AN EXPERIENCE IN DETERMINING A COST VERSUS QUALITY OF SERVICE CHARACTERISTIC IN ORDER TO DEFINE OPTIMAL INVESTMENT LEVEL

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ABSTRACT

This paper presents a study that sought to determine the characteristic between Cost and Quality of Service.
The results presented in the proposed paper correspond to the actual distribution system, consisting of two substations and twenty-five feeders of a Brazilian distribution utility. Initially, the study of optimized configuration for the installation of automatic reclosers is presented, reallocating the existing devices, and the impact on quality of service indices are compared with the values observed in reality. Then, it is made a study considering the allocation of additional devices and the expected values of improvement in the quality of service indices are calculated.

INTRODUCTION

In Brazil, the current levels of quality of service indicate that the SAIDI is around 30 hours per year. An effort has been made by the power distribution companies, associations and the regulator in order to determine the optimal levels of investment that would be necessary in order to reduce the values for the quality of service indices. The determination of optimal levels of investment attempts to reconcile the service quality levels required by consumers with the investment costs in the distribution system. The determination of this optimal level is a very arduous task, requiring the compilation and adequacy of a very large amount of data.
One of the problems is the initial condition of distribution networks. Typically, the actual distribution networks do not match the application of optimized investment. Therefore, it is necessary to determine how much of today's networks are far from the optimal condition.
Another difficulty is how to measure the effects of different improvement actions that can be made in a distribution system. Therefore, the present study focused on only one possible action: the installation of automatic reclosers in the medium voltage (MV) networks. The installation of reclosers is an interesting alternative, because the acquisition of these assets is recognized by the regulator as well as investment (CAPEX) and its value added to asset base. Unlike other improvement actions, which impact only on the operating costs of companies (OPEX). In any case, the installation of reclosers is costly and must be properly designed in order to maximize the benefit (in terms of reduction of quality of service indices) and provide the appropriate level of enhancement to be offered to consumers.
In the present work, a computational tool was used to determine the positions optimized for installation of reclosers, considering the possibility of installing normally open and normally closed devices simultaneously. The tool determines the best combination to be installed, maximizing of the relationship between the reduction in quality of service indices (SAIDI, SAIFI and Energy Not Supplied - ENS) and equipment costs.

CONCEPTUAL BASIS

The reliability of a distribution network can be observed from two points of view. For the point of view of the utility, the reliability is related to the average amount of disruptions and the average duration of interruptions. For the society, besides the frequency of interruptions and service restoration time, there are other important variables as the average consumption and cost of energy not supplied (CENS).
The concept of energy not supplied, in its usual definition, is the energy that is not consumed due to an interruption. The societal cost of energy not supplied (SCENS) is the monetization of the direct and indirect costs to society resulting from the energy not supplied. This value differs from the cost of the energy not billed by the utility, because, the SCENS may add the interruption cost of several agents to represent society as a whole, in a concession area, indicating the average interruption cost in R$/MWh.
The CENS is not static; it depends on the level of the network reliability and the expectations of society. In general, the better the network reliability, more expensive for the utility to reduce one unit of energy not supplied, i.e., there is a marginal incremental cost to reduce each MWh unit (energy not supplied). In this article, we stayed only in the quantification of this incremental cost to reduce the energy not supplied.
When the utilities are seeking to improve their reliability, there are typically three basic solutions:

- Optimization of existing resources.
- Additional investments in works for quality of supply of energy (CAPEX).
- Change (increase) on the operational expenditure (OPEX) in a great way.

The importance of knowing the marginal cost to improve the energy quality, in relation to the energy not supplied, is the possibility to define its optimal quality level (OQL). This way, the suitable values of investments may be measured according to the society demands. Such incremental quality cost calculations can be made through engineering methods (or reliability methods) or statistical methods (econometric methods), both approaches to calculate optimized incremental costs to improve the quality are valid. We will quote two works that uses these forms.

The economic analysis on reliability optimization of a power electric network was introduced by Professor Munasinghe (1979). The technical approach of Munasinghe, which is standard in the international experience, is to compare the social benefits of an improvement in the network reliability with the cost to provide it. To this end, the utility is modeled as the responsible to maximize the net social benefit, considering the differences between the expected provision to pay for a certain reliability level and the expected costs to provide this service (or the sum of the expected costs and the cost of energy not supplied).

