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AUTOMATION OF ENERGY LOSSES CALCULATION IN 10(6) kV DISTRIBUTIVE NETWORKS

New approaches aimed at increase of efficiency of energy losses calculations methods in 10(6) kV distributive networks in conditions of partially indetermined initial information are suggested: methods of determinationt of group load graph form and evaluation coefficients of observability of distributive electric networks for problems of losses calculation are elaborated. The realization of observability evaluation algorithm within the context of the solution of the problem dealing with the implementation of computer-based system of commercial account of electric energy in distributive electric networks by means of programming complex "ВТРАТИ-110-0,4" (LOSSES-110-0,4 is shown).

***Key words**: distributive electric networks, electric energy losses, observability, indetermined, initial information, probability evaluation, coefficient of total load graph forms, fuzzy sets, computer-based systems of commercial account of electric energy.*

Introduction

High world prices for such energy resources as gas, oil, coal predetermine rigid control in Ukraine over the efficiency of generation, transportation and consumption of electric energy, since greater part of these resources is used for generation of electric energy.

As it is well known, technological charges for electric energy transmission from the source of power supply to consumer are one of the main indices of energy usage efficiency. Detailed analysis [1] of real consumption of electric energy in Ukraine in recent years shows their high level as compared with the countries of Western Europe. Especially it concerns distributive grids of 10(6) kV.

One of the main reasons of high losses is low efficiency of measures aimed at losses reduction, that, in its turn, is due to low level of automation of control and monitoring of these electric grids operation modes. Taking into account high level of development of modern computing facilities and introduction of automatic system of commercial account of electric energy (ASCAE) in distributive grids, there appeared the possibility, first, to use databases of this system of account in the problems of energy losses determination [2], second, to integrate the accounting system with automated system of dispatching control [3].

Problem set-up

Basic assessment of ASCAE usage efficiency in distributive grids of 10(6) kV is the growth of profit of energy supply companies P due to reduction of accounted technological losses of electric energy on condition of minimum of involved capital investments C.

Efficiency function:

$$P = f(\delta W_{tech}, O) \to \max \qquad (1)$$

if

$$C \to \min, \qquad (2)$$

where δW_{tech} – expected reduction of technological losses of energy as a result of measures taken; O – level of payment for consumed energy.

The value of expected reduction of energy losses is determined correspondingly [4]

$$\delta W_{tech} = (1 - \frac{\Delta}{50}) \cdot (\Delta W_{tech1} - \Delta W_{tech2}),$$

where ΔW_{tech1} – value of technical losses of electric energy prior to performing optimization measures ; ΔW_{tech2} – value of technological losses of electric energy after realization of optimization measures; Δ – relative value of mean square error of the method of energy losses calculation.

Solution of efficiency function (1) without limitation (2) will foresee the installation of ASKAE facilities at all TS-10/0,4 kV, which, in automatic mode, transmit by communication channels information to data collection and transmission unit (Fig.1).

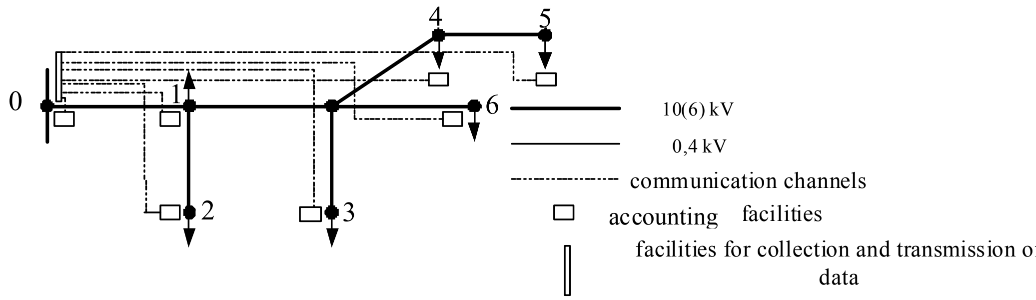


Fig. 1. Realization of ASCAE facilities in distributive grids 10(6) kV

Taking into consideration great number of load nodes, ASCAE in distributive grids 10(6) kV cannot provide their complete observability. Organization of teleinformation system for all transformer substations (TS) 10(6)/0.4 kV is not expedient, due to profitability and payback period. Thus, the problem of identification of EG 10(6) kV modes and energy losses on condition of partial indetermination of initial information remains actual even after ASCAE realization.

