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Electrical Losses in Primary Distribution Networks: Case in Holguin Province

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A B S T R A C T

The electrical losses constitute an indicator of the technical state of the electrical networks, which can reach up to 70% of the total losses that occur in an electrical circuit. In this work, the calculation of the technical losses in 140 electrical distribution networks was carried out in the school belonging to the Holguín province in Cuba. The statistical calculation is performed in order to understand the electrical losses in primary distribution networks of the Holguín province. The method used by Empresa Eléctrica Holguín was acquired for power losses, which considered the number of customers, the maximum demand, and the length belonging to the circuit under study. The Buller Equation was used to calculate energy losses, which relates the load and loss factors utilizing a coefficient k obtained by statistical considerations. The most affected municipalities were Sagua de Tánamo, Calixto García, and Cacocún, whose losses represented 45% of the total losses. On the other hand, the characteristic k coefficient for local primary distribution networks was 0.27.

A R T I C L E I N F O

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1. INTRODUCTION

One of the indicators of the current state of the electrical network is the values of losses that are produced. The technical department of the electrical companies is responsible for acting on those produced by the technologies used in the system, or those called technical losses. Usually, the electrical losses relate to the energy supplied defined by the efficiency of the networks. These also affect the electricity rate range from 4 to 15 %, where the techniques can reach 70 % of these (Chernykh *et al.*, 2022), (Komolafe & Udofia, 2020), (Gulakhmadov *et al.*, 2022), (Zaghwan & Gunawan, 2021).

Calculating this component is a complex task, especially for large circuits. Some authors have considered simplified calculation methods, loss forecasting, and demand monitoring to maintain control or an actual result of the behavior (Tsygulev

& Khlebnikov, 2019), (Musaev *et al.*, 2020), (Farshchian *et al.*, 2021), (Gayibov *et al.*, 2021).

The Cuban electricity company pays great attention to reducing this indicator, detecting the areas with the most significant difficulties, and taking measures. Academic institutions continuously support this work by presenting their results in numerous investigations (Gomez *et al.*, 2021), (Laurencio *et al.*, 2022), (Grau *et al.*, 2020), (Fraga *et al.*, 2021).

The energy losses are directly proportional to the loss factor, related to the load factor through a coefficient k. Based on the literature, this k factor is commonly characterized as having a value of 0.3 or 0.4, according to different methodologies or standards. However, some others consider it to be 0.5 in areas where there is a high number of offices (commercial area) (Rahmat *et al.*, 2021), (Greenwood *et al.*, 2019).

The literature is limited in terms of the behavior of technical losses and the appropriate value of the coefficient k for its calculation, in the primary distribution networks of the province. In this paper, the calculation of technical losses in the lines of 140 primary distribution networks of the Holguín province in Cuba is carried out. This allows characterizing of the state of the networks by the municipality from the technical point of view. The maximum power losses are obtained through a calculation using the Empresa Eléctrica Holguín method. In contrast, the loss factor is used to calculate the energy losses so that a characteristic k factor is established for the power network primary distribution of the province.

2. METHODOLOGY

The study is carried out for the lines of 140 primary distribution networks in the Holguín province, distributed in 14 municipalities. These networks are characterized by voltage levels of 13.2 and 4.16 kV and are not very extensive radial types, with many customers. The most complex task for this study type is the search for the required information since it is sometimes impossible or difficult to obtain for various reasons, including economic ones. This tends to make the calculation difficult and, on occasions, forces us to estimate or assume values that play with the precision of the results.

The information on the demand for each circuit is taken from the measurement equipment of the characteristic NULEC devices in the distribution networks and those present in the SIGERE platform (Network Management System). The latter is implemented to control losses in the distribution of electrical energy using computerized digital equipment for measurements and decision-making to decrease these losses significantly (Pérez *et al.*, 2019). For most circuits, measurements for one year are obtained.

Parameters such as energy, maximum demand, load factor, and maximum load duration time, among others, are obtained from the load graph of each circuit.

