Loss Factor in Distributive Area of Utility "Elektrodistribucija" Nis

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Abstract – **In this paper new coefficients in loss factor equations which are used for calculation of variable energy losses in distribution networks are proposed. These coefficients are found on the base of statistic elaboration of annual load diagram database in distributive area of utility "Elektrodistribucija" Nis. Coefficient values are established in the equations of polynomial and exponential form. The equations with proposed coefficients have been tested at many consumption diagrams, when average error is established less than one percentage and maximal error does not exceed 2,36%. At the same time, it is found that standard formulae from the literature make a mistake in the calculation of energy losses in the range from 5% to nearly 20%.**

Keywords – **Energy losses, Loss factor, Load factor, Distribution networks.**

I. INTRODUCTION

In a process of power transmission and distribution, power and energy losses appear unavoidably in all network elements from the sources to the consumers, in all voltage levels. They depend on many factors, mostly on network condition and on network operation mode. One part of energy losses is a consequence of constructive features of electrical devices and whole network and they can not be avoided by any measure, while the other part depends on operation mode of distribution network. Both parts can be considered as technical losses of electrical energy. According to the way of appearance, technical losses are divided on:

- dependable on voltage or constant losses and
- dependable on load or variable losses.

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Constant energy losses are mostly consequence of voltage, and they exist in no-loaded network. They appear as iron losses of power and measuring transformers, as dielectric losses in cables and capacitors and the losses due to corona and leakage currents through shunt admittance of overhead lines. Beginning from the fact that network voltage is kept in relatively narrow limits, it can be considered that voltage dependable power losses are approximately constant. It enables simple determination of energy losses in any period of time.

Variable energy losses appear, duo to current flow, in all network element in a path of power transmission and distribution from the source to the consumption place. These losses are proportional to the second power of total current and they are the most expressed in lines and power transformers. A task of almost all methods for energy losses calculation is to find variable energy losses in the network as more realisic and complete as it possible, with the aim to discover the locations where the biggest unjustified losses appear and where are bottlenecks in transmission and distribution. After that, the measures for loss reduction are undertaken and to bring the network as closer as it possible to techno-economical state of optimality from the point of view of energy losses.

In utilities, energy losses are calculated as a difference between available and sold electrical energy and these are so called account losses. The losses obtained on that way are significantly bigger than aforementioned technical losses, because they include nontechnical, so called commercial, losses. Commercial losses appear due to unregistered consumption (thefts, unauthorised network connections, selfconsumption of utilities). The losses due to allowed tolerance in set up of measuring devices also belong to this group. Besides, commercial losses appear due to impossibility of simultaneous reading of all measuring devices.

Great number of papers, in the world [1,2] and in our country [3,4,5,6,7,8] are dedicated to the problem of energy losses calculation. They give empirical formulae for evaluation of losses or discussions about their accuracy and domain of application. All proposed formulae for calculation (evaluation) of losses became as result of statistic elaboration of available data about consumption diagrams for particular country or region. Existence of many formulae says that none of them is absolutely accurate, and can not be unreservedly applied to any network. Fundamental intention is to find connection between energy losses and maximum power losses in the same period of time. In that way, power losses calculation only for one, maximum, operation condition enables to find energy losses with sufficient accuracy.

Formulae give equivalent duration of maximum losses (τ) or of loss factor (ϑ) in analytical form. There is unique connection between these two quantities.

This paper only concerns to technical loss subgroup which is a function of loads (variable losses). Variable losses can be well evaluated in power system parts as distributive systems and radial transmission subsystems are, because of one direction of power flow and easy finding of load diagram characteristics. Formulae for energy loss calculation, used in our country, originate from the first half of twentieth century and in the middle of this century they are slightly modified. Taking into account specificity of our network, researches in [3]s proposed the methodology for calculation of losses in transmission networks and established formulae for loss calculation in some regions in former Yugoslavia. Some loss studies has been done, but they mostly relate to transmission lines.

