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# Modified Fuzzy Clustering Method for Energy Loss Calculations in Low Voltage Distribution Networks

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## Introduction

Determination of electrical energy losses in low voltage distribution networks is very important for any electrical utility. The proper calculation of energy losses is one of the most complex problems in power distribution systems analysis, demanding consideration of many factors. The accessibility and credibility of data used in calculations is of the greatest importance here.

The accessibility and credibility of parameter's database are very low for low voltage networks. This problem can be solved by further involvement on reviewing database. The other very difficult problem is small number of measurements in low voltage networks. Therefore, the data about low voltage loadings does not exist. The delivered energies and peak loadings of distribution transformers, are usually the only available measured data.

The problem of losses calculation is simplified in [1,2] classifying low voltage networks in two groups: town's and village's. Regression method is also proposed in [2] for calculation of losses in low voltage networks. Fuzzy arithmetic [3], clustering and fuzzy clustering techniques are used for calculation of energy losses in medium voltage distribution networks [4, 5, 6].

A method for energy loss calculations in low voltage distribution networks is developed in this paper. The method is based on the modified fuzzy clustering technique. Process of clustering is made on a space consisting of objects with following attributes: lengths of lines, number of line segments, number of customers, conductor's cross section area, conductor's material, electrical energy delivered by distribution transformers and load factors.

## Fuzzy Clustering Algorithm

Clustering is one of the most fundamental issues in pattern recognition. Given a finite set of data *X*, the problem of clustering is to find several cluster centres that can properly characterize relevant classes of *X*. In classical cluster analysis, these classes are required to form a partition of *X* such that degree of association is strong for data within blocks of the partition. When the requirement of a crisp partition of *X* is replaced with a weaker requirement of a fuzzy partition or a fuzzy pseudopartition of *X*, we refer to the emerging problem area as fuzzy clustering [3]. Fuzzy pseudopartitions are often called fuzzy *c* partition, where *c* designates the number of fuzzy classes in the partition. There are two basic methods of fuzzy clustering. One of them, which is based on fuzzy *c* partitions, is called fuzzy *c*-means clustering method.

Let $X = \{x_1, x_2, ..., x_n\}$ be a set of given data. A fuzzy pseudopartition or fuzzy *c* partition of *X* is a family of fuzzy subsets of *X*, denoted by $P = \{A_1, A_2, ..., A_c\}$ which satisfies:

$$\sum_{i=1}^{c} A_i(x_k) = 1, \quad k \in N_n, \tag{1}$$

for $N_n = \{1,2,...,n\}$, and

$$0 < \sum_{k=1}^{n} A_i(x_k) < n \quad i \in N_c, \tag{2}$$

where $c$ is positive integer and $N_c$ set of integers $N_c = \{1,2,...,c\}$. Given a set of data $X = \{x_1, x_2, ..., x_n\}$, where $x_k$ in general is a vector:

$$x_k = [x_{k1}, x_{k2}, ..., x_{ka}] \in R^a \tag{3}$$

for all $k \in N_n$, the problem of fuzzy clustering is to find a fuzzy pseudopartition and associated cluster centres by which the structure of the data is represented as best as possible.

The *c*-means algorithm is based on the assumption that the desired number of clusters *c* is given and, in addition, a particular distance, a real number $m \in (1, \infty)$, and a small positive number ε, serving as a stopping criterion, are chosen. The algorithm consists of four steps:

Step 1.

Let $t=0$. Select an initial fuzzy pseudopartition $P^{(0)}$.

Step 2.

Calculate the *c* cluster centers $v_1^{(t)},...,v_c^{(t)}$ by relation:

$$v_i = \frac{\sum_{k=1}^{n}[A_i(x_k)]^m x_k}{\sum_{k=1}^{n}[A_i(x_k)]^m} \tag{4}$$

for $P^{(t)}$ and the chosen value of *m*.

Step 3.

Update $P^{(t+1)}$ by the following procedure: For each $x_k \in X$, if $\left\|x_k - v_i^{(t)}\right\|^2 > 0$ for all $i \in N_c$, then define

$$A_i^{(t+1)}(x_k) = \left[\sum_{j=1}^{c}\left(\frac{\left\|x_k - v_i^{(t)}\right\|^2}{\left\|x_k - v_j^{(t)}\right\|^2}\right)^{\frac{1}{m-1}}\right]^{-1} . \tag{5}$$

If $\left\|x_k - v_i^{(t)}\right\|^2 = 0$ for some $i \in I \subseteq N_c$, then define $A_i^{(t+1)}(x_k)$ for $i \in I$ by any non-negative real numbers satisfying

$$\sum_{i \in I} A_i^{(t+1)}(x_k) = 1 \ , \tag{6}$$

and define $A_i^{(t+1)}(x_k) = 0$ for $i \in N_c - I$.

Step 4.

Compare $P^{(t)}$ and $P^{(t+1)}$. If $\left|P^{(t+1)} - P^{(t)}\right| \le \varepsilon$, then stop; otherwise, increase *t* by one and return to Step 2.

In Step 4, $\left|P^{(t+1)} - P^{(t)}\right|$ denotes a distance between $P^{(t+1)}$ and $P^{(t)}$ in the space $R^{n \times c}$. An example of this distance is

$$\left|P^{(t+1)} - P^{(t)}\right| = \max_{i \in N_c, k \in N_n}\left|A_i^{(t+1)}(x_k) - A_i^{(t+1)}(x_k)\right| . \tag{7}$$

For energy loss calculations in low voltage distribution networks we have developed a modified *c*-means method. Modification of fuzzy *c*-means method is using of known cluster centres. Therefore, algorithm has only three steps (Step 2 of presented algorithm is not comprehended), and if inequality into Step 4 is not satisfied, we should return to Step 3.

