# TECHNICAL LOSSES CALCULATION USING SIMPLIFIED MODELS FOR REGULATORY PURPOSES

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## *ABSTRACT*

*Undoubtedly, load flow is one of the best practices to calculate technical losses in distribution systems. The network's actual characteristics are taken into account and the load characterization is the main issue that has to be tackled to achieve a good accuracy. But unfortunately, the method is data-demanding and time-consuming and, therefore, is not suitable for regulatory purposes when the regulator is responsible for the technical losses calculation in every single distribution company, which is the case of Brazil. ANEEL, the Brazilian regulator, has been using a simplified model of its own for the past last years. However, it presents several flaws. This paper discusses the problems of ANEEL's model and proposes new simplified models for the calculation of losses in MV and LV networks for regulatory purposes. It also presents the results of an international survey aiming to identify regulatory treatments given to technical losses.*

## INTRODUCTION

The regulatory treatment of technical losses in Brazil aims at determining a loss value that will be recognized in the utility's tariff. To achieve that goal, ANEEL – the Brazilian regulator – has established a simplified calculation model to be utilized in the utilities' tariff review [1].

One of the main problems related to simplified models for losses calculation concerns the accuracy of the results. ANEEL's model is biased and the regulatory technical loss is frequently lower if compared to load flow-based methods, which better represent distribution networks. This problem is larger in the case of medium voltage (MV) and low voltage (LV) networks models.

However, despite the importance of the matter, it seems that ANEEL did not spend enough time on research aiming better robustness and accuracy in current methodology. Furthermore, the involved stakeholders had little time to discuss the proposed methodology, which was recently submitted by the regulator to a public hearing. Consequently, the MV network model, which is an econometric one, presents remarkable flaws, including lack of representativeness of the sample, lack of relevant explanatory variables, and other problems in the calculation of the observed variable (losses) through load flow, which will be discussed in the paper.

The objective of this work is to present the results of an accomplished research that aimed at improving the Brazilian regulatory simplified model for calculation of losses in MV and LV networks for all national distribution areas. Still, it will also present the results of an extensive investigation performed in several regulators worldwide, aiming to identify and compare regulatory treatments given to technical losses.

The international survey shows that load flow analysis is a common practice. However, load flow studies are data-demanding, time-consuming and very responsive to the quality of the database and, therefore, accurate simplified models would be invaluable.

In order to improve the current Brazilian econometric model to calculate losses in MV networks, the following issues were taken into account: i) the improvement of the representativeness of the sample by including over 4,000 feeders using the Kolmogorov-Smirnov Test (ANEEL's sample had 270 feeders); ii) inclusion of new explanatory variables, such as number of transformers, load centre/radius ratio (parameter that explains the load distribution along the feeder, wherein the radius is the distance from the substation to the farthest distribution transformer), and lateral conductor's resistance. Furthermore, the observed variable was obtained through load flow calculation on the feeders of the new sample in order to consider the network's actual characteristics.

Similar procedure was used in the case of LV networks, which comprises over 700,000 LV circuits in the sample.

The new econometric models are better fitted than ANEEL's model and, hence, they present better results, which are closer to those obtained through load flow (observed loss), as it will be shown along the paper.

## ANEEL'S MODEL

ANEEL's methodology for calculation of losses comprises several models in order to obtain the losses of each segment of the distribution system. The highest discrepancies between the results obtained through ANEEL's models and those obtained through load flow-based methods occur in MV and LV networks.

ANEEL's model for calculation of losses in MV networks is an econometric model and one of its main problems is the lack of representativeness of the sample used to obtain the regression model. That sample comprised 270 feeders of two distribution companies [1] and it obviously does not represent the wide variety of MV feeders all over the country. A calculation accomplished for several companies is a proof of that, in which high discrepancies between the regulatory loss and the loss calculated through load flow-based methods can be observed. In some companies, the losses in the MV network segment are equal to 50% of those calculated through load flow, whereas in other companies that value reaches 150%.

The second main problem is related to the load flow calculation performed by ANEEL to obtain the observed variable (loss) to investigate and define a proper econometric model. In that calculation, ANEEL made some assumptions that lead to lower losses, but the most important was the use of 3-phase networks with balanced 3-phase load [1]. Such assumption does not represent the majority of the Brazilian MV networks since 1-phase and 2-phase loads are very common as well as 1-phase and 2-phase networks, mainly in rural areas with low load density. Thus, the regression model may be well-fitted, but it is fitted to lower losses.