2.1. Calculation of power losses

The power losses are obtained using the method used by the Empresa Eléctrica de Holguín. This method considers radial circuits in which the loads distributed along the circuit can be concentrated at a point on the network at a certain distance, depending on the type of circuit, as shown in the Equation (1).

$$\Delta P = nf \cdot \mathrm{I_t}^2 \cdot r_t \cdot L \cdot fdp, \qquad (1)$$

where nf is the number of phases, $\mathrm{I_t}$ is the total current of the circuit, r_t is the total specific resistance of the conductor,

L is the total length of the circuit, and fdp is the loss distribution factor. The latter is a function of the number of clients connected to the circuit, whose value is obtained from Equation (2).

$$fdp = \frac{1}{3} + \frac{1}{2n} + \frac{1}{6n^2}\,, \tag{2}$$

where n represents the number of clients connected to the circuit.

The behavior of the loss distribution factor as a function of the number of clients, when the latter is greater than 30, tends to be fdp = 0.33. Therefore, since the number of clients connected to the networks under study exceeds this value, it is standardized to this number.

2.2. Calculation of energy losses

Energy losses constitute a fundamental indicator of knowing the technical state of the electrical network. One method used in technical loss studies relates to the loss factor, as shown in Equation (3).

$$\Delta E = \Delta P \cdot fp \cdot t\,, \tag{3}$$

where ΔE are the energy losses, fp is the loss factor, and t is the time under study, in this case, one year (8760 h).

The loss factor is commonly related to the load factor through expression called the Buller formula (Equation (4)) (Hassan et al., 2020), (Gören et al., 2022), (Duan et al., 2022).

$$fp = (1-k)fc^2 + kfc\,, \tag{4}$$

where k is a coefficient dependent on statistical approximations (k = 0.3 European practice and 0.4 American practice) and fc is the load factor. Likewise, the load factor is obtained with the mathematical ratio between the average and maximum power using Equation (5).

$$fc = \frac{\sum_{i=1}^{n} P_i}{tP_{max}}\,. \tag{5}$$

Likewise, the load factor can be obtained by solving Equation (6).

$$fp = \frac{\tau}{t}\,, \tag{6}$$

where t is the time in which the study is carried out, and τ is the maximum loss time or equivalent loss time, which can be calculated using the Equation (7).

$$\tau = \frac{\sum_{i=1}^{n} {P_i}^2}{{P_{max}}^2}\,, \tag{7}$$

where P_i is the power or demand at time i and P_{max} is the maximum demand.

2.3. Statistical considerations

For the determination of the characteristic value of the coefficient k in the calculation of the loss factor, a hypothesis test on the mean μ with known variance σ_2 is considered. For this, a bilateral test is carried out, which considers the relationship in Equation (8).

$$H_0: \mu_1 = \mu_2; H_1: \mu_1 \neq \mu_2\,, \tag{8}$$

where H_0 and H_1 represent the null and alternative hypotheses, respectively, μ_1 and μ_2 are the arithmetic mean of populations 1 and 2, respectively.

Under this study, the null hypothesis is that the mean of the loss factors obtained by real coefficients k equal to the mean of the loss factors obtained for a factor k considered by American or European practice. Instead, the alternative hypothesis is considered that they are different. In this way, the factor k for primary distribution networks in the province is characterized.

The test statistic to be considered is related to Equation (9) (William & Douglas, 1996).

$$Z_0 = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{{\sigma_1}^2}{n_1} + \frac{{\sigma_2}^2}{n_2}}}\,, \tag{9}$$

where n_1 and n_2 are the sizes of samples 1 and 2, respectively. While σ_1 and σ_2 are the variances of sample 1 and 2, respectively. In this case, the rejection criterion would be $|Z_0| > Z_{\alpha/2}$.

