

Review scientific paper/Pregledni naučni rad

ESTIMATION OF ELECTRICITY LOSSES IN DISTRIBUTED ELECTRICITY NETWORK USING AN IMPROVED THREE MODE METHOD

PROCJENA GUBITAKA ELEKTRIČNE ENERGIJE U ELEKTRODISTRIBUTIVNOJ MREŽI KORITEĆI POBOLJŠANU METODU TRI MODA

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Abstract: Increasing the energy efficiency of electricity distribution networks is the commitment of all national and private electricity distribution companies. One of the basic goals is to reduce losses in electricity distribution networks. It is known that losses in the distribution network can be defined as the differences between taken and delivered electricity. Determining losses has several basic tasks. The first task is to determine the difference between the calculated losses and the actual losses, and to determine the reason for this difference and to determine the necessary guidelines for taking measures to reduce losses. The second task is to estimate the loss index for planning and formulating different plans. This paper presents a new approach to reduce the error between calculated and actual losses using a new method based on the Three Mode method. The main purpose of the study was to investigate the power losses in distribution area. The method proposed in this paper significantly reduces the error compared to the classical Three modes method, which is the original contribution of this paper.

Keywords: losses, power, calculation, method, three modes, electricity and power losses, distribution network

Sažetak: Povećanje energetske učinkovitosti elektrodistributivne mreža je opredjeljenje svih nacionalnih i privatnih elektrodistributivnih kompanija. Jedan od osnovnih ciljeva je smanjenje gubitaka u elektroenergetskim distributivnim mrežama. Poznato je da se gubici u distributivnoj mreži mogu definirati kao razlike preuzete i predane električne energije. Određivanje gubitaka ima nekoliko osnovnih zadataka. Prva zadatak jeste odrediti razliku između izračunatih gubitaka i stvarnih gubitaka, te odrediti razlog za tu razliku i određivanje neophodnih smjernica za poduzimanje mjera za smanjenje gubitaka. Drugi zadatak je procjena indeksa gubitaka za planiranje i formulaciju različitih planova. U ovom radu je prikazan novi pristup za smanjenje pogreške između izračunatih i stvarnih gubitaka korištenjem nove metode koja se bazira na metodi Tri moda. Glavna svrha istraživanja bila je istražiti gubitke snage u distribucijskom području. Predložena metoda u ovom radu znatno se smanjuje pogreška u odnosu na klasičnu metodu Tri moda što predstavlja izvorni doprinos ovog rada.

Ključne riječi: gubici, snaga, proračun, metoda, tri moda, gubici električne energije i snage, distributivna mreža

INTRODUCTION

Loads and losses in the power system are random variables that cannot be accurately determined in advance.

Theoretical determination of losses in the power system is an important economic indicator for the preparation of the plan for the development and management of the power system [1]. Therefore, it is very important to develop reliable and advanced methods of calculating electricity

losses and present the most accurate data on losses in the power system.

When the load curve changes to the load duration curve, then the load current can be expressed with probability. From this fact, a number of methods that analyse load curves, and are based on probability theory, have been developed.

One of the methods is the Three modes method [2], which can be used in networks of all voltage levels. In [3], a modified Three modes method, which reduced the error of the original method by approximately 40%, was presented.

Three mode methods divide the loads into three groups of a certain time interval. The minimum mode represents the minimum load in a certain period of time, the normal mode represents the exploitation of the source in the

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optimal capacity, i.e. the usual exploitation of the system and the maximum mode represents the maximum load of the considered area [1], [4].

In [5], difficulties in obtaining the necessary measured values for determining losses are presented.

The problem of electricity losses in distribution networks is expressed both in our country and in the surrounding countries. In general, the total level of electricity losses realized by the Branch "Elektro distribucija" Tuzla, does not show significant deviations compared to the surrounding countries [6].

In [7]-[14] the authors made a "rough" classification of losses, and the same classification can be applied in our country. Technical losses occurred in the transit of active and reactive energy through the distribution network, while non-technical losses are caused by errors in the process of metering, reading, bookkeeping and invoicing, as well as unrealized payments for energy consumed by customers.

Connection between the Three Modes

The time of occurrence of any of the load modes in the power system is a random variable so that a rough estimate of the phenomenon can be made [1], [2], [4]. Observing the monthly or annual duration curve of average hourly loads, it is evident that in certain periods of the day we have jumps in power consumption (daily maximum or peaks) as well as a decrease in power consumption (daily minimum). If the observed period is long, e.g. one year, it is noticeable that the daily maximum and daily minimum change during the year [1]. One of the problems of the original Three Modes method is determining the point of separation of the three modes in terms of probability. Therefore, in order to determine the point of separation, several different factors must be taken into account, such as the quality of voltage, the price of electricity, weather conditions, etc. [4]. The modified Three Modes method presented in [2] simplifies the determination of the separation point of individual modes by sorting all loads by value and dividing them into three equal time segments, thus determining the load values of each mode.