**Table 1.** Input database for 60 test networks

| Test network | Number of sections | Line length [m] | $S_{p\,max}$ [mm] | $S_{n\,max}$ [mm] | $S_{p\,min}$ [mm] | $S_{n\,min}$ [mm] | Material of conductor | Delivered energy W [kWh] | $T_m$ [h] | $\Delta W$ [%] |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 24 | 815 | 35 | 35 | 16 | 16 | Al | 109021 | 2632.7 | 3.375 |
| 2 | 24 | 670 | 70 | 70 | 10 | 10 | Al | 162374 | 2060.5 | 2.371 |
| 3 | 25 | 920 | 50 | 50 | 25 | 25 | Al | 184620 | 1212.4 | 4.675 |
| 4 | 28 | 765 | 70 | 70 | 16 | 16 | Al | 191987 | 4684.9 | 2.758 |
| 5 | 4 | 90 | 150 | 150 | 6 | 6 | Cu | 246451 | 3638 | 0.55 |
| 6 | 28 | 2005 | 70 | 70 | 10 | 10 | Al | 105591 | 4766.4 | 9.048 |
| 7 | 24 | 1325 | 50 | 50 | 16 | 16 | Al | 134996 | 2853.7 | 8.016 |
| 8 | 50 | 1435 | 70 | 70 | 10 | 10 | Al | 280943 | 2104.2 | 4.631 |
| 9 | 37 | 1445 | 70 | 70 | 10 | 10 | Al | 226103 | 2721.4 | 6.949 |
| 10 | 23 | 640 | 70 | 70 | 6 | 6 | Al | 230611 | 4385.4 | 3.131 |
| 11 | 26 | 665 | 70 | 70 | 10 | 10 | Al | 147180 | 3864.0 | 1.249 |
| 12 | 24 | 1055 | 50 | 50 | 25 | 25 | Al | 63065 | 1615.2 | 2.391 |
| 13 | 43 | 1140 | 30 | 30 | 10 | 10 | Al | 382195 | 6028.6 | 7.546 |
| 14 | 33 | 1865 | 50 | 50 | 10 | 10 | Al | 89099 | 2627.9 | 5.068 |
| 15 | 17 | 640 | 70 | 70 | 10 | 10 | Al | 40852 | 2736.0 | 0.459 |
| 16 | 27 | 815 | 25 | 25 | 10 | 10 | Al | 43278 | 4069.7 | 0.748 |
| 17 | 10 | 455 | 35 | 35 | 10 | 10 | Al | 45039 | 3727.5 | 0.493 |
| 18 | 8 | 695 | 35 | 35 | 25 | 25 | Al | 32361 | 1361.7 | 2.143 |
| 19 | 6 | 205 | 25 | 25 | 10 | 10 | Al | 35914 | 1147.0 | 2.593 |
| 20 | 8 | 66.8 | 95 | 95 | 95 | 95 | Al | 216714 | 2715.0 | 0.224 |
| 21 | 25 | 920 | 50 | 50 | 25 | 25 | Al | 184648 | 1239.8 | 4.794 |
| 22 | 6 | 67 | 95 | 95 | 95 | 95 | Al | 159202 | 3794.7 | 0.448 |
| 23 | 12 | 568 | 95 | 95 | 25 | 25 | Al | 159976 | 1410.7 | 4.359 |
| 24 | 4 | 1190 | 25 | 25 | 25 | 25 | Al | 46898 | 2575 | 4.17 |
| 25 | 5 | 1410 | 25 | 25 | 25 | 25 | Al | 50733 | 2380 | 4.76 |
| 26 | 3 | 2680 | 25 | 25 | 25 | 25 | Al | 52970 | 1941 | 11.17 |
| 27 | 11 | 6315 | 35 | 35 | 25 | 25 | Al | 225020 | 7738 | 20.41 |
| 28 | 8 | 5130 | 35 | 35 | 25 | 25 | Al | 196906 | 4824 | 38.79 |
| 29 | 1 | 290 | 50 | 50 | 50 | 50 | Cu | 60599 | 1358 | 1.11 |
| 30 | 3 | 160 | 150 | 150 | 70 | 70 | Cu | 203882 | 5518 | 0.50 |
| 31 | 2 | 135 | 150 | 150 | 95 | 95 | Cu/Al | 131338 | 5171 | 0.40 |
| 32 | 1 | 20 | 16 | 16 | 16 | 16 | Cu | 63430 | 3272 | 0.68 |
| 33 | 5 | 1040 | 25 | 25 | 16 | 16 | Al | 80056 | 3196 | 19.79 |
| 34 | 8 | 2225 | 25 | 25 | 16 | 16 | Al | 64009 | 2620 | 16.05 |
| 35 | 3 | 156 | 35 | 35 | 35 | 35 | Cu | 149042 | 2273 | 1.40 |
| 36 | 1 | 85 | 70 | 70 | 70 | 70 | Al | 51901 | 1812 | 0.35 |
| 37 | 13 | 1850 | 35 | 35 | 25 | 25 | Al | 66414 | 3647 | 2.74 |
| 38 | 3 | 45 | 150 | 150 | 50 | 50 | Cu | 752115 | 6250 | 0.34 |
| 39 | 1 | 10 | 120 | 120 | 120 | 120 | Al | 77935 | 887 | 0.05 |
| 40 | 1 | 550 | 25 | 25 | 25 | 25 | Al | 32236 | 5494 | 11.68 |
| 41 | 3 | 1290 | 25 | 25 | 25 | 25 | Al | 25536 | 2790 | 1.73 |
| 42 | 6 | 2940 | 25 | 25 | 25 | 25 | Al | 117494 | 2491 | 25.46 |
| 43 | 1 | 70 | 70 | 70 | 70 | 70 | Cu | 98528 | 2484 | 0.28 |
| 44 | 2 | 380 | 50 | 71.5 | 50 | 71.5 | Al | 91949 | 1959 | 2.15 |
| 45 | 3 | 910 | 70 | 71.5 | 25 | 25 | Al | 72514 | 1635 | 3.50 |
| 46 | 3 | 1440 | 25 | 25 | 25 | 25 | Al | 70219 | 7297 | 6.11 |
| 47 | 7 | 2080 | 50 | 50 | 25 | 25 | Cu/Al | 269400 | 5690 | 11.84 |
| 48 | 4 | 1050 | 70 | 70 | 25 | 25 | Cu/Al | 131606 | 3834 | 9.42 |
| 49 | 6 | 1050 | 35 | 35 | 35 | 35 | Al | 138332 | 3770 | 12.39 |
| 50 | 6 | 1250 | 35 | 35 | 16 | 16 | Al | 93512 | 3039 | 6.47 |
| 51 | 3 | 1040 | 50 | 50 | 25 | 25 | Cu/Al | 131612 | 2780 | 7.03 |
| 52 | 3 | 1100 | 35 | 35 | 25 | 25 | Al | 118829 | 2510 | 12.60 |
| 53 | 1 | 250 | 70 | 70 | 70 | 70 | Al | 304431 | 8297 | 6.26 |
| 54 | 1 | 200 | 70 | 70 | 70 | 70 | Cu | 293935 | 8010 | 2.91 |
| 55 | 12 | 2170 | 35 | 35 | 25 | 25 | Al | 58023 | 2985 | 3.31 |
| 56 | 2 | 334 | 70 | 70 | 70 | 70 | Cu | 79494 | 1948 | 0.75 |
| 57 | 3 | 165 | 70 | 70 | 25 | 25 | Cu/Al | 100316 | 1926 | 0.51 |
| 58 | 12 | 1570 | 50 | 50 | 25 | 25 | Al | 43549 | 1915 | 3.70 |
| 59 | 13 | 910 | 50 | 50 | 25 | 25 | Al | 367256 | 6125 | 8.68 |
| 60 | 7 | 2290 | 35 | 35 | 16 | 16 | Al | 7815 | 788 | 2.75 |

## Calculation of Energy Losses

Presented fuzzy clustering algorithm and its modification can be used for energy loss calculations in low voltage distribution networks. Following steps should be made for set of $N_n$ low voltage networks:

Step 1

Select $N_t$ test networks. Make additional measurements that enable to determine technical losses for test networks using well known methods.

