# Estimation and Allocation of Losses in Distribution Networks

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## Abstract

Loss allocation in distribution networks remains nowadays an open problem of considerable importance, especially in a competitive energy market environment. This paper proposes a methodology for the distribution of network losses among the loads. The process is based on the knowledge of load profiles and on the usual consumption measures. Simulation of representative HV, MV and LV networks has been carried out to obtain a portrait of the typical loss intervals. The losses are allocated to consumers according to the network level, the achieved typical values and the representative diagrams of each type of consumer. The allocation criterion is established assuming a distribution proportional to the squared power. Illustration results support the feasibility of the proposed methodology.

**Keywords:** Distribution systems, loss allocation, load profiling

## 1. Introduction

Loss allocation constitutes an important tool for efficient planning and operation of power systems, especially in a free energy market environment. The assignment of a given portion of network losses to a given consumer remains nowadays an open problem. Distinct approaches are being proposed or adopted by different authors and regulatory authorities [1-7].

The present work was developed within the framework of a contract with the Portuguese incumbent distributor (EDP Distribuição), aiming at acquiring competitive knowledge in face of the eminent opening of the Spanish-Portuguese energy market. The following main objectives of this project were:

1. Consumers' characterization (including load profiling);
2. Loss estimation (loss allocation);
3. Load factors estimation;
4. Load research.

The first task (consumers' characterization) consists of assessing the typical diagrams, able to characterize the load curves of the different types of consumers. A measurement campaign was implemented, allowing the collection of load diagrams for a variety of consumers. The conception of these campaigns may assume different delineations, according to the objectives [8-12]. Since it is not in the scope of this paper, details about this topic will be not present here.

Acquired diagrams are able to characterize consumers load curves as a function of voltage level (HV, MV, LV), month, day type (workday, Saturday, Sunday) and consumer class. The consumer class depends on the voltage level. For instance, LV consumers were consumers where first divided by tariff type, depending on the meter type (one, two or three meter periods) and then subdivided into 5 categories (domestic, commercial, industry, hotels/restaurants and others).

The second objective of the project includes: a) losses estimation in HV, MV and LV networks, and b) implementation of a loss allocation algorithm. This algorithm shall be able to assign a given amount of losses to each individual consumer.

The diagrams gathered in the measurement campaign constitute the basis of the present task. This information was used both for loss estimation and loss allocation. Loss estimation was essentially based on networks simulation, where the consumers' loads are characterized by the corresponding diagrams. The loss allocation algorithm considers the load level and assumes a loss distribution proportional to the squared load power on each hour of the diagram.

Given the confidentiality commitments assumed by authors in this project, no specific losses values will be presented, being the emphasis focused in the description of the methodology.

This paper is organized as follows. Section 2 presents the methodology used for the estimation of typical losses in HV, MV and LV networks. Section 3 describes the adopted approach for the allocation of losses loss by voltage level. Next section explains how to assess the global losses, given the information and conclusions obtained in the previous tasks. Section 5 describes the procedure for allocating losses to individual consumers. Finally, last section presents the main conclusions of the work.

## 2. Estimation of losses

Losses estimation may be globally computed through global energy balance. However, it becomes more and more difficult to assess as one intends to obtain more disaggregated information. In fact, even for a single load regime (for instance, peak hours) and exclusively for networks (transformer loss energy also vary a lot depending on the transformer type and its age), losses depend on the network electrical parameters, on the lines' lengths, on the simultaneity of consumptions and on the geographical distribution of loads (the largest loads near the feeder provide lower losses that if they are distant).

Given the large quantity of potential parameters with influence on losses, it is not feasible to characterize losses by sampling all possible combinations. Being so, it was decided to base this task on studies over typical networks (a concept itself difficult to characterize). The studies include network simulation for different load levels and different consumers, whose load diagrams are drawn from the sample database.

In this project, the methodology used for the estimation of losses includes the following steps:

1. Selection of typical networks and exploring conditions for the three voltage levels (HV, MV and LV), considering different load magnitudes and load distributions;
2. For each case referred in step 1, network simulation, calculation and results analysis;
3. Determination of the key loss intervals to be considered for each case (HV, MV and LV).

