ASSESSMENT OF THE INVESTMENT EFFORT IN HV AND MV NETWORKS TO REDUCE ENERGY LOSSES

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ABSTRACT

In re-regulated markets, the maximization of profits creates the tendency to postpone investments in the network infrastructure, with negative effects on losses. In order to oppose this tendency, several countries adopt regulation directives that reward the distributors if losses are reduced and penalize them if losses increase. This is the case of Portugal which adopted loss penalty/reward scheme may be found in [1]. Given the current framework, EDP Distribuição (EDP Group), Portugal, a Distribution System Operator (DSO), has established a loss reduction program, which includes line reinforcement investments, among other actions. The main idea is to make the best investments in HV and MV network lines, considering the trade-off between benefits and costs. The ideal scenario would be, of course, to analyse all HV and MV networks and simulate possible reinforcement alternatives. However, the large number of MV feeders (about 4,000) makes this alternative unworkable. Thus, the first phase consists of developing a procedure to rank MV networks according to their potential to reduce losses. The highest scored networks are then analysed using a power system simulator. This analysis takes into account the different reinforcement alternatives and evaluates the investments costs and the saved energy over a period of 30 years – the economic time span usually considered by EDP Distribuição for this kind of operation. For the HV case, all networks were analysed. This paper synthetizes the main results obtained in these studies.

INTRODUCTION

Loss reduction has a direct impact on both economic and energy efficiency. In fact, the total amount of losses represent a substantial amount of energy and consequently a large cost – in Portugal, it represented about 300 M€ in 2010. This context has motivated EDP Distribuição to establish a loss reduction program, which includes, among other actions, line reinforcement investments to increase the cross sectional area of overhead and underground lines, based on installation of new lines for remodelling existing ones or in parallel for doubling existing circuits.

The main idea is to make the most adequate investments considering the relation benefits/costs, as well as the total amount of energy saved. Given the large number of about 4,000 medium voltage feeders (each one feeding a MV network from a HV/MV substation), it is not feasible to analyze all HV and MV networks. Therefore, the initial stage involves the development of a methodology to classify the MV networks in conformity to their loss reduction potential. The best ranked networks would then be analyzed in detail to access the impact of the different reinforcement alternatives in terms of investment costs and the energy saved over an economic time span of 30 years.

Although more complex (higher dimension), the number of Portuguese HV sub-networks is rather limited: although interconnected, the HV network is usually divided into 8 sub-networks, according to the geographical region. In this case all networks were analyzed.

This paper describes the methodology adopted and the main results obtained in the project allowing to EDP Distribuição the best prioritization of their investment in loss reduction, taking into account the voltage level of the distribution network and the geographical identification of "hot spots" to be eliminated.

METHODOLOGY

To develop this project, the research team used the following available data for the MV case:

1. A general Technical Information Database (TID) that contains the description of physical (such as type and cross section area) and electric line parameters (such as voltage level, R and X per kilometre);
2. Current intensity at the MV substations' feeders, recorded in a 15 min time base, as well as related load and loss factors;
3. List of available lines and corresponding data: type (overhead, underground), length and costs (line cost per kilometre and dismantling costs for overhead lines). and dismantling costs for overhead lines).

Loss estimation

Network ranking is a crucial phase of the proposed methodology, given the practical impossibility of performing simulation studies for all MV networks.

The ranking process (network classification according to their loss reduction potential) has to be based on the data available in the TID database, and on network charge (here represented by the current at the substation feeder). In brief, for each network, the available data for the ranking process is the current in the main branch and the physical and electrical parameters of the network. To establish a loss ranking, a key step is to obtain estimates of the loss value for each network. Therefore, this is the first goal in this task. This phase started with the analysis of a restrict number (24 to be exact) of MV networks. This analysis includes:

1. The loss evaluation in the base case for a set of test networks;
2. The simulation of reinforcement alternatives for each network branch: assessment of investments, estimation of loss savings and the corresponding money recovery

Step 1 comprises the simulation of 24 typical MV networks in order to compute their annual energy losses. Once step 1 is concluded, a regression tool is developed, aiming at obtaining a relation between the evaluated losses and the current in the main branch, and the physical and electrical parameters. The regression was based on the Generalized Reduced Gradient algorithm [5].