Step 2

Form a space consisting of $N_t$ objects. Any object has $N_a$ attributes, whereat value of energy losses is one attribute (absolute or percentage).

Step 3

Calculate cluster centres for chosen number of clusters $c$ and real number $m \in (1,\infty)$. Store objects that represent cluster centres in memory.

Step 4

Form a spice that consists of $N_n$-$N_t$ objects. Any object has $N_a$-1 attributes because of energy losses are not considered as attribute.

Step 5

Determine pseudopartition of formed space by the modified *c*-means method for cluster centres determined in step 3 (energy losses attributes of cluster centres are not considered).

**Table 2.** Input database for 90 low voltage networks for which we will calculate losses

| network | Number of sections | Line length [m] | $S_{p\,max}$ [mm] | $S_{n\,max}$ [mm] | $S_{p\,min}$ [mm] | $S_{n\,min}$ [mm] | Material of conductor | Delivered energy W [kWh] | $T_m$ [h] | $\Delta W$ [%] | network | Number of sections | Line length [m] | $S_{p\,max}$ [mm] | $S_{n\,max}$ [mm] | $S_{p\,min}$ [mm] | $S_{n\,min}$ [mm] | Material of conductor | Delivered energy W [kWh] | $T_m$ [h] | $\Delta W$ [%] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 8 | 2225 | 25 | 25 | 16 | 16 | Al | 64009 | 2620 | 16.05 | 46 | 23 | 640 | 70 | 70 | 6 | 6 | Al | 230611 | 4385.4 | 3.131 |
| 2 | 34 | 1080 | 70 | 70 | 10 | 10 | Al | 180388 | 2905.0 | 1.213 | 47 | 1 | 20 | 35 | 35 | 35 | 35 | Cu | 55460 | 3228 | 0.83 |
| 3 | 6 | 2940 | 25 | 25 | 25 | 25 | Al | 117494 | 2491 | 25.46 | 48 | 1 | 20 | 120 | 120 | 120 | 120 | Al | 128106 | 2815 | 0.08 |
| 4 | 34 | 1080 | 70 | 70 | 10 | 10 | Al | 260231 | 3095.2 | 1.913 | 49 | 4 | 80 | 140 | 140 | 50 | 50 | Cu | 656249 | 2695 | 0.59 |
| 5 | 8 | 5130 | 35 | 35 | 25 | 25 | Al | 196906 | 4824 | 38.79 | 50 | 24 | 815 | 35 | 35 | 16 | 16 | Al | 109021 | 2632.7 | 3.375 |
| 6 | 46 | 1215 | 70 | 70 | 16 | 16 | Al | 246170 | 3202.1 | 3.038 | 51 | 1 | 180 | 70 | 70 | 70 | 70 | Cu | 65114 | 2600 | 1.38 |
| 7 | 8 | 695 | 35 | 35 | 25 | 25 | Al | 32361 | 1361.7 | 2.143 | 52 | 3 | 1440 | 25 | 25 | 25 | 25 | Al | 70219 | 7297 | 6.11 |
| 8 | 38 | 2130 | 50 | 50 | 10 | 10 | Al | 183465 | 3006.3 | 6.113 | 53 | 8 | 2090 | 25 | 25 | 25 | 25 | Al | 45457 | 2073 | 23.30 |
| 9 | 1 | 200 | 70 | 70 | 70 | 70 | Cu | 293935 | 8010 | 2.91 | 54 | 12 | 568 | 95 | 95 | 25 | 25 | Al | 159976 | 1410.7 | 4.359 |
| 10 | 1 | 20 | 16 | 16 | 16 | 16 | Cu | 63430 | 3272 | 0.68 | 55 | 8 | 66.8 | 95 | 95 | 95 | 95 | Al | 216714 | 2715.0 | 0.224 |
| 11 | 6 | 67 | 95 | 95 | 95 | 95 | Al | 159202 | 3794.7 | 0.448 | 56 | 17 | 640 | 70 | 70 | 10 | 10 | Al | 40852 | 2736.0 | 0.459 |
| 12 | 1 | 70 | 70 | 70 | 70 | 70 | Cu | 98528 | 2484 | 0.28 | 57 | 3 | 810 | 25 | 25 | 25 | 25 | Al | 73401 | 5487 | 9.37 |
| 13 | 24 | 695 | 70 | 70 | 35 | 35 | Al | 131899 | 1875.7 | 2.530 | 58 | 5 | 1300 | 35 | 35 | 25 | 25 | Al | 92489 | 5118 | 11.29 |
| 14 | 21 | 495 | 50 | 50 | 25 | 25 | Al | 74334 | 1737.7 | 1.825 | 59 | 5 | 1210 | 25 | 25 | 25 | 25 | Al | 67497 | 3940 | 8.86 |
| 15 | 3 | 160 | 150 | 150 | 70 | 70 | Cu | 203882 | 5518 | 0.50 | 60 | 1 | 40 | 70 | 70 | 70 | 70 | Cu | 145969 | 3769 | 0.17 |
| 16 | 17 | 149 | 95 | 95 | 95 | 95 | Al | 410521 | 4845.3 | 1.154 | 61 | 3 | 1400 | 50 | 71.5 | 35 | 71.5 | Al | 236347 | 3730 | 8.08 |
| 17 | 1 | 10 | 120 | 120 | 120 | 120 | Al | 77935 | 887 | 0.05 | 62 | 2 | 570 | 25 | 25 | 25 | 25 | Al | 10696 | 3255 | 2.04 |
| 18 | 30 | 665 | 35 | 35 | 16 | 16 | Al | 43673 | 2575.0 | 1.064 | 63 | 1 | 110 | 50 | 50 | 50 | 50 | Cu | 65819 | 2983 | 0.41 |
| 19 | 15 | 540 | 50 | 50 | 10 | 10 | Al | 30640 | 2552.0 | 1.125 | 64 | 1 | 130 | 70 | 70 | 70 | 70 | Cu | 200634 | 2714 | 1.01 |