Fig. 1 to Fig. 3 presents a synthesis, in the form of losses' histograms, of the results outputted by the simulations just described.

As shown, losses may vary a lot depending on the network operation conditions (load level and load distribution are particularly important). This is especially true for the LV case. In fact, the calculation of losses in the simulated LV networks has revealed that losses depend to a large extent on the network load level (quotient among the total load and the installed power). Being so, for a matter of generalization, it is necessary to clarify this relation. Besides, it is important to acquire knowledge about the most common scenarios in what respect to load level. Moreover, the scenarios considered in this case include decreasing, homogeneous and increasing load distributions. (Here, one considers "decreasing" when largest loads are closer to the feeder).

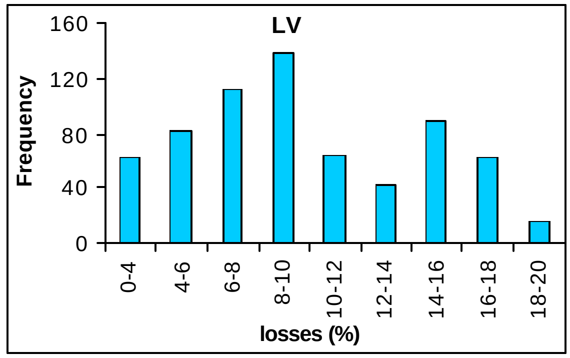


Fig. 1. Losses' histograms for LV case

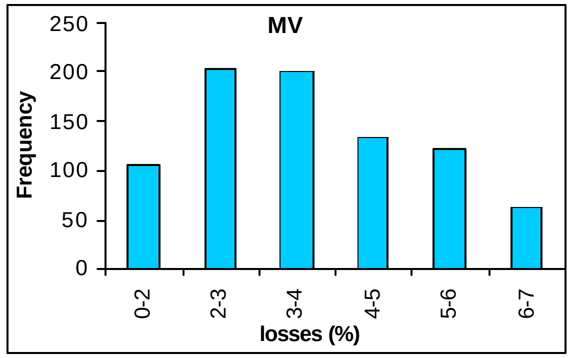


Fig. 2. Losses' histograms for MV case

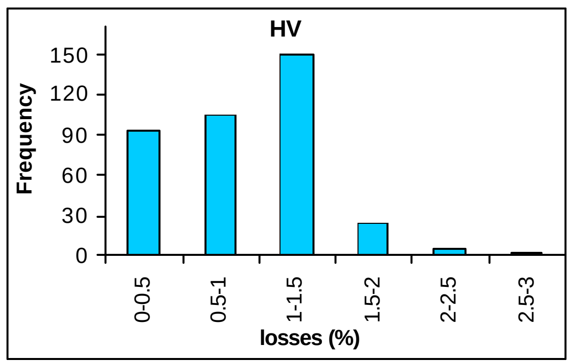


Fig. 3. Losses' histograms for HV case

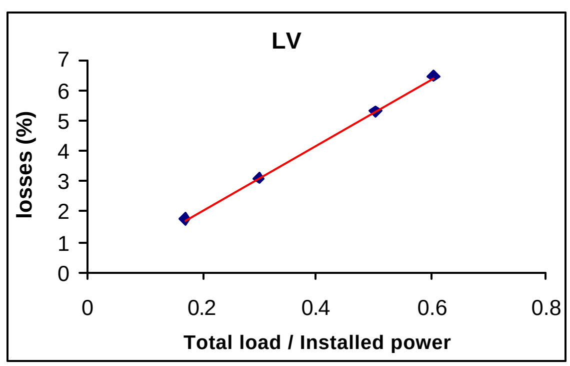


Fig. 4. LV losses (%) as a function of the relation total load divided by installed power

Fig. 4 represents the relation among the percentage of LV losses and the load factor, in the simulated network. This percentage is referred to the power injected in the network. In this figure, each point represents the mean of ten simulations performed for the same load level but with a random selection of diagrams and considering a decreasing load distribution along the network, the most common situation according to the information provided by the distribution company. Based on Fig. 4, and given the most typical load levels of the LV networks, it was possible to estimate the most probable LV losses interval.

