

Technical and Economic Assessment of the Implementation of Measures for Reducing Energy Losses in Distribution Systems

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Abstract. This paper develops a methodology to assess a group of measures of electrical improvements in distribution systems, starting from the complementation of technical and economic criteria. In order to solve the problem of energy losses in distribution systems, technical and economic analysis was performed based on a mathematical model to establish a direct relationship between the energy saved by way of minimized losses and the costs of implementing the proposed measures. This paper aims at analysing the feasibility of reducing energy losses in distribution systems, by changing existing network conductors by larger cross-section conductors and distribution voltage change at higher levels. The impact of this methodology provides a highly efficient mathematical tool for analysing the feasibility of implementing improvement projects based on their costs which is a very useful tool for the distribution companies that will serve as a starting point to the analysis for this type of projects in distribution systems.

1. Introduction

Until nowadays ninety percent of the energy needs of our planet are satisfied with the use of fossil fuels (oil, gas, coal), all extinguishable, heavily polluting and inefficiently used due to the predominant interest on energy production, rather than on its ecological effect. The importance of reducing the consumption of these primary sources has transformed from an economic problem to a vital problem and even worse, from a vital problem for the future it has transformed to one of the major accidents suffered in the development of mankind. The acidity of rainfall, natural disasters, the consequences of the greenhouse effect and the reduction of the ozone layer, are consequences that must be cured with a new way of energy production based mainly on efficiency [1]. The ability we have today in the energy distribution companies to produce and transmit electricity is due to the continuous action in the preparation of electrical workers, who install, operate and give maintenance to generating plants and the thousands of kilometers lines, towers, cables and poles that distribute electricity. For that reason, improving processes, optimizing network management and minimizing losses in transmission and distribution are key issues to reduce energy waste [2].

To achieve energy efficiency in a systematic way, the proper application of a body of knowledge and methods to ensure this practice is necessary. They constitute a technology and they are applied to the means of labor, human resources, processes and methods of management, control and planning [3].



Electrical power losses are inherent to real physical systems, in the electro - energy systems they are classified into two groups: technical and non-technical. Technical losses are largely related to the state of the physical characteristics of the system and its parts, which are a consequence of planning and designing criteria used in the past, initially in the materials used to construct the electric machines, conductors, insulators and other devices, and then, in the constructive characteristics and operative conditions in the analysed period [4]. Moreover, non-technical losses are the reflection of the activity of billing systems, the accuracy of the measuring equipment, the difficulties of the company to collect the service, the level of tariffs and the service quality.

The design and the construction of networks have a decisive influence on its subsequent operation, and even though technical losses will always be present, we should project adequately, so that they can be minimum [5].

Losses in electrical systems, reported in studies and measurements of electrical circuits, are not due to a sudden change in the conditions previously cited. Electrical losses are mostly caused by the natural aging of the systems which are not renewed promptly or it is not yet profitable to replace them, and they gradually reveal the consequences of design criteria that could be economic in the past or erroneously determined as economic.

The solution of these and other problems should be holistically evaluated to reduce the losses levels to minimum values [1][6].

This paper proposes a technical and economic assessment of measures to minimize energy losses in distribution systems, making emphasis on improving the resistance of the conductors and the exchange or conversion of distribution voltage at a higher level [7][8]. It also makes a planning model for estimation and classification of electrical losses in distribution networks [9] [10].

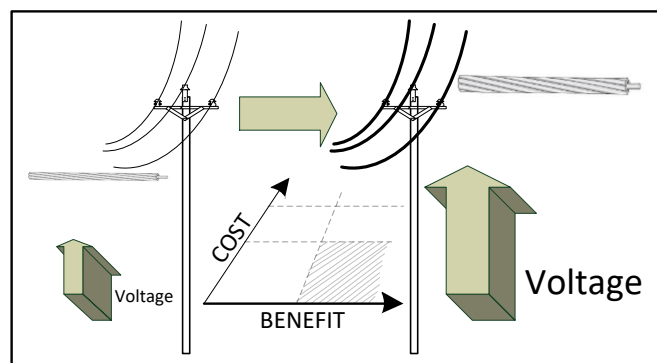


Figure 1. Planning diagram of the technical and economic improvements in distribution networks.

