DEFINING TECHNICAL LOSSES TARGETS USING DATA ENVELOPMENT ANALYSIS AND TECHNICAL-ECONOMIC ANALYSIS

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ABSTRACT

Reducing the technical losses is one of the great challenges for the Brazilian power utilities. The Brazilian regulator has adopted a simplified method to calculate losses, wherein there are some assumptions that lead to lower losses. Its main goal is giving the same treatment to all distribution companies in the tariff review process, in which the technical losses are one of the inputs. However, one has to consider that each system has its own characteristics and achieving lower losses may not be feasible. Thus, it is quite important to know the level of technical losses that would represent the maximum efficiency for a distribution system considering its characteristics. This work is intended to achieve that goal by means of two different approaches: using efficiency and productivity analysis and technical-economic analysis. The techniques are presented and the obtained results are shown and discussed.

INTRODUCTION

Nowadays, technical losses have great relevance in Brazil. On the one hand, distribution companies aim at computing losses in an increasingly accurate way because they are one of the main inputs of the tariff calculation. On the other hand, the regulator has aimed to give utilities the same treatment in the technical losses calculation, through a simple methodology of its own, wherein it makes some assumptions that lead to an optimized network. Thus, the regulator aims to avoid that a possible mismanagement is conveyed to the consumers.

At the same time, ANEEL – Agência Nacional de Energia Elétrica –, the Brazilian regulator, is aiming to establish technical losses targets and a reduction curve to be achieved by distribution companies. With that prospect, it is evident the importance of the targets definition, which must be as fair as possible.

The aim of this work was to develop a set of methodologies so to establish technical losses targets and a reduction curve that sets a target for each year within a certain period of study. To do so, two methods have been studied and developed. The first one establishes targets based on the relative efficiency of an utility in comparison to other utilities (referential targets). In that method, Data Envelopment Analysis (DEA) was used. The second one uses Technical-Economic Analysis of some works which main objective is to reduce the technical losses. By accomplishing the feasible works, absolute targets are obtained for the losses. Whatever is the method chosen, the objective is to obtain a target or an optimum value for the technical losses. With that target, it is possible to establish a reduction curve and a set of targets for multiple years.

By means of DEA, it is possible to obtain the efficiency for each utility in the dataset used. However, an efficiency of 100% does not guarantee that the utility is actually efficient. It only guarantees that the leading company is the most efficient of all.

Through the technical-economic analysis, it is possible to study some works which main objective is to reduce technical losses and determine their benefit/cost ratio. As long as that ratio is worthwhile, the work enforcement will be feasible and the optimum value has not been achieved yet.

It is important to highlight that this work is a result of a research and development project involving CEMIG D – the distribution company of Minas Gerais State, in the Southeast of Brazil –, which supplies energy to over 8 million clients.

REFERENTIAL TARGETS

The determination of referential targets comprises comparisons to be made among several companies. To do so, this work utilized a dataset containing 33 Brazilian utilities and it is divided into two parts. In the first step, descriptive attributes were defined for the utilities in order to characterize each company regarding its technical losses. The chosen attributes must represent the explanatory variables of losses. In order to determine the descriptive attributes a first list of attributes that could explain the observed losses was prepared. Through a multivariate analysis [3] [5], the Factor Analysis, the first list of attributes was reduced to a shorter set so to remove correlated variables and variables not correlated to the observed variable (losses). Even so, the final set was still oversized and more variables were needed to be removed.

In the second part, Data Envelopment Analysis (DEA) was applied to a dataset in order to obtain individual targets for the losses, based on the efficiencies calculated by the method. It is important to notice that the efficiencies obtained this way are the relative efficiencies of each company regarding the other companies in the dataset and, therefore, those targets are the referential targets.

In the next subsections each one of the two steps previously mentioned are detailed.

Selection of Attributes

At first, 22 explanatory attributes were divided into 5 groups: Market, Technical-Market, Technical, Topologic-Technical and Topologic, as it follows (units in brackets and variable names in parenthesis).