A similar approach was adopted for the determination of basis losses intervals for MV and HV distribution networks.

The transformer losses were also taken into account for the LV and MV cases. The losses of MV/LV transformer is added to the LV losses. In the same way, HV/MV transformer losses are added to MV losses. This operation defines the total losses' intervals for each case (HV, MV and LV).These intervals are the basis for the loss allocation algorithm presented in the next section. However, one must stress that other information may be drawn from the study performed. For instance, Fig. 5 shows the percentage of losses as a function of the generated power in the MV network. Note that the percentage of losses grows linearly with the generated power.

Fig. 6 illustrates the HV losses variation with the generated power, screening the quadratic nature of losses.

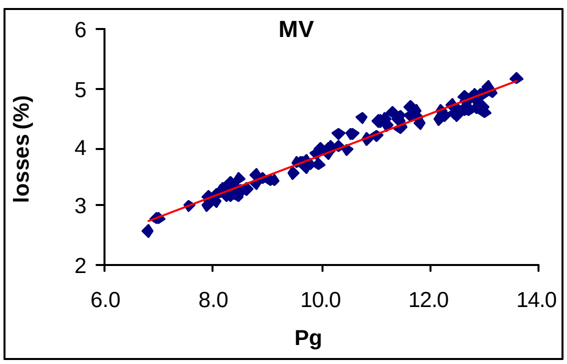


Fig. 5. MV losses (%) as a function of generated power

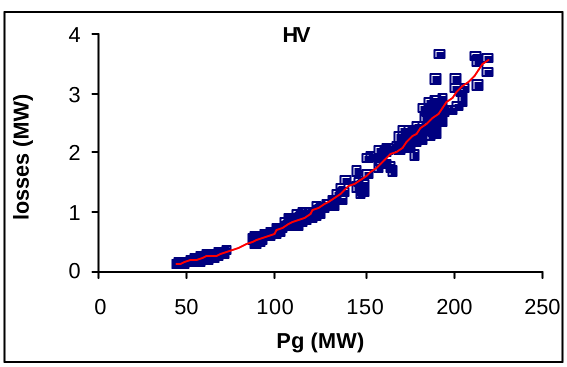


Fig. 6. HV losses as a function of generated power

## 3. Loss allocation by voltage level

Loss allocation is also an operation that may be performed according to distinctive alternative approaches, especially because of the quadratic nature of losses, the effects of geographical consumer location on the network and the presence of other consumers.

Having defined the loss basis values for each voltage level, the next step consists of the application of a loss distribution criterion.

The allocation of losses to the different types of consumers (diagrams) was founded in the following assumptions:

1. Consumers are grouped into three distinctive sets according to the voltage level. Set A includes all LV consumers: normal LV, special LV and public illumination. Sets B and C group respectively all MV and HV consumers (having or not contracts with other energy dealers).

2. For each considered set (A, B and C), losses are distributed by the respective total annual diagram, proportionally to the squared hourly consumption. This operation is performed in such a way that the total losses, for each case, match the losses' basis values, determined in the previous section. The loss allocation is defined through the equation:

$$p(g,m,d,h) = \frac{E^2(g,m,d,h)}{\sum_{cons_g} E^2(g,m,d,h)} \, p_b(g)\, E(g,m,d,h) \qquad (1)$$

where:

$p(g,h)$ – losses of consumers group g, in month m, day type d and hour h;

$E(g,m,d,h)$ – Hourly consumption of consumers group g, in month m, day type d and hour h;

$p_b(g)$ – basis loss percentage considered for group g;

3. Transformer losses are assigned to the consumers of voltage level equal or smaller than the secondary;

4. For ht e case of the costumers of the type "special LV", only transformer losses are attributed because they are generally close to the MV/LV substations;

5. For the public illumination case, no losses are assigned in the LV level because their energy counters already include losses (they are made in the MV/LV substations).

This way, losses' diagrams were obtained for all types of consumers considered, for each month and type of day. These diagrams provide not only the calculation of the of the global losses in the distribution system, but also the evaluation of the loss importance of a given consumer, assuming its consumption is know.

