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SOME ASPECTS CONCERNING THE MATHEMATICAL MODELS AND SOFTWARE APPLICATION FOR EVALUATION OF TECHNICAL LOSSES IN OPERATION OF MEDIUM VOLTAGE PUBLIC DISTRIBUTION NETWORKS

BY

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Abstract. According to available information, the paper presents some mathematical models and software application to evaluate power and energy losses of the MV distribution networks elements (lines and transformers). Are presented both classical mathematical models based on the load type profiles of different consumer categories, and the developments in Fourier series of these types of load profiles. Are also presented the results obtained using different mathematical models, accompanied by observations and conclusions.

Key words: repartition systems; load type profile; power losses; standard day.

1. Introduction

In Romania, the public distribution of electricity is largely realized through two voltage levels: MV (6, 10, 20 kV) and LV (400 V). MV and LV public distribution networks are highly developed in our country, containing a large number of step-down transformer stations of 110 kV/MV, MV and LV

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feeders, MV/LV substations. Through these networks are supplied with electricity a total of about 8,358,500 small consumers, of which 8,35 million LV power contracted less than 100 kW, and the remaining 8,500 at MV with contracted power over 100 kW.

Regardless of the network layout – radial, tree or meshed – MV and LV public distribution networks work usually in trees or radial schemes, operating conditions due to simplifying and reducing the investment with switching, protection and automation devices. In distribution networks operation, the technical losses level is an important indicator that reflects the station operation. Technical losses level should be identified and determined to assess the economic efficiency of electricity distribution process (Albert *et al*., 1997; Gavrilă, 1994; Georgescu, 2007; Ruduick, 1996; EDF, 1995).

Basically, the value of this indicator (ΔW) is determined as the difference between an active energy entered ($W_{ent.}$) and active energy sold to consumers (W_{sold}), according to the relation

$$\Delta W = W_{ent.} - W_{sold} . \qquad (1)$$

According to the literature (Albert *et al*., 1997; Georgescu *et al*., 1997; Georgescu, 2007), the difference given by (1) includes three components:

a) *own technological consumption* (ΔW_{oct}), determined by computation in electricity transmission and distribution process for estimated condition of design facilities;

b) *technical losses* (ΔW_{tech}), due to irregularities of the designed operation state;

c) *evidence losses* (ΔW_{ev}), assessed as the difference between the indications of meters that measure energy injected into network contour and the electricity sold to consumers.

Given the aforementioned, for power or energy losses level estimating and monitoring in electric networks operation process can use the following general analysis model: the formation of a computing subsystem for evidence losses, the development and introduction of a computing subsystem to determine technical losses, with a greater or lesser precision using different analytical methods. In addition, in distribution network, the computation must be performed on characteristic shapes, so that can be established by record losses, and the technical ones. In this sense, in the MV distribution networks, such calculations can be performed separately for each processing station or network segment.

Public distribution networks are urban or country areas spread over a wide area, containing a large number of elements, not yet adequately equipped with instrumentation to monitor the loads on various components thereof. For these reasons, mining, and, energy loss calculation in power distribution networks is laborious, and, often, inaccurate, if it is not taked into account the temporal variation of active and reactive loads of network nodes, during the period under review.

2. Deterministic Methods for Computing Technical Losses

In the operation process of MV distribution networks, the technical losses present a special importance. Established methods for determining them should consider the following requirements: the necessary information for computations must be in operative evidences, errors in determining the total values to be minimal always proper purpose computation (post calculation, norms, determines the effectiveness of different measures reduction, etc.). For this purpose must be used appropriate methods to assess the energy technical losses for analysed period, based on calculations made for days or characteristic levels.

For MV distribution networks which operate in radial or tree configuration, one of the methods used in many concrete situations, especially for her simplicity, is the technical losses evaluation using the load curves parameters. This method can lead to percentage errors which may exceed 5% in some cases. The transition from technical power losses to energy losses at peak load on a T_0 analysed time (day, week, month, etc.), is made through the time losses, according to the following expressions (Albert, 1997; Georgescu *et al.*, 2001; Poeată *et al.*, 1987):

$$\Delta W = \Delta P_{\max_\Sigma} t_s + \Delta P_{0_\Sigma} T_0 \tag{2}$$

or

$$\Delta W = \frac{1}{U_n^2}\sum_{i=1}^{n_L} S_{\max_{L_i}}^2 R_{L_i} t_{L_i} + U_n^2 \sum_{i=1}^{n_L} G_{L_i} t_{L_i} + \sum_{k=1}^{m_T} \Delta P_{\mathrm{sc}_{T_k}} \left(\frac{S_{\max_{T_k}}}{S_{n_{T_k}}}\right) t_{T_k} + \sum_{k=1}^{m_T} \Delta P_{0_{T_k}} t_{T_k}\ , \tag{3}$$

