Evaluation and Forecast of Electric Energy Losses in Distribution Networks Applying Fuzzy-Logic

P. Lezhniuk, S. Bevz, A. Piskliarova

***Abstract*-The paper considers new approaches aimed at improvement of methods of electric energy losses calculation applying Mamdani's means of fuzzy-logic conclusions. The paper reveals the possibility to determine the error of energy losses calculation presenting fuzzy sets of this calculation in the forms of alpha-levels. Practical implementation of suggested solutions in mathematical environment MATLB has been shown.**

***Key words* – Estimation, fuzzy sets, knowledge based systems, losses.**

I. Introduction

Rapid growth of world prices for oil, natural gas and coal attracts attention to the solution of such problem as improvement and introduction of energy-saving installations and technologies. One of the components of the given problems is the reduction of energy losses for its transmission from generating unit to consumers. In the countries of the former USSR this problem concerns first of all distribution networks [1] which were designed and constructed during recent decades. The reason is that in the process of electric systems design great attention was paid to save financial resources.

The cross-section of wires was to correspond to current density, of approximately 1 A/mm^2, level of reactive power compensation, as a rule, didn't exceed 0,3 kvar/kW, feeders were too long, deep bushing were not often used. Non-sufficient attention was paid to development of control and metering systems as well as systems of optimal control of power flows and voltage.

Saving of capital investments in the process of distribution systems construction inevitably leads to greater expenditures for their operation, particularly, due to considerable losses of electric energy in the networks and its poor quality. In order to improve the present state the reconstruction of electric networks must be performed as well as measures aimed at reduction of energy losses and improvement of quality of energy must be introduced.

To make a decision regarding the reconstruction of the networks and introduction of measures leading to reduction of energy losses the real values of energy losses must be calculated. It is quite obvious, that accuracy of calculation depends on available information support.

The given paper considers the method aimed at determination, evaluation and forecast of energy losses in distribution networks in condition of limited information by means of fuzzy logic.

II. Determination of Energy Losses in Networks by Total Length of Transmission Lines

The most exact method of electric energy losses calculation is elementwise computational model [1]

$$\Delta W_n = 3\Delta t\sum_{i=1}^{k} R_i \sum_{j=1}^{n} I_{ij}^2 \qquad (1)$$

where k number of network elements;

Δt - time interval between measurement sequences of elements loading;

$n = T / \Delta t$ – number of intervals;

I_{ij} – mean value of ith element current;

R_i – element resistance.

Taking into account that characteristic features of the countries of the former USSR are long distances of distribution networks and low level of information support, method of technical energy losses calculation by generalized parameters [1] has found wide application:

$$\Delta W = 3225 \cdot k_L \cdot k_t \cdot k_N \cdot k_{ns} \cdot k_f^2 \cdot (1+tg^2\varphi) \cdot \frac{W_F^2 \cdot L_F}{N_F^2 \cdot T \cdot U^2 \cdot F}, \qquad (2)$$

k_L – coefficient, that takes into consideration the influence of load distribution along the line on losses (its value is within 0,33-0,5);

k_f – coefficient of loading graph form;

k_{ns} – coefficient of losses growth in the line with non-symmetrical loading by network phases k_{ns} = 1.15-1.55 for lines with distributed loading. For lines with concentrated loading k_{ns} =1.05-1.1;

k_N – coefficient, that takes into consideration mutual difference of current densities at main sections of different lines (may be within 1.04-1.16);

k_t – coefficient, that takes into consideration the reduction of energy losses if taps are available, where current density is less than the density in feeder head;

$tg\varphi$ – coefficient of reactive power usage;

W_F – total energy (kWh) of lines with wires of F,mm^2 cross-section;

L_F – total length, km;

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N_F – number of feeders;
U – voltage, kV;
F – cross-section value, mm^2;

In practice, the coefficients of influencing factors are determined in the form of their average values that considerably increases calculation error.