In the case of ANEEL's model for calculation of losses in LV networks, discrepancies are more severe. This model involves the use of LV network typologies, which are shown in Figure 1. Each one of them refers to a standard network configuration that must be assigned to every single LV network [1].

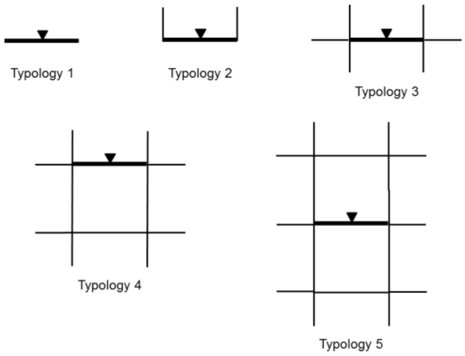

Figure 1. LV network typologies

ANEEL's model is intended to accomplish a load flow calculation on those typologies using the actual load, length, and conductors' resistances of a given LV network. In that calculation, the load is assumed as a 3-phase balanced load and its distribution along the circuit is considered to be uniform. In this case, the model always results in losses much lower than the losses obtained through load flow-based methods.

The problems mentioned led to a biased model that tends to result in losses, for the most part, lower than the actual losses. Although the regulator does not want to calculate the actual losses, but instead of that, the losses free of mismanagement regarding the control held by the companies, regulatory losses extremely lower than the actual ones do not encourage utilities to tackle them.

Therefore, a simplified method must be as accurate as possible, not biased, and there should be some kind of policy to encourage utilities to reduce losses.

## INTERNATIONAL SURVEY

An extensive investigation was performed in several regulators worldwide, aiming to identify and compare regulatory treatments given to technical losses. Basically, it aimed to answer the following questions: i) What is the method utilized to calculate losses for regulatory purposes? and; ii) Who is held responsible for that calculation? The international survey was conducted in the following countries: Portugal, Colombia, Chile, Peru, Argentina, Australia, UK, USA, France, Germany, and Norway. The investigation was limited to public documentation available at the regulators of those countries and was accomplished in March 2013.

In the investigated countries it was verified that the regulators adopt two different approaches, but the utilities are generally held responsible for the calculation of losses, which is accomplished through specific studies.

In some countries, the regulators do not specify the methodology to be used by utilities, which have to define a methodology of their own to obtain the so-called loss factors. The loss factors are obtained through specific studies and must be proposed by utilities to regulators. Thus, the regulator has to analyse the utilities' calculation and decide about its approval. This is the case of Portugal, Argentina (provinces of Buenos Aires and Jujuy), Australia, and UK.

In other countries, regulators establish some guidelines in other to recognize in the tariff only the losses produced in an efficient way. Thereby, they define the concept of efficient networks. In this case, regulators and utilities share the responsibility of the calculation. This is the case of Colombia, Chile, and Peru.

Except for France, whose calculation is accomplished by the transmission system operator using a quadratic equation, none of the regulators investigated compels utilities to use a specific method. Germany defines two approaches and allows the utilization of a methodology even more accurate than the regulator's approaches. Specific studies in this matter are generally accomplished using load flow calculations on real networks, representative networks, or theoretical networks of efficient utilities. Table 1 shows an overview of the main characteristics encountered in the international survey.

One remarkable issue regards the regulatory treatment given to losses in Portugal, wherein the regulator establishes an incentives policy to encourage utilities to reduce their technical losses. According to that policy, the regulator gives the utilities a reward or a penalty whether the companies comply with the targets agreed or not.