where: $\Delta P_{\max_\Sigma}$ is the sum of longitudinal active power losses by heat effect in all network elements at peak load; ΔP_{0_Σ} – the sum of transversal active power losses in all network elements; t_s – time losses; $S_{\max_{L_i}}, S_{\max_{T_k}}$ – maximum load through *i* section and *k* transformer from network; $S_{n_{T_k}}$ – apparent power of the transformer *k* from network; R_{L_i}, G_{L_i} – *i* section resistance and conductance of network; t_{L_i}, t_{T_k} – time losses for *i* section and *k* transformer from network; $\Delta P_{\mathrm{sc}_{T_k}}, \Delta P_{0_{T_k}}$ – losses in short-circuit and empty load for *k* transformer of network; t_{L_i}, t_{T_k} – operation time of *i* section and *k* transformer of network.

To simplify computations for distribution networks which contain a large number of transformers with no data fabrication available, it is recommended for k transformer, the calculation of short-circuit losses and empty load consumption with following regression equations:

$$\Delta P_{\mathrm{sc}_{T_k}} = a_1 S_{n_{T_k}}^{b_1}\ ;\ \ \Delta P_{0_{T_k}} = a_2 S_{n_{T_k}}^{b_2}\ , \tag{4}$$

where α_1 , α_2 , β_1 , β_2 are coefficients which are computed according to transformer type, by regression. Thus, for MV/LV transformers used frequently in our country, the mentioned coefficients for a 0.85 correlation coefficient, have following values: $\alpha_1 = 0.0132$, $\beta_1 = 1.023$, $\alpha_2 = 0.0043$, $\beta_1 = 0.0907$ (for copper-winding transformers), $\alpha_1 = 1.1213$, $\beta_1 = 0.29$, $\alpha_2 = 0.2265$, $\beta_1 = 0.26$ (for aluminium-winding transformers). Considering the dependence relations between the P and Q powers, proposed by various authors were obtained the following expressions for time losses, τ_{s*} according to τ_{p*} and filling coefficient k_{UP} (Albert *et al.*, 1997; Georgescu, 2007; Poeată *et al.*, 1987; Potrebici , 1990):

$$t_{s*} = t_{p*} \cos^2 j_{\max} + k_{UP} \sin^2 j_{\max}\ , \tag{5}$$

$$t_{s*} = \left(t_{p*} - k_{UP}\right)\cos^2 j_{\max} + k_{UP}. \tag{6}$$

Another possibility for establishing a more precise time losses (τ_s) is those which takes into account the period of operation of apparent peak load on analysed duration, according with the following expressions:

$$T_S = \sqrt{\left(T_P \cos j_{\max}\right)^2 + \left(T_Q \sin j_{\max}\right)^2} = \frac{\sqrt{W_a^2 + W_r^2}}{S_{\max}}\ , \tag{7}$$

$$t_s = \left(0.124 + 10^{-4} T_P\right)^2 8,760, \tag{8}$$

where W_a , W_r are the active, respectively reactive energy flow in analysed period.

In distribution networks, if active and reactive loads vary correspondingly, the time losses for apparent load can be determined using the following expression:

$$t_{s*} = t_{P*} \cos^2 j_{\max} + t_{Q*} \sin^2 j_{\max} \tag{9}$$

and in general case of inaccurate variations, with

$$t_{s*} = t_{P*} \cos^2 j_{\max} - k_q t_{Q*} \sin^2 j_{\max}\ , \tag{10}$$

where k_q is the non-lapping over coefficient of the maximum active and reactive power from daily load curve (Albert *et al*., 1997; Georgescu *et al*., 1997).

Energy losses under load, which appear in normal optimized scheme of MV public distribution networks, can be determined by calculating their characteristic seasonal states, summer and winter, in working and rest days. Also, to increase the accuracy in losses determination, can be analysed the characteristic states for each month of year in four standard days (Georgescu *et al*., 1997; Georgescu, 2007). In this case, the energy losses under load are determined for characteristic days, considered constant when they periodically repeated. The influence of irregularity factor due to connecting or disconnecting and load curve deviations of consumer from one day to another can be considered using the irregularity coefficients ($k_{z\,\mathrm{reg}}$), for daily operating states (Albert *et al*., 1997; Georgescu *et al*., 2001; Georgescu, 2007).