| 20 | 2 | 380 | 50 | 71.5 | 50 | 71.5 | Al | 91949 | 1959 | 2.15 | 65 | 4 | 710 | 50 | 71.5 | 35 | 71.5 | Al | 202955 | 2686 | 3.48 |
| 21 | 28 | 2005 | 70 | 70 | 10 | 10 | Al | 105591 | 4766.4 | 9.048 | 66 | 24 | 670 | 70 | 70 | 10 | 10 | Al | 162374 | 2060.5 | 2.371 |
| 22 | 7 | 2080 | 50 | 50 | 25 | 25 | Cu/Al | 269400 | 5690 | 11.84 | 67 | 24 | 1055 | 50 | 50 | 25 | 25 | Al | 63065 | 1615.2 | 2.391 |
| 23 | 23 | 750 | 35 | 35 | 10 | 10 | Al | 89801 | 3748.3 | 1.351 | 68 | 2 | 410 | 25 | 25 | 10 | 10 | Cu | 58872 | 2344 | 2.29 |
| 24 | 3 | 45 | 150 | 150 | 50 | 50 | Cu | 752115 | 6250 | 0.34 | 69 | 2 | 690 | 50 | 71.5 | 50 | 71.5 | Al | 129307 | 2204 | 3.88 |
| 25 | 6 | 1050 | 35 | 35 | 35 | 35 | Al | 138332 | 3770 | 12.39 | 70 | 10 | 455 | 35 | 35 | 10 | 10 | Al | 45039 | 3727.5 | 0.493 |
| 26 | 26 | 665 | 70 | 70 | 10 | 10 | Al | 147180 | 3864.0 | 1.249 | 71 | 1 | 290 | 50 | 50 | 50 | 50 | Cu | 60599 | 1358 | 1.11 |
| 27 | 1 | 85 | 70 | 70 | 70 | 70 | Al | 51901 | 1812 | 0.35 | 72 | 3 | 156 | 35 | 35 | 35 | 35 | Cu | 149042 | 2273 | 1.40 |
| 28 | 19 | 571 | 50 | 50 | 25 | 25 | Al | 124494 | 1190.3 | 0.393 | 73 | 5 | 1950 | 25 | 25 | 25 | 25 | Al | 66814 | 797 | 10.86 |
| 29 | 6 | 39 | 95 | 95 | 95 | 95 | Al | 120109 | 5261.7 | 0.132 | 74 | 6 | 205 | 25 | 25 | 10 | 10 | Al | 35914 | 1147.0 | 2.593 |
| 30 | 3 | 770 | 35 | 50 | 25 | 25 | Al | 182613 | 4138 | 6.64 | 75 | 1 | 400 | 120 | 120 | 120 | 120 | Al | 296955 | 3920 | 3.32 |
| 31 | 4 | 170 | 95 | 95 | 95 | 95 | Cu | 200768 | 3854 | 0.47 | 76 | 2 | 1080 | 25 | 25 | 25 | 25 | Al | 109839 | 3866 | 11.54 |
| 32 | 1 | 360 | 70 | 70 | 70 | 70 | Al | 114811 | 3278 | 2.60 | 77 | 25 | 920 | 50 | 50 | 25 | 25 | Al | 184648 | 1239.8 | 4.794 |
| 33 | 1 | 90 | 35 | 50 | 35 | 50 | Al | 62691 | 2086 | 0.71 | 78 | 2 | 135 | 150 | 150 | 95 | 95 | Cu/Al | 131338 | 5171 | 0.40 |
| 34 | 3 | 2680 | 25 | 25 | 25 | 25 | Al | 52970 | 1941 | 11.17 | 79 | 1 | 350 | 120 | 120 | 120 | 120 | Al | 148842 | 1849 | 2.06 |
| 35 | 28 | 765 | 70 | 70 | 16 | 16 | Al | 191987 | 4684.9 | 2.758 | 80 | 1 | 320 | 25 | 25 | 25 | 25 | Al | 60668 | 1464 | 4.49 |
| 36 | 3 | 910 | 70 | 71.5 | 25 | 25 | Al | 72514 | 1635 | 3.50 | 81 | 50 | 1435 | 70 | 70 | 10 | 10 | Al | 280943 | 2104.2 | 4.631 |
| 37 | 43 | 1140 | 30 | 30 | 10 | 10 | Al | 382195 | 6028.6 | 7.546 | 82 | 1 | 200 | 150 | 150 | 150 | 150 | Al | 79848 | 5328 | 0.77 |
| 38 | 3 | 1040 | 50 | 50 | 25 | 25 | Cu/Al | 131612 | 2780 | 7.03 | 83 | 12 | 1880 | 25 | 25 | 25 | 25 | Al | 141541 | 4041 | 7.54 |
| 39 | 3 | 100 | 150 | 150 | 70 | 70 | Cu | 221679 | 5092 | 0.24 | 84 | 5 | 460 | 70 | 70 | 35 | 35 | Cu | 83812 | 3813 | 0.34 |
| 40 | 3 | 200 | 50 | 50 | 50 | 50 | Cu | 526029 | 4967 | 4.95 | 85 | 1 | 120 | 70 | 70 | 70 | 70 | Cu | 233238 | 2637 | 0.92 |
| 41 | 6 | 1760 | 25 | 25 | 16 | 16 | Al | 184644 | 4762 | 14.33 | 86 | 13 | 3936 | 25 | 25 | 25 | 25 | Al | 46927 | 2346 | 8.80 |
| 42 | 3 | 170 | 95 | 95 | 95 | 95 | Cu | 251863 | 4731 | 0.90 | 87 | 16 | 5500 | 25 | 25 | 25 | 25 | Al | 44849 | 2324 | 7.99 |
| 43 | 1 | 100 | 70 | 70 | 70 | 70 | Cu | 256222 | 4344 | 0.71 | 88 | 1 | 80 | 70 | 70 | 70 | 70 | Cu | 93062 | 2109 | 0.28 |
| 44 | 3 | 160 | 120 | 120 | 50 | 50 | Cu/Al | 879374 | 4013 | 2.34 | 89 | 11 | 1730 | 25 | 25 | 25 | 25 | Al | 45045 | 2059 | 6.20 |
| 45 | 4 | 90 | 150 | 150 | 6 | 6 | Cu | 246451 | 3638 | 0.20 | 90 | 18 | 925 | 35 | 35 | 25 | 25 | Al | 154758 | 1707 | 3.40 |

Step 6

Calculate absolute or percentage energy losses for any low voltage network summing the memberships values multiplied by the attributes of corresponding centre of cluster that represent energy losses.