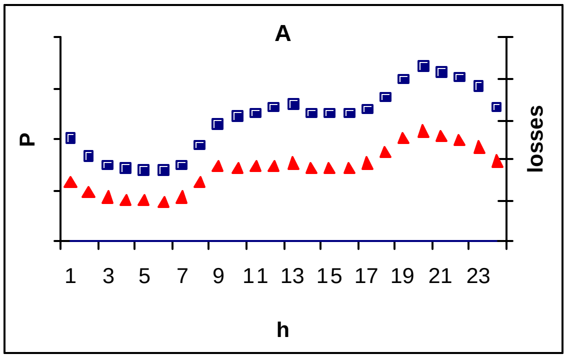


Fig. 7. Diagrams of load (squares) and losses (triangles) for set A (January, workday)

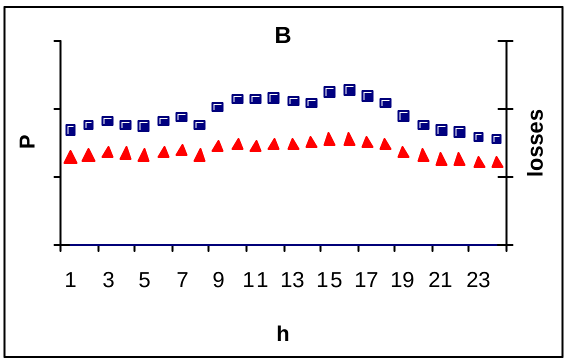


Fig. 8. Diagrams of load (squares) and losses (triangles) for set B (March, workday)

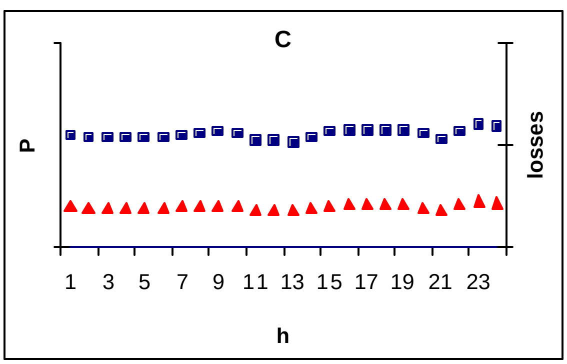


Fig. 9. Diagrams of load (squares) and losses (triangles) for set C (May, workday))

Fig. 7 to Fig. 9 show the diagrams of load and losses for the set A, B and C respectively. In this case, the figures represent the aggregated load diagrams for each case as well as the corresponding aggregated losses diagram. In these figures the scale is omitted because of confidentiality commitments.

## 4. Assessing the global losses

The assessment of the distribution network global losses is based on the following phases:

1. Evaluation of the losses diagrams corresponding to the representative diagrams of each type of consumer, for each month and day type. For each consumer type, one considers the loss basis value resulting from the sum of two loss components: line losses and transformer losses.
2. For each applicable case, one must also consider the inherent losses caused in the upper voltage levels. The total MV losses are computed by taking into account two terms corresponding to:
   a. MV consumers load;
   b. Total LV load (LV diagrams plus its losses in the LV network);

   The global HV losses value is calculated by adding the following three components:
   a. HV consumers load;
   b. Total MV load (MV diagrams plus its losses in the MV network);
   c. Total LV load (LV diagrams plus its losses in the LV and MV networks);
3. The total losses value in the distribution network is obtained by totaling the HV, MV and LV loss components, identified in the previous phase.