The originality of the seminal work of Munasinghe was to consider electricity as an intermediate product needed to produce goods which are demanded by consumers. Therefore, the researcher quantifies the outage as an impact on the production of final goods and services in various sectors of the economy (residential, industrial, services, etc.). Following this approach, we avoid the problem to determine the willingness to pay (WTC) to calculate the SCENS. The reliability optimization methodology consists in weight the expected costs and benefits associated to different reliability levels considering the tariff of the base scenario. Once optimized the reliability level for the base case, the next step is to simulate an increase on the costs in order to improve the reliability. This increase will result in a new tariff, which must be compared with the benefit to demand, and so this process is repeated until we find the long term balance.

Regarding the use of econometric methods for the calculation of the incremental reliability cost an article written by Jamasb, Orea and Pollitt (2012), in which the authors estimate the quality marginal cost in utilities from Great-Britain during the period between 1995 and 2003, through a parametric analysis. This work applies a distance function multi-input (Totex 800, Opex or Capex) and multi-product (power supplied, network extension, energy losses), besides that it applies a series of cost drivers like energy supplied, network extension, energy losses, total time of interruption, temporal trends and environmental variables.

The approach of Munasinghe was made to evaluate which was the appropriate network topology to be used in the expansion of the distribution system. Once defined the topological model, the network reliability would have an expected level.

However, as a result of many advances in electrical networks, like smart grid capabilities and reducing cost of reclosers, we can evaluate how the marginal improvement of reliability can be applied on the network, without the need of new standards. This way, aerial three-phase unprotected networks may improve its SAIDI and SAIFI.

APPROACH OF THIS WORK

In order to calculate the cost of the energy not supplied through reliability methods, we used data from a real network. This data are from georeferenced electrical networks connected in medium voltage and we have all the information about their consumers connected in both low and medium voltage. For such a network is possible to perform the power flow analysis to calculate the energy supplied for each distribution transformer on each hour of the day.

The information about the electrical network protection is also used, as well as the load transfer characteristics.

Besides that, the interruptions over a year are observed; these interruptions are characterized by the equipment that operated to protect the network. The software used (SinapGRID Reliability) allows to simulate an electrical network model in a way that the results of SAIDI and SAIFI observed in the simulations are the same as those observed in the real network.

After we got the electrical network model suitable for the reliability calculation, the software did the calculation of energy not supplied (ENS) for different reclosers position. The optimization of the reclosers allocation seeks the configuration that minimizes the energy not supplied levels in the network. An article detailing this methodology will be published in the future.

We also had access to the distribution costs for the installation of reclosers in field. With these data it was possible to create an economic model to assess the variation in the marginal cost of energy not supplied.

The company had already allocated in the network 45 reclosers, only using the experience of its crews as a criterion. Based on the outage values for this utility it was possible to calculate the ENS after a new allocation of the 45 reclosers using the software SinapGRID and its methodology. After that we compared the results of this simulation with the ENS observed on the current situation of the utility. This comparison shows the difference between the current situation of the company and a network ideally optimized

This way, two cases were simulated:

- Optimization: it is considered the reclosers reallocation to reduce quality indicators (SAIDI and SAIFI) and energy not supplied.
- Evaluation of investments: it is considered as a starting point the network without reclosers, and then we simulated cases with addition of reclosers, seeking the optimized marginal cost reliability.

Network Used

Two distribution substations located in adjacent areas were chosen as a pilot area for testing, we called them SE1 and SE2.

For these substations there were considered only the occurrences in 2014. It is worth to note that the occurrences are used to calculate the service time and failure rates for each block of the medium voltage network. Once the rates and times are calculated in order to be the same as the verified SAIDI and SAIFI, the consideration of the interruptions allows defining proportional failure rates for each block of the network. For these simulations, there were used the SAIDI and SAIFI recorded in 2014 by the utility. In order to do not allow the identification of the substations that were used in the simulations, we showed in tables 1 and 2 approximated values.

The values of SAIDI and SAIFI indicated as a "limit" are defined by the Brazilian electric energy regulatory agency (ANEEL) as the suitable values to that network for 2014.

Table 1 - SAIDI and SAIFI recorded in 2014

SE	Number of clients	SAIDI [h]	SAIDI limit [h]	SAIFI [out.]	SAIFI limit [out.]
1	26,000	13.00	10.00	10.00	8.00
2	61,000	9.00	12.00	8.00	10.00

The SE1 is composed of 9 MV feeders, including 1 emergency feeder. The SE2 is composed of 16 MV feeders, including 2 emergency feeders .

There are 17 reclosers installed on the feeders served by SE1, including 4 normally open (NO) reclosers. There are 28 reclosers installed on feeders served by SE2, including 8 NO reclosers. The 45 reclosers are already installed in these networks.