Step 2 characterizes the different reinforcement alternatives for each of the 24 networks under study. In a later stage these results will be combined with network loss estimation (Step 1) in order to enlighten the cases for which the reinforcement investments are valuable.

Impact analysis of possible reinforcement alternatives for MV networks

The initial part of this task consists of determining the worthy reinforcement actions for loss decrease.

The savings valuation mentioned in step 2 considers an economic lifetime of 30 years for benefit accounting after the reference year (designated by “year 0” when the last investment is done and used as base for updating all the economic values), a 10% annual update rate and considering a 3% annual load growth rate until achieving the 10th year of the economic lifetime period – these are the usual parameter values considered by EDP Distribuição as their typical economic analysis. The scale saving policy adopted by EDP Distribuição restrains the reinforcement alternatives to a small set of cross sectional areas (four for underground lines and four for overhead lines). Naturally, for each line, only the alternatives that lead to loss reductions are considered. For each viable alternative, the following investment quality measures are also evaluated: the number of years to recover the investment, the Net Present Value (NPV) obtained as the difference between the both updated values of total cost (C) and total benefit (B), and the ratio B/C. The value C is the sum of all total costs annually updated to “year 0” and spent up to this reference year. The value B is the sum of the energy saved since “year 1” to “year 30” and annually updated to the reference year. The best reinforcement alternative for each line is then selected according to these quality measures and, within these, only the cases for which B/C > 1 are considered “eligible for reinforcement”. Then, for each eligible action, all the possible reinforcement alternatives are analyzed.

For the referred loss reduction program two reinforcement alternatives were considered for each line:

1. Replacing the original line by another with a smaller resistance per meter, i.e., bigger cross sectional area (applied when the cross sectional area is smaller than 50 mm^2 for overhead lines or 120 mm^2 for underground lines). Dismantling costs are only considered for overhead lines because replaced underground lines are simply abandoned and there are no dismantling costs to be accounted;
2. Introducing a new line in parallel with the original one.

The set of equations used for the procedures adopted in this task are:

$$C = K \times (c_{New} + c_{Dism}) \times l \tag{1}$$

$$B = \gamma \times c \times E_{saved\ "year\ 1"} \times T_{life} \tag{2}$$

$$E_{saved} = \varphi \times E_{saved\ "year\ 1"} \times T_{life} \tag{3}$$

$$E_{saved\ "year\ 1"} = \frac{R - R'}{R} \times P \times \beta \times h \tag{4}$$

where,

C	- Total cost for line reinforcement, k€
c_{New}	- Cost per km of the new line to be installed, k€/km
c_{Dism}	- Dismantlement cost per km for overhead lines, k€/km
B	- Benefit (revenue) of avoided energy losses, k€
c	- Energy cost, €/MWh
K	- Administrative costs rate, p.u.
l	- Length of the line, km
E_{saved}	- Energy saved by losses during T_{life} , MWh
$E_{saved\ "year\ 1"}$	- Energy saved by losses during “year 1”, MWh
R	- Resistance per km of the previous line, Ω/km
R'	- Resistance per km of the new line, Ω/km
P	- Power losses in the considered line, MW
β	- Losses factor of the annual losses diagram, p.u.
ur	- Update rate (ur =10%=0,1 p.u.)
gr	- Load growth rate (gr =3%=0,03 p.u.)
φ	- Growing (considers gr since “year 1” to “year 9”), p.u.
γ	- Updating (considers both ur and gr)
h	- Number of hours per year (h =8760 hours/year)
T_{life}	- Economic lifetime (T_{life} = 30 years)

For the referred economic parameters adopted the growing value is $\varphi = 1.576$ p.u. and the updating value is $\gamma = 0.445$ p.u.

Once this phase is completed, the best reinforcement actions for each network line are aggregated in order to provide a high-level perspective of the network's potential in terms of loss reduction. These results are combined with the outcomes of step 1 in order to create a rule for network ranking. The key idea here is to relate network parameters (such as line length, R) and network charge with the network's annual loss, in a first phase, and the network potential to reduce losses in a second phase.

