), and which power could be restored automatically if the Self-Healing automation was implemented before.

IV. CONCLUSIONS

Although the potential benefits of smart grids are widely advertised around the world, their implementation in Brazil is yet in an incipient stage. The main possible reasons are related to the need of regulatory incentive policies, leading to balanced socio-economical benefits to customers and utilities.

However, this does not mean that the issue is not being considered by utilities, where there are several ongoing pilot projects. In addition, there are manufacturers who have a huge range of equipment and technologies available.

Various research and educational institutions are involved in this issue together with the utilities through a diversity of R&D projects in progress.

Despite the limitations outlined, the paper presents a proposal for the implementation of low cost self-healing, applied to distribution grid supplying Brazilian municipalities in CEMIG-D concession area. Even though it has some limitations of functions and operating times, it presents a practical solution for system automatic restoration, with power service to 250 municipal headquarters, and with improvements in the quality of energy to about 2 million consumers.

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