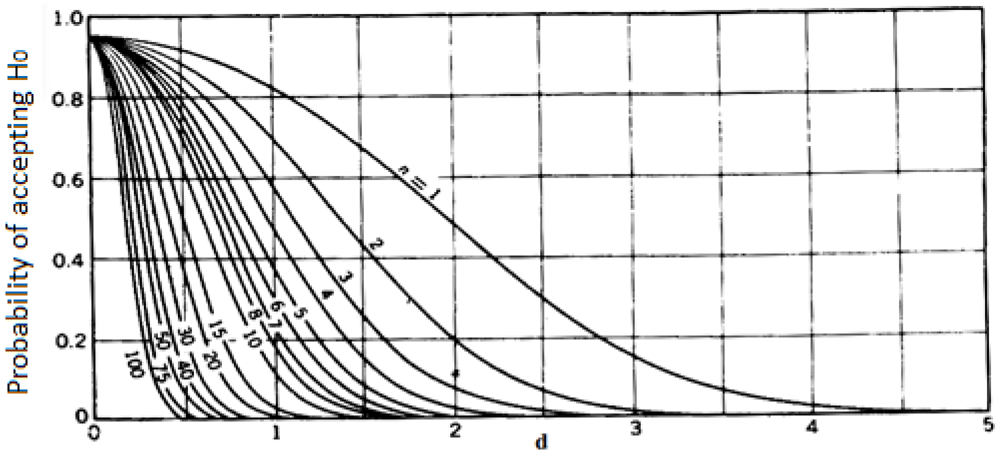

Figure 1. CO curve for different values of n for the two-sided normal test at a significance level of 0.05 (d is standardized difference) (William & Douglas, 1996).

The type II error can be verified by considering β, the probability of accepting a false hypothesis. Therefore, the higher β the better result will be. The characteristic operation curve (CO curve) is used, which is shown in **Figure 1**. The value of standardized difference, d, can be obtained from the Equation (10).

$$d = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{{\sigma_1}^2 + {\sigma_2}^2}}, \quad (10)$$

The data for the test must be considered to be normally distributed. Since the sample size is large (140), the random variable Z has an approximately standard normal probability distribution. The central limit theorem is used for this analysis.

3. RESULTS AND DISCUSSION

The results obtained are for each circuit. In the case of electrical losses, they are grouped by the municipality to simplify the information presented. However, in practical terms, it is occasionally more comfortable to work by municipalities.

3.1. Coefficient k and loss factor

The loss factor and load factor results for the 140 circuits are obtained. In addition, the corresponding coefficient k is obtained. **Figure 2** shows the distribution of the coefficients k in a histogram. It can be seen that the values obtained from each circuit are between 0.26 and 0.28 for 86.4% of the cases.

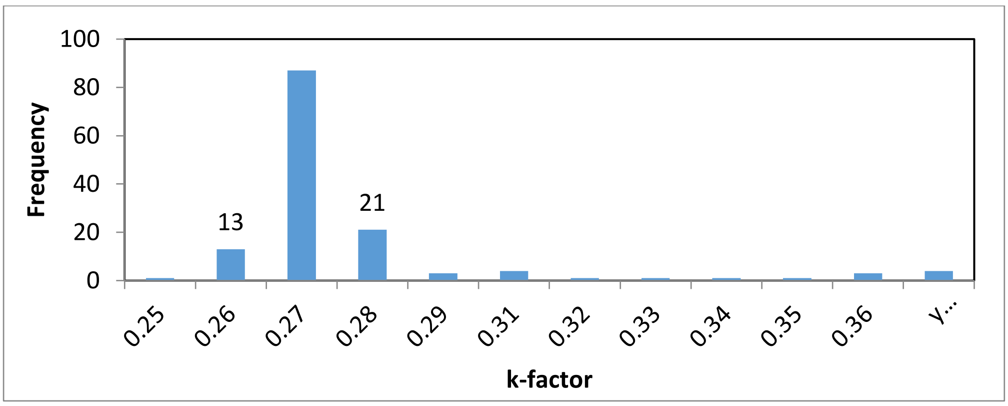

Figure 2. Histogram of the k coefficients of the 140 primary distribution networks (Own elaboration)

Table 1. Result of the hypothesis test between the real fp and the calculated fp with $k = 0.3$

	Real fp	Calculated fp
Mean	0.2611021	0.2676681
Variance (known)	0.013312	0.013936
Observations	140	140
Hypothetical mean difference	0	
z	-0.470653	
P(Z<=z) a tail	0.3189444	
Critical value of z (a tail)	1.6448536	
Critical value of z (two tails)	0.6378888	
Critical value of z (two tails)	1.959964	

Based on the results, the arithmetic mean of the coefficients k is 0.27. This constitutes the characteristic value for the distribution circuits of the province. These effects resulted in the closest value for the calculations resulting from applying the European practice, which considers a coefficient k = 0.3.

