TECHNICAL LOSS CALCULATION BY DISTRIBUTION SYSTEM SEGMENT WITH CORRECTIONS FROM MEASUREMENTS

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ABSTRACT

This paper aims to present a methodology for the calculation of technical losses per segment of a power distribution system. One of the most important data is the billed energy of each customer. After this calculation, it is achieved the energy supplied by each feeder. This calculated energy is, then, compared with the measured energy. As a result of this comparison, it is possible to correct the technical losses calculated previously, considering the flow of the non-billed energy (theft and fraud) through the network. Consequently, it is achieved a new value for the technical losses and for the non-technical losses. On this paper it is presented the methodology for the calculation of technical losses with the correction through the measurements and the results obtained.

INTRODUCTION

On previous work [1], it was developed a methodology for the calculation of technical losses per segment of the power distribution network. In order to use this methodology, it is required the topological data of the primary and secondary networks and the billing data of the customers.
From the monthly energy of each customer and from the typical load curves of the utility company, it is obtained a daily load curve (24 values) for each customer. Thus, the load representation issue is solved. After obtaining the load curves for each customer, it is executed a three-phase unbalanced load flow calculation for each one of the 24 day instants, in order to obtain the loss curve for each equipment in the system. Once the loss curve is assembled, the energy loss can be easily obtained. After the calculation, it is also provided the estimated load curves the primary feeders.
The methodology presented in this paper was implemented in a software, which was installed in many Brazilian utilities. Later, it was possible to verify if the estimated load curves for some feeders were close or not of their measured load curves. On the vast majority of the cases, it was observed that the behaviour of the estimated load curves were pretty close to behaviour of the measured load curves, despite of some discrepancies on the energy associated to them. On this paper, it is discussed the origin of such discrepancies and it is proposed a method to correct the energy and the maximum demand of the estimated load curves, using the data available from the measurements.

THE DISCREPANCIES ORIGIN

Through the methodology of loss calculation using the typical load curves [1], it is possible to estimate the load curves on the primary feeders. Applying this methodology in the system of some utilities that have remote monitoring in their feeders, it was possible to compare the estimated load curve with the measured load curve from several feeders. In order to perform the comparison, it was chosen a few months and, as the load curves for every single day of each month were available, it was calculated an average load curve for each month. The average load curve obtained from the measurements was then compared with the estimated load curve.
During the comparison, the following situations were observed: i) estimated and measured curves with similar profiles and energies; ii) estimated and measured curves with similar profiles and different energies; iii) estimated and measured curves with different profiles and energies.
Through this finding, it was carried out a search for the discrepancies origins that were noticed, which probably occurred due to four main factors: i) possible record errors; ii) non-technical losses; iii) different time basis for the billed consumptions; iv) switched load-blocks.
On the following items, it will be discussed how each one of these four main factors, which were mentioned before, may have contributed for the discrepancies between the calculation and the measurements.

Switched Load-Blocks

When the discrepancy observed among the measured load curves and estimated load curves is too high, in terms of energy and consumption profile, it is possible that some load-blocks were switched temporally or even permanently. Usually, the load-block switching is a resource used to minimize contingencies during emergency situations, when it is necessary to repair the power network, or even for maintenance scheduling. The main objective is to minimize the number of customers that will not be supplied by the feeder, transferring the load-blocks where they are connected to other feeders. During these special situations, the some of the feeders that received the load-blocks may become overloaded, what is acceptable if the overloading is within pre-defined limits for magnitude and duration, i.e., on this situation the switching is temporally. However, the effects of such event may be quite high on the average of the measured load curve in a specific month for the feeder involved. The topological database can not “see” such event.
The load switching may also solve voltage drop and loadability problems for a specific region, and when it happens, the switching becomes permanent. For this situation the topological database will be able to “see” such event, but it does not happen instantaneously.
No matter the reason for the switching, it is important to notice that the measured load curve will be affected and discrepancies will appear for sure. Generally, this kind of

errors remain restricted to the feeders involved in the switching for the period that such events last and will not affect significantly the general losses indices for the segment if observed through an annual time basis.

Possible Record Errors

Without any doubt, the existence of record errors in databases is the factor that contributes the most for the discrepancies between the estimated load curves and the measured load curves. The amount of information required for the losses calculation is pretty high; therefore the records errors may completely change the calculation results.