Table 1. Overview of the international survey

| Country | Losses calculation method | Responsibility |
|---|---|---|
| **Portugal** | Specific study | Utility |
| **Colombia** | Load flow on optimized networks | Regulator / Consultant |
| **Chile** | Specific study on optimized networks | Regulator / Utility / Consultant |
| **Peru** | Specific study on optimized networks | Regulator / Utility / Consultant |
| **Argentina – Buenos Aires** | Specific study | Utility |
| **Argentina – Jujuy** | Specific study | Utility |
| **Australia** | Specific study / load flow | Utility |
| **UK** | Specific study / load flow | Utility |
| **USA** | Specific study | Utility |
| **France** | Quadratic equation | Tramission System Operator |
| **Germany** | Measurement, quadratic equation or other method | Utility |
| **Norway** | Load flow | Utility |

The results of the international survey can be shown in a chart wherein three types of degrees were assigned to each country: complexity, exigency and intrusion. The degree of intrusion represents how much the regulator interferes in the task of calculating losses accomplished by utilities. A degree of complexity was assigned to the calculation methodology. The degree of exigency represents how much the regulator compels utilities to be more efficient by recognizing losses lower than the actual losses. Figure 2 depicts a bubble chart wherein the degree of complexity is plotted as a function of the degree of intrusion and the degree of exigency is represented by the bubble size. The chart includes Brazil, but it does not include USA and Argentina (province of Buenos Aires) because there was not sufficient information to assign the three degrees to them.

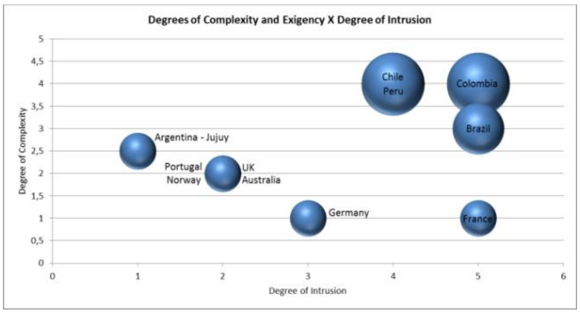

Figure 2. Degree of complexity X Degree of intrusion

## NEW MODEL FOR MV NETWORKS

In order to overcome the problems of ANEEL's MV network model, several econometric models were investigated using a new sample. The new sample comprises 7,933 feeders of 10 utilities from all over the country. Despite the sample's size, there is no guarantee that it represents the population of feeders in a proper way. The sample must have the same cumulative distribution function of the population so to avoid the problem of lack of representativeness.

In order to assess the representativeness of the new sample, the Kolmogorov-Smirnov Test [2] was used to evaluate the similarity between the cumulative distribution functions of a given variable in the population and in the sample. The following variables were considered: average current ($I_{avg}$), main feeder's length ($L_M$), lateral's length ($L_L$), main feeder conductor's resistance ($R_M$), and number of distribution transformers ($N_{tr}$ – not available in ANEEL's sample).

In the case of the 7,933 feeders of the sample, geographical information was available and a load flow calculation was accomplished so to obtain the losses of each feeder considering its actual characteristics. In addition, non-geographical information of 15,288 feeders of 41 utilities that represent 80% of Brazil's electric energy market was also available, which is almost the whole population. In this case, only a few attributes of each feeder were available, but they were sufficient to assess the similarity between two cumulative distribution functions. It was verified that the new sample does not represent the population as well as ANEEL's sample, although statistics show the new sample is better. Tables 2 and 3 show the results of Kolmogorov-Smirnov Test applied to ANEEL's sample and new sample, respectively. The null P-Values (lower than the 5% level of significance) indicate that all variables have cumulative distribution functions different from the population's cumulative distribution function.

Table 2. Kolmogorov-Smirnov Test in ANEEL's sample

| Variable | D Statistic | P-Value |
|---|---|---|
| $\ln(R_M)$ | 0.321 | 0.00 |
| $\ln(L_M)$ | 0.125 | 0.00 |
| $\ln(L_L)$ | 0.153 | 0.00 |
| $\ln(I_{avg})$ | 0.412 | 0.00 |

Table 3. Kolmogorov-Smirnov Test in new sample

| Variable | D Statistic | P-Value |
|---|---|---|
| $\ln(R_M)$ | 0.035 | 0.00 |
| $\ln(N_{tr})$ | 0.030 | 0.00 |
| $\ln(L_M)$ | 0.062 | 0.00 |
| $\ln(L_L)$ | 0.044 | 0.00 |
| $\ln(I_{avg})$ | 0.031 | 0.00 |

Through a genetic algorithm whose fitness function is a linear combination of the results of Kolmogorov-Smirnov Test applied to the available variables, a new set of feeders was determined from the new sample. The new set comprises 4,012 feeders, which do represent the population. Tables 4 shows the results of Kolmogorov-

Smirnov Test applied to the small sample. The P-Values greater than the 5% level of significance indicate that all variables have cumulative distribution functions similar to the population's cumulative distribution function.