Beginning from the fact that in the meantime it came to significant consumption overdistribution between voltage levels and to consumption structure change, authors of this paper consider that it is a deadline to research consumption diagrams and to propose new formulae for energy loss calculation. In this purpose, appropriate (ten years) database about consumption diagrams for distributive area of utility "Elektrodistribucija" Nis is used. Namely, from the year 1993., load data in the points of electrical energy purchasing, obtaining from ARES measuring device, are systematically recorded and processed. By elaboration of these data, load factors are identified and loss factors are found for all substations where utility "Elektrodistribucija" Nis is buying electrical energy for consumer supply at it's territory. Loss factor is expressed as second degree polynomial and in the shape of exponential function. Polynomial coefficients and the exponent are found for all months in the year, winter and summer season and for whole year. At the end, average values of coefficients are given for five years period. It is shown, consumption characteristics at complete distributive area of utility "Elektrodistribucija" Nis are almost the same, and there is small dispersion of calculation results. Based on found coefficient values in the formulae for loss factor, the accuracy of most frequently used formulae is tested.

Calculations show that existing formulae for loss energy evaluation, in some cases, give result with not tolerable error of 10%, and sometimes near to 20%. It leads to conclusion that it is indispensably to discover accurate coefficient values in formulae used for loss evaluation in the utilities of Elektoprivreda Srbije.

II. Loss Calculation Methodology

Active energy losses in a line of resistance R , at variable load $I(t)$, in a period of time T , can be calculated as:

$$\Delta W = 3R\int_0^T I^2(t)dt \,. \qquad (1)$$

If a load was constant in whole interval T , i.e. if $I(t) = I_m = const$, corresponding energy losses would be:

$$\Delta W = 3RI_m^2 T \,. \qquad (2)$$

The ratio between real losses which arise from time variable current $I(t)$ and the losses which originate from constant maximum current I_m is called *loss factor.*

$$\vartheta = \frac{\Delta W}{\Delta W_m} = \frac{3R\int_0^T I^2(t)dt}{3RI_m^2 T} \,. \qquad (3)$$

If it was assumed that voltage and power factor stood constant, then loss factor could be expressed by means of active power as a parameter:

$$\vartheta = \frac{\Delta W}{\Delta W_m} = \frac{\int_0^T P^2(t)dt}{P_m^2 T} \,. \qquad (4)$$

Beginning from the fact that in most cases maximum (peak) power data are available, energy losses in a period of T hours, in accordance with Eqs. (1) and (2), will be:

$$\Delta W = 3RI_m^2 T\vartheta \,, \qquad (5)$$

or

$$\Delta W = R\frac{P_m^2}{U_n^2\cos^2\varphi}T\vartheta \,. \qquad (6)$$

Important characteristic of load diagram is load factor defined as the ratio between total transmitted (taken over) energy and energy which could be transmitted at maximum load during the same observed time:

$$m = \frac{W}{P_m T} = \frac{\int_0^T P(t)dt}{P_m T} = \frac{P_{av}}{P_m} \,, \qquad (7)$$

where P_{av} is average load power in a period T **.**

Load factor value can be easy found from available data about transmitted energy *W* and maximum power P_m, for example from Eq. (7), because at energy purchasing locations the measuring devices for energy and peak power registration are regularly installed. Therefore, many researchers searched the connection between loss factor and load factor. There are many analytical expressions in literature which give connection between them. These expressions are derived so that load duration curve is firstly normalised and then appropriate symbolic curve is found by fitting. It is shown [6] that loss factor has values in the range from m^2 to *m*.