Sometimes the estimated and the measured load curves have different profiles due to the fact that the consumption records for some customers are wrongly stored among other types of customers. For example, the company records show that some customers are classified as commercial type or industrial type, but, in fact they are residential customers. When a load curve is related with a customer, it is the information stored in the database that is used in the calculations, while the measurement data show how the situation is in reality.

Depending on the amount of the billed consumption involved and on the number of customers, the use of a wrong typical load curve may generate a significant change in the load curve profile, and making it completely different from the measured load curve.

In order to have a reliable results for the losses calculation or even for any other processes which may use corporative databases, it is important to notice that the quality of the data stored in the database is vital. That is why each utility company must have a policy of constant maintenance over the quality of their own data, since they are changing frequently. The type of error mentioned before is just one of the many types that may change completely the calculation results.

Non-Techinal Losses

Even after the elimination of every single record error, and considering that there are not switched load-blocks, it is possible that the discrepancies may persist. On this case, the first aspect to be verified refers to the existence of energy theft over the power network or even if there are fraudulent customers changing their consumption measurements.

All the customers involved in energy theft or the ones that change their consumption measurements consume an amount of energy that is not billed. As this amount of energy is not billed, it is not "seen" by the calculation method either. As the calculation method depends on the exactly values for the billed consumptions, there will be discrepancies between the estimated load curves and the measured load curves. Initially, this difference could be completely assigned to the non-technical losses. Nevertheless, the flow of non-billed energy through the power network causes technical losses too, and the difference observed is the sum of the non-technical losses with the technical losses due to the flow of non-billed energy.

Besides causing difference between the estimated energy and the measured energy, energy theft may also cause differences between the estimated load curve profile and the measured load curve profile. This actually occurs because these customers are not "seen" by the method, since they are not stored in the company database. If the profile of the curve composed by the sum of the energy consumed by customers that are stealing energy is different of the estimated profile, the profile of the estimated load curve may be completely different from the profile of the measured load curve (the measurement can "see" the energy theft), depending on the number of customers that are stealing energy, on amount of energy that is being stolen, and on their consumption profile. Normally, the customer that are stealing energy appear in large quantities and are all group together in regions that were occupied in an irregular way. Due to the characteristics of these occupations, and due to the way they actually occurred, this group of customers may schedule together the use of their electrical equipments, leading to a consumption profile completely different from the one observed on the regular customers of the same type.

The part of the discrepancy caused by the existence of non-technical losses in the power network (non-billed energy) could be eliminated though the use of an energy and demand correction method, which is described in this paper.

Different Time Basis for the Billed Consumptions

When a measured curve is being compared with an estimated curve, it is important to note that the billed consumption of each customer is in a different time basis, i.e., each billed consumption has a specific duration and a specific instant of time when the measurement started, which are different from the other billed consumptions. Figure 1 illustrates the problem described above.

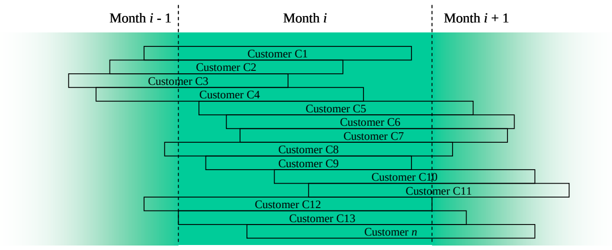

Figure 1 – Reading sequence for a group of customers

Figure 1 presents a hypothetical billing cycle for some customers (reading sequence). The first aspect to be noticed refers to the beginning of the cycle for each customer. For a specific customer the cycle starts in a day of the month that differs from the other customers. The second aspect refers to the fact that each cycle may present a duration is not 30 days. Besides that, depending on the day of the month *i* which the losses calculation is executed, for some customers it is recorded on the database their billed consumption for the month *i*, while for the other customers it is still recorded the consumption for the month *i-1*. The billing cycle for each customer is based on the reading sequence established by the utility, which is a necessary practice, since it would not be feasible for the reading agents (the reading is not automatic) to perform the measurements reading for all meters simultaneously at the end of every month.

After collecting the measurements, it is common to use a complete civil month (from 1st day until the 30th day) to calculate the average of the measured load curve.