The following questions required answer:

- What is optimal number of clusters?
- What is optimal value of real number *m*?
- Which attributes do we consider in analyses?

These questions have do not have unique solution, and as will be seen from the following example, answers depend on accessibility of input data.

## Test Example

Presented method is applied for energy loss calculation on the set of real low voltage networks, for which the measuring data is available. At first we select 60 test networks from this set of networks by generating random numbers. The input data for test networks is shown in Table 1.

The following data is comprehended in analysis:

1. Number of line sections;
2. Maximal median cross section area of line $(3 \cdot S_{p\max} + S_{n\max})/4$;
3. Minimal median cross section area of line $(3 \cdot S_{p\min} + S_{n\min})/4$;
4. Resistivity of conductor's material,
5. Energy delivered by distribution transformers $W$,
6. load factor ( $LF = T_m / 8760$ ).

where $S_p$ and $S_n$ are cross section areas of phase and neutral conductors respectively.

For this set of test networks we determined cluster centres for 23 different combinations of parameter *m* (1.05-1.75), number of clusters (6-20), and chosen data set comprehended in analysis (selection 1,2 or 3). Selection 1 comprehend all accessible data. Selection 2 does not comprehend resistivity of conductors, and selection 3 does not comprehend load factors.

Table 2 gives data for 90 networks for which we will calculate energy losses. The column $\Delta W\%$ of the Table 2 gives the measured percentage losses. We will compare losses calculated using presented method with losses given in this column in order to show applicability of the method. Total energy losses (for all 90 networks) determined from measuring are 3.81%. Table 3 shows results of calculation for second and third selection of input data and different number of clusters as well as different values of parameter *m*.

**Table 3.** Results of energy loss calculations for selections 2 and 3 of input data

| | selection 2 | | | | | | selection 3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *m* | 1.05 | | | 1.2 | | | 1.05 | | 1.2 | | 1.4 | |
| cl. num. | 6 | 12 | 20 | 10 | 15 | 20 | 10 | 20 | 12 | 20 | 12 | 20 |
| 1 | 6.36 | 14.4 | 16.8 | 16.4 | 20.4 | 17.4 | 15.6 | 18.1 | 16.0 | 9.79 | 15.6 | 13.7 |
| 2 | 3.52 | 4.54 | 3.20 | 3.55 | 4.50 | 3.15 | 4.45 | 2.55 | 3.28 | 3.09 | 3.31 | 3.15 |
| 3 | 6.36 | 14.5 | 25.5 | 16.3 | 18.9 | 17.6 | 15.6 | 18.1 | 15.4 | 25.4 | 13.5 | 25.5 |
| 4 | 3.52 | 4.54 | 3.20 | 3.56 | 4.50 | 3.13 | 4.45 | 5.25 | 3.28 | 3.68 | 3.32 | 3.70 |
| 5 | 29.3 | 32.1 | 38.8 | 29.6 | 29.6 | 38.8 | 29.6 | 38.8 | 29.6 | 38.8 | 29.5 | 29.5 |
| 6 | 3.52 | 4.54 | 3.20 | 3.56 | 4.50 | 3.13 | 4.45 | 5.25 | 3.28 | 3.68 | 3.32 | 3.70 |
| 7 | 6.33 | 1.93 | 2.78 | 3.87 | 2.39 | 2.85 | 3.29 | 12.0 | 3.57 | 2.00 | 3.45 | 7.02 |
| 8 | 6.34 | 4.88 | 9.29 | 13.2 | 8.06 | 6.23 | 6.15 | 6.73 | 5.04 | 6.55 | 6.62 | 7.00 |
| 9 | 2.01 | 3.17 | 4.59 | 4.58 | 4.59 | 4.59 | 1.19 | 2.91 | 1.19 | 1.31 | 1.28 | 1.29 |
| 10 | 6.36 | 1.93 | 0.64 | 4.39 | 2.19 | 0.67 | 1.19 | 1.06 | 1.22 | 1.06 | 1.84 | 1.05 |
| 11 | 0.47 | 0.32 | 0.24 | 0.24 | 0.24 | 0.24 | 1.89 | 0.24 | 0.24 | 0.24 | 0.27 | 0.62 |
| 12 | 0.47 | 0.93 | 0.93 | 0.93 | 0.93 | 0.93 | 1.19 | 0.52 | 1.19 | 1.31 | 1.21 | 1.26 |
| 13 | 3.52 | 2.63 | 2.24 | 3.46 | 2.63 | 2.29 | 4.45 | 2.55 | 3.28 | 2.48 | 3.59 | 2.93 |
| 14 | 3.52 | 2.63 | 2.78 | 3.81 | 2.64 | 2.87 | 3.29 | 12.2 | 3.84 | 3.11 | 4.43 | 6.37 |
| 15 | 2.01 | 0.32 | 0.50 | 0.41 | 0.45 | 0.45 | 0.42 | 0.50 | 0.42 | 0.50 | 0.48 | 0.50 |
| 16 | 2.01 | 0.38 | 0.25 | 0.77 | 0.96 | 1.10 | 1.89 | 6.12 | 0.35 | 4.55 | 0.99 | 0.90 |
| 17 | 0.47 | 0.32 | 0.24 | 0.24 | 0.24 | 0.24 | 0.05 | 0.24 | 0.24 | 0.24 | 0.29 | 0.06 |
| 18 | 6.36 | 1.93 | 3.55 | 3.84 | 2.17 | 8.24 | 3.29 | 3.18 | 3.57 | 1.90 | 3.40 | 1.96 |
| 19 | 3.52 | 1.93 | 3.65 | 3.86 | 2.87 | 5.71 | 3.29 | 3.33 | 3.80 | 2.22 | 4.38 | 3.94 |
| 20 | 3.52 | 0.93 | 0.93 | 0.93 | 0.93 | 0.93 | 1.89 | 1.25 | 2.92 | 1.25 | 2.86 | 2.48 |
| 21 | 6.91 | 4.54 | 9.23 | 6.42 | 4.52 | 9.18 | 4.45 | 6.73 | 3.97 | 6.43 | 4.66 | 5.50 |
| 22 | 6.91 | 9.36 | 9.69 | 6.45 | 9.34 | 11.8 | 7.20 | 11.8 | 7.19 | 9.43 | 7.14 | 11.8 |
| 23 | 6.36 | 1.93 | 0.64 | 4.24 | 3.65 | 0.97 | 3.29 | 3.19 | 3.58 | 1.91 | 3.62 | 2.40 |
| 24 | 2.01 | 3.17 | 0.34 | 0.43 | 0.34 | 0.34 | 0.42 | 0.34 | 0.42 | 0.34 | 0.34 | 0.34 |
| 25 | 6.36 | 14.4 | 9.30 | 8.71 | 6.67 | 14.8 | 6.12 | 12.2 | 7.44 | 12.8 | 7.18 | 12.8 |
| 26 | 3.56 | 4.54 | 3.20 | 3.67 | 4.50 | 3.47 | 4.45 | 2.55 | 3.28 | 2.45 | 3.32 | 2.47 |
| 27 | 0.47 | 0.93 | 0.93 | 0.93 | 0.93 | 0.93 | 1.89 | 1.25 | 2.92 | 1.25 | 2.81 | 2.40 |
| 28 | 3.52 | 2.63 | 2.78 | 3.79 | 2.64 | 2.86 | 4.30 | 12.2 | 3.95 | 4.87 | 4.64 | 6.94 |
| 29 | 1.82 | 0.32 | 0.26 | 0.53 | 0.55 | 0.63 | 1.89 | 0.24 | 0.24 | 0.24 | 0.27 | 0.62 |
| 30 | 6.91 | 7.91 | 9.30 | 4.59 | 5.98 | 13.2 | 3.32 | 12.2 | 4.79 | 8.17 | 5.84 | 11.0 |
| 31 | 0.47 | 0.32 | 0.24 | 0.24 | 0.24 | 0.24 | 1.19 | 2.39 | 1.14 | 1.31 | 1.26 | 1.28 |
| 32 | 0.47 | 0.93 | 0.93 | 0.93 | 0.93 | 0.94 | 1.89 | 1.25 | 2.92 | 1.25 | 2.81 | 2.40 |