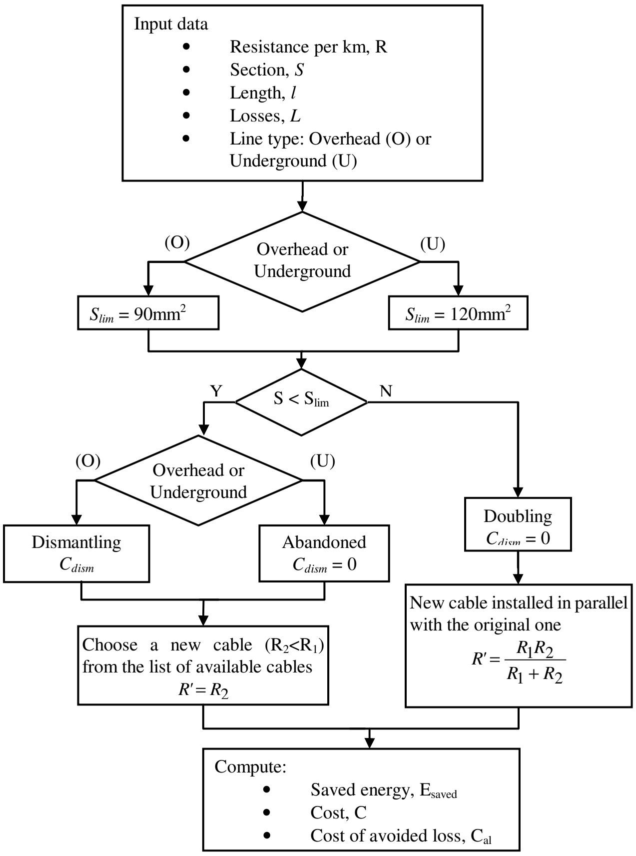

Figure 1 - Flowchart of impact analysis on loss reduction procedure for MV lines

Impact analysis of possible reinforcement alternatives for HV networks

The number of HV networks is quite small but their complexity is considerable – some of the networks include more than 30,000 nodes. Therefore, it is not wise to compute all the possible reinforcement alternatives for all lines. In this case there is a first selection step to pick out the most loaded lines – the ones that contribute to, at least, 50% of the total network losses. The choice of the largest contributors leads to about 20 to 40 lines per network to be scrutinized. Since the calculation principles are comparable a similar scheme to that used for MV lines (Figure 1) is applied to the HV lines.

RESULTS

This section present the results obtained in the project's core phases.

Concerning loss estimation the best two regression alternatives are illustrated in Figure 2, which shows the actual annual energy losses and the energy obtained with regression formulas (Hip1, and Hip3). Given the proximity between real and estimated values, the next step will be to apply the regression formulas to the entire set of MV networks.

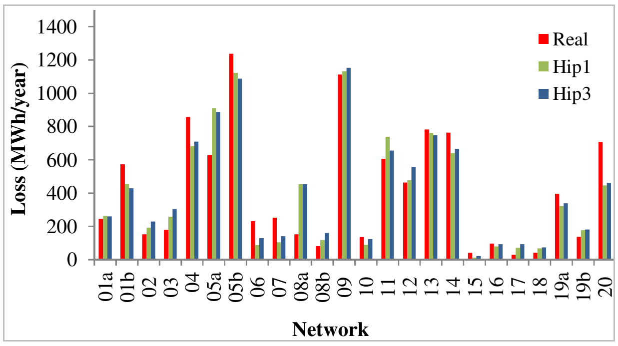

Figure 2 – Estimation of annual energy loss – real values and the best two regression alternatives

The following expressions formalize the regression result:

$$E_{loss\,1} = k_0 + k_1 \times \langle l \times R \rangle^{k_2} \times (I_{15})^{k_3} \times \alpha^{k_4} \times n_b{}^{k_5} \times V^{k_6} \quad (5)$$

$$E_{loss\,3} = k_0 + k_1 \times \langle l \times R \rangle^{k_2} \times (I_{15})^{k_3} \times \beta^{k_4} \times (L_{total})^{k_5} \quad (6)$$

where,

k_0, …, k_6 are the regression parameters

E_{loss} - Energy loss, MWh

$\langle l \times R \rangle$ - Average line resistance, i.e., $(l \times R)_{av}$, Ω

I_{15} - Current peak filtered from the daily peak records (obtained by eliminating the highest 2% values registered and computing the average of the highest 15 values among the remaining ones), A

V - Voltage, kV

n_b - Number of lines in the considered network

L_{total} - Total network line length, km

Relation between investment and energy losses reduction in the MV and HV distribution networks

The results summary presented in Figure 3 show the expected energy loss reduction in the distribution network as a function of the HV network investment. This curve was settled considering just the interventions for which the benefit-cost relations are larger than one. The curve points near the axis origin present a bigger relation B/C that decrease as more money is invested on network reinforcement since less attractive operations take place. On the rightmost where B/C ≥ 1 the graphic shows that for an investment of 31 M€ the expected loss reduction will be about 115 GWh/year (0,25% of total distribution losses).