In authors opnion, most simple and for practice most acceptable function of loss factor is this one proposed by Buller and C.A. Woodrow in [1]:

$$\vartheta = mx + (1-x)m^2 \,. \qquad (8)$$

Problem of energy loss evaluation is to find a coefficient *x* for typical load diagrams at examined territory or in the whole utility. Based on available database on load diagram it is easy to calculate load factor and loss factor and then coefficient x from Eq. (8), as:

$$x = \frac{\vartheta - m^2}{m - m^2} \,. \tag{9}$$

Using normalised values of load diagrams in one year period, load factor is calculated according to Eq. (10) and loss factor according to Eq. (11):

$$m = \frac{1}{8760}\sum_{i=1}^{8760} P_i \,, \tag{10}$$

$$\vartheta = \frac{1}{8760}\sum_{i=1}^{8760} P_i^2 \,. \tag{11}$$

If load diagram was expressed through appropriate fitted curve, *f(P)*, load factor could be calculated using Eq. (12)

$$m = \frac{1}{8760}\int_0^{8760} f(P)dt \,. \tag{12}$$

In similar way, loss factor is calculated

$$\vartheta = \frac{1}{8760}\int_0^{8760} f(P_i^2)dt \,. \tag{13}$$

Sometimes loss factor is given in dependence on load factor as an exponential function (14)

$$\vartheta = m^k \,. \tag{14}$$

Exponent k would be simply calculated, if the values for θ and m were previously found, as

$$k = \frac{\ln\vartheta}{\ln m} \,. \tag{15}$$

III. Calculation Results and Its Analysis

Since June 1993., thanking to the installation of registration device ARES, the power in nine points, where utility "Elektrodistribucija" Nis is buying electrical energy, has been attended continuously. Appropriate database has been created so it enables elaboration of load diagrams on this territory. Data elaboration results about consumption in period from the year 2001. to 2004. are shown in this paper for following three transformer substations called:

- NIS 1 110/35 kV,
- NIS 2 400/220/110 kV,
- NIS 3 110/35 kV.

In substations NIS1 and NIS 3 power and energy measuring is performed at 35kV level and in substation NIS 2 at level 110kV. These substations supply biggest part of the area of utility "Elektrodistribucija" Nis, which encircles Nis town and its wider surroundings, except the area of town Aleksinac.

The data from ARES are recorded every 15 minutes, so total data number per measuring location is 4x24x365=35040 for ordinary and 4x24x366=35136 for leap-year. These data are elaborated per years, per seasons (summer and winter) and monthly.

Load factor and loss factor are calculated in concordance with Eqs. (10) and (11), real number of points are taken into account (N=35040 for ordinary and N=35136 for leap-year):

$$m = \frac{1}{N}\sum_{i=1}^{N} P_i \,, \tag{16}$$

and

$$\vartheta = \frac{1}{N}\sum_{i=1}^{N} P_i^2 \,. \tag{17}$$

Inside this investigation, 70 sets of annual data, for nine measuring locations, are elaborated for five to ten years in dependence of available data. There were mostly nine annual data which represented consumers supplied from Nis 2 substation. The oldest data were from the year 1993. and the newest ones from 2004.

Calculation results for 12 data sets are shown in Table I. Annual load factor is changing in narrow limits from the least value 0.367634 to 0.54892, and average value is 0.490312. Annual loss factor of considered load diagrams varies from the minimum value of 0.16762 to the maximum of 0.33629, and its average value is 0.278565.

Constant coefficient x in Eq. (8), for load factor, is obtained from Eq. (9) as the result of putting average values of loss factor and load factor. Thus, it is obtained $x = 0.1533585$, and loss factor from Eq. (8) becomes

$$\vartheta_1 = 0{,}1533585m + 0{,}846641m^2 \,. \tag{18}$$

Equation (17) can be written in exponential form with exponent $k = 1.792457$,

$$\vartheta_2 = m^{1{,}792457} \,. \tag{19}$$

Exponent k is calculated from Eq. (14).

Proposed formulae for loss factor calculation, Eqs. (18) and (19), are tested for all considered cases. At the same time, two following empirical formulae, which are most frequently used for annual loss calculation, are checked:

$$\vartheta_3 = 0{,}17m + 0{,}83m^2 \tag{20}$$

and

$$\vartheta_4 = (0{,}124 + 0{,}876m)^2 \,. \tag{21}$$

Original form of Eq. (21) shows equivalent time of annual losses

$$\tau = \left(0{,}124 + \frac{T_m}{10000}\right)^2 8760 \,, \tag{22}$$

where T_m denotes duration of maximum load.