Figure 1 shows the purpose of the paper, which is to improve the energetic efficiency applying technical measures minimizing the investment costs.

2. General methods of economic analysis.

The most common electrical power losses are evaluated in association with heat dissipation in conductors (in the lines and the windings of electric machines), and they are linked in quadratic form with the current. For this reason, it should be treated by all means that in none of the parts of a network, current values exceed the nominal [5][10]. They are also related to the electrical resistance of the conductive materials, so it is absolutely necessary to properly calculate the circuits to choose wire sizes to satisfy the current and voltage values that will exist in them. The losses which depend on the voltage in distribution channels with voltage levels below 35 kV are small compared with those that

depend on current and mainly occur by the transformation to heat energy, from the electrical energy transmitted by drivers due to its electrical resistance[11]. The greater the amount of energy to be transmitted (consumer demand), and the greater the resistance of the conductors, the greater the losses would be [12]. But current and resistance values can be limited to optimal levels, so that the only losses which would occur are the strictly necessary in the process of transmission [5].

In many cases the power systems are in unwanted regimes, as a product of problems or deficiencies in them, and in order to solve them, we must implement measures aiming at achieving technical and economic improvements [5][13] [14], That is why for many years, methods of economic balance that serve to demonstrate whether a measure is applicable or not, have been studied. In this chapter different economic methods will be analyzed, to prove whether the technical measures applied in this paper, are feasible or not[1].

General methods of economic analysis:

Net Present Value (NPV)

$$NPV = -K + \sum_{J=1}^N \frac{FC_J}{(1+TD)^J} \quad (1)$$

Where:

K - Cost of the initial investment

TD - Discount rate

FC_J - Cash flow

$$FC_J = E_J - S_J$$

E_J - Inputs

S_J - Operating expenses

Si: $NPV > 0$ the measure is economically feasible.

$NPV \leq 0$ The measure is not applied.

The best variant is the highest NPV.

Net present value cost (NPVC)

The NPVC in an electric network can be expressed as follows:

$$NPVC = K + \sum_{j=1}^N \frac{(G_E + G_a + \Delta E \cdot \beta(1+r)^J)_J}{(1+TD)^j} \quad (2)$$

Where:

K - Equipment cost or initial investment as corresponds.

$G_E = pE \cdot K$; $G_a = pa \cdot K$ Annual operating expenses and by amortization concept, which can be expressed in percent of the investment K .

pE , pa - Coefficients of annual expenses (ordinary maintenance and repairs); amortization coefficients, including the renewal discount of the equipment and those meant to the capitalized or general reparations, the latter are not included nowadays in the planned fixed expenses, and they are made according to the needs of the net.

ΔE - Energy losses through the electrical net.
 β - Cost of kV of losses.
 TD - Annual discount rate.
 N- Number of years of exploitation evaluated.
 r - Coefficient of vegetative annual load growth.

Here the best option is the one with the least Vanc.

Let's evaluate the application of a determined technical measure, from the analysis of the Net Present Value Cost, this may arise as follows:

The introduction of a technical measure, aiming at reducing energy losses, will be considered economic if:

$$NPV_{c1} \leq NPV_c \quad (3)$$

Where:

NPV_{c1} - Net Present Value of the costs of the new variant (variant or improvement measure whose application is object to analysis)

NPV_c - Net Present Value of the costs of the previous variant.

Substituting equation (2) in (3) and making some mathematical arrangements we have:

$$\frac{\Delta E - \Delta E_1}{\Delta K} \geq \frac{1 + p_{\Sigma} \sum_{j=1}^N \frac{1}{(1+TD)^j}}{\beta \sum_{j=1}^N \frac{(1+r)^j}{(1+TD)^j}} \quad (4)$$

Where:

$$pS = p_e + p_a$$

$\Delta K = K_1 - K$ - Additional costs required to implement the technical measure.

