METHODOLOGY OF INVESTMENTS FOR MEDIUM VOLTAGE NETWORKS AND IMPROVEMENT OF RELIABILITY INDICES

M. A. Burgos*, A. U. Antunes †, N. Kagan †, C. C. B. Oliveira †, M. R. Gouvea, G. F. Vasconcelos †
* Polytechnic School of the University of São Paulo
Brazil
burgos@pea.usp.br

Summary: This paper presents an evaluation methodology of investments for medium voltage networks and improvement of reliability indices, as proposed by ANEEL (Brazilian Government Regulation Agency), in Resolution 024/2000. This methodology considers operation and maintenance actions as alternatives to expanding the electrical system. This objective is accomplished by using an aggregate investment planning methodology that proposes appropriate modeling concerning: the network and the load representation, the evaluation of the operational performance and the network expansion model. In this model the following operation and maintenance actions were included: tree trimming, compact network installation, recloser installation, network rebuilding, lightning-arrester (maintenance actions); and increasing of maintenance teams. These actions allow the improvement of reliability indices. The competition between expansion reinforcements, operation and maintenance actions is carried out by a benefit/cost evaluation, which was expressed by the Initial Profitability Rate of Investment (IPRI), limited to the annual budget.

I. INTRODUCTION

The regular tools of aggregate planning, presently used by the companies operating in the Brazilian electric sector, include the resources necessary for planning optimized investment as well as the a of the actions proposed during the expansion of the system. The basic concepts for this model were the subject of several other articles by the authors [2], [3], [4].
Those models focus mainly on network expansion aimed at meeting the needs of market expansion. Thus, the models presently being used by the sector do not include actions directed towards maintenance and operation.
The problems regarding the violation of the continuity indicators DEC (average duration of interruptions per customer) and FEC (average number of interruptions per customer) are handled by means of actions that also address the issue of market expansion, as for example, new distribution feeders.
This article presents the changes that were introduced in such tools to include operation and maintenance actions and solve the issues related with the continuity indices. The aim is to reduce the network investment costs, considering that the alternative actions tend to be less costly than the expansion projects.
The article also presents the comparison between the results obtained through the simulations performed with the classic models and those resulting from the changes that were introduced.

II. CHANGES INTRODUCED IN THE MODEL

The aggregate investment planning models, presently in use, focus on meeting the needs of market expansion. Thus, the options for actions to adapt the technical criteria are mainly directed towards solving the problems of circuit and substation loading as well as those of network voltage drops. Although these actions have an impact on the continuity indicators, their cost, compared with that of the operation and maintenance actions, tends to be higher.

Defining New Actions

Through the combined effort of several companies in the electric sector, a research was carried out with the database information of network occurrences, aimed at investigating the main reasons for the failures. Once this data became available and based on the experience at CERJ – (Electricity Company from Rio de Janeiro), the electrical utility of Rio de Janeiro, it was possible to determine a set of preventive maintenance actions, effectively put into practice to reduce the number of power outages or network restoration time.
The following actions were added to the system, to aid in reducing the company's total continuity indices:

- Compact network installation;
- Tree trimming;
- Installation of lightning-arresters;
- Network rebuilding;
- Recloser installation.

The main characteristic of these actions is the reduction in the failure rates of the feeders, except for the recloser that isolates load blocks reducing the DEC and FEC, thus reducing the duration of momentary interruptions.
Besides the actions mentioned above, the decision was made for the software to include the effect of expanding the maintenance crews, which is basically an action in the operation area. The effect of such an increase is a drop in

restoration time, after the outage occurs, by reducing the time spent on preparing the crews.

Implementation

One of the criteria used for the implementation was to consider the effect of each one of these actions for each individual feeder. The reason for this is that not all of the company's feeders undergo all the actions being considered, and besides this, the actions themselves may vary in size and in the way they impact each feeder.

In order for these actions to be included in the program, the unit cost of each one had to be determined. Initially, the reduction in the generic failure rate for each one of these actions was also assessed, i.e. the reduction in the failure rate, as a result of the action, and regardless of the feeder on which it was implemented. This information may be used when specific data is not available for a given feeder.