Possibilities of practical application of the Three Modes method

The three mode method performs a practical and real calculation of the values of measured power flows and typical loads at three points of the load duration curve and further uses it to obtain corresponding average power losses according to typical daily loads [3].

In theory and practice, it has been shown that three types of daily average active losses can represent total energy losses if multiplied over time. With three modes, three characteristic loads or points of the curve are presented. The goal of using the Three-mode method is to determine the loss index within the entire period. The mathematical

model of electric power flow and the minimization of power loss is given in [15] - [18]. The total loss index is obtained by integrating the individual loss indices of all three modes. Reference [1] describes the steps for calculating electricity losses based on three modes.

1. ANALYTICAL DESCRIPTION OF THREE MODE METHODS

1.1. Method Three modes

The calculation of typical load flows is performed in three points or three modes, to obtain the corresponding average power losses under typical daily loads [3]. Obviously, three types of daily average active losses multiplied by time can represent total energy losses within the three modes of operation. The line loss index is integrated in three modes to obtain the loss index within the whole period, which is the basic concept of calculating electricity losses in energy networks based on power losses in three modes.

The theoretical calculation of long-term losses serves as a check and is described in the following steps:

1. The application of a long period determined from the amount of energy, in order to obtain the average loads and the application of the measured maximum loads to obtain a long period of active load f_p and the minimum load index β_p , thus obtaining the load change index $1/\lambda$. Permissible mean powers for 3 modes are selected as P_{1*} , P_{2*} , P_{3*} and are calculated according to the expressions

$$\begin{aligned} P_{1*} &= (\beta_p + P_{s,m}), & P_{2*} &= f_p, \\ P_{3*} &= \frac{P_{m,b} + 1,0}{2} \end{aligned} \quad (1)$$

Where are:

- P_{1*} , P_{2*} , P_{3*} - allowed average power of minimum, medium and maximum mode,
- β_p - minimum load index,
- f_p - load factor,
- $1/\lambda$ - load change index,
- $P_{s,m}$ - power during minimum mode,
- $P_{m,b}$ - power during maximum mode.

2. It is necessary to select typical daily load curves for three modes and allow them a daily maximum load, i.e. P_{1max} , P_{2max} , P_{3max} . It is also necessary to multiply the actual maximum load for the whole period to the value per unit of average power. Compare the daily maximum load with the product and take $(P_{\Sigma max} P_{1*})/P_{1max}$, $(P_{\Sigma max} P_{2*})/P_{2max}$, $(P_{\Sigma max} P_{3*})/P_{3max}$ as the coefficients of proportionality for adjustment, thus obtaining a new distribution of the three modes of typical daily loads.

$$(P_{\Sigma max} P_{1*})/P_{1max}, (P_{\Sigma max} P_{2*})/P_{2max}, (P_{\Sigma max} P_{3*})/P_{3max}$$

represent the proportionality coefficients for obtaining a new distribution of typical daily loads.

Where are:

- $P_{\Sigma, \max}$ – daily maximum loads
 P_1, P_2, P_3 – average power of Three-mode sections
 $P_{1\max}, P_{2\max}, P_{3\max}$ – daily maximum load for the three points

- By performing the calculation of 24-hour power flows adjusted by the distribution of three modes of typical daily loads, to obtain the average daily power losses $\Delta P_1\%, \Delta P_2\%$ and $\Delta P_3\%$.
- Using a typical daily network load curve in three ways to calculate the coefficients K_1, K_2, K_3 and using formula 2 we calculate the loss index $\Delta A_1\%, \Delta A_2\%$ and $\Delta A_3\%$ according to three division methods. The pattern below represents the relationship between the percentage of energy loss and the percentage of power loss [1].

$$\frac{\Delta A\%}{\Delta P_{eq}\%} \approx \frac{\sum_{j=1}^n P_{eq,j}}{\sum_{j=1}^n P_{av}} = K_{\Sigma}$$

Where are:

- $\Delta A\%$ – Percentage of energy losses,
- $\Delta P_{eq}\%$ – Percentage of power losses,
- $\sum_{j=1}^n P_{eq,j}$ – Equivalent power of nodes,
- $\sum_{j=1}^n P_{av}$ – Daily average power of all network loads.