As a result, error of described method may exceed 30%. To reduce losses determination error in [2], method, based on fuzzy clusterization is suggested. The given method provides the formation of teaching sample, comprising 15-20% of grids. Additional measurements are performed for the given sample and losses calculation is carried out applying the most exact model (1). Performing fuzzy clusterization of 80-85% of grids, we determine losses in them. Main drawbacks of the given method are the need to perform additional measurements and dependence of result on statistical data.

III. Identification of Coefficients by Fuzzy Knowledge Bases

For more accurate and adequate determination of influencing factors coefficients from (2), it is suggested to identify these coefficients applying fuzzy knowledge bases "IF-THAN" in accordance with [3]. Thus, these coefficients { $k_f^2, k_{ns}, k_L, k_N, k_t, k_{tg}$ } are outputs. As inputs we suggest to use the following spectrum of influencing factors which represent expert information.

1. For k_f^2:

k_M – relative number of consumers with maximum coefficient of minimum, %;
t_m – relative number of consumers with maximum time of maximum usage,%;
σ_S – fraction of consumers with minimal coefficient of simultaneity,%;

2. For k_{ns}:

F_0 – cross-section of zero wire in greater part of feeders, mm^2;
F_f – cross-section of phase wire in greater part of feeders, mm^2;
n_{ns} – part of non-uniformly distributed by phases loading, %;

3. For k_t:

n_L – part of taps length,%;
n_c – relation of tap wire cross-section to main section, relative units;
p – part of load, connected to taps, %;

4. For k_L:

d – part of load, concentrated at the end of the feeder, %;

5. For k_N:

N_f – part of feeders with the same cross-section of wire, %;
P_f – part of feeders with quite different loads, %;

6. For $k_{tg} = (1 + tg^2\varphi)$:

Q_{con} – relative consumption of reactive power, %;
Q_{com} – part of compensated reactive power, %;

The realization of above-mentioned identification of correction factors by fuzzy knowledge bases provides presentation of these bases as well as influencing factors in the form of fuzzy sets, namely, by three terms "small", "average", "large" [3-5].

For identification of the coefficients by means of sensitivity analysis the following rules are formulated (on the example of the coefficient of loading graph form) (Table 1).

TABLE I

FUZZY KNOWLEDGE BASE FOR k_f^2 DETERMINATION

If			Than
k_S	t_{max}	σ_S	k_f
L	L	–	L
L	A	L	L
A	A	L	L
S	L	A	L
S	L	S	A
S	A	S	S

Fuzzy logic equations required for creation of fuzzy knowledge base will have the following form:

$\mu^L(\kappa_f^2)=[\mu^L(K_M)\cap\mu^L(t_{max})]\cup[\mu^L(K_M)\cap\mu^A(t_{max})\cap\mu^L(\sigma_S)]\cup[\mu^A(K_S)\cap\mu^A(t_{max})\cap\mu^L(\sigma_S)]\cup[\mu^S(K_S)\cap\mu^L(t_{max})\cap\mu^A(\sigma_S)]$;

$\mu^A(\kappa_f^2)=[\mu^S(K_S)\cap\mu^L(t_{max})\cap\mu^S(\sigma_S)]$;

$\mu^S(\kappa_f^2)=[\mu^S(K_S)\cap\mu^A(t_{max})\cap\mu^S(\sigma_S)]$.

In accordance with [4] fuzzy logic conclusion of Mamdani type is realized:

$$\bigcup_{p=1}^{k_j}\left[\bigcap_{i=1}^{n}\left(x_i = a_i^{jp}\right)\right] \longrightarrow y = d_j\,,\ \ j=\overline{1,m}\,,$$

where $\vee$ and $\wedge$ – t-norm and s-norm, i.e. operations over independency functions, which correspond to fuzzy logic operations AND and OR in Mamdani knowledge base. These norms are realized by operations of minimum and maximum determination.

Defuzzification operation will be carried out using maxima centre method [3]. As a result, we obtain well defined value of the coefficient.