Table 4. Kolmogorov-Smirnov Test in small sample

| Variable | D Statistic | P-Value |
|---|---|---|
| $\ln(R_M)$ | 0.014 | 0.64 |
| $\ln(N_{tr})$ | 0.019 | 0.24 |
| $\ln(L_M)$ | 0.014 | 0.60 |
| $\ln(L_L)$ | 0.018 | 0.28 |
| $\ln(I_{avg})$ | 0.012 | 0.77 |

Figure 3 depicts the cumulative distribution functions of the 4 sets of feeders for the mentioned attributes: ANEEL's sample (270 feeders), large sample (7,933 feeders), small sample (4,012 feeders), and the population. It can be observed that even though some cumulative distribution functions may look similar, as it may be seen in the case of the number of distribution transformers, the results of Kolmogorov-Smirnov Test indicate that only the small sample has a cumulative distribution function similar to the population's cumulative distribution function at 5% level of significance.

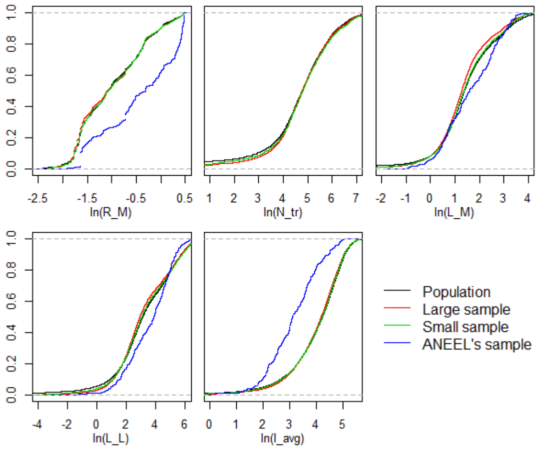

Figure 3. Cumulative distribution functions of the three samples and population for 5 variables

The small sample was used to obtain a new econometric model for the calculation of losses in MV networks. In addition to the variables used in ANEEL's model (average current, main feeder's length, lateral's length, and main feeder conductor's resistance), the following exogenous variables were also tested: lateral conductor's resistance, number of distribution transformers, and load centre/radius ratio. The last two variables are intended to include some information regarding the load distribution. All variables tested were statistically significant at 5% level and the average demand loss of a feeder in kW can be calculated from equation (1):

$$loss_{MV} = 1.0093 \cdot \exp\begin{bmatrix} +1.8296 \cdot \ln(I_{avg}) + 0.6543 \cdot \ln(L_M) \\ +0.3532 \cdot \ln(L_L) + 0.7384 \cdot \ln(R_M) \\ +0.0949 \cdot \ln(R_L) - 0.2071 \cdot \ln(N_{tr}) \\ +1.0116 \cdot \ln(LCRR) - 5.9799 \end{bmatrix} \qquad (1)$$

wherein $I_{avg}$ is the average current [A]; $L_M$ is the main feeder's length [km]; $L_L$ is the lateral's length [km]; $R_M$ is the main feeder conductor's resistance [Ω/km]; $R_L$ is the lateral conductor's resistance [Ω/km]; $N_{tr}$ is the number of distribution transformers; and $LCRR$ is the load centre/radius ratio. The adjusted coefficient of determination of the new model is 0.9457. Figure 4 shows the results of the overall demand losses in MV networks for each utility using the new model. Losses are presented in % of the observed losses (those obtained through load flow). Results greater than 100% mean fitted losses are greater than observed losses. In a similar way, results lower than 100% mean fitted losses are lower than the observed losses.

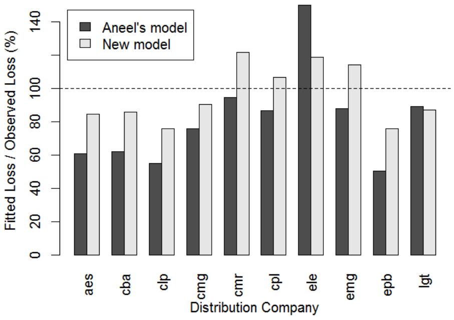

Figure 4. Fitted/observed loss ratio in MV networks

It can be noticed that the new model presents a more regular behaviour than ANEEL's model and also more accurate results, for the most part. Although the new model requires more information, the extra variables are easy to be obtained.