Percentage errors of proposed Eqs. (18) and (19) and of Eqs. (20) and (21) from literature are cited in Table I. Proposed Eqs. (18) and (19) for loss factor calculation give the least errors; middle errors are 0.89% for polynomial Eq. (18) and 0.84% for exponential Eq. (19). Maximum errors are 1.9% and 1.924% , respectively. Equation (20) gives the result with average error of 2,21% and maximum error of 4.426%, while Eq. (21) makes average error of 10.987% and maximum of 18.69%. It is interesting to mention that Eq. (18) and (19) have positive and negative errors in the range from the least to the biggest load factor. On the other side, the errors of Eqs. (20) and (21) are always positive and they are greater at lower load factors. Equation (21) errors are the biggest and almost three times bigger than the errors obtained by application of Eq. (20). It is reasonable, because Eq. (21) is proposed on the base of experimental measurements which were performed in the middle of the last century in Russia.

TABLE I
CHARACTERISTIC VALUES OF CONSUMPTION DIAGRAMS AND PERCENTAGE ERRORS OF PARTICULAR EQUATIONS

No. of discrete loads	Peak load	Load factor	Loss factor	Constant coefficient	Percent error using			
N	P_m [kW]	m	ϑ	x	Eq. 18	Eq. 19	Eq. 20	Eq. 21
35040	63252	0.520681	0.310252	0.15684151	-0.280180	0.058158	2.208326	8.471571
35040	127260	0.443068	0.232846	0.14806668	0.560802	-0.173770	4.173554	12.63867
35040	126192	0.367634	0.167621	0.13965222	1.900971	-0.757440	6.656013	18.69531
35040	64260	0.532025	0.316568	0.13462187	1.473599	1.924369	5.945658	9.980669
35040	117740	0.473874	0.258564	0.13640214	1.634998	1.407878	6.157528	12.40679
35040	103224	0.455617	0.242965	0.14263649	1.094554	0.579951	5.131308	12.63147
35040	65688	0.540334	0.326927	0.14078078	0.955556	1.474740	4.829255	9.139415
35040	115080	0.508480	0.295632	0.14836303	0.422318	0.636887	3.721507	9.679870
35040	103048	0.484358	0.271983	0.14966779	0.338909	0.261172	3.620840	10.53274
35136	65604	0.548920	0.336290	0.14125523	0.891151	1.477254	4.691965	8.789828
35136	113680	0.504228	0.291163	0.14767906	0.487617	0.655036	3.865479	9.911186
35136	96712	0.504528	0.293966	0.15768292	-0.367730	-0.198380	2.113956	8.964340
Maximum	127260	0.548920	0.336290	0.15768292	1.900971	1.924369	2.113.956	18.69531
Minimum	63252	0.367634	0.167621	0.13462187	0.277667	0.003372	4.426282	8.471571
Average	96811.67	0.490312	0.2787314	0.14530414	0.867366	0.800419	2.208326	10.986820

IV. CONCLUSION

This paper shows results of load diagram researches during the last ten years in the area of utility "Elektrodistribucija" Nis, which supplies near 150.000 consumers. Based on statistic data elaboration, new coefficient values in equations for loss factor calculation are proposed. Equations with new coefficients give significantly better results in wide range of loss factors then equations from literature. These equations can be used in the networks where current is proportional to the power, that is a case in distribution systems and radial transmission networks.

Although these coefficients are found for consumption area of utility "Elektrodistribucija" Nis, they are recommended for the other areas, because load characteristics in almost all utilities of "Elektroprivreda Srbije" are the same.

Present computer abilities and available database enable that exposed methodology for loss factor calculation can be used for finding equations corresponding to load characteristics on particular territory.

Further researches should be oriented to load diagrams classification according to the type of settlements and consumer structure.

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