IV. Evaluation of Methodical Error of Technical Losses Calculation Applying Alpha-Level Presentation of Fuzzy Coefficients

In the process of solution of the problem dealing with calculation of energy losses there appears the problem of evaluation of calculation error. As a rule, root-mean square methodical error of calculation is determined by 3σ rule, that is, by means of uncertainty interval.

In the given paper the authors suggest to evaluate the error by means of coefficients fuzzy values presentation in the form of alpha-levels (single $[\underline{k_i}, \overline{k_i}]_1$ and zero $[\underline{k_i}, \overline{k_i}]_0$). As a result of coefficients multiplication in accordance with (1) applying the rules of alpha-level principle of generalization we obtain losses in the form of alpha-levels (Fig. 1). Thus, we can compare single alpha-level with uncertainty interval, in which the losses will fall with almost 100% certainty of the expert. Defuzzification by the method of maxima centre gives the possibility to speak about the lack of systematic error.

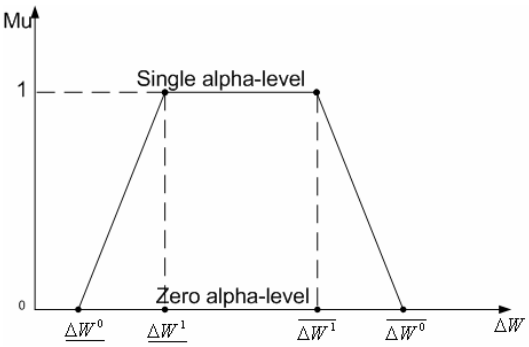

Fig. 1. Alpha-level presentation of fuzzy coefficients

$\underline{\Delta W^0}, \overline{\Delta W^0}$ – minimal and maximal value of losses on zero alpha-level;

$\underline{\Delta W^1}, \overline{\Delta W^1}$ – minimal and maximal value of losses on single alpha-level.

Minimal values of energy losses

$$\Delta W_{p.min} = \underline{\Delta W^1} = 9.3 \cdot \prod_{i=1}^{6} \underline{k_i} \cdot \frac{W_F^2 \cdot L_F}{N_F^2 \cdot Д \cdot F}.$$

Maximal values of energy losses

$$\Delta W_{p.max} = \overline{\Delta W^1} = 9.3 \cdot \prod_{i=1}^{6} \overline{k_i} \cdot \frac{W_F^2 \cdot L_F}{N_F^2 \cdot Д \cdot F}.$$

Root-mean square methodical error of losses determination is

$$\Delta W_p = \frac{\Delta W_{p.max} - \Delta W_{p.min}}{6 \cdot \Delta W_p} \cdot 100 \qquad (3)$$

where ΔW_p – average value of energy losses. Value of losses in the given case is determined by defuzzificated factors.

V. Forecasting of Energy Losses in Distribution Networks

In order to elaborate measures aimed at reduction of energy losses, there appears the necessity to determine factors from (1) as parameters of divergence model of forecast, oriented at determination of losses by the level of energy consumers loading in distribution network:

$$\Delta W_* = A_{np} \cdot \sum_{r=1}^{m} W_{r*} \cdot \prod_{j=1}^{6} k_{rj}^{\alpha_j}, \qquad (4)$$

where $\Delta W_* = \dfrac{\Delta W}{\Delta W_б}$, $W_{r*} = \dfrac{W_r}{W_{rб}}$ – relative values of losses and electric loading of r-th consumer, correspondingly; k_{rj} – parameters, determined at the stage of model construction at different values of W_{r*}. In this case it is quite expedient to choose the first point of retrospective data as the basis, taking into consideration that investigated period is divided into intervals of the same length, having the duration of 24 hours ± 1 hour (in case of transition to "winter" / "summer" time); initial value of horizontal coordinate and step of lead time are recommended to assume as one.