The full methodology wherein the MV network model was replaced by the new econometric model was applied to 6 utilities in order to obtain the energy losses after the energy balance, which is accomplished to fit the results to measured energy in all voltage levels. Figure 5 shows the energy losses of MV networks in % for each utility.

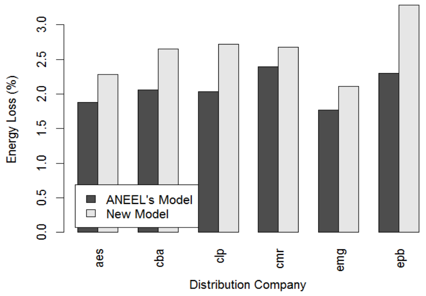

Figure 5. Energy loss in MV networks

## NEW MODEL FOR LV NETWORKS

In order to improve ANEEL's LV network model, the same approach as for MV networks was utilized, that is to say, an econometric model was obtained to replace the typology-based method. The procedure used to obtain the new MV network model was also used to obtain a new LV network model. In this case, over 700,000 LV circuits were used. Besides the well-known attributes regarding current, length and conductors' resistances, the following attributes were also tested: number of conductors (including phase and neutral conductors), typology number, network type (1-phase, 2-phase or 3-phase), and transformer type (1-phase or 2-phase).

By using the possible combinations of those variables, 64 models were obtained and the best model presented an adjusted coefficient of determination of 0.8601. The average demand loss for each LV circuit in kW can be calculated from equation (2):

$$loss_{LV} = 1.2742 \cdot \exp\begin{bmatrix} -7.6787 + 1.7261 \cdot \ln(I_{avg}) + 0.7381 \cdot \ln(L) \\ +0.6464 \cdot \ln(R_M) + 0.1249 \cdot \ln(R_L) \end{bmatrix} \quad (2)$$

wherein $I_{avg}$ is the average current [A]; $L$ is the circuit's total length [km]; $R_M$ is the main circuit conductor's resistance [Ω/km]; and $R_L$ is the lateral conductor's resistance [Ω/km]. Figure 6 shows the results of the overall demand losses in LV networks for each utility using the new model and they are presented in % of the observed losses. The full methodology wherein the LV network model was replaced by the new econometric model was applied to 6 utilities in order to obtain the energy losses after the energy balance. Figure 7 shows the energy losses of LV networks in % for each utility.

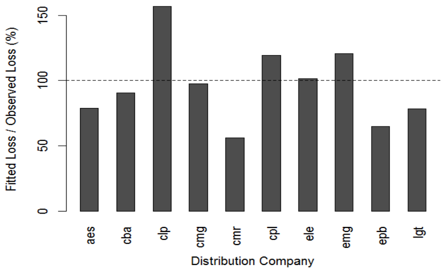

Figure 6. Fitted/observed loss ratio in LV networks

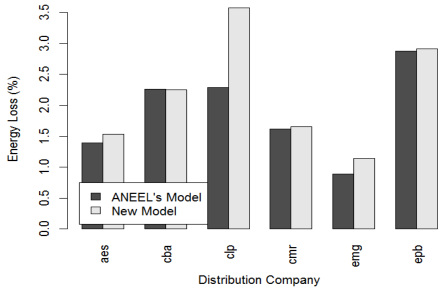

Figure 7. Energy loss in LV networks

## CONCLUSIONS

In June 2014, ANEEL pointed to a new method to calculate losses through load flow using OpenDSS, which will probably supersede ANEEL's current simplified model in 2015. Although the calculation of losses through load flow is one of the more accurate methods, it is data-demanding, time-consuming and is very responsive to the quality of the database. Because of that, such method is not recommended for regulatory purposes. It is used in countries where the utility is responsible for the calculation of losses.

Simplified models require less information and are quicker. They are suitable for regulatory purposes and give all utilities the same treatment, but must be defined very carefully in order to deliver good results. The simplified models for MV and LV networks presented in this work achieved that goal and could be used for regulatory purposes in Brazil. For other countries, similar procedure can be used in order to obtain econometric models for application on those countries.

The international survey showed that Brazil is the only country whose regulator established a methodology for calculation of losses and, in addition, is responsible for that calculation.

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