The market group contains 7 attributes: maximum load [MW] (DemMax), energy density [MWh/km^2] (DensEn), number of low voltage clients per transformer (NUC/NT), overall energy consumption [MWh] (MercGlob), percentage of overall energy consumed in low voltage [%] (MercGlobBT), number of low voltage clients (NUC), and load density [MW/km^2] (DensCa).

The technical-market group contains only 2 attributes: average utilization factor of distribution transformers [%] (FU) and consumption-weighted average load factor considering each voltage level [%] (FC).

The technical group contains 4 attributes: rated power of distribution substations [MVA] (PotInst), non-technical losses [%] (PerNTec), and average maximum current of feeders in [A] (Imed) and in [%] (Imed%).

The topologic-technical group contains 4 attributes: average resistance of medium voltage (ResMT) and low voltage networks (ResBT) in [Ω] (considers the network length) and in [Ω/km] (ResMT_esp and ResBT_esp).

Finally, the topologic group contains 5 attributes: number of distribution transformers (NTrafo), network total length [km] (CompTot), average length of medium voltage networks [km] (CompMT), average length of low voltage networks [km] (CompBT), and network total length per unit of the concession area [km/km^2] (CompTot/AC).

After defining the attributes that may explain the losses, a reduction in the number of variables was performed aiming to identify the attributes which have most influence in the losses. The reduction process of the number of variables began with a factor analysis in each group. Possible correlations among explanatory variables of the same group were determined, and then some variables were removed from it. Afterwards, the chosen attributes in each group were submitted to a global factor analysis including all the remaining variables. Thus, a new set of attributes with different characteristics and most correlated to losses were determined.

By performing a factor analysis in each group and a global factor analysis, 14 attributes were selected to represent the networks' characteristics regarding technical losses. Table 1 shows the correlations between each selected attribute and the observed variable: the technical losses.

After an analysis of the results shown in Table 1, 6 attributes were chosen for the establishment of losses targets: DensEn, MercGlobBT, PerNTec, ResMT_esp, ResBT_esp, and CompTot/AC.

Table 1. Correlation between selected attributes and technical losses

Attribute	Correlation between attribute and losses
DensEn	-0.37
MercGlobBT	0.49
FU	-0.50
Imed%	-0.42
PerNTec	0.40
ResMT_esp	0.16
ResBT_esp	0.34
NUC/NT	-0.26
MercGlob	-0.23
FC	0.08
CompTot	0.24
CompMT	0.68
CompBT	0.14
CompTot/AC	-0.62

The attributes related to medium voltage (MV) and low voltage (LV) networks' resistance in Ω/km – respectively ResMT_esp and ResBT_esp – were combined into only one variable (ResMTBT_esp), calculated from the length-weighted average. The other attributes have not been selected because the correlation between each one of them and the losses is low (in the case of FC, for instance) or the expected behavior has not been verified (the attribute must be positively correlated to losses). This is the case of MercGlob, FU, and Imed%. It is expected that, the higher the overall energy consumption in MWh, the higher the technical losses in MWh. Nevertheless, nothing can be concluded concerning the technical losses in %, because they can be higher, lower or the same. That depends on how the losses and the energy consumption (both in MWh) increase (the energy consumption is the basis for the calculation of technical losses in %).

The average length of MV and LV networks (CompMT and CompBT) has not been selected because the influence of the network length is already represented by the attribute CompTot/AC.

The low correlations between the majority of the attributes in Table 1 and the losses are remarkable. However, the overall technical losses are composed of several parts related to each segment of the distribution system. The correlation between each attribute and the losses of each segment varies depending on the segment. Since there is a constraint in the next step of this approach regarding the number of variables, the new reduction after the factor analysis was mandatory.

Establishment of Targets

After defining the explanatory attributes, an efficiency and productivity analysis technique is used to determine the efficiency of each company in the dataset regarding its technical losses. In this work, DEA has been used.