The given paper considers the elaboration of: method of modes parameters identification in non-telemeasuring nodes of load, method of evaluation of distributive electric grids 10(6) kV observability in the problems of calculation of variable (loading) electric energy losses .

Method of identification of the coefficients of group load graph form

Method of identification of mode parameters at non-telemeasuring TS-10(6) / 0.4 kV, suggested in the given paper, allows to estimate the value of the coefficient of load graph form in the problems of calculation of variable energy losses by means of fuzzy sets.

As it is known from [4], energy losses comprise conventially constant losses (losses for idle mode of distributive transformers) and variable losses in the equipment (losses, determined by the value of load current). The most accurate value of variable energy losses during time interval *j* can be obtained applying the method of elementwise calculation :

$$\Delta W_{Hj} = \sum_{i=1}^{n} \frac{(S_{Hi} \cdot k_{ui} \cdot \cos\varphi_i)^2 + (S_{Hi} \cdot k_{ui} \cdot \sin\varphi_i)^2}{U_i^2} \cdot R_i \cdot t_j \cdot k_{fi}^2, \qquad (3)$$

where ΔW_{Hj} – variable losses of energy in the grid, consisting of n elements, during j-th time interval; n – amount of elements of the grid; S_{Hi} – nominal power of i-th transformer; k_{ui} – utilization factor of i-th transformer; $\cos\varphi_i$ – power factor at the buses of high-voltage side of i-th transformer; R_i – active resistance of i-th element of EG; t_j – duration of calculation period; U_i – node value of the voltage; k_{fi} – load graph form coefficient of i-th element of EG.

Graph form coefficient for greater part of real consumers k_{fi} varies within the interval [1,0 1,15]. Having set the step of coefficient change 0,015, we obtained a number of possible values of graph form coefficient of individual consumer:

$$K_f = \{1; 1{,}015; 1{,}03; 1{,}045; 1{,}06; 1{,}075; 1{,}09; 1{,}105; 1{,}12; 1{,}135; 1{,}15\}$$

For identification of load graph form coefficient of separate TS-10(6)/0.4 the following representation of 10(6) kV consumer classes is used:

$$\widetilde{k}_{type\_con} = (\frac{k_{fi}}{\mu_{kfi}}), i = \overline{1,n}, \quad (4)$$

where k_{fi} – graph form coefficient of individual consumer, i.e., vector element K_f; μ_{kfi} – value of belonging function of form coefficient k_{fi} to corresponding class of consumers.

Below in accordance with (4) the following classes of consumers are listed [5]:

1. Home consumer (HC). Consumers with considerable irregularity coefficient of load graph belong to this class. TS-10(6)/0.4 kV, supplying blocks of flats and municipal buildings can be referred to this class:

$$\widetilde{k}_{HC} = (\frac{1.135}{0.15}, \frac{1.15}{1});$$

2. Mixed consumer, comprising considerable share of HC. Substations, that supply more than 80 % of energy to home consumers can be referred to this class:

$$\widetilde{k}_{MHS} = (\frac{1.105}{0.15}, \frac{1.12}{1.0}, \frac{1.135}{0.15});$$

3. Industrial consumer of 1 (IC_1) type. This definition refers to industrial consumer with two-shift operation

$$\widetilde{k}_{IC\_1} = (\frac{1.075}{0.15}, \frac{1.09}{1.0}, \frac{1.105}{0.15});$$

4. Mixed consumer with considerable share of IC_1 (MIC_1). TS, supplying more than 80 % of electric energy to consumers with two-shift operation, can be referred to this class:

$$\widetilde{k}_{MIC\_1} = (\frac{1.045}{0.15}, \frac{1.06}{1.0}, \frac{1.075}{0.15});$$

5. Industrial consumer of 2 (IC_2) type. Industrial consumers with three-shift operation can be referred to this class:

$$\widetilde{k}_{IC\_2} = (\frac{1}{1.0}, \frac{1.015}{0.15});$$

6. Mixed consumer with considerable share of IC_2 (MIC_2). TS, where more than 80 % of energy consumption is the share of industrial consumers with three-shift operation can be referred to this class. TS-10(6) / 0.4 kV, supplying pumping stations, regional or urban thermal power stations can be referred to this class:

$$\widetilde{k}_{MIC\_2} = (\frac{1.015}{0.15}, \frac{1.03}{1.0}, \frac{1.045}{0.15}).$$

As a result of computation the coefficient of group load graph form will be equal to intersection of fuzzy sets, which represent one of the suggested terms for each TS-10(6) / 0.4:

$$\widetilde{k}_{\Sigma f} = \widetilde{k}_{f1} \cup \widetilde{k}_{f2} \cup \ldots\ldots \cup \widetilde{k}_{fn}, \quad (5)$$

where n – number of TS-10(6)/0,4 kV, to which the energy is supplied by the set EG 10(6) кВ. Operation of intersection of fuzzy values of graph forms coefficients of separate TS, according to Zade [6], will correspond to the operation of maximum determination.