The data mentioned above is necessary because the criterion used to prioritize working on one circuit, rather than on another, is that of cost/benefit. The benefit in this case is calculated based on the reduction in the failure rate, resulting from the action.

During the implementation stage, the decision was made to set a default value for the failure reduction rate as well as for the unit cost. Yet, it should be mentioned that such values can be entirely configured for each one of the feeders.

Figure 1 presents the screen displaying which actions may be implemented for a specific feeder, to what extent, and what is the failure reduction rate such an action brings about.

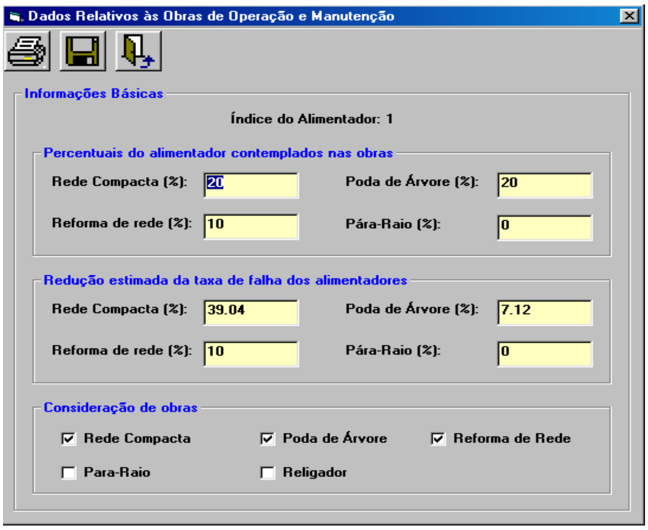

Fig. 1. Screen displaying the failure reduction rate

Figure 2, in turn, presents the screen showing the cost for each one of the implemented actions. This screen also displays the failure reduction rate, as a result of the recloser, and the effect of reducing restoration time, by adding one maintenance crew.

In the case of the recloser, the option was to set a single percentage of failure reduction for all the feeders. Regarding the increase in the number of crews, the cost was considered as that of adding one vehicle for the maintenance teams, and the restoration time was estimated by the company.

Another change that was introduced refers to the possibility of assessing the amount allocated for each set of consumers, based on the proposed investments. For this purpose, the program includes an application named "SISREGIONAIS", which allows the assessment of the investments. It also evaluates the behavior of the main operation performance indicators, as technical losses, voltage drops, DEC, FEC, END and loading of circuits and transformers, for the company's different regions.

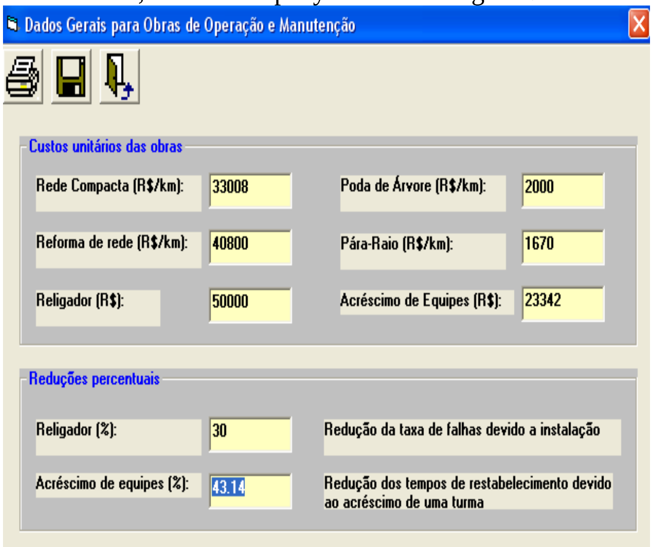

Fig. 2. Screen displaying costs

Additionally, an option of significant relevance is that of assessing the total selected investments, i.e. expansion, maintenance and operation.

III. PERFORMED SIMULATIONS

Based on the changes introduced in the software, it was possible to perform a series of simulations to define the figures for the initial investment, as well as the actions needed to comply with the technical criteria. The data regarding circuits, costs, failure reduction rate and other necessary information was supplied by the company.

