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MODEL FOR ESTIMATING THE QUALITY PARAMETERS OF ELECTRIC ENERGY SUPPLIED TO CUSTOMERS IN RURAL AREAS

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Key words: unbalanced load, simulation model, electric energy quality.

Abstract

The paper presents a model for estimating selected quality parameters of electric energy supplied to rural customers from the low-voltage (nN) level under unbalanced load conditions. The input values taken into account in the simulation model developed in the study were as follows: length of low-voltage line (nN), number of customers, distribution of customers along the line, installed capacity, values of duty factors and of phase cosines at particular customers. The above simulation model and results of own research enabled to determine the values of selected quality parameters of electric energy and analyze them with respect to admissible values specified in relevant standards and regulations.

MODEL OCENY PARAMETRÓW CHARAKTERYZUJĄCYCH JAKOŚĆ ENERGII ELEKTRYCZNEJ DOSTARCZANEJ ODBIORCOM WIEJSKIM

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Słowa kluczowe: asymetria obciążeń, model symulacyjny, jakość energii elektrycznej,

Streszczenie

Przedstawiono model oceny wybranych parametrów charakteryzujących jakość energii elektrycznej dostarczanej odbiorcom z linii niskiego napięcia (nN), w warunkach asymetrii obciążeń. Na podstawie zbudowanego modelu symulacyjnego dla wielkości wejściowych, które obejmowały: długość linii nN, liczbę odbiorców, ich rozmieszczenie wzdłuż linii, wartości mocy zainstalowanych, wartości współczynników wykorzystania mocy i wartości cosinusów fazowych u kolejnych odbiorców, a także badań własnych było możliwe wyznaczenie wartości wybranych parametrów jakościowych energii elektrycznej i ich analiza w odniesieniu do wartości dopuszczalnych określonych w stosownych przepisach normatywnych.

Introduction

The reason for unbalanced load in three-phase low-voltage lines is non-uniform distribution of energy reception by single-phase receivers, and random character of their inclusion into the network. Unbalanced load is also affected by line asymmetry caused by different values of mutual impedance of conductors. Unbalanced load and its consequences (including increased voltage drops, voltage deviations and unbalanced load coefficients, power and energy losses) are most clearly visible in rural low-voltage lines. A low-voltage (nN) four-wire single-circuit overhead line, supplying energy to the so called dispersed customers, was considered in the study, as most typical of such networks. A two-plate system of conductors was assumed, since it is both most common and most disadvantageous in terms of impedance, due to unbalanced load. The section of phase and neutral conductors considered in the study was $s = s_n = 50$ mm^2, i.e. most common in rural low-voltage lines.

Model structure

All energy customers using single-phase receivers affect unbalanced load observed in low-voltage lines. For this reason the paper presents a simulation model whose application (cf. the algorithm in Fig. 1). enables to estimate the values of selected quality parameters of energy for a single-circuit low-voltage line (nN).

A computer program was developed on the basis of the simulation algorithm. The first value generated in this program was length of low-voltage line l, from the Weibull distribution with parameters $p = 2$, $\lambda = 0.8$. This distribution corresponds to the data on circuits, acquired in Poland. These data show, among other, that circuit lengths vary from 100 to 2100 m, mean value being 865 m (length of main circuit – 608 m).

At the next stage of the study the following parameters were generated from the uniform distribution: number of energy customers n, and the distance between them and the beginning of line li. The distribution values were bounded by line length l (upper bound) and minimal distance (lower bound). The minimal distance corresponded to the distance between neighboring poles (50 m)

$$l_i = \sum_{k=1}^{i} \Delta l_k \tag{1}$$

where:

Δl_k – distance between the (k-1) and the k-th supply point (terminal).

Then the value of installed capacity P_{zi} at the i-th customer (i.e. at the i-th terminal) was generated from the normal distribution with parameters $m = 28$ and $\sigma = 3.33$. Installed capacity is understood as total values of the capacities of receivers owned by the customer:

$$P_{zi} = \sum_{k=1}^{n} P_{oik} \tag{2}$$

where:

P_{oik} – capacity of the k-th receiver at the i-th customer.

The distribution of installed capacity values was adopted arbitrarily, based on its mean level, which according to TROJANOWSKA (2002) is 24 kW for farms covering an area of less than 5 ha arable land, and 32 kW for farms covering an area of more than 5 ha arable land.