For account of differences of average loads of separate TS-10(6)/0,4, weight coefficients $k_{вi}, i = \overline{1,n}$ are to be used. Thus, the expression (5) will have the following form:

$$\widetilde{k}_{\Sigma f} = \widetilde{k}_{f1} \cdot k_{f1} \cup \widetilde{k}_{f2} \cdot k_{w2} \cup ..... \cup \widetilde{k}_{fn} \cdot k_{wn} \qquad (6)$$

Taking into account the lack of information regarding the coefficients of distributive transformer utilization of separate TS-10(6)/0,4, weighting coefficients from (6) are determined in the form of relation of separate TS W_j load to total load W_{Σ}:

$$k_{Wj} = \frac{W_j}{W_{\Sigma}}$$

The final stage of identification of the coefficient of group load graph form is the operation of fuzzy value identification of the given coefficient. In the given paper we suggest to apply "center of gravity" method, which is characterized by higher accuracy:

$$k_{\Sigma f} = \frac{\sum_{i=1}^{m} k_{\Sigma f_i} \cdot \mu_{k_{\Sigma f}}(k_{\Sigma f_i})}{\sum_{i=1}^{m} \mu_{k_{\Sigma f}}(k_{\Sigma f_i})}$$

Method of evaluation of probability of calculated values of variable energy losses with preset error

Variable character of loading losses according to (3) is due to changes of such mode indices as: utilization factor (k_l), power ($\cos\varphi$) of load graph form and voltage value in the center of supply (U_{cs}). Buses 10(6) kV of step-down substation 110 and 35 kV are referred to as center of supply.

The suggested method of evaluation of existing state of separate feeders of 10(6) kV observability is based on the analysis of sensitivity of the probability of variable losses accurate determination if the information regarding distributive transformers utilization coefficient, voltages in supply centers and load graph forms is not complete. For determination of the probability of accurate calculation of losses the reverse problem is solved – determination of mean square error Δ_L by calculated boundaries of the interval of energy losses indeterminacy interval, which corresponds to set probability of real losses ΔW_p determination within the limits of the given interval [6]:

$$\Delta_L = \frac{(\Delta W_c - \Delta W_{c.\min})}{3 \cdot \Delta W_c} \qquad (7)$$

where ΔW_c – calculated real value of variable energy losses, determined by mode measurements data; $\Delta W_{c.\min}$ – calculated minimum value of variable energy losses.

Using calculated value, we obtain the possibility to evaluate the probability of variable energy losses with needed, preset accuracy Δ_S (for instance 5 %). It is necessary to determine calculated value of the parameter, which shows to what number of Δ_L intervals the set interval corresponds and what probability it corresponds:

$$t_p = \frac{\Delta_S}{\Delta_L} \qquad (8)$$

By the calculated values, using corresponding values of Laplasse integrals, the probability of calculation of variable energy losses is determined with preset accuracy, characterizing the quality of calculations performed.

The given paper suggested to approximate data given in the Table in [8] for determination of the probability of energy losses calculation with preset error by the value of t_p parameter by the polynominal of the fifth order of the following form:

$$p_i = (0{,}0001 + 0{,}3953 \cdot t + 0{,}0201 \cdot t^2 - 0{,}1073 \cdot t^3 + 0{,}037 \cdot t^4 - 0{,}004 \cdot t^5) \cdot 2 \qquad (9)$$

For formation of information infrastructure, which will provide the required accuracy of variable energy losses calculation as the balance component, we may use integral value of losses determination truth as optimum criterion, which characterizes the probability of ΔW calculation with preset accuracy for the list of characteristic periods of ES operation (modes). Considering the achievement of preset accuracy of losses determination in *m* separate characteristic ES modes as independent events, the probability of the fact that they will occur simultaneously, can be evaluated as the product of probabilities of achieving the preset accuracy in separate modes, i.e.:

$$\chi_{\Delta W} = \prod_{i=1}^{m} p_i \qquad (10)$$

Index of efficiency of telemeasuring equipment installation, calculated in this way characterizes the quality of 10(6) kV grid information subsystem and its sensitivity can be corrected at the expense of variation of the number of characteristic modes *m*, being considered.