The determination with good precision of power ($\Delta P(t)$) and energy (ΔW_{day}) losses is obtained by state repeated calculations, considering the active and reactive daily load curves in network nodes, as 24 hourly levels, for characteristic states analysed, namely

$$\Delta W = \sum_{t=1}^{24} \Delta P_i(t)\,. \tag{11}$$

The energy losses determination for a longer period of time (such as a year) monthly states analysis is necessary, in four days standard, respectively, and the annual energy losses are

$$\Delta W_{\mathrm{year}} = \sum_{l=1}^{12}\sum_{k=1}^{4} n_{lk}\,\Delta W_{\mathrm{day}_{lk}} = \sum_{l=1}^{12}\sum_{k=1}^{4} n_{lk} \sum_{t=1}^{24} \Delta P_{lk}(t), \tag{12}$$

where: n_{lk} is the number of k type standard days in monthly state l; $\Delta W_{\mathrm{day}_{lk}}$ – energy losses associated with k type standard day in monthly state l; $\Delta P_{lk}(t)$ – power losses on t level from k standard day, in monthly state l.

To utilize this calculation method is necessary simultaneous recording of active and reactive daily load curves, for all network nodes analysed, in characteristic daily states. If in operation process is not possible for all network nodes these recordings, the daily load curves can be modelled using a database which contain: the load type profiles of various consumer categories for different months of the year and standard days, the standard structure of consumption from network nodes and a small number of informations obtained through direct measurements in distribution network, such as the measured current in nodes at any hour of day, the daily active energy which flows through node, the loading statistics average coefficients of the transformer, etc. When a part of the load curves associated with network nodes were established by described methodology in order to improve the load curves modelling accuracy, they can be corrected to achieve the balance of hourly powers in a portion or whole distribution network analysed (Georgescu *et al.*, 2001; Georgescu, 2007; Poeată *et al.*, 1987).

In the MV distribution networks developed case, the methodology presented above provides the energy losses evaluation with good precision, having the disadvantage that requires the calculation of a large number of hourly operating states. This drawback can be reduced through development of the load curves from network nodes in a Fourier series, such as (Georgescu *et al.*, 1995; Potrebici, 1990)

$$\begin{cases} P_i(t) = \overline{P_i} + \sum_{k=1}^{N} A_{ik}^{P} \sin\left(\frac{2kp}{T} t\right) + \sum_{k=1}^{N} B_{ik}^{P} \cos\left(\frac{2kp}{T} t\right), \\ Q_i(t) = \overline{Q_i} + \sum_{k=1}^{N} A_{ik}^{Q} \sin\left(\frac{2kp}{T} t\right) + \sum_{k=1}^{N} B_{ik}^{Q} \cos\left(\frac{2kp}{T} t\right), \end{cases} \tag{13}$$

where: N is the number of harmonics taken into account in series development; t – number of hourly level from daily load curves; $\overline{P_i}$, $\overline{Q_i}$ – average values of active and reactive power from the i node daily load curve; A_{ik}^P, B_{ik}^P, A_{ik}^Q, B_{ik}^Q – Fourier coefficients corresponding to k harmonic, for active and, respectively, reactive power of node i.

Considering the load curves developed in Fourier series, for public distribution networks operating in radial configuration of normal steady state, the power losses under load on a network element with resistance R can be computed using only loads average values or the Fourier coefficients of the different harmonics according to the relation

$$\Delta W = \overline{\Delta P} T + \sum_{t=1}^{N} \left(\Delta P_k^{'} + \Delta P_k^{''}\right) T + e_W, \tag{14}$$

where: $\overline{\Delta P} = R\left(\overline{P}^2 + \overline{Q}^2\right) \Big/ U^2$ is the active power losses due to active and reactive average loads flows;

$$\Delta P^{'} = \frac{R}{U^2}\left[\left(\frac{A_k^P}{\sqrt{2}}\right)^2 + \left(\frac{A_k^Q}{\sqrt{2}}\right)^2\right]; \quad \Delta P^{''} = \frac{R}{U^2}\left[\left(\frac{B_k^P}{\sqrt{2}}\right)^2 + \left(\frac{B_k^Q}{\sqrt{2}}\right)^2\right]$$

– power losses associated with k harmonic in two steady-states of the network nodes considering the following loads: $P_{ik}^{'} = A_{ik}^{P} / \sqrt{2}$; $Q_{ik}^{'} = A_{ik}^{Q} / \sqrt{2}$; $P_{ik}^{''} = B_{ik}^{P} / \sqrt{2}$; $Q_{ik}^{''} = B_{ik}^{Q} / \sqrt{2}$, respectively; ε_W – the error caused by neglecting harmonics with rank greater then N of the Fourier series.

According to the mathematical model above described, for computing the energy losses under load in distribution network it is necessary to analyse the $2N + 1$ operating states: one state for active and reactive loads from network nodes and twin steady-states for each harmonic considered. From made studies has been found that the error in losses evaluation under load is kept fewer than 2.5%, if in Fourier series development is considered only three harmonics (Georgescu, 2007; Potrebici, 1990).