- As combinations of low load factor coefficients appear in most long periods, according to Table 3.4 or part of this table, from the literature [1] the ratio between electrical quantities in three ways $A_1: A_2: A_3$ is obtained, and we calculate the ratio of electrical quantities in three ways of dividing the total amount of electrical $\alpha_1: \alpha_2: \alpha_3$.

Where are:

- A_1, A_2 and A_3 – electrical quantities in three divided modes,
 α_1, α_2 and α_3 – coefficients from Table 3.4 from the literature [1]

- The calculation of the loss index of the entire period is calculated according to the following formula:

$$\Delta A_{\Sigma}\% = \frac{\Delta A_{\Sigma}}{A} = \frac{\Delta A_1\% A_1 + \Delta A_2\% A_2 + \Delta A_3\% A_3}{A_1 + A_2 + A_3} \quad (3)$$

Where are:

- $\Delta A_{\Sigma}\%$ – loss index of the whole period,
 ΔA_{Σ} – total electricity losses,
 $\Delta A_1, \Delta A_2, \Delta A_3$ – loss indices for the three modes of division,

Substituting the ratio of average load obtain:

$$\Delta A_{\Sigma}\% = 0,233\Delta A_1\% + 0,660\Delta A_2\% + 0,107\Delta A_3\% \quad (4)$$

Where are:

- $\Delta A_{\Sigma}\%$ – loss index of the whole period,
 $\Delta A_1\%, \Delta A_2\%, \Delta A_3\%$ – loss index of the individual period.

According to formula (4), the total losses divided into three modes have a different degree of influence on the total loss index: the normal mode has the largest impact, followed by the minimum mode and finally the smallest effect with the maximum mode.

1.2. Modified method Three modes

The method proposed in [3] represents an improved approach compared to the method described in [3], or in point 2.1 of this paper, and differs in the actual determination of the load values for the minimum, maximum and normal mode.

The modified Three Modes method consists of the following steps:

- Determining the period, load and region,
- Calculation of parameters: $A, P_{av}, P_{min}, f, \beta, 1/\lambda, \Delta P\%$
- Calculation of power points in three modes: $P_{s,m}, P_{s,m}, P_{m,b}, P_{m,b}$,
- Calculation of the average load of each mode: $P_{s,av}, P_{b,av}$
- Determining the change in the loss index. Forming a table of losses, sorting and division into three modes. $P_{s,av}, P_{av}, P_{max,av}, \Delta P_s\%, \Delta P_m\%, \Delta P_b\%$
- Determining the ratio of the amount of electricity energy for three modes. $\alpha_1, \alpha_2, \alpha_3$
- Determination of losses for each mode. $\Delta A_s, \Delta A_m, \Delta A_b$
- Determination of total losses according to the loss index $\Delta P_{\Sigma}\%$, loss factor F , curve shape coefficient K , loss index for the whole period $\Delta A_{\Sigma}\%$ and total losses ΔA_{Σ} .

The calculation of the loss index of the whole period is obtained according to formula (1) while according to formula (2) the total loss index is obtained.

2. EXAMPLE OF CALCULATION OF ELECTRICITY LOSSES IN THE TRANSMISSION NETWORK

2.1. Example of calculation of losses in the distribution network by the improved method of Three modes

Using the modified method of three modes, real data from the real network published in [3] were used for the presentation of the methods for calculation of losses.

Table I and Figure 1. show a daily diagram of loads and losses of the analysed region. Table II shows the sorted data by loads and divided into three equal parts, and Table III show the calculation results obtained using the MATLAB software tool.

Table I. Daily diagram of load and losses of the distribution area of one region

Hour	1	2	3	4
Load (MW)	4.875	4.685	4.402	4.210
Losses (MW)	359	323	277	259
Hour	5	6	7	8
Load (MW)	4.105	4.320	4.810	5.296
Losses (MW)	253	271	335	411
Hour	9	10	11	12
Load (MW)	5.498	5.492	5.405	5.352
Losses (MW)	444	442	438	429
Hour	13	14	15	16
Load (MW)	5.294	5.235	5.088	5.147
Losses (MW)	418	411	389	400
Hour	17	18	19	20
Load (MW)	5.556	5.853	5.842	5.823
Losses (MW)	458	523	521	511
Hour	21	22	23	24
Load (MW)	5.735	5.618	5.382	5.118
Losses (MW)	489	459	435	390
Total Load (MW)	124.141			
Total Losses (MW)	9.645			