If after applying the new measure aiming at reducing energy losses, transmitted energy increases, the expression

(4) can be written as:

$$\frac{\Delta E - \frac{\Delta E_1}{h}}{K(1-h) + K} \geq \frac{1 + p_{\Sigma} \sum_{j=1}^N \frac{1}{(1+TD)^j}}{h\beta \sum_{j=1}^N \frac{(1+r)^j}{(1+TD)^j}} \quad (5)$$

Where:

$$\frac{E_1}{E} = h$$

- Coefficient that shows how many times the transmitted energy has increased.

Internal Rate of Return (IRR)

$$0 = -K + \sum_{J=1}^N \frac{FC_J}{(1+IRR)^J} \quad (6)$$

Here the best variant is the highest IRR.

2.1. Voltage change at a higher level[1][12].

For the voltage change in the expression (4) the term ΔK is expressed as:

$$\Delta K = Kd + Km1 + Keq + Kr - K \quad (7)$$

Where:

Kd – Cost of dismantling transformers (if necessary) and the old structures.

Km1 – Cost of installation of new transformers and new structures.

Keq - Cost of equipment needed for the new voltage level.

Kr – Unamortized costs of the initial investment (structure and equipment to be dismantled).

$$Kr = K(1 - pr * tj)$$

pr - Coefficient of renewal. Reverse of the regulatory duration of equipment for the previous voltage level.

tj – Equipment operating time when the change is applied

As it is already deduced from the application of the term:

$$\frac{\Delta E - \Delta E1}{\Delta K}$$

It's the relationship that expresses the energy savings invested additional monetary value which is actually achieved with the implementation of the measure, which must be greater than the term of the right of expression (4).

2.2. Change of conductors to superior transversal section [1][12].

In this case ΔK expression takes the following form:

$$\Delta K = Kd + (a + b * F1) - pr * tj * (a + b * F) \quad (8)$$

Where:

F1, F – New and old section respectively

- Coefficient expressing the part of the investment that doesn't depend on the caliber or cross section. For lines up to 13kV it is calculated by the following expression:
- Coefficient expressing the part of the investment that depends on the caliber or cross section.

$a + b * F1 = Km1 + Keq1$ - Represents the cost of mounting plus the equipment (structures, insulators, etc.) of the new caliber.

$a + b * F = Km + Keq$ - Represents the cost of mounting plus the equipment (structures, insulators, etc.) of the initial caliber.

As, $Kd = 0.2 * (Km1 + Keq1)$ then the expression ΔK is:

$$\Delta K = 1.2 * (a + b * F1) - pr * tj * (a + b * F) \quad (9)$$

Substituting the terms of ΔE , $\Delta E1$ y ΔK in the expression (4), and clearing I, we obtain the equation to determine the value of the maximum current (I_m).

$$I_m = \sqrt{\frac{\left[1 + p_{\Sigma} \sum_{j=1}^N \frac{1}{(1 + TD)^j}\right] [a(1.2 - p_r t_j) + b(1.2 F_1 - F \cdot p_r t_j)]}{3\rho\beta \left(\frac{1}{F} - \frac{1}{F_1}\right) \sum_{j=1}^N \frac{1}{(1 + TD)^j}}} \quad (10)$$

The maximum current is defined as the current value, from which it becomes feasible. From an economic point of view, change the section F by the F1, since from that value; the Net Present Value Cost (VANC) will be lower with the new section than with the previous one.

If the caliber change, aiming at reducing the losses, increases power transmission capacity of the line, we introduce the coefficient h, expressing the increase of transmitted energy, in the equation. Then the expression to maximum current is:

$$I_m = \sqrt{\frac{\left[1 + p \sum_{j=1}^N \frac{1}{(1+TD)^j}\right] \left[a(2.2 - h - p_r t_j) + b(F - Fh + 1.2F_1 - Fp_r t_j)\right]}{3\rho\beta\left(\frac{1}{F} - \frac{1}{F_1 h}\right) \sum_{j=1}^N \frac{1}{(1+TD)^j}}} \quad (11)$$

Notice that h is a coefficient greater than 1, in the case h=1 (when there is not an increase of the energy that will be transmitted), the expression (11) transforms in (10).