Another methodology for compute the energy losses under load, which occur in public networks, supposes the knowledge or monitoring of active and reactive power flows in various elements of MV distribution network in analysed period. It is also necessary to know the relative dispersions $\beta^2(P)$ and $\beta^2(Q)$, compared with the average value, for active and reactive power of the daily load curves in characteristic days (Georgescu, 2007; Georgescu *et al.*, 1999; Ionescu *et al.*, 1998)

$$\begin{cases} b^2(P) = \dfrac{\dfrac{1}{n}\displaystyle\sum_{t=1}^{n}\left(P_i - \overline{P}\right)^2}{\left(\overline{P}\right)^2} = \dfrac{1}{n}\displaystyle\sum_{t=1}^{n}\left(P_i^* - 1\right)^2, \\ b^2(Q) = \dfrac{\dfrac{1}{n}\displaystyle\sum_{t=1}^{n}\left(Q_i - \overline{Q}\right)^2}{\left(\overline{Q}\right)^2} = \dfrac{1}{n}\displaystyle\sum_{t=1}^{n}\left(Q_i^* - 1\right)^2 \end{cases} \tag{15}$$

where: n is the number of measurements during the analysed period; P_i , Q_i – active and, respectively, reactive power measured in i range; $\overline{P}$, $\overline{Q}$ – the P_i and Q_i average values measured during the analysis.

Using this methodology, the energy losses under load, for a year, which appear on a network element with R resistance, can be evaluated with the expression

$$\Delta W = \frac{R}{24U_n^2}\sum_{l=1}^{12}\sum_{k=1}^{4} N_{lk}\left\{W_{a_{lk}}^2\left[1 + b_{lk}^2(P)\right] + W_{r_{lk}}^2\left[1 + b_{lk}^2(Q)\right]\right\}10^{-3}, \tag{16}$$

where: $W_{a_{lk}}$, $W_{r_{lk}}$ represents the active and, respectively, the reactive energy flows in k type standard day, of the month l expressed in kWh and kVAr respectively; N_{lk} – number of *k* type standard days in month *l*, $b_{lk}^2(P)$, $b_{lk}^2(Q)$ – relative dispersion toward the average value of active and, respectively, reactive loads for *k* type standard day, in month *l*.

For the consumers supplied with electricity from public distribution networks through statistical processing of a large number of daily load curves, in the specialized literature (Georgescu *et al.*, 2001; Georgescu, 2007; Georgescu *et al.*, 1999) are presented the relative dispersions corresponding to the urban/rural household and tertiary consumption (hotel, school, hospital, etc.). The presented method leads to satisfactory results in the accurate assessment of energy losses in public distribution networks, as percentage errors in the range ±3%…±3.5%.

3. Examples, Obtained Results and Comparisons

Using different methods or mathematical models for computing technical losses in MV public networks were analysed a relatively large number of electrical networks, aiming to establish the level of these losses and comparing the results provided by different considered methods. For technical losses computation were used a software application for each method specified in detail previously (Georgescu *et al.*, 2001; Georgescu, 2007; Georgescu *et al.*, 1995; Georgescu 1999).

Thus, for MV networks analysed were considered the following variants for technical losses computation, depending on the available data obtained by monitoring the loads (energy), which are recorded by existing meters or by three phase electronic meters installed in certain points of the network, and the LV substation bars current intensity, measured at a certain time of analysed day:

a) Daily load curves of active and reactive power on each departure (MV feeders) from station and all substations, obtained using ALPHA three phase electronic meters.

b) Installation of active and reactive energy meters on each MV departure or feeder from station and each LV substation bars. In this way were available for computation the active and reactive energies in 24 h, to each departure from station and each substation. The daily load curves for each network node were modelled using the typical load profiles of consumers; the structure consumption of nodes and daily active energy which flows through networks node was studied using variant B_{PT}. Also, another B_{SF} study variant was considered, when the daily load curves of the nodes were developed in Fourier series. The load curves modelled in the two specified variants have been corrected to meet the balance of active and reactive power on each MV feeder, and on a whole distribution network analysed, respectively.

c) The active and reactive daily load curves from network nodes were modelled in similar way as *B* variant, except that, in this case, were attached the measured currents on the LV substations, at certain hours of day, thereby obtaining two study variants – C_{PT} and C_{SF} – with the same characteristics as above variant. Also, in this case, were made corrections regarding load curves modelled, and for computations, the active and reactive daily load curves of the network nodes were considered as 24 hourly levels or developed into Fourier series.

d) The installation of energy meters, in similar way as in *B* variant, where active and reactive energy on the LV stations bars are available for computation. In this study variant the losses in the network are determined according to available data and relative dispersions toward the average value of active and reactive loads.