Figure 4 shows a similar analysis for the MV network verifying that its range of values falls within the shaded area of Figure 3. The curve shapes are similar but to the HV case although it is more linear, i.e., the derivatives at the extremes (left and right) are more similar. Comparing the same investment amount of 4 M€ applied to reduce energy losses in the HV or MV networks, we obtain respectively 30 GWh/year (Figure 3) and 18 GWh/year (Figure 4). This shows the much more limited influence of the investment to reduce energy losses if applied to reinforce MV lines instead of HV lines.

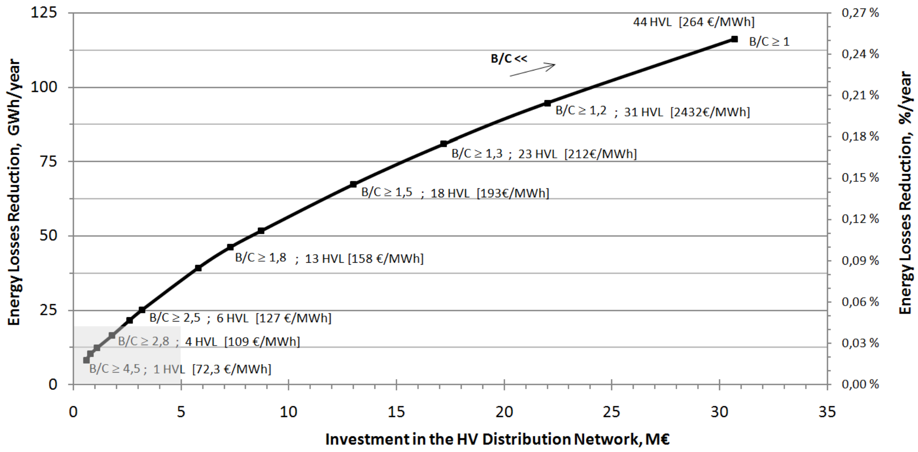

Figure 3 – Annual reduction of energy losses by investment in the HV distribution network

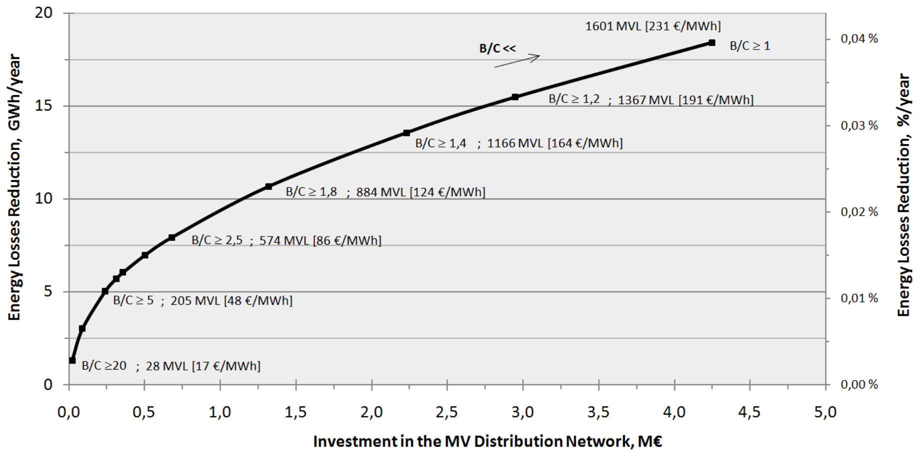

Figure 4 – Annual reduction of energy losses by investment in the MV distribution network

CONCLUSIONS

Investments in loss reduction may present interesting paybacks in terms of valorisation of avoided losses, both in MV and in HV networks.

The previous results also show that in order to obtain the same amount of loss reduction in the distribution network, the investment efforts on HV networks results in more interesting than on MV networks in terms of global loss reduction in the distribution network. Besides, as the main goal is to reduce global energy losses, HV interventions present a higher potential impact.

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