Consequently, the comparison between the estimated energy and the measured energy becomes complex, once the estimated energy is the energy sum considering different time bases. The energy correction method described on this paper eliminates the discrepancies caused by the time basis of the billed consumption.

CALCULATION OF THE CORRECTION FACTORS

Aiming the complete elimination of the discrepancies between the estimated load curves and the measured load curves, it is necessary to calculate the correction factors, which will be used to multiply the load values of the feeders. This multiplication will result in a new estimated load curve, which the energy is equal to the energy of the measured load curve. It is important to notice that the correction factor does not change the estimated load curve profile, once the main objective of this methodology is to achieve a new value for the losses, matching the energy of the measured load curve with the sum of the energy from the loads and the energy losses in every network. The correction factor for the energy is already enough for the calculation of the non-technical losses and of the technical losses due to the non-billed energy. The correction factor for the energy changes only the energy of the estimated curve, keeping its profile intact. In practice, it is observed that only the energy correction is enough, since the profile of the estimated load curve is very similar to the profile of the measured curve.
Through the use of the correction factors, it is possible to calculate the non-technical losses for each feeder. It is also possible to obtain the part of the technical losses that is caused by the existence of non-technical losses, i.e., non-billed energy flowing through the power network. At the end of this correction calculation, the non-technical losses achieved are composed by the stole energy and/or by the energy that was not measured due to fraud and/or the measurement errors at the customers. The non-technical losses are also composed by the losses due to the flow of billed and non-billed energy through the power network.
Considering that the load from the feeders are the MV customers, which are directly connected to the MV network, and the distribution transformers, which supply the LV customers; it will carried out a correction method only for the LV loads.

Correction of the MV Loads and LV Loads

On the calculation method for the correction factors, it is considered that the energy (or demand for a specific instant of time) difference between the estimated load curve and the measured load curve should be distributed among the LV customers. The estimated energy for a feeder is calculated by:

$$E_{est} = E_{MV} + E_{LV} + E_{lvar} + E_{lfixed} \qquad (1)$$

in which: E_{est} is the estimated energy at the end of the feeder [kWh]; E_{MV} is the billed energy for the customers connected at the MV network [kWh]; E_{LV} is the billed energy for the LV customers [kWh]; E_{lvar} is the energy for the variable losses (depend on the load) [kWh]; E_{lfixed} is the energy for the fixed losses (do not depend on the load) [kWh].

The energy due to the variable losses E_{lvar} is given by:

$$E_{lvar} = e_{cc} + e_{sn} + e_{dt,Cu} + e_{pn} \qquad (2)$$

in which: e_{cc} is the energy losses at the customer connections [kWh]; e_{sn} is the energy losses for the secondary networks [kWh]; $e_{dt,Cu}$ is the energy loss on the copper of the distribution transformers [kWh]; e_{pn} is the energy loss for primary networks [kWh].
And the energy of the fixed losses E_{lfixed} is given by:

$$E_{lfixed} = e_{pm} + e_{dt,Fe} \qquad (3)$$

in which: e_{pm} is the energy loss on the power meters [kWh]; $e_{dt,Fe}$ is the energy loss on the iron of the distribution transformers [kWh].
In order to calculate the energy correction factor k_e, it is required to match the measured energy E_{meas} with the estimated energy E_{est}. This matching is performed through the multiplication of the billed energies on the LV loads by the correction factor that is not known yet. As it is known, the demand loss is proportional to the square of the apparent demand. Thus, the energy loss is also proportional to the square of the energy. The terms used on (1) are then changed, in order to promote the matching between measured energy and the estimated energy, resulting in (4):

$$E_{meas} = E_{MV} + k_e \cdot E_{LV} + k_e^2 \cdot E_{lvar} + E_{lfixed} \qquad (4)$$

It important to notice that the variable losses are affected by k_e^2, once the fixed losses do not depend on the load. Solving (4), which is a second order polynomial, it is achieved expression (5) that is used to calculate the correction factor for the energy. The correction factor is the root of this equation.

$$k_e = \frac{-E_{LV} + \sqrt{E_{LV}^2 - 4 \cdot E_{lvar} \cdot \left(E_{lfixed} - E_{meas} + E_{MV}\right)}}{2 \cdot E_{lvar}} \qquad (5)$$