It is noted that the database containing the typical load profiles for different categories of households and tertiary consumers supplied with electricity from public distribution systems, in standard day, during a year, was updated in 2009…2010 years.

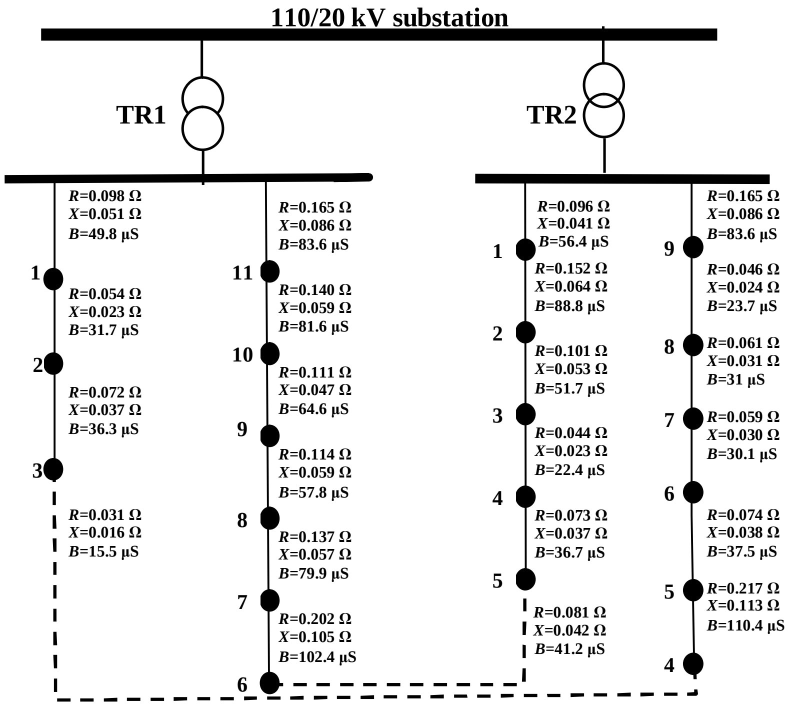

Fig. 1 – Single line diagram of the analysed MV distribution network.

In Table 1 are presented the results obtained by using the software application developed to assess the power and active energy technical losses under symmetrical load, for all variants aforementioned. For this purpose were analysed an existing MV public network, corresponding to a 110/20 kV substation which supplies with electricity a large number of urban households and a smaller number of tertiary consumers: thermal points, central heating, church, school, etc. The single line diagram of the MV network analysed with topological and material parameters is represented in Fig. 1.

Table 1
Active Power Loss of the Peak Load on a Working Day from December

Disponible data variant Calculation Method	Distribution network elements		Distributors (departures) of MV transformer station								Total MV distribution network	
			Departure PT 600		Departure PT 599		Departure PT 607		Departure PT 713			
			kW	%	kW	%	kW	%	kW	%	kW	%
A	Lines		0.669	0.053	1.764	0.118	1.524	0.117	1.226	0.088	5.183	0.095
	PT	Cu	11.86	0.937	8.765	0.587	9.559	0.735	9.068	0.648	39.25	0,720
		Fe	3.530	0.279	7.430	0.497	5.950	0.458	5.760	0.411	22.67	0,415
	Total		16.149	1.269	17.959	1.202	17.033	1.310	16.054	1.147	67.20	1.230
B_{PT}	Lines		0.656	0.052	1.718	0.115	1.532	0.117	1.265	0.090	5.171	0.095
	PT	Cu	12.03	0.953	8.652	0.580	9.564	0.736	9.122	0.652	39.37	0.721
		Fe	3.530	0.279	7.430	0.497	5.950	0.458	5.760	0.411	22.67	0.415
	Total		16.216	1.284	17.800	1.192	17.049	1.311	16.147	1.153	67.231	1.231
B_{SF}	Lines		0.559	0.044	1.587	0.106	1.388	0.107	1.139	0.081	4.673	0.086
	PT	Cu	11.16	0.879	7.492	0.502	8.795	0.677	8.794	0.628	36.24	0.664
		Fe	3.530	0.279	7.430	0.497	5.950	0.458	5.760	0.411	22.67	0.415
	Total		15.249	1.202	16.509	1.105	16.133	1.242	15.693	1.120	63.58	1.165
C_{PT}	Lines		0.581	0.046	1.815	0.122	1.519	0.117	1.141	0.082	5.056	0.093
	PT	Cu	11.21	0.886	8.823	0.591	9.517	0.732	8.811	0.629	38.36	0.703
		Fe	3.530	0.279	7.430	0.497	5.950	0.458	5.760	0.411	22.67	0.415
	Total		15.321	1.211	18.068	1.210	16.986	1.307	15.712	1.122	66.08	1.211
C_{SF}	Lines		0.509	0.040	1.612	0.108	1.344	0.103	0.923	0.066	4.388	0.080
	PT	Cu	10.35	0.818	7.622	0.511	8.537	0.657	7.988	0.571	34.49	0.632
		Fe	3.530	0.279	7.430	0.497	5.950	0.458	5.760	0.411	22.67	0.415
	Total		14.289	1.137	16.664	1.116	15.891	1.218	14.671	1.048	61.55	1.127