The simulations were made for the following scenarios:

1. Classic planning (meeting only the needs of market expansion), not including operation and maintenance actions.
2. Global planning, considering market expansion, continuity indices, expansion, operation and maintenance actions.
3. Same as item 2, but including only the expansion actions and disregarding operation and maintenance.

Based on the results of the above mentioned simulations, one may determine the total difference in the investments between the two versions of the software, as well as present a broad idea of the impact of the continuity indices on the company's total investments.
The annual upper boundary values that define the continuity criterion (maximum annual figures allowed for DEC and FEC) are set for each family of feeders. For the purpose of the present article, those values were set in compliance with the respective predefined goals for the 98 groups of preset consumer units, as per ANEEL's resolution. (ANEEL is the Brazilian Federal Regulatory Entity, responsible for the electric sector). This means that as these boundaries are reached, some action is proposed so that the adequate standard can be restored.
The results achieved through these simulations are presented in the following items. However, before addressing this issue, some remarks are in order, to clarify the procedures that were adopted.

Simulation I – Market expansion

This simulation considered only the market expansion – proposal of actions due to violations of the technical criteria regarding maximum voltage drop and loading at feeders and substations.
In this case, only the mandatory actions were taken into consideration, besides de minimum annual budget, allowing actions with the lowest cost.
The top limit for the study was set at 6 years to coincide with the period of ANEEL's ensuing tariff review.
The criterion regarding loading of feeders was set at 70% for the simulations, i.e. it is assumed that an action will be necessary every time the loading reaches 70% of the upper boundary of the feeder.
Finally, with regard to the criterion for maximum voltage drop at the primary feeders, it was set at 5.0%, in compliance with the present legal value, as per Resolution Nr. 505, issued in November 2001.
Table I shows the actions suggested to meet the needs of market expansion, in accordance with the criteria defined above. The first column shows the year in which the analysis was made and the bottom line the total of actions. The other columns contain the information as follows:

I – Total number of new feeders proposed for the existing substation during the planning period.

II – Total number of proposed actions of recabling medium voltage networks during the planning period;

III –Total number of voltage regulators installed at the feeders during the planning period;

IV – Total number of new transformers installed at the existing substations during the planning period;

V – Total number of proposed new substations during the planning period;

Table II presents the investment costs, on a yearly basis, associated with the actions shown in Table I.

Simulation II – Expansion Planning and Assessment of Continuity Levels

The simulation presented in this item takes into consideration the same basic conditions of the previous item, regarding the technical criteria, but it includes the criterion of continuity (DEC and FEC) as well as the operation and maintenance actions.
Tables III and IV illustrate, respectively, the list of expansion as well as operation and maintenance actions, proposed on a yearly basis.
Table V shows the investment costs, on a yearly basis, associated with the proposed actions.

TABLE I - EXPANSION ACTIONS PROPOSED FOR SIMULATION 1

Year	New Feeders (I)	Recabling Networks (II)	Voltage Regulators (III)	Transformers HV/MV (IV)	New Substations (V)
1	39	0	2	13	0
2	33	0	1	0	3
3	12	0	2	3	0
4	16	0	2	8	0
5	44	0	6	4	6
6	36	0	1	5	7
Total	180	0	14	33	16

TABLE II - TOTAL INVESTMENTS FOR SIMULATION 1

Year	Investment (1000 R$)
1	16210.84
2	16116.13
3	5440.93
4	8600.62
5	23374.14
6	21524.28
Total	91266.94

TABLE III - EXPANSION ACTIONS PROPOSED FOR SIMULATION 2

Year	New Feeders	Recabling Networks	Voltage Regulators	Transformers HV/MV	New Substations
1	62	0	1	19	0
2	33	0	2	1	4
3	16	0	6	2	2
4	17	0	2	6	0
5	39	0	9	4	4
6	46	0	1	3	8
Total	213	0	21	35	18