Thus, evaluation of observability index of 10(6) kV grids for problems of energy losses determination is reduced to the solution of the problem of non-liner optimization with limitations in the form of equalities and inequalities. As a result of the given optimization there appears the necessity to solve systems with great number of equations by means of known iteration methods. From [8] it is known, that iteration methods of incomplete networks modes are characterized by divergence of calculation process. In such conditions the authors of the paper suggest to determine utilization coefficients of distributive transformers 10(6) / 0.4 kV, which correspond to minimum value of losses by simplified scheme, which requires prior equivalizing of the grids to radial form and account of limitations imposed on the value of utilization coefficient k_U =[0,1 0,8] in the form of inequalities by means of iteration process. As a result of the above-mentioned transformations utilization coefficients for minimum value of variable energy losses can be determined applying the following formula:

$$k_{i0} = \frac{(P_{arr} - \Delta P_{cal})}{P_{Hi} \cdot \left[\sum_{j=1}^{n} \frac{U_{ja}^2 \cdot r_{0i}}{r_{0j}} \right]} \cdot U_{ia}^2 \qquad (11)$$

where k_{i0} – utilization coefficient of i-th transformer, value of which corresponds to $\Delta W_{p.\min}$; P_{arr} – average value of active power, supplied to the main part of the feeder 10(6) kV; ΔP – calculated value of active power losses, determined in the process of equivalization of radial-trunk grids to radial form; P_{Hi} – nominal active power of i-th transformer; U_j – voltage at j-th node ($j = \overline{1,n}$) equal $U_j = 11{,}5 - \Delta U_{0j}$; r_{0i} – active resistance of the section (0-i).

Value 11,5 kV in the formula (7) corresponds to maximum value of the voltage of supply center, which provides minimum of variable energy losses in 10(6) kV grid.

Values of minimum energy losses are determined in accordance with the expressions (7)-(10) and elaborated method of identification of group load form coefficient.

$$\Delta W_{p.\min} = \sum_{i=1}^{n} (\Delta P_{p.\min i} \cdot k_{ф.\min \Sigma P}^2) \cdot T$$

$\Delta P_{p.\min i}$ – minimum value of reactive power losses at i-th section, which is determined correspondingly by the expression (3), taking into account expression (11).

Algorithm, suggested in Fig. 2 is realized in programming complex of calculation and analysis of energy losses LOSSES-10-0,4 in the form of separate programming module [9]. Taking into account the given block of truth analysis, the sequence of ES mode calculation and energy losses determination in ASCAE for given time section will have the following form (Fig. 2):