| | selection 2 | | | | | | selection 3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *m* | 1.05 | | | 1.2 | | | 1.05 | | 1.2 | | 1.4 | |
| cl. num. | 6 | 12 | 20 | 10 | 15 | 20 | 10 | 20 | 12 | 20 | 12 | 20 |
| 46 | 6.91 | 4.54 | 3.20 | 6.38 | 4.50 | 3.15 | 4.45 | 2.55 | 3.28 | 3.64 | 3.32 | 3.46 |
| 47 | 6.35 | 1.93 | 0.77 | 4.29 | 2.26 | 8.20 | 1.19 | 1.06 | 1.19 | 1.06 | 1.23 | 1.05 |
| 48 | 0.47 | 0.32 | 0.24 | 0.24 | 0.24 | 0.24 | 0.05 | 0.24 | 0.24 | 0.24 | 0.28 | 0.06 |
| 49 | 2.00 | 0.34 | 0.34 | 0.53 | 0.45 | 0.46 | 0.42 | 0.34 | 0.42 | 0.34 | 0.34 | 0.34 |
| 50 | 6.36 | 1.93 | 9.30 | 3.85 | 2.20 | 8.66 | 3.29 | 11.8 | 3.58 | 2.04 | 3.61 | 7.53 |
| 51 | 0.47 | 0.93 | 0.93 | 0.93 | 0.93 | 0.93 | 1.19 | 0.52 | 1.19 | 1.31 | 1.21 | 1.26 |
| 52 | 6.91 | 8.90 | 8.90 | 4.53 | 8.90 | 6.11 | 15.6 | 3.17 | 15.9 | 14.0 | 14.7 | 4.33 |
| 53 | 6.36 | 14.3 | 4.38 | 16.2 | 16.4 | 16.9 | 15.6 | 18.1 | 16.1 | 5.33 | 15.9 | 12.3 |
| 54 | 3.52 | 2.63 | 2.24 | 3.52 | 2.67 | 2.29 | 4.45 | 2.55 | 3.28 | 2.47 | 3.48 | 2.83 |
| 55 | 0.47 | 0.32 | 0.24 | 0.24 | 0.24 | 0.24 | 1.89 | 0.24 | 0.24 | 0.24 | 0.28 | 0.62 |
| 56 | 3.52 | 2.63 | 2.24 | 3.55 | 2.67 | 2.36 | 4.45 | 2.55 | 3.32 | 2.46 | 3.84 | 2.68 |
| 57 | 6.91 | 8.90 | 8.90 | 4.10 | 8.9 | 11.7 | 3.29 | 12.2 | 3.57 | 7.39 | 3.43 | 13.1 |
| 58 | 6.91 | 8.90 | 8.89 | 4.11 | 8.84 | 11.6 | 3.29 | 3.17 | 9.70 | 13.3 | 7.95 | 9.97 |
| 59 | 6.36 | 14.4 | 2.11 | 4.85 | 7.15 | 12.3 | 4.56 | 3.20 | 3.81 | 14.0 | 5.09 | 10.6 |
| 60 | 0.47 | 0.93 | 0.93 | 0.96 | 0.99 | 1.12 | 1.19 | 0.52 | 1.19 | 1.31 | 1.21 | 1.26 |
| 61 | 6.70 | 4.54 | 8.98 | 6.44 | 5.73 | 7.81 | 4.45 | 6.08 | 5.28 | 6.05 | 5.82 | 6.28 |
| 62 | 6.36 | 1.93 | 0.64 | 4.91 | 2.17 | 1.87 | 3.29 | 11.8 | 3.57 | 2.05 | 3.52 | 5.23 |
| 63 | 3.55 | 0.93 | 0.93 | 1.00 | 1.04 | 1.58 | 1.19 | 1.06 | 1.19 | 1.08 | 1.19 | 1.25 |
| 64 | 0.47 | 0.93 | 0.93 | 0.93 | 0.93 | 0.93 | 1.19 | 2.91 | 1.19 | 1.31 | 1.21 | 1.26 |
| 65 | 3.52 | 1.50 | 9.19 | 2.76 | 3.08 | 5.21 | 4.45 | 1.45 | 3.07 | 3.27 | 3.92 | 4.68 |
| 66 | 3.52 | 2.63 | 2.24 | 3.55 | 2.64 | 2.29 | 4.45 | 2.55 | 3.28 | 2.45 | 3.31 | 2.48 |
| 67 | 3.52 | 2.66 | 2.78 | 3.84 | 2.93 | 2.85 | 3.29 | 5.82 | 4.50 | 6.39 | 4.81 | 6.52 |
| 68 | 6.36 | 1.93 | 2.73 | 4.09 | 2.17 | 4.30 | 1.19 | 1.06 | 1.23 | 1.06 | 1.92 | 1.06 |
| 69 | 3.52 | 0.93 | 0.93 | 0.93 | 0.93 | 0.93 | 1.89 | 1.25 | 2.92 | 1.25 | 2.92 | 2.64 |
| 70 | 6.36 | 1.93 | 0.64 | 4.13 | 2.45 | 0.65 | 3.29 | 3.30 | 3.57 | 1.90 | 3.6 | 1.97 |
| 71 | 3.52 | 0.93 | 0.93 | 0.94 | 0.94 | 0.97 | 1.19 | 1.06 | 1.19 | 1.08 | 1.19 | 1.25 |
| 72 | 4.79 | 1.93 | 2.78 | 3.99 | 2.31 | 9.47 | 1.19 | 1.06 | 1.19 | 1.06 | 1.22 | 1.05 |
| 73 | 6.36 | 6.71 | 4.37 | 8.76 | 6.86 | 6.10 | 15.6 | 18.1 | 16.1 | 6.52 | 16.2 | 7.12 |
| 74 | 6.33 | 1.93 | 2.78 | 4.23 | 2.31 | 2.93 | 3.29 | 7.52 | 3.58 | 1.91 | 3.79 | 2.30 |
| 75 | 0.52 | 0.32 | 0.24 | 0.25 | 0.25 | 0.25 | 0.05 | 0.24 | 0.24 | 0.24 | 0.35 | 0.35 |
| 76 | 6.36 | 14.3 | 0.98 | 5.13 | 5.91 | 14.4 | 8.02 | 12.2 | 3.84 | 14 | 5.04 | 13.5 |
| 77 | 3.52 | 2.63 | 2.78 | 3.91 | 2.72 | 2.90 | 4.45 | 6.73 | 4.17 | 6.46 | 5.19 | 6.65 |