TABLE IV - PROPOSED OPERATION AND MAINTENANCE ACTIONS

Year	Compact Network Installation	Tree Trimming	Network rebuilding	Lightning-arresters Installation	Recloser Installation	Expanding the maintenance Crews
1	27	9	6	21	4	20
2	1	3	0	1	0	2
3	0	6	1	5	2	2
4	1	8	0	4	4	1
5	0	5	0	2	0	1
6	0	3	0	2	0	2
Total	29	34	7	35	10	28

TABLE V - TOTAL INVESMENTS

Year	Investment (1000 R$)
1	41594.80
2	16782.43
3	9547.86
4	10608.23
5	18810.54
6	23559.15
Total	120903.01

Simulation III – Market Expansion, Assessment of Continuity Goals and Proposal of only Expansion Actions

The simulation presented in the following item follows basically the same guidelines as those in Simulation II.
In this case, however, it includes only the expansion actions needed to solve the violations of the technical criteria under consideration, i.e. voltage drops, loading, upper boundaries of DEC and FEC.
This simulation allows the assessment of the actual impact of the operation and maintenance actions for the improvement of the continuity indicators.
Table VI presents the results obtained for this simulation in terms of the annual volume of investment.

TABLE VI - TOTAL INVESTMENT

Year	Investment (1000 R$)
1	68089.70
2	40502.78
3	18321.09
4	22464.37
5	25177.70
6	34650.93
Total	209206.57

IV. RESULTS AND CONCLUSIONS

Simulation I is a classic case of expansion planning in which only the technical criteria of voltage drop and loading are taken into consideration. It includes just the actions that are necessary, and proposed, as a result of technical criteria violations. It also includes the minimum annual budget to support low cost actions that allow optimal operation of the system during the research period, in compliance with all the criteria. The results are displayed in Tables I and II.
Simulation II represents the basic and most relevant case study in this article. Besides the traditional analysis of expansion planning, loading and voltage drop criteria, it includes an analysis of the continuity indicators, namely, maximum DEC and FEC criteria. This simulation takes into consideration, not only the actions for system reinforcement, in terms of increasing its capacity, but also operation and maintenance actions aimed at reducing the number of supply interruptions as well as the restoration time. The corresponding results for this simulation are presented in Tables III, IV and V.
By means of the 'SISREGIONAIS' application, the investment can be disaggregated in its components of expansion, operation and maintenance actions. The results for simulation II are as follows:

Total investment (1000R$):	120903.01
Expansion investment (1000R$):	108010.10
Maintenance inv. (1000R$):	12239.38
Operation inv. (1000R$):	653.53

Table VII summarizes the results obtained for both simulations with regard to expansion actions.

TABLE VII - COMPARISON BETWEEN SIMULATIONS I AND II

Case	New Feeders	Voltage Regulators	Transformers HV/MV	New Substations	Investment (1000 R$)
Expansion	180	14	33	16	91266.94
Expansion & Continuity	208	22	34	18	108010.10

Thus, for the system to have a development that is feasible and in compliance with all the technical criteria, during the period of research, the expansion investment had to be increased by 18%. At the same time, approximately 13000.00 (1000 R$) had to be added to this expansion investment, in the form of operation and maintenance actions.
Simulation III presents an extreme scenario in which, both the expansion criterion and the continuity goals were taken into consideration, but the operation and maintenance actions were disregarded. In this way, all the violations of the technical criteria are solved via the proposed system reinforcement.
Observing the results shown in Table VI, a substantial increase in the number of actions and volume of investment can be noticed, as a result of the most limited scenario that was analyzed.
Table VIII summarizes the results in terms of the investment. These results were obtained from a comparison with the basic simulation, equal to the present one, but including the operation and maintenance actions.

TABLE VIII - COMPARISON - SIMULATIONS II AND III

Operation and Maintenance Actions	Total Investment (1000 R$)	Expansion Investment (1000 R$)	Maintenance Investment (1000 R$)	Operation Investment (1000 R$)
Yes	120903.01	108010.10	12239.38	653.53
No	209206.57	209206.57	-	-

Thus, the above results indicate that an investment of approximately R$ 13 million in operation and maintenance actions brings about savings of about R$ 100 million in expansion investments.
Clearly, these results show that, in order to respect the continuity criterion, it is much more advantageous to invest in operation and maintenance actions than to expand the primary distribution network.

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