The hypothesis test is performed on the mean with known variance for both cases to verify that there is no significant difference between the actual results and the values calculated using the coefficient k used in European practice. The hypothesis test shows that the computed value of z is less than the critical value obtained with a significance level of 0.05, as shown in **Table 1**. Therefore, there is no significant difference between the loss factor obtained with k =0.27 and k =0.3, respectively. In this way, it is statistically justified that the use of k =0.3 in the loss calculations does not constitute a sufficiently large error for the primary distribution networks of the Holguín province.

Figure 1 also verifies that a type II statistical error is not produced. Using the graph in **Figure 1** with the calculated value d = 0.06, for n=140, β=0.93 approximately is obtained. Since β is a high value, the null hypothesis is accepted with an acceptable level of significance in engineering.

3.2. Electrical losses

Figure 3 shows the results of electrical energy losses by municipalities.

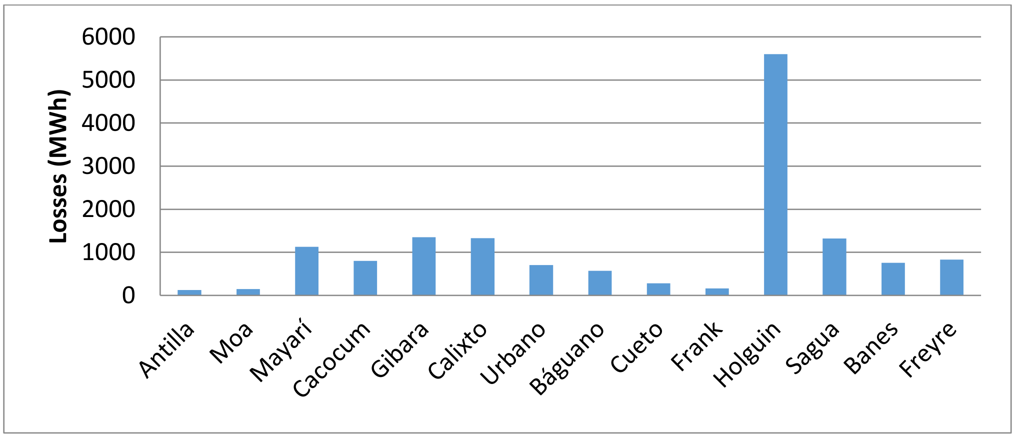

Figure 3. Energy losses by municipalities.

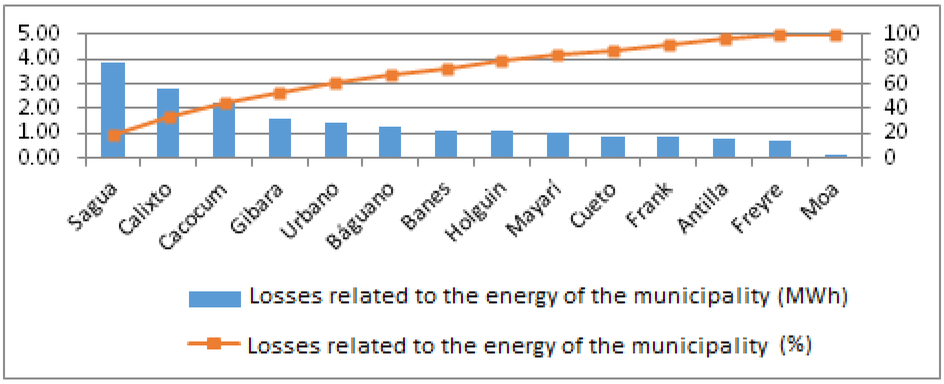

Figure 4. Energy losses by municipalities refer to the energy supplied.

As expected, the most significant effects occur in the main municipality. This can be happened due to much higher consumption than in the rest of the localities. However, a correct indicator to evaluate and/or compare these results would be concerning each municipality's energy supplied or demanded, as shown in **Figure 4**.

Figure 4 shows the municipalities of Sagua de Tánamo, Calixto García, and Cacocúm, the most critical cases. This allows an analysis of the circuits, considering their characteristics, to correct these indicators for the technical improvement of the network.

4. CONCLUSIONS

The characteristic k coefficient for distribution networks in the Holguín province is equal to 0.27. However, there is no significant difference in the results when k = 0.3 (European practice). Hence it can also be used in technical loss assessment. The energy losses in primary distribution lines are established with a value of 15097.5 MWh per year. The municipalities with the most incidents relative to the energy supplied are the municipalities of Sagua, Calixto, and Cacocum.

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