DEA is a technique for monitoring the efficiency and the productivity of decision making units (DMU), which supplies quantitative data about possible actions to improve those units when they are inefficient. The technique is based on a production process, wherein an input set generates an output set. There are several ways to do that, but the existing technology is a limitation. Figure 1 depicts a grey area in the chart, which is defined as the Production Possibility Set (PPS). The PPS contains several ways to transform inputs into outputs that are limited to a frontier function, which is determined by the existing technology [4] [7].

It can be noticed, in Figure 1, that company A, which is inside the PPS, could produce the same quantity of outputs as company B without the need for an increase in the quantity of inputs (product orientation). Alternatively, company A could produce the same quantity of outputs as company C with a lower quantity of inputs (input orientation). Therefore, it is said that company A is not efficient when compared to companies B and C, while the latter, located on the frontier, are efficient companies.

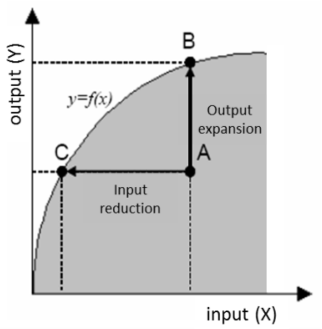

Figure 1. Production Possibility Set (PPS) [4]

DEA uses linear programming techniques to calculate an efficiency index that compares the performance of a company to the most efficient combination of the other inputs/outputs observations. The value 1.0 is assigned to the efficiency index of the DMUs which productivity is better and a value lower than 1.0 is assigned to inefficient DMUs. The method allows the calculation of the necessary output expansion or input reduction to optimize the production process.

In this work, the technical losses value corresponds to the output variable and the input variables are represented by the network descriptive attributes defined in the first step.

DEA can be used when, in the analysed dataset, an increase in the inputs leads to an increase in the outputs [2]. In case of that feature is not present in the dataset, transformations in the variables must be done. The input variable is the technical loss, which is an undesirable output. Since the aim is to minimize the inputs, it is necessary to perform a transformation in the loss variable. The transformation used for losses was the inverse function. Thus, the lower the loss, the higher the output. The same type of transformation was performed in the case of the input variables when an increase in their quantity led to a decrease in the output.

Furthermore, one has to choose the model and the orientation that shall be used. Among the possible models are the CRS (Constant Returns to Scale) and the VRS (Variable Returns to Scale). Regarding the orientation, one has to choose between output orientation and input orientation. In this work, the VRS model and the output orientation have been adopted.

By using DEA, it is possible to establish reduction curves for the technical losses of each company. After defining the target, which is calculated from the efficiency obtained for each company, it is assumed that the target must be achieved within a tariff period. In Brazil, the tariff period is generally 4 years. That means that a company should reduce its losses from the current value toward its target, complying with a linear reduction curve. The reduction curve will define the intermediate targets for each year of the tariff period. Efficient companies shall maintain the current losses index.

ABSOLUTE TARGETS

The second approach to obtain the losses targets is based on a technical-economic analysis of some works which main objective is to reduce technical losses. By defining targets through a technical-economic analysis, the goal is to obtain an optimum value of losses for a certain distribution company without making comparisons to other companies. In this case, the optimum value consists of an absolute target of losses.

The optimum value of losses that will be the target corresponds to the level of economic operation. It is the break-even point from which any additional investment in the network aiming solely at the losses reduction will not be feasible because the benefit obtained from the losses reduction does not compensate its investment.

The first step of this analysis is to select the types of works that will be studied aiming at the losses reduction. For each type of work, a method for evaluating the losses reduction must be established. The following works were considered: reconductoring of customer connection, LV client's energy meter replacement, distribution transformer relocation and replacement, MV and LV load phase balancing, capacitor placement, new feeders, reconductoring of MV and LV networks and LV network split.

In order to evaluate the benefit on losses reduction obtained from the accomplishment of each work, an initial calculation is performed to determine the initial losses, wherein a detailed model including a load flow and typical daily load curves is used. Next, to evaluate the effect of a certain work on certain equipment, simple rules are utilized to determine the new losses value after the work execution. In the case of transformer replacement and reconductoring, line segment and transformer sizing economics are used [6].