The value of power used by the customer is only part of installed capacity. The value of peak power at the i-th supply point P_{si} equals the value of power consumed by the customer at peak load. In this way the duty factor referring to installed capacity assumes the form:

$$k_{wi} = \frac{P_{si}}{P_{zi}} \tag{3}$$

The next stage was to generate the value of duty factor (demand) k_{wi} for particular customers, from normal distribution with parameters $m = 0.348$ and $\sigma = 0.0067$, adopted on the basis of the data provided by the Design Office "Eltor" Bydgoszcz (1983). Due to the fact that according to these data the value of installed capacity does not differ from that given by TROJANOWSKA (2002), it was assumed that load level would not differ significantly from that included in up-to-date data.

The values of unbalanced load coefficients k_{1i}, k_{2i} at the i-th terminal were adopted on the basis of Weibull distributions with parameters ($p = 2$, $\lambda = 0.7$) and ($p = 2$, $\lambda = 0.3$), referring to results of phase load measurements performed for 12 days on a farm covering an area of approx. 30 ha, located in the Kujawy-Pomorze Province. The coefficients of unbalanced load were determined using the following relationships:

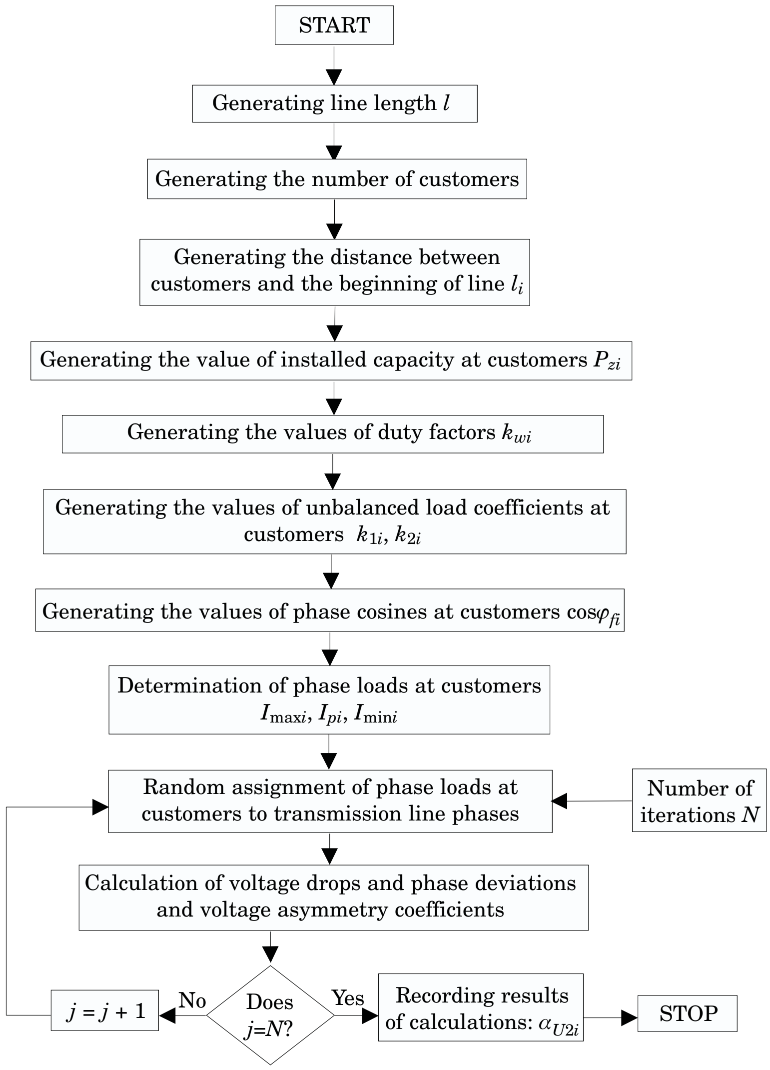

Fig. 1. Algorithm of simulation program operation

a) coefficient of transmitted load:

$$k_{1i} = \frac{I_{pi}}{I_{\max i}} \tag{4}$$

b) coefficient of minimal load:

$$k_{2i} = \frac{I_{\min i}}{I_{\max i}} \tag{5}$$

where:

$I_{\max i}$, $I_{\min i}$, I_{pi} – maximal, minimal and transmitted phase loads, respectively, at the i-th terminal.

The values of phase cosines were generated for respective phase loads $I_{\max i}$, $I_{\min i}$, I_{pi} from a probability density function: $0.6+0.4 \cdot f_B(4.2)$, where $f_B(4.2)$ – beta probability density function with parameters: $a = 4$, $b = 2$.