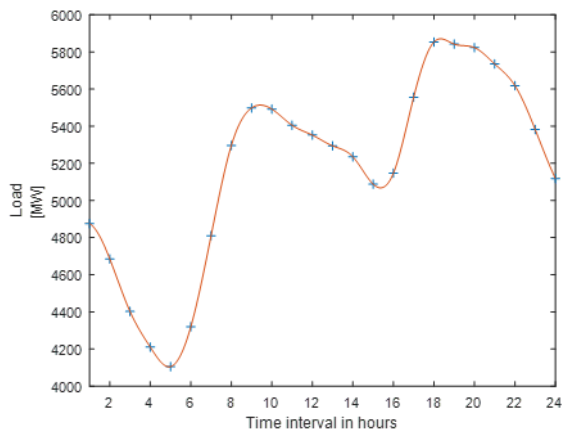


Figure 1. Daily load diagram of the analysed region

Table II. Losses in one region sorted by load, calculated averages of values of losses and loads corresponding to each mode

Hour	Losses (MW)	Load (MW)	Losses - average (MW)	Load - Average (MW)	The mod
5	253	4105	308,25	4561,88	minimal
4	259	4210			
6	271	4320			
3	277	4402			
2	323	4685			
7	335	4810			
1	359	4875			
15	389	5088	416,50	5278,63	medium
24	390	5118			
16	400	5147			
14	411	5235			
13	418	5294			
8	411	5296			
12	429	5352			
23	435	5382	480,88	5677,13	maximal
11	438	5405			
10	442	5492			
9	444	5498			
17	458	5556			
22	459	5618			
21	489	5735			
20	511	5823			
19	521	5842			
18	523	5853			

Table III. The calculation results obtained using the MATLAB software tool.

The sum of all losses in 24 hours:	9.645,00 MWh
Sum of all loads in 24 hours:	124.141,00 MW
Load factor:	0.88
Nominal load index:	0.70
The index of load change:	0.64
Minimum mode losses:	1.015,37 MWh
Losses in normal mode:	5.626,62 MWh
Losses in maximum mode:	2.975,39 MWh
Total losses calculated by the method of Three modes:	9617,38 MWh
Loss factor calculated using the coefficient f and beta:	0.79
The coefficient of the shape of the total load curve is:	1.005
Full period loss index:	0.08
Total losses by error method:	9.692,15 MWh
Relative error:	0.77 MWh

3. RESULTS AND DISCUSSION

The application of different methods of calculating the losses is tested on the example of distribution network. The new methods for calculating losses of distribution network take advantage of other methods that calculate losses by adopting the principle of “probability multiplication” for solving the problems above by dividing the curve into three modes of operation.

Results of the analysis that are obtained by calculations with the application of the methods used were compared with the results of measurements in practice, which allowed us a proper evaluation in the selection of the method.

A new approach for the calculation of the losses of the distribution network has demonstrated the advantages of the new methods for solving the calculation of losses in the network by solving the problems with the division into three modes.

4. CONCLUSION

New approaches to the calculation of losses in the distribution network are expressed through a number of advantages. The constant increase in energy consumption and the physical limitations of power lines initiate the need to develop new methods and tools for determining losses. The results of the analysis presented in this paper were obtained on the basis of the actual measured results and the calculation results of the modified three-mode method. Using the proposed approach to determine the loss index for the three-mode method significantly reduces the relative error compared to the original method. In addition to reducing the relative error in the calculation, the advantage of this method is seen through the increase in reliability, which significantly contributes to the improvement of existing methods and the overall actual estimate. The proposed approach excludes subjectivity in the selection of input parameters and thus the error in determining it.

Table III shows the results obtained using the MATLAB software tool, while the results obtained using the LACEPSYS online system are attached. The obtained results are almost identical

5. FUTURE WORK

The improved three modes method for reducing the loss prediction error presented in this paper shows a clear process and steps in the computer implementation of the method. This algorithm eliminates the error that can occur when subjectively determining the boundary between modes. The method is suitable for short and long time intervals. In the future, the work will focus on different voltage levels, as well as analyses of electricity losses of one region in which there are several different voltage levels, sources and consumers of electricity (Community grid) [20].

ANNEX



Calculation for region: TEST at date:2020-08-12

Sum of all losses in 24 hours: 9 645,00 MW
Sum of all loads in 24 hours: 124 141,00 MW
Load factor: 0,88
Nominal load index: 0,70
Load change index: 0,64
Minimum mode losses: 1 015,38 MW
Losses in normal mode: 5 626,84 MW
Losses in maximum mode: 2 975,36 MW
Total losses calculated by the method of three modes: 9 617,38 MW
Total losses measured: 9 645,00 MW
Loss factor calculated using the coefficient f and β : 0,79
The coefficient of the shape of the total load curve is: 1,00
Full period loss index: 0,08
Total losses by error method: 9 692,15 MW
Relative error: 0,77

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BIOGRAPHY

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