Each work is automatically simulated according to some rules previously defined by the user so to avoid simulations in all network equipment. Basically, the user must define the maximum value allowed for losses and, thus, the works are simulated only in the equipment with losses greater than the maximum value.

The automatic simulation is imperative for this type of technical-economic analysis, because the amount of information generally associated to a distribution network is extremely high.

For each simulated work some economic indices are calculated, such as benefit/cost ratio, internal rate of return, payback, and initial rate of return.

From the obtained results, it is possible to select only the feasible works and determine the amount of technical losses that could be avoided in each segment and, therefore, determine the optimum value of losses for each segment and for the company.

RESULTS

DEA was applied to a dataset containing 33 Brazilian distribution companies in order to obtain referential targets for their technical losses. The technique was simulated using the software SIAD [1]. Table 2 shows the results obtained for 15 companies due to space limitation.

Table 2. Efficiencies and losses targets using DEA

Utility	Technical Losses [%]	Efficiency [%]	Target [%]
1	6.799	100.0	6.799
2	7.060	100.0	7.060
3	4.970	94.7	4.706
4	6.572	100.0	6.572
5	8.920	78.2	6.975
6	9.066	78.7	7.138
7	6.167	86.5	5.336
8	9.410	100.0	9.410
9	8.210	97.5	8.004
10	9.769	100.0	9.769
11	12.419	100.0	12.419
12	9.859	100.0	9.859
13	9.204	82.9	7.630
14	5.670	100.0	5.670
15	8.627	93.3	8.050

In the case of the technical-economic analysis, a software named Pertec AE has been developed to allow the simulation of the works previously mentioned. It is important to notice that it can be used by any distribution company after interface customizations to fit the corporate database.

Among Pertec AE's main characteristics are:

- Tool for importing topologic database, load data and billing data;
- Energy consumption forecasting during the planning time period (from 5 to 10 years), through the insertion of load growth rates;
- Calculation of the overall technical losses and technical losses per segment at the end of the time period and estimation of technical losses for the previous years;
- Evaluation and proposal of a set of improvement actions and expansion works complying with technical criteria;
- Reports including technical results (original losses, losses after work execution, reduction losses), costs and economic indices to help the user define the best set of actions and works;
- Selection of a proper set of actions and works in order to obtain several possible reduction curves for technical losses as well as their optimum value.

Figures 2 and 3 present some screenshots of Pertec AE's graphical user interface. Figure 2 depicts the window to configure the simulation parameters. The user can select the substations he wants to simulate, as well as the types of works and their respective execution rules. Figure 3 portrays the results window, which allows viewing the overall and detailed results. Moreover, it allows the selection of which substations and types of works recorded in the database must be retrieved to create the report. The user can also select a set of works which complies with the desired criteria of benefit/cost ratio, internal rate of return, initial rate of return or payback and create the optimized losses report (Figure 4). That report shows the losses evolution over the time in case of the selected works are accomplished. If the user selects only the works that have benefit/cost ratio greater than 1.0, the losses evolution curve will represent the optimum targets. Within the evolution curves presented, the blue line represents the losses evolution curve in case of no work is accomplished. The green line represents the losses evolution curve in case of the proposed works are accomplished in the proposed years.

Pertec AE has been applied to 2 substations of CEMIG D: São João Del Rei 1 (SDEU) and São João Del Rei 2 (SDED). That system has 13 MV feeders and 8,315 distribution transformers supplying energy to 68,556 clients.