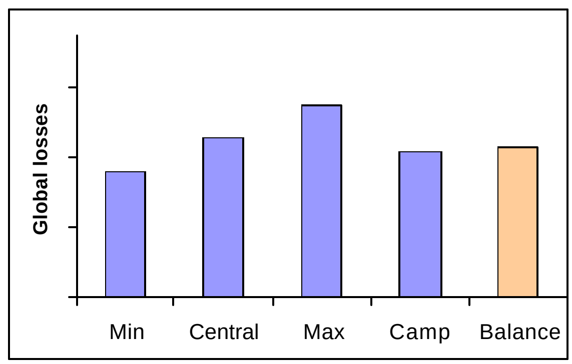


Fig. 10. Global loss percentage for different scenarios

In section 2, one has mentioned that typical losses for the different voltage levels are computed in the form of intervals. Being so, the total losses shall also appear as an range of possibilities. Different scenarios were considered for the characterization of the total losses. Fig. 10 presents a collection of typical scenarios. Once again, the scale is not shown because of confidentiality commitments. This figure shows the attained loss values for the following cases:

1. Min – obtained with the minimum values of the intervals losses;
2. Central - obtained with the maximum values of the intervals losses;
3. Max - obtained with the central values of the intervals losses;
4. Camp – obtained considering the average load level drawn from the measurement campaign data;

5. Balance – global energy losses, according to the annual energy balance

As shown, the Balance case remains between the Min and Max values of the losses. Besides, the losses obtained in the different scenarios, in particular the Central and Camp cases are provide losses remarkably similar to the Balance case, considered here as a reference value.

## 5. Allocating losses to individual consumer

The previous sections describe the proposed methodology to estimate losses in the different levels of the network. However, this is not enough to allocate losses to a given consumer. This section describes a procedure to accomplish this task. The following algorithm was applied:

1. Assignment the corresponding diagram to the selected consumer (for instance, the representative diagram of LV consumers, simple meter, domestic, April, Saturday);
2. Adjust the diagram scale in order to accommodate the consumers energy measure;
3. Compute its losses diagram (the product of its representative diagram by the corresponding percentage losses diagram);
4. Compute its energy loss (area below losses diagram).

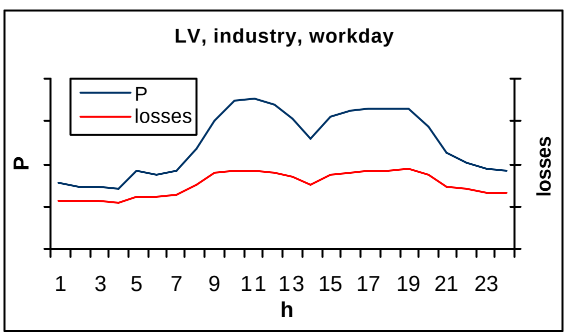


Fig. 11. Load diagram and associated losses for and individual consumer (LV, industrial, workday)

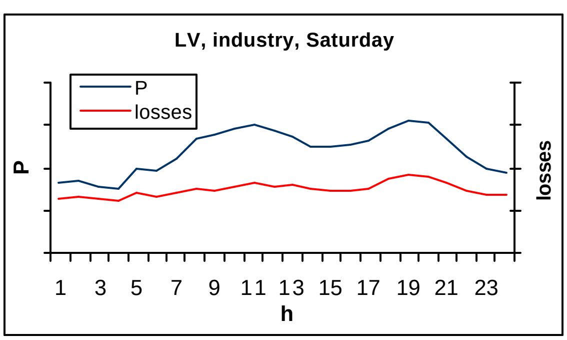


Fig. 12. Load diagram and associated losses for and individual consumer (LV, industrial, Saturday)

Although the present methodology has been developed to the sampling data, representative of the mean consumer behavior, for each type, the same algorithm may be applied with other possible subdivision or aggregation of consumers.

Fig. 11 shows an example of a typical load diagram for an individual consumer, in this case of industry type, in a workday of January. The same type of consumer and respective losses diagram is shown in Fig. 12, in this case for a Saturday of January.

## 6. Conclusions

The proposed methodology is based in the data gathered in the measurement campaign. This information was used both for loss estimation and loss allocation. Loss estimation was essentially based on networks simulation, where the consumers' loads are characterized by the corresponding diagrams. The loss allocation algorithm considers the load level and assumes a loss distribution proportional to the squared load power on each hour of the diagram. It allows not only the allocation of losses to consumers but also the estimation of the global distribution losses. Moreover, with the information collected, it is also possible to compute the losses for other groups of consumers or in a period basis (peak hours, valley hours, in between). This work is currently under development.

Results obtained support the adequacy of the adopted approach.

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