**Continuation of Table 3**

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 4.11 | 1.93 | 2.78 | 2.96 | 2.18 | 4.10 | 3.29 | 12.2 | 3.72 | 2.96 | 4.42 | 7.91 | 78 | 2.01 | 0.36 | 0.40 | 0.86 | 0.54 | 0.55 | 0.05 | 0.24 | 0.25 | 0.26 | 0.55 | 0.11 |
| 34 | 6.36 | 12.9 | 25.5 | 16.1 | 6.95 | 17.6 | 15.6 | 18.1 | 15.8 | 25.4 | 14.2 | 14.8 | 79 | 0.47 | 0.32 | 0.24 | 0.24 | 0.24 | 0.24 | 0.05 | 0.24 | 0.24 | 0.24 | 0.28 | 0.06 |
| 35 | 6.91 | 4.54 | 7.43 | 6.44 | 4.50 | 5.92 | 4.45 | 2.55 | 3.28 | 2.48 | 3.31 | 2.59 | 80 | 6.35 | 1.93 | 2.78 | 4.05 | 2.20 | 2.91 | 3.29 | 12.2 | 3.57 | 1.95 | 3.66 | 5.47 |
| 36 | 3.52 | 2.63 | 2.24 | 3.55 | 2.63 | 2.29 | 4.45 | 2.55 | 3.31 | 2.47 | 3.80 | 2.71 | 81 | 3.52 | 2.89 | 3.19 | 3.56 | 4.50 | 3.13 | 4.45 | 5.25 | 3.29 | 3.68 | 3.51 | 3.70 |
| 37 | 6.91 | 9.36 | 9.69 | 6.43 | 9.34 | 8.11 | 4.79 | 5.25 | 8.08 | 8.11 | 7.99 | 8.09 | 82 | 2.00 | 0.32 | 0.40 | 0.37 | 0.44 | 0.45 | 0.05 | 0.24 | 0.26 | 0.28 | 0.76 | 0.18 |
| 38 | 3.52 | 4.87 | 9.30 | 3.93 | 6.83 | 5.94 | 7.20 | 8.23 | 7.19 | 9.43 | 7.15 | 5.81 | 83 | 6.36 | 14.4 | 17.9 | 15.7 | 17.0 | 11.2 | 15.6 | 18.1 | 16.1 | 12.8 | 16.1 | 8.84 |
| 39 | 2.01 | 0.32 | 0.50 | 0.41 | 0.45 | 0.45 | 0.42 | 0.50 | 0.42 | 0.50 | 0.49 | 0.50 | 84 | 3.52 | 4.54 | 9.23 | 3.54 | 4.33 | 7.72 | 1.19 | 0.52 | 1.19 | 1.23 | 1.24 | 1.38 |
| 40 | 6.91 | 9.36 | 8.68 | 6.14 | 8.79 | 8.17 | 1.19 | 2.91 | 1.28 | 1.37 | 2.05 | 2.59 | 85 | 0.47 | 0.93 | 0.93 | 0.93 | 0.93 | 0.94 | 1.19 | 2.91 | 1.19 | 1.31 | 1.23 | 1.26 |
| 41 | 6.91 | 10.1 | 9.73 | 5.56 | 10.9 | 10.7 | 15.6 | 18.1 | 16.0 | 12.8 | 14.6 | 9.64 | 86 | 6.36 | 32.1 | 25.5 | 15.4 | 9.58 | 17.5 | 29.0 | 34.6 | 21.0 | 25.6 | 18.1 | 23.1 |
| 42 | 1.59 | 0.32 | 0.24 | 0.31 | 0.33 | 0.36 | 1.19 | 2.91 | 1.08 | 1.30 | 1.27 | 1.29 | 87 | 29.3 | 32.1 | 37.3 | 24.6 | 15.9 | 34.5 | 29.6 | 38.8 | 29.6 | 37.4 | 29.4 | 29.1 |
| 43 | 0.47 | 0.98 | 0.98 | 2.02 | 2.28 | 3.52 | 1.19 | 2.91 | 1.19 | 1.31 | 1.24 | 1.27 | 88 | 0.47 | 0.93 | 0.93 | 0.93 | 0.93 | 0.93 | 1.19 | 0.52 | 1.19 | 1.31 | 1.21 | 1.26 |
| 44 | 2.01 | 3.17 | 0.34 | 0.99 | 0.35 | 0.35 | 0.42 | 0.34 | 1.05 | 0.49 | 1.59 | 2.24 | 89 | 6.36 | 14.4 | 4.38 | 14.5 | 18.8 | 4.09 | 15.6 | 18.0 | 16.1 | 5.99 | 16.1 | 3.92 |
| 45 | 2.04 | 4.13 | 0.50 | 1.21 | 2.29 | 2.64 | 0.42 | 0.50 | 0.43 | 0.51 | 1.33 | 1.07 | 90 | 6.31 | 2.58 | 2.78 | 3.89 | 3.45 | 2.90 | 3.30 | 12.2 | 4.38 | 12.0 | 5.52 | 13.0 |