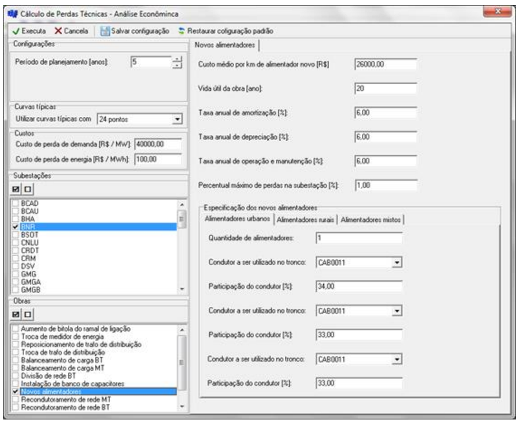

Figure 2. Execution rules for the work "new feeders"

The main technical and operational characteristics verified in the distribution system of that area are: MV feeders with large length; the maximum load is relatively low; low load density; high load imbalance; high number of distribution transformers operating at no load conditions; LV networks with low load.

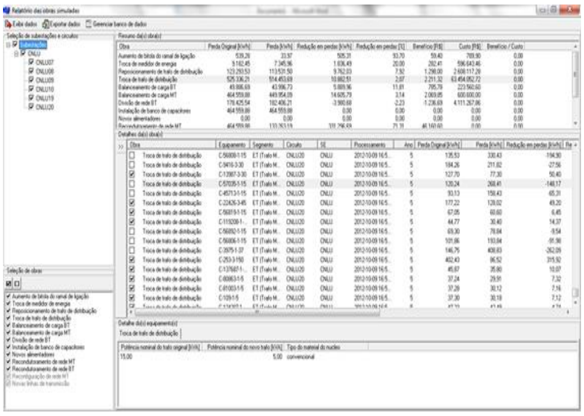

Figure 3. Overall results window

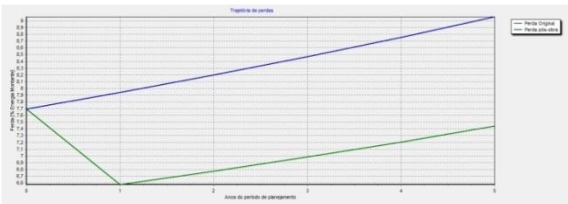

Figure 4. Energy losses evolution curves [%]

The segments which most contribute to technical losses are the distribution transformer (47.15%) and the MV feeders (26.78%), which are responsible for almost 75% of the overall losses.

The simulations results suggest the following aspects:

- The high load imbalance shows that a significant losses reduction can be obtained through phase balancing actions;
- The economical conductor must be used, mainly in the new projects of MV networks, since a significant losses reduction was obtained through reconductoring, even though the benefit/cost ratio is not so good;
- The high number of distribution transformers replacement for other ones of lower rated power points to a need to verify into much detail the projects of LV networks.

None of the improvement actions or works presented an initial rate of return greater than 1.0. The highest value was 0.27 and is due to the relatively works' high cost for a modest losses reduction.

CONCLUSIONS

In this work, a set of methodologies for establishing referential and absolute targets of technical losses have been developed.

In order to establish the referential targets, DEA was used to obtain targets based on the efficiencies of the companies, which are characterized by 5 descriptive attributes that are correlated to losses. By using the proposed method, the technical efficiency becomes the performance index and an individual target is defined. The use of the technical losses as a performance index is inadequate, since inefficient companies with low losses may exist, as well as efficient companies with high losses. Such conditions depend on the characteristics of the concession area, in which higher losses are expected in a less advantageous environment. DEA allows identifying what would be the proper losses of a company according to its network characteristics, by comparing it to other companies.

In order to establish the absolute targets, a method based on a technical-economic analysis of works aiming at the losses reduction has been developed, as well as a software that allows to simulate several types of works in an automatic manner according to rules defined by the user. The software also allows selecting the works with the best economic indices so to obtain the ideal value of losses or the absolute target to be achieved by the company. Unlike the case of the referential targets, in this case the target is obtained by using only the data from the company under analysis and no comparison is made.

Therefore, CEMIG D now possesses a set of tools to obtain proper values for losses, which are the values that lead to a better solution regarding cost and present a trade-off between operational costs and investments to reduce losses, which will benefit consumers, since such costs have great impact in the energy tariff. Also, it will guide the actions to mitigate the technical losses.

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