Generalized coefficient of forecasting model in most determining forms characterizes the influence of additional parameters, namely, volume of energy consumed by non-industrial consumers, number of days of calculated period, number of feeders, total length of transmission lines, cross-section of transmission lines.

Claimed power of r-th consumer determines electric loading W_r. Model (4) is revised by means of introduction of weighted coefficient, which is determined by relation of planned and real values of energy consumption. The quantities of forecast values of electric loading of consumers can be determined by means of multifactoral model of critarial forecast applying. It should be noted that suggested method of forecast is characterized by high accuracy and simplicity of results obtaining.

VI. The Example of Suggested Method Realization

Applying the resources of mathematical environment MATLAB [6, 7] we suggest practical realization of the given methods.

The first step. Identification of coefficients (Fig. 2).

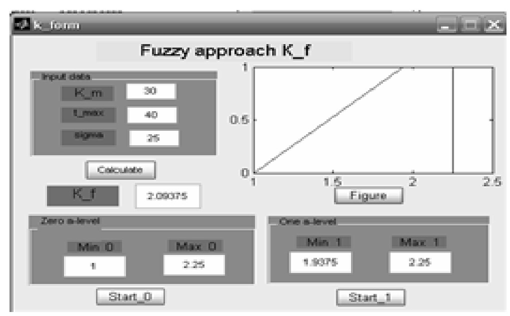

Fig. 2. Identification of correction factors and their division into alpha-levels

The second step. Calculation of electric energy losses by generalized parameters (Fig. 3)

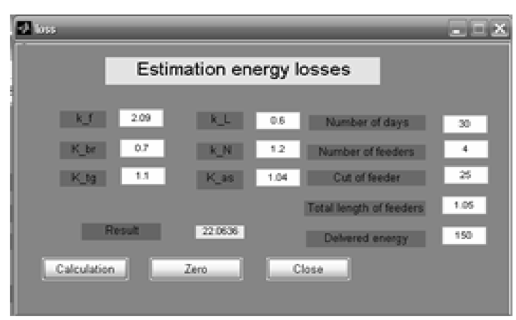

Fig. 3. Calculation of electric energy losses

The third step. Estimation of methodological error of electric energy losses calculation (Fig. 4)

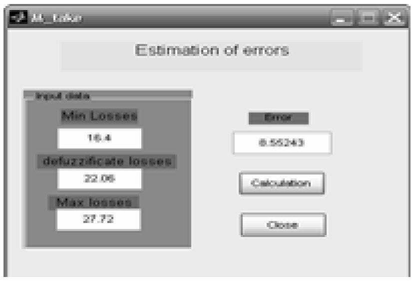

Fig. 4. Estimation of methodological error

Table 2 contains the results of electric energy losses calculation method (1), computation method by generalized parameters (2) and new method, suggested in the given paper for one of 0.38 kW feeders.

TABLE 2
RESULT COMPARISONS

Methods		Model (1)	Model (2)	New model
ΔW, kWh	January	1202	1521	1264
	February	907	1263	1000
	March	763	888	768
	April	675	805	673
	May	582	640	574
	June	426	530	410
	July	501	630	488
	August	634	752	629
	September	803	1000	812
	October	864	1120	879
	November	1015	1230	1049
	December	1083	1380	1127

Having analyzed computation results, we can make a conclusion: new method is more accurate than (2) and requires far less input data, than (1).

VII. CONCLUSIONS

The given paper considers the possibility of improvement of the methods of electric energy losses calculation in distribution networks applying the means of fuzzy logic. For the first time the possibility of methodical error estimation of losses calculation by means of presentation of fuzzy values of losses in the form of alpha-levels was shown.

Application of intellectual resources in problems of analysis of electric energy losses in distribution networks gives the possibility:

- reduce methodological error of losses calculation by means of improving the accuracy of influencing factors coefficients from (2);
- estimate methodological error of losses calculation (2), that facilitates the choice of measures aimed at their reduction at the expense of estimation of economic expediency of their implementation;

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