RESULTS ACHIEVED

On this item it is presented the study carried out with reap power distribution networks. It is compared the calculated losses without any correction, with the calculated losses after the correction. It was selected a set of networks composed by 8 distribution substations, 83 primary circuits and 6,243 low voltage networks. It was assured that all the data related with these networks was available the company database. For the selected set it is known the measurements at the MV bus (secondary side) for the substation transformers.
On this study, the set of networks was carefully selected; in order to guarantee that there would not present load-switching history. Besides that, it was considered that the billed consumption for the customers was corrected and that there is no problem referring to different time bases. So, the discrepancies observed between the measured load curves and the calculated load curves would caused due to record errors and non-technical losses.
The results achieved through the correction calculation were compared with the ones achieved without any correction. The results for the calculated losses without any correction and for the calculated losses with the correction are shown on Table 1. For the correction calculation, the correction

factor obtained was applied to the LV loads.
The percentage loss for the power meters decreased, since it does not depend on the load and their kWh losses are the same. Nevertheless, the calculation basis increased for this case. For the loss percentage, the calculation basis is the billed consumption for the LV customers added to the losses in the power meters, i.e., it is the upstream energy. As the billed consumption is increased through the correction, the calculation basis is also increased. As a result of this, the percentage loss is reduced.
For the customer connections, for the secondary network and for the primary network the loss percentage increased, which was already expected, once the energy correction increased the load and, then, the losses were increased too. For these segments, the losses are composed by a part that varies according to the load, which is different from what occurs with the distribution transformers and with the substation transformers.

Table 1 – Energy losses without and with correction

Segment	Energy Loss Without Correction		Energy Loss With Correction	
	[kWh]	[%]	[kWh]	[%]
Distribution Substation	886,416.56	0.75	1,208,268.21	0.77
MV Network	926,523.29	0.79	1,859,674.44	1.19
Distribution Transformer	1,867,897.58	2.59	2,571,956.99	2.55
LV Network	793,703.35	1.13	1,563,717.50	1.59
Customer Connection	219,445.15	0.32	381,670.78	0.40
Power Meter	253,261.72	0.37	253,261.72	0.26
Others	494,724.77	0.42	783,854.96	0.50
Technical Losses	**5,441,972.42**	**4.63**	**8,622,404.60**	**5.47**
Non-Technical Losses	**-**	**-**	**36,957,776.46**	**23.44**

For the power distribution transformers, the results were reversed, i.e., the loss percentage was reduced. This situation may occur depending on the load level of the transformers. For transformers with low load, the loss percentages are high and may be reduced when the load is increased. This happens due to the fact that the transformer losses are composed by parts: one that varies according to the load (copper losses) and another one that is fixed. The loss percentage increased for the substations, showing that the substation transformers are operating with a certain amount of load which may increase the loss percentage due to the load increase. Finally, it is possible to note that the global result for the losses is increased due to the execution of the energy correction. As it was already explained previously, the difference occurs due to the flow of non-billed energy through the power network, beside the records errors in the company's database. Moreover, the non-technical losses were calculated for each substation. Table 2 shows the non-technical losses for each one of the 8 substations selected for this study.
Through these results, the utility company is able to evaluate which regions may present higher indices for theft and/or fraud, guiding actions for their elimination.

Table 2 – Non-technical losses per Substation

Distribution Substation	Non-Technical Losses [%]
2	8.18
9	30.50
27	44.38
31	24.18
33	12.43
34	17.96
43	7.58
45	24.35

CONCLUSIONS

The work described on this paper showed that the conventional methodology for the losses calculation [1] estimates the load curves which may present large discrepancies if compared with the measured load curves. The origins of such discrepancies were discussed and it was presented a method to correct the achieved results.
The proposed method is based on the calculation of some factors that will be multiplied by the load values, in a way that the estimated energy or demand becomes equal to the measured energy or demand. Besides the discrepancies elimination, the losses calculation also helps on the calculation of the non-technical losses for each feeder. It also helps on the calculation of the losses that depends on energy theft or on fraudulent customers, which change the results of their energy measurements. So, through this methodology it is possible to achieve real value for the technical losses and for the non-technical losses, which may help on the execution of a fraud/theft combat plan.

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