The table 2 illustrates the values of the indicators corresponding to SAIDI and SAIFI recorded considering the two substations as one network. Note that the network used on this example has a good quality of service, when considered the Brazilian average, especially in SAIDI (Brazilian average values may differ depending on the year analyzed).

Table 2 – SAIDI, SAIFI and ENS recorded in 2014

SAIDI [h]	SAIFI [out.]	ENS [MWh]
11.42	9.31	783.17

The parameters of the simulation were compatible in order to the results of the simulations matched with the values measured in the field, based on the information of each occurrence. The values of the indicators were calculated from the simulation, with values of Customers stopped and Customers Stopped time, however the results are presented in DEC, FEC and ENS to facilitate interpretation of the data.

Optimal allocation of reclosers

In the first series of simulations, the optimal allocation of reclosers was simulated, based on the georeferenced information of all valid emergency occurrences. The network was first simulated without reclosers and then with the optimal allocation of the same 45 reclosers. The last one is the case of network optimization based on available assets, as shown in table 3. The Figure 1 presents the results of SAIDI (hours).

Table 3 - Network continuity indexes for 3 different cases

Condition of the network	SAIDI [h]	SAIFI [out.]	END [MWh]
Without reclosers	16.77	13.44	1116.13
With 45 reclosers and without allocation optimization	11.42	9.31	783.17
With 45 reclosers and with allocation optimization	8.04	6.72	560.25

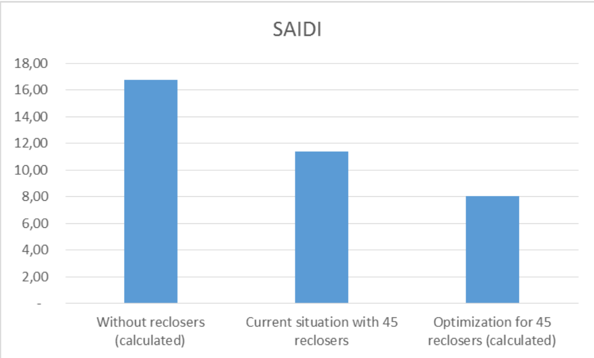

Figure 1 - Evolution of the SAIDI index after start using reclosers and with optimal allocation of reclosers. Source: own elaboration.

In the simulated case, for the same set of historical occurrences, it is possible to optimize the allocation of reclosers in the network (both normally closed and normally open). The optimal allocation methodology is the result of various R&D projects performed by the utility and of the information and database obtained with years of work experience.

It is important to note that when the utility initially installed the reclosers, the available methodologies were used to better allocate them, which resulted in significant improvement of quality indexes, as shown in reducing the SAIDI index from 16.8 hours to 11.4 hours.

Marginal cost calculation of reliability

The second step of this case study calculates the cost of reliability. The relationship between the amount of reclosers and network reliability is analyzed until the reliability results are little sensitive to adding another recloser. Based on the cost of installation of the recloser, considering the main value of the equipment, costs of smaller components and additional costs, it is possible to calculate the marginal cost of quality improvement. In this case study, the total cost of the recloser was annualized at a 10% rate, as shown in table 4.

Table 4 - Recloser values (primary value + COM + CA) and annualized cost (10%)

Installation of the Recloser	**Cost [R$]**
Cost of installation (COM + CA)	R$ 30,000.00
Cost of the Recloser (primary value)	R$ 30,000.00
Total	R$ 60,000.00
Annualized Cost	R$ 6,000.00

The analysis of the relationship between reclosers and quality was made as follows:
I) The reliability rates are stipulated based on the actual values of the continuity indexes of the network.
II) The network is simulated according to the a priori reliability model: the simulation parameter is the number of reclosers; optimal allocations are generated by optimization algorithms for both normally closed and normally open reclosers.
III) Given the optimal position of a determined number of reclosers, the SAIDI, SAIFI and ENS indexes are calculated.
IV) The marginal cost is calculated based on the additional annualized value to the installation of reclosers.
The results of stages 1 to 3 are presented in table 5.
The valuation of marginal cost is presented in table 6, already considering the annualized values.