The previously generated values provided the basis for determining the values of phase power at particular supply points (terminals):

$$\begin{gathered} P_{\max i} = \frac{1}{1 + k_{1i} + k_{2i}} k_{wi} P_{zi} \\ P_{pi} = k_{1i} P_{\max i} \\ P_{\min i} = k_{2i} P_{\max i} \end{gathered} \tag{6}$$

The vales of phase current received at the i-th terminal were calculated from the relationship:

$$I_{fi} = \frac{P_{fi}}{U_n \cos \varphi_{fi}} \tag{7}$$

where:

P_{fi} – value of phase power at the i-th terminal ($P_{\max i}$, P_{pi}, $P_{\min i}$),

$\cos\varphi_{fi}$ – value of phase cosine at the i-th terminal,

U_n – value of rated voltage.

Particular loads (currents) at the customer were randomly assigned to the phases of a low-voltage line (nN). In this way the determined values of phase current and phase cosines at particular supply points (terminals) distant by l_i from the beginning of the line were adopted as input data for calculations of voltage drops, voltage deviations and voltage asymmetry coefficients in a given generation cycle. In successive generation cycles loads were randomly assigned to line phases N times, taking into account previously determined current values. In this way voltage drops, voltage deviations and asymmetry coefficients were measured in successive repetitions. Conducting a greater number of generation cycles allows to obtain distributions of the values of quality parameters of supplied energy.

Phase voltage deviations are defined by the following relationship:

$$\delta U_{fi} = \frac{U_{fi} - U_n}{U_n} 100\% \tag{8}$$

where:

U_{fi} – phase voltage at the i-th supply point.

The coefficient of voltage asymmetry at the i-th terminal is expressed by the relationship:

$$\alpha_{v_{2i}} = \frac{U_{2i}}{U_{1i}} 100\% \tag{9}$$

where:

U_{2i}, U_{1i} – symmetric components of phase voltages corresponding to negative and positive phase sequence, respectively, at the i-th terminal.

$$U_1 = \frac{1}{3}\sqrt{U_A^2 + U_B^2 + U_C^2 - 2U_AU_B\cos(\alpha + \frac{\pi}{3}) - 2U_BU_C\cos(\beta + \frac{\pi}{3}) - 2U_CU_A\cos(\alpha + \beta - \frac{\pi}{3})}$$

$$U_2 = \frac{1}{3}\sqrt{U_A^2 + U_B^2 + U_C^2 - 2U_AU_B\cos(\alpha - \frac{\pi}{3}) - 2U_BU_C\cos(\beta - \frac{\pi}{3}) - 2U_CU_A\cos(\alpha + \beta + \frac{\pi}{3})} \tag{10}$$

$$\alpha = arc\cos\frac{U_A^2 + U_B^2 - U_{AB}^2}{2U_AU_B} \quad \beta = arc\cos\frac{U_B^2 + U_C^2 - U_{BC}^2}{2U_BU_C} \tag{11}$$

U_A, U_B, U_C, U_{AB}, U_{BC}, U_{CA} – values of phase and forward voltage.

According to the Polish Standard PN-EN 50160 (1998), the values of the above parameters of electric energy should remain within admissible limits:

$$-10\% \le \delta U_{fi} \le +10\%, \ \alpha_{U_{2i}} \le 2\% \tag{12}$$

Figure 2 presents a histogram of the values of the voltage asymmetry coefficient at the supply point at the end of a low-voltage line nN – an example of simulation program application ($N = 1000$).

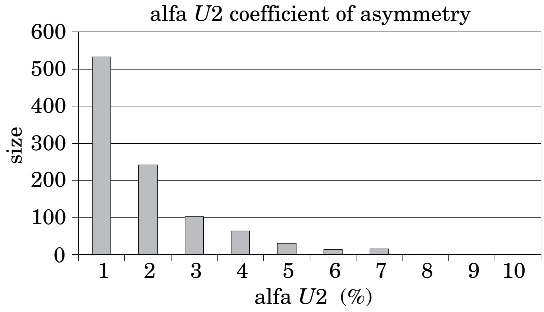

Fig. 2. Histogram of the values of the asymmetry coefficient α_{U2} at the end of a low-voltage line (nN)

Summary

The interrelated problems of unbalanced load and the quality of electric energy supplied to customers are complex, since the quality parameters of energy are affected by all customers supplied from the low-voltage level (nN). It follows that not only the energy supplier is responsible for ensuring adequate values of the above parameters. Thus, simulation models reflecting the processes occurring in low-voltage lines under unbalanced load conditions should be developed. Such models enable to determine actual values of energy parameters that may be observed under the above conditions. The extent to which their values are exceeded at particular points of the network, as compared with admissible values, may provide the basis for making the necessary decisions aimed at ensuring the right parameters of supplied energy.

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