3. Necessary information for estimating losses in distribution systems [1].

In any study of losses it is advisable to start the analysis with adequate knowledge of the system under study. The necessary information is related to:

Technical characteristics:

- Line Diagram.
- Voltage level.
- Length of conductors.
- Types of conductors.
- Features of conductors.
- Geometric setting of structures.
- Phases by circuits.
- Routes of circuits.
- Location of transformers.
- Electrical characteristics of transformers.
- Location of other equipment (capacitors for example)

Charge information [15] [16].

- Charge factor.
- Hourly demand of power plants, distribution substations, primary feeders, distribution transformers, etc. According to the scope of the study.
- Power factor.
- Sales of energy according to the type of user.
- Users associated with each distribution transformer.

Necessary information for the study of electric losses [1][17].

- Zoning of the city circuit.
- Visual inspection of the networks to classify the status of existing materials (poles, fittings, transformers, conductors, etc.) and the percentage use in the event of remodelling networks.
- Statistical data analysis and estimate global demand for global growth rates into the future.
- Measurement of losses in typical existing transformers (study protocol or test) to determine the appropriateness of their use in case of remodelling, economic chargeability, etc [18].

- Selection of sample size for measuring transformers secondary circuits, representative for the sectors in which the city was divided.
- Update, if necessary with lifting planes of primary networks, number of phases, size, drivers, length of sections, location, capacity and power factor, sectioning points and interconnection with neighboring circuits.
- Collection and analysis of information related to the future growth of the city in the short and medium term (roads, residential, commercial, industrial plans, etc.) [19].
- Projections of growth of new consumers by consumption category and geographic location.
- Estimate of number of current and future consumers of the city circuit.
- Data collection and analysis of data on existing circuits operation, including location, type and duration of interruptions, cost of materials and labor, etc [20].
- Data collection and analysis of information on business practices according to the design, use of type and wire size, type of primary and secondary distribution, chargeability of transformers, chargeability of primary circuits, connections, etc[18].
- Collection and analysis of information on unit costs of materials and labor for later use in the preparation of budget and economic analysis.

General methodology for estimating losses in distribution circuits [1].

To estimate power and energy losses, the following considerations must be taken into account:

For distribution substations losses can be evaluated from the value of losses in the peak demand and the loss factor of the system, then:

$$\Delta E = F_p \Delta P T$$

Calculating the loss factor depends on each particular system. In first approximation, its value can be estimated from the charge factor. It can be shown that the loss factor is bounded by the following values:

$$F_C^2 < F_p < F_C$$

An empirical relationship between the loss factor and the charge factor (developed by Bullery Woodrow) is:

$$F_p = X * F_C + (1 - X) * F_C^2$$

Where the variable $X \leq 1$ and depends on the characteristics of each system.

Usually, the power supplied by the substation and the value of the voltage are known, but as the considered points are taken away from it, the voltage value decreases [21].

This is due to the voltage drops occurring in the elements (feeders, transformers), by the effect of the current.

4. Conclusions and future works

The model proposed allows us to verify the technical and economic feasibility for the implementation of measures of electrical improvements in distribution nets, by posing different scenarios for future energy in the study circuits.

Specific cases were modelled, such as voltage conversion at a higher level and the replacement of low caliber conductors or crossed section, where all implementation activities in each of the improvements with their associated costs were related, using tools of economic calculation, which allows us to

visualize the coefficients that define the feasibility in terms of possible future increase in the transmitted energy.

For changing primary voltage to a superior level, it was established a relation expressing the energy savings by invested additional monetary value, which is actually achieved with the application of the measure.

To replace low caliber conductors by others with larger cross section, it was defined a value of current from which it becomes feasible, from an economic point of view, to change the section F of an existing circuit by the new proposed section. If the caliber change, aiming at minimizing losses, increases the capacity of power transmission of the line, we introduce a coefficient h in the equation, expressing the increase of the transmitted energy, from which a result of final calculation is obtained, verifiable for any situation of the project, whether current or future.

It was made a collection of necessary information and basic activities of analysis in study of electrical losses.

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