Electric Energy Losses Estimation in Power Distribution System—Tuzla Canton Case Study

Šeila Gruhonjić Ferhatbegović[1](✉), Izet Džananović[1],
and Samir Avdaković[2]

[1] PE Elektroprivreda B&H, Sarajevo, Bosnia and Herzegovina
`s.gruhonjic@epbih.ba`
[2] Faculty of Electrical Engineering, University of Sarajevo, Sarajevo, Bosnia and Herzegovina

Abstract. The method for estimation of electrical energy losses in distribution system from the place of taking electrical energy from network of transmission company or other suppliers to the place of delivery to the end customers and determination the structure of losses by voltage levels is presented. For part of the distribution network for which the losses are calculated, constant losses, load dependent losses and losses in components of electrodistribution network are taken into account. Distribution losses by voltage levels is made by balancing the total electrical energy losses and losses estimated by method of stationary load flow calculations on medium-voltage (MV) of certain electrodistribution network. The presented method is very practical and by its application the parts of electrodistribution system with increased losses are located with high reliability. Results of analysis of electrical energy losses, which is done by presented method, can be taken as a reliable basis for taking action in the aim of reducing total losses in electrodistribution network. The results of practical analysis are presented for the area of Tuzla Canton—Bosnia and Herzegovina.

1 Introduction

The problem of electrical power and energy losses in electrodistribution systems is continuing and relevant topic for companies engaged in distribution of electrical energy. The electrical power losses respectively electrical energy losses are presented as one of the key indicator of business efficiency and quality of the business processes of electrical energy distribution. The total losses of electrical energy in distribution system are monitored on a monthly and annual basis and calculated as the difference between total taken and delivered electrical energy. Technical (physical) and non-technical (i.e. commercial) losses are included in the total losses. It is necessary to determine the technical and commercial losses by analysis in the aim of making business decisions which are intended to reduce the total amount of electrical energy losses in the observed network. Technical losses in the network are calculated by using appropriate computational method, but it should be noted that the estimation of losses in the distribution network especially demanding because of the specific topology and a

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large number of customers. In electrodistribution companies there are commonly used computer programs for calculation of electrical power losses and methods for calculation of electrical losses has been developed too. Electric power distribution system, for which the losses are calculated should be fully modeled by applying the methods for modeling all elements of the system. Due to unavailability of time load diagram and large number of customer connections, certain approximations often are applied in the estimations of losses in the aim of obtaining a more reliable results from the available data. Generally, in the literature a large number of paper dealing with domain of losses in electrodistribution systems can be found [1–6].

The current method of monitoring losses in the actual electrodistribution (in the part relating to the Tuzla Canton) are described in the paper and the procedure of estimation technical losses of electrical power and electrical energy in 10 and 20 kV network, transformer 10/0,4 and 20/0,4 kV are shown. For the estimated technical losses of electrical power and electrical energy on the observed network part, it is necessary to determine structure of losses to the network elements and make separation of losses to constant losses and load dependent losses. The presented methodology of losses estimation is based on the existing resources in terms of available measurement of electrical energy, calculations and network model. The purpose of the analysis of energy losses is to locate places in the network where the losses are greater than the average. After the analysis the corrective investment activities are undertaken, such as rehabilitation or reconstrucions of existing networks or building new parts of network, or procedures and activities to optimize load distribution, balancing network and control of connection places at the end customers are implemented in the existing network. In the case of losses analysis, it operates with a large number of data, but the main objective of analysis is to identify the parts of the network to which is necessary to implement corrective actions and by priority of largest effect (economic and technical).

The estimation and monitoring methodology of losses are coordinated with business policy and strategic business decision in the field of electrical energy losses in distribution activities of JP Elektroprivreda BiH d.d. Sarajevo (JP EP BiH). Distribution activity of electrical energy in JP EP BiH is realised in five Branches (Bihać, Mostar, Sarajevo, Tuzla i Zenica) hereinafter described as the distribution parts or abbreviated ED. Branches are divided into several business units of distribution (PJD), which usually include the area of a municipality. A concrete example of analysis of losses for the Branch Tuzla (ED Tuzla) and twelve associated PJD, is presented in the paper, in 2015.

Generaly observed, the total losses of electrical energy in electrodistribution network of JP EP BiH, are in the level of losses in electrodistribution networks in neighboring countries or even lower. According to available reports, technical losses in the distribution, according to the experience of the developed electric power company, should not exceed 4,5% of taken electrical energy. The method of losses separation by voltage levels can be carried out for distribution areas which belong to certain PJD, supply transformer station (TS) or 10(20) kV feeder. The advantage of this method is application to smaller distribution areas (PJD, TS or 10 and 20 kV outputs) to get a more realistic presentation about causes of losses and easier determination of methods to reduce them.

2 Methodology of Estimation and Monitoring Losses in ED Units of JP EP BiH

2.1 Tuzla Canton and Related Power Distribution Grid

Tuzla Canton is one of the ten