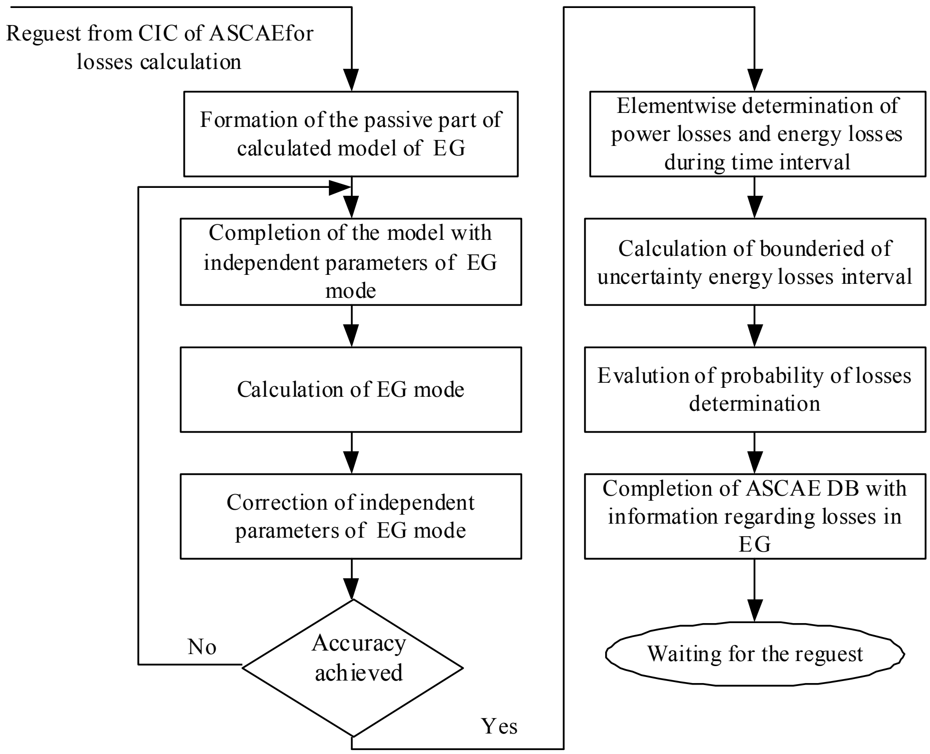
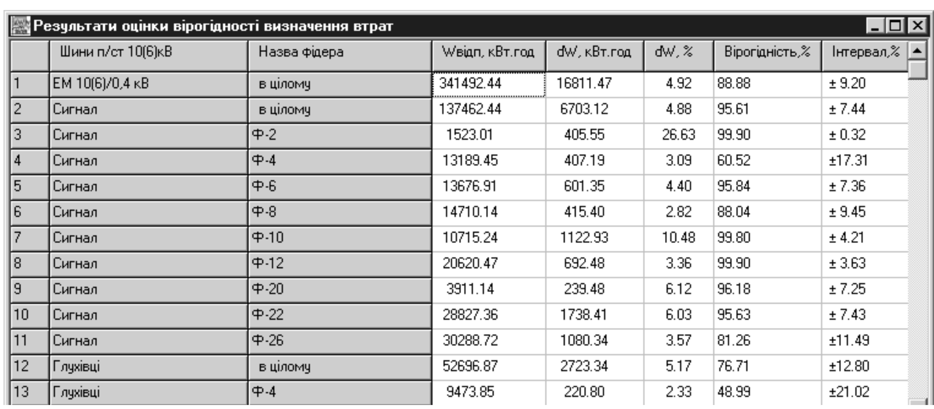


Fig. 2 Sequence of energy losses determination in ASCAE

The results of programming modulus are shown in Fig. 3.



Результати оцінки вірогідності визначення втрат

	Шини п/ст 10(6)кВ	Назва фідера	Wвідп, кВт.год	dW, кВт.год	dW, %	Вірогідність,%	Інтервал,%
1	ЕМ 10(6)/0,4 кВ	в цілому	341492.44	16811.47	4.92	88.88	± 9.20
2	Сигнал	в цілому	137462.44	6703.12	4.88	95.61	± 7.44
3	Сигнал	Ф-2	1523.01	405.55	26.63	99.90	± 0.32
4	Сигнал	Ф-4	13189.45	407.19	3.09	60.52	±17.31
5	Сигнал	Ф-6	13676.91	601.35	4.40	95.84	± 7.36
6	Сигнал	Ф-8	14710.14	415.40	2.82	88.04	± 9.45
7	Сигнал	Ф-10	10715.24	1122.93	10.48	99.80	± 4.21
8	Сигнал	Ф-12	20620.47	692.48	3.36	99.90	± 3.63
9	Сигнал	Ф-20	3911.14	239.48	6.12	96.18	± 7.25
10	Сигнал	Ф-22	28827.36	1738.41	6.03	95.63	± 7.43
11	Сигнал	Ф-26	30288.72	1080.34	3.57	81.26	±11.49
12	Глухівці	в цілому	52696.87	2723.34	5.17	76.71	±12.80
13	Глухівці	Ф-4	9473.85	220.80	2.33	48.99	±21.02

Fig. 3 Results of evaluation of energy losses calculation in 10(6)/0.4 kV grids

Conclusions

1. The paper shows that one of the determining factors of inefficiency of measures aimed at reduction of energy losses in distributive grids 10(6) kV is low level of control automation of their modes. The only way to solve the given problem is epy introduction of ASCAE in these grids.

2. Taking into account the fact that it is impossible to install simultaneously the accounting facilities of ASCAE in all TS-10(6)/0,4 kV, the method of calculation of load graph forms coefficients is elaborated on the basis of fuzzy sets theory. The given method enables to perform the computation of coefficients, using only expert information.

3. For efficient implementation of ASCAE the method of probability evaluation of variable energy losses calculation with preset accuracy is suggested. The given method can be applied for electric grids with partially indetermined initial information.

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