Table 5 - Relationship between the number of reclosers on the network and quality indexes

Number of reclosers installed	**SAIDI [hours]**	**SAIFI [out.]**	**END [MWh]**
Without reclosers	16.77	13.44	1116.13
15	11.52	9.86	840.97
30	9.30	7.85	696.63
45	8.04	6.72	560.25
50	7.69	6.46	534.66
55	7.44	6.25	510.75
60	7.22	6.09	491.10
65	7.09	5.98	472.78
75	6.82	5.77	450.13
90	6.58	5.62	432.06

Table 6 - Relationship between the number of reclosers on the network and quality indexes

N° of Reclosers installed	**Quality increase [kWh]**	**Annual cost increase (R$)**	**CENSmg [R$/kWh]**	**Average cost [R$/kWh]**
0	-	-	-	-
15	275,156	90,000	0.33	0.33
30	144,345	90,000	0.62	0.43
45	136,376	90,000	0.66	0.49
50	25,596	30,000	1.17	0.52
55	23,909	30,000	1.25	0.55
60	19,646	30,000	1.53	0.58
65	18,327	30,000	1.64	0.61
75	22,645	60,000	2.65	0.68
90	18,068	90,000	4.98	0.79

Finally, based on the obtained results, the SAIDI index and the marginal cost of improvement are plotted in Figure 2. On this graph, each point represents a number of reclosers allocated on the network, however this number is implicitly related to the quality index (SAIDI) obtained. It is evident that with the marginal limited to 5.00 R$/kWh, it is possible to reduce the SAIDI index to a value near 6 h/year. It is also evident the saturation of the curve after a determined number of reclosers. After 75 reclosers on the network, adding new reclosers does not have significant influence on ENS reduction, compared to the amount invested.

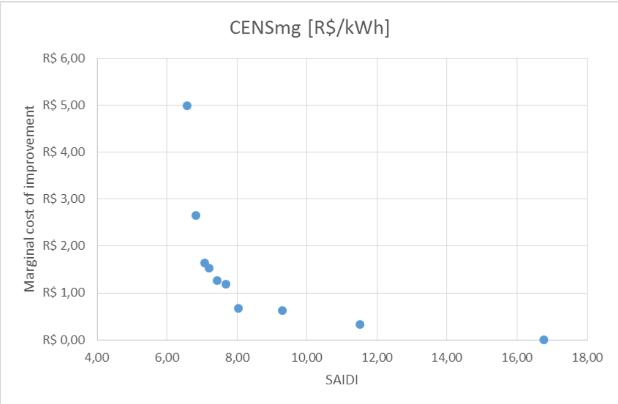

Figure 2 - SAIDI index and the marginal cost of improvement. Source: own elaboration.

This case study points out the following results:
I) It is possible to simulate a network and get data according to the real situation observed in the field.
II) With a unique work of increasing reliability (installation of reclosers, allocated optimally) it is possible to get marginal cost no more than 5.00 R$/kWh in a typical urban distribution network, being in the range of 1.00 R$/kWh to DEC in the order of 10h/year (starting from 16h/year).

III) It is possible to observe that any other works, to be justified as improving reliability criteria, the reliability marginal cost should be less than or equal to such value.

COMPARISON WITH THE COST OF ENERGY NOT SUPPLIED (CENS) IN BRAZIL

We compared the results obtained from the perspective of the utility with the results from the point of view of the consumer. For consumers, there are some studies in Brazil that claims the cost of the ENS must be between 10.00 and 20.00 R$/kWh, only for reference when this study was accomplished the exchange rate to dollar was on 3.50 R$/dollar.

It is important to notice that most of the values calculated in this article are marginal values. For example, the CENS, which represents by costing society present average values concerning a SAIDI 10:00 and 30 h between.

At last, we conclude from the comparison between the possible CENS for the utility and the one regulated by the government agency that the current reliability levels are not in accordance with the required by the society. On the other hand the research does not allow the exactly determination for the SAIDI and SAIFI points, but it indicates a SAIDI below 8h.

COMMENTS AND FURTHER WORK

We also showed through this job that investments are not being made at the Optimal Quality Level. This may be occurring for several reasons, which include both technical and economic factors. From a technical point of view, the distributors are not obliged to collect, treat and organize information of failure rate and restoration time the same way it is presented in this article. In doing so, the utilities did not have enough information and methodologies knowledge to allocate the reclosers the most suitable way. From an economic point of view, the regulation itself may be leading the utilities to prioritize some customers at the expense of others. This can occur because the penalties are different according to the type of consumer. In our study we utilized the information of customer consumption, so it is unlikely that this happened in this case.

There are some studies that must be made to verify the assumptions of this article. The main point is to prove that using past information to predict the current failure rate on the network is the most suitable way to allocate reclosers.

This article also indicates a possible problem in the use of comparative methods to evaluate the adequacy of the great investments in the distribution network: if the utilities are not investing on the Optimal Quality Level, the econometric comparisons may result on misconceptions.

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