**Table 4**. Total percentage losses, number of properly, erroneously or not identified networks with large value of energy losses

| Input data set | selection 1 | | | | | | | | | | | selection 2 | | | | | | selection 3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *m* | 1.05 | | | 1.2 | | 1.4 | | | 1.75 | | | 1.05 | | | 1.2 | | | 1.05 | | 1.2 | | 1.4 | |
| Number of clusters | 6 | 12 | 20 | 10 | 20 | 6 | 12 | 20 | 6 | 12 | 20 | 6 | 12 | 20 | 10 | 15 | 20 | 10 | 20 | 12 | 20 | 12 | 20 |
| Total percentage losses [%] | 4.03 | 3.86 | 4.12 | 3.92 | 3.63 | 4.06 | 3.8 | 3.98 | 5.02 | 4.17 | 4.92 | 3.91 | 4.22 | 4.15 | 3.67 | 3.78 | 4.35 | 3.53 | 4.57 | 3.45 | 3.95 | 3.61 | 3.97 |
| Number of networks with large value of losses, which are not identified | 2 | 0 | 0 | 1 | 6 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 4 | 5 | 6 | 1 | 1 | 7 | 3 | 5 | 0 | 3 | 2 |
| Number of networks with large value of losses, which are identified properly | 22 | 24 | 24 | 23 | 18 | 23 | 23 | 24 | 24 | 24 | 24 | 23 | 20 | 20 | 18 | 23 | 23 | 17 | 21 | 20 | 24 | 21 | 22 |
| Number of networks on which large value of losses is erroneously identified | 0 | 1 | 4 | 1 | 0 | 16 | 3 | 0 | 26 | 9 | 16 | 12 | 1 | 5 | 3 | 1 | 9 | 0 | 12 | 0 | 3 | 1 | 10 |

Table 3 shows only a small piece of results, and authors made analysis for different number of networks. Meanings of different colours in tables 3 and 4 are:

- networks with a large value of electrical losses that are not identified,
- networks with a large value of electrical losses that are identified properly,
- networks for which a large value of electrical losses is identified erroneously.

Table 4 shows calculated total energy losses in percents. Additionally, table shows number of networks on which large value of losses are properly or erroneously identified, and number of networks on which large value of losses is not identified. On the basis of results shown in Table 4, we can conclude that the best results are given in the following two cases:

- $m$=1.05, for 12 clusters and all data comprehended,
- $m$=1.4, for 20 clusters and all data comprehended.

## Conclusions

A new method for calculation of energy losses in low voltage distribution networks is developed in this paper. The method is based on using fuzzy clustering and modified fuzzy clustering techniques. Besides the database of network parameters, the method requires knowledge of energies delivered by distribution transformers as well as pick loadings of distribution transformers. Additionally, measurements that enable determination of technical losses calculation are required for set of test networks.

On the basis of analyses we can conclude the following. All accessible data should be comprehended in calculations. Optimal number of clusters depends on the number of test networks and shall be 15% to 30% of the number of test networks. Minimal number of test networks is 50. Parameter $m$ that defines fuzziness of clustering gives an optimal value in the range of 1 to 1.5. Optimal value of $m$ increases with increasing the number of clusters. If proposed values of parameter $m$ and number of clusters are used, we can calculate the total technical losses of all networks quite accurately. Additionally, we can identify networks with large value of losses.

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**D.S. Tasić, M. S. Stojanović. Modified Fuzzy Clustering Method for Energy Loss Calculations in Low Voltage Distribution Networks // Electronics and Electrical Engineering. – Kaunas: Technologija, 2006. – No. 2(66). – P. 50–55.**

There is presented a new method for calculation of energy losses in low voltage distribution networks. The method is based on the fuzzy clustering and modified fuzzy clustering techniques, and requires input data that we can collect easily: lengths of lines, number of line segments, number of customers, conductor's cross section area, conductor's material, electrical energy delivered by distribution transformers, and peak loadings of distribution transformers. Additional measurements that enable exact calculation of energy losses are required for set of test networks. Presented method is tested on the example of ninety low voltage networks. Optimal number of clusters as well as the optimal value of the parameter *m* that defines fuzziness of fuzzy clustering was determined. Bibl. 6 (in English; summaries in English, Russian and Lithuanian).

**Д.С. Тасич, М.С. Стоянович. Модифицированный нечеткий кластерный метод для расчета потерь энергии в распределительных сетях низкого напряжения // Электроника и электротехника. – Каунас: Технология, 2006. – № 2 (66). – С. 50–55.**

Предлагается новый метод расчета потери энергии в электрических сетях напряжения 0,4 кВ, который базируется на модифицированный технике нечетких кластеров. Метод требует следующие исходные данные: длине линии, число участки линии, число потребителей, сечения проводов, максимальные нагрузки трансформаторов. Используя предложений метод, рассчитаны потери энергии для девяноста электрических сетей напряжения 0,4 кВ, и предложены оптимальное число кластеров и оптимальный коэффициент, который определяет нечетность кластеров. Библ. 6 (на английском языке; рефераты на английском, русском и литовском яз.).

**D.S. Tasić, M. S. Stojanović. Modifikuotas „fuzzy“ klasterinis metodas nuostoliams žemos įtampos paskirstymo tinkluose apskaičiuoti // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2006. – Nr. 2(66). – P. 50–55.**

Pateikiamas naujas metodas energijos praradimams žemos įtampos paskirstymo tinkluose apskaičiuoti. Šis metodas pagrįstas „fuzzy“ klasterių sudarymu ir modifikuoto „fuzzy“ klasterizavimo metodais ir reikalauja pradinių (įėjimo) duomenų, kuriuos galima lengvai surinkti. Tai linijų ilgis, linijų segmentų skaičius, vartotojų skaičius, laidininko skerspjūvio plotas, medžiaga, elektros energija, tiekiama paskirstymo transformatorių, bei paskirstymo transformatorių maksimalios apkrovos. Papildomi matavimai, įgalinantys tiksliai apskaičiuoti energijos nuostolius, reikalingi testiniams tinklams. Pateiktas metodas yra testuojamas 90 žemos įtampos tinklų. Nustatytas optimalus klasterių skaičius, taip pat optimali parametro *m* vertė, kuri nurodo „fuzzy“ klasterizavimo laipsnį. Bibl. 6 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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