The 110/20 kV step-down transformer station is equipped with two transformers of the same power, each with S_n = 25 MVA, which supply a MV bars sector; these bars are longitudinally sectioned. The analysed network has four MV underground feeders. In normal steady-state, the MV distribution network operate in radial configuration, supplying with electricity 22 substation (*PT*) of 20/0.4 kV each one, equipped with transformers of 400 kVA or 630 kVA apparent rated power. The MV cables used are A2YSY and NAHKBA, with 150 mm^2 or 185 mm^2 sections.

To compute the power loss of maximum daily load duration, and daily energy losses respectively, by all methods previously mentioned, was adopted a simplified assumption for transversal active power losses (active power losses in MV cables and iron transformer from substations), which are considered constant, thus neglecting their variation with the voltage level in different hourly state, throughout the day. As regards the power losses at peak load and daily energy losses, these were computed for all standard days of December 2010. For lack of space, below, are clearly presented only the obtained results for a working day (Tuesday, Wednesday, Thursday) and a rest day (Sunday) in all methods of computation presented and for all options mentioned according to obtained data by measurements or recordings from analysed network (*A*, *B*, *C*, *D*), which are the input data for each computation method used.

Thus, in Tables 1 and 2 are presented the obtained results using the software application, regarding the active power losses of the peak load duration from lines and transformers of the substation, for a working day, and rest day, respectively, in December 2010, for all study variants above presented. Active power losses in peak load duration over a day are presented both in absolute size (kW) and percentage (%) reported to the maximum load of each feeder or to the entire network analysed.

Table 2
Active Power Loss of the Peak Load on a Rest Day from December

Disponible data variant Calculation Method	Distribution network elements		Distributors (departures) of MV transformer station								Total MV distribution network	
			Departure PT 600		Departure PT 599		Departure PT 607		Departure PT 713			
			kW	%	kW	%	kW	%	kW	%	kW	%
A	Lines		0.435	0.043	0.977	0.089	1.012	0.097	0.749	0.071	3.193	0.076
	PT	Cu	8.198	0.805	4.903	0.415	7.397	0.711	5.981	0.567	26.479	0.628
		Fe	3.530	0.346	7.430	0.675	5.950	0.572	5.760	0.546	22.670	0.538
	Total		12.163	1.194	13.310	1.209	14.359	1.380	12.490	1.184	52.342	1.242
B_{PT}	Lines		0.436	0.043	0.974	0.088	1.031	0.099	0.748	0.071	3.189	0.075
	PT	Cu	8.264	0.810	4.918	0.447	7.410	0.712	5.972	0.566	26.564	0.630
		Fe	3.530	0.346	7.430	0.675	5.950	0.572	5.760	0.546	22.670	0.538
	Total		12.230	1.199	13.322	1.210	14.391	1.382	12.480	1.183	52.423	1.244
B_{SF}	Lines		0.397	0.039	0.818	0.074	0.897	0.086	0.695	0.066	2.208	0.067
	PT	Cu	7.334	0.719	4.019	0.365	7.103	0.682	5.180	0.491	23.636	0.561
		Fe	3.530	0.346	7.430	0.675	9.950	0.572	5.760	0.546	22.670	0.538
	Total		11.261	1.104	12.267	1.114	13.950	1.340	11.635	1.103	49.113	1.165
C_{PT}	Lines		0.400	0.039	0.944	0.086	0.999	0.096	0.675	0.064	3.018	0.072
	PT	Cu	7.684	0.753	4.542	0.413	7.288	0.700	4.893	0.464	24.407	0.579
		Fe	3.530	0.346	7.430	0.675	5.950	0.572	5.760	0.546	22.670	0.538
	Total		11.614	1.138	12.196	1.174	14.237	1.368	11.328	1.074	50.095	1.189
C_{SF}	Lines		0.381	0.037	0.798	0.073	0.842	0.081	0.602	0.057	2.623	0.062
	PT	Cu	7.107	0.697	3.886	0.353	6.872	0.660	4.521	0.429	22.386	0.531
		Fe	3.530	0.346	7.430	0.675	5.950	0.572	5.760	0.546	22.670	0.538
	Total		11.018	1.080	12.114	1.101	13.664	1.313	10.883	1.032	47.679	1.131

Table 3
Daily Active Energy Losses in Public Distribution for a Working Day in December 2010

Disponible data variant Calculation Method	Distribution network elements	Distributors (departures) of MV transformer station								Total MV distribution network	
		Departure PT 600		Departure PT 599		Departure PT 607		Departure PT 713			
		kWh	%	kWh	%	kWh	%	kWh	%	kWh	%
A	Lines	9.086	0.054	19.214	0.100	17.202	0.098	15.074	0.077	60.576	0.082
	Transformer	130.898	0.779	95.583	0.497	108.232	0.620	105.884	0.542	440.598	0.603
	Total	139.984	0.833	114.797	0.597	125.454	0.718	120.958	0.619	501.193	0.685
B_{PT}	Lines	9.035	0.054	19.014	0.099	17.121	0.098	15.134	0.077	60.304	0.082
	Transformer	131.090	0.780	95.483	0.496	108.140	0.619	105.278	0.538	439.991	0.602
	Total	140.125	0.834	114.497	0.595	125.261	0.717	120.412	0.615	500.295	0.684
B_{SF}	Lines	8.988	0.053	18.365	0.095	16.793	0.096	14.624	0.075	58.770	0.080
	Transformer	129.438	0.775	94.047	0.489	106.838	0.612	102.779	0.526	430.102	0.589
	Total	137.426	0.828	112.412	0.584	123.631	0.708	117.403	0.601	488.872	0.669
C_{PT}	Lines	8.498	0.050	17.879	0.093	17.004	0.097	14.804	0.075	58.185	0.079
	Transformer	124.757	0.742	91.253	0.474	106.976	0.613	103.967	0.532	427.953	0.586
	Total	133.255	0.792	109.032	0.567	123.980	0.710	118.771	0.607	486.138	0.665
C_{SF}	Lines	8.359	0.049	16.993	0.088	16.023	0.092	14.764	0.075	56.143	0.077
	Transformer	121.686	0.730	90.746	0.473	98.254	0.563	99.886	0.511	411.572	0.563
	Total	131.045	0.779	107.739	0.560	114.277	0.655	114.650	0.586	467.715	0.640

Similarly in Tables 3 and 4 are presented daily active energy losses by thermal effect for working and rest day; the values of those losses are presented both in absolute values (kWh) and percentage (%) reported to active energy which flows on each feeder of network in a day or the daily active energy which flows across the network analysis. It should be noted that in A, B_{PT}, C_{PT} variants the daily active power losses were determined by summing the active power losses for each hourly level of daily load curves. Regarding B_{SF} and C_{SF} variants, to determine daily energy losses were calculated following steady-states: a state for average active and reactive loads of network nodes and two stationary regimes for each of the three harmonics taken into account.

Table 4

Daily Active Energy Losses in the Public Distribution for a Rest Day in December 2010

Disponible data variant Calculation Method	Distribution network elements	MV feeders (departures) of station								Total MV distribution network	
		Departure PT 600		Departure PT 599		Departure PT 607		Departure PT 713			
		kWh	%	kWh	%	kWh	%	kWh	%	kWh	%
A	Lines	4,652	0.036	10,815	0.071	10,507	0.077	7,912	0.056	33,886	0.060
	Transformer	79,875	0.614	48,011	0.318	71,832	0.528	54,025	0.386	253,743	0.456
	Total	84,527	0.650	58,826	0.389	82,339	0.605	61,937	0.442	287,629	0.516
B_{PT}	Lines	4,461	0.034	10,916	0.072	10,612	0.078	7,986	0.057	33,975	0.061
	Transformer	80,027	0.615	48,145	0.319	72,443	0.533	54,418	0.389	255,033	0.458
	Total	84,488	0.649	59,061	0.391	83,055	0.611	62,404	0.446	289,008	0.519
B_{SF}	Lines	4,328	0.033	10,297	0.068	10,069	0.074	7,669	0.055	32,363	0.058
	Transformer	78,975	0.607	47,678	0.316	71,695	0.527	53,917	0.385	252,265	0.452
	Total	83,303	0.640	57,975	0.384	81,764	0.601	61,586	0.440	284,628	0.510
C_{PT}	Lines	3,988	0.031	10,291	0.068	10,475	0.077	7,809	0.055	32,563	0.058
	Transformer	75,537	0.581	48,117	0.318	72,028	0.529	54,112	0.387	249,794	0.448
	Total	79,525	0.612	58,408	0.386	82,503	0.606	61,912	0.442	282,348	0.506
C_{SF}	Lines	3,881	0.030	9,987	0.066	9,843	0.072	7,507	0.053	31,218	0.056
	Transformer	75,324	0.579	46,857	0.310	70,996	0.522	53,065	0.379	246,242	0.442
	Total	79,205	0.609	56,844	0.376	80,839	0.594	60,572	0.432	277,459	0.498

Table 5

Daily Active Energy Losses Determined with the Methods of the Load Curves Parameters, or Daily Energy/Relative Dispersions, Compared to Average Daily Load for a Working Day in December

Computation Method	Distribution network elements	Daily energy losses in network elements			
		Working day		Rest day	
		kWh	%	kWh	%
Energy and relative dispersions	Lines	55,342	0.076	30,715	0.055
	Windings transf.	405,786	0.556	235,637	0.423
	Total	461,128	0.632	366,352	0.478
Parameters of daily load curves	Lines	50,672	0.069	26,963	0.048
	Windings transf.	374,514	0.512	206,832	0.371
	Total	425,186	0.581	233,795	0.419

Also, in Table 5 are presented the obtained results of the daily active energy losses under load, which appear in MV public distribution network elements by heat effect (Joule). These results were obtained using the following methods:

a) Parameters of daily load curves method, when the power losses at peak load duration were considered as indicated in Tables 1 and 2, correspond to the exact variant of the input data – variant A. For the maximum load duration and for losses duration of different categories of household and tertiary sectors have been used updated values for the year 2010.

b) Knowing the daily active and reactive energy, as input data, which flow from LV substation bars and relative dispersions toward the average value of active and reactive loads – variant *D*. Similarly, for the relative dispersions aforementioned were used updated values of these parameters in the year 2010.

4. Conclusions

The operation in a competitive environment leads to enhance efforts made by territorial electricity distribution unit in order to increase efficiency and service quality.

Actually, the increased performance of computations or electronic systems and digital data acquisition (records relating to electric loads or the daily load curves, etc.), inevitably leads to the development of concepts and methods of supervision (monitoring) and management of public electricity distribution systems, with very positive consequences in improving their technical and economical parameters.

Considering the low level monitoring of electrical energy repartition and distribution systems which currently exists in our country, to compute the permanent steady-state, and power and energy losses in the elements of these systems, a mathematical modelling of daily load curves of systems nodes is proposed, in standard days over a year, using typical load profiles of consumers, the consumption structure of nodes (expressed as percentages), and a few direct measurements in distribution network, such as: daily energy which flows by node within 24 h, the measured current in network node at a some time from day, etc.

For the computation of steady-state and daily technical losses of energy under load, a series of mathematical models and software application are proposed which allow these losses using daily load curves in 24 hourly levels, by making some repeated computations of the state for each hour considering the daily load curves developed in Fourier series, followed by calculation of 3×2 steady-states: a state for daily average load and two states for each harmonic considered in the decomposition series of daily load curves modeled and corrected in order to achieve balance in distribution network analysed, between the hourly energy injected and energy sold of the different consumers supplied from the grid.

It can be seen that the obtained results by using mathematical models and software application proposed in the paper, to assess daily active power and energy losses, are similar to those provided in variant a), when the daily load curves of all analysed distribution network nodes were monitored by recording them using ALPHA meter.

Regarding the result accuracy (error) in assessing the losses evaluation, according to results presented in this paper, it must use, in order, the following mathematical models: the typical load profiles for modelling the daily load curves in the form of hourly level, attaching the energy flow through nodes or the current at a some hour of day; the Fourier series development of the daily load curves modelled by typical load profiles; the active and reactive energies flow through the network nodes, accompanied by the relative dispersions of loads; the load curves parameters method. Note that the load curves parameters method leads to large errors in evaluating the daily energy losses.

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ASPECTE PRIVIND UNELE MODELE MATEMATICE ŞI PROGRAME DE CALCUL DESTINATE EVALUĂRII ÎN EXPLOATARE A PIERDERILOR TEHNICE ÎN REŢELELE PUBLICE DE DISTRIBUŢIE DE MEDIE TENSIUNE

(Rezumat)

În funcţie de datele disponibile, în lucrare sunt prezentate câteva modele matematice şi programe de calcul pentru evaluarea pierderilor de putere şi energie care apar în elementele componente (linii şi transformatoare) ale reţelelor publice de distribuţie de medie tensiune. Sunt trecute în revistă atât modelele matematice tradiţionale, cât şi cele bazate pe profilele tip de sarcină ale diferitelor categorii de consumatori, precum şi dezvoltarea în serii Fourier a acestor profile tip de sarcină. De asemenea sunt prezentate rezultatele obţinute cu ajutorul diferitelor modele matematice, fiind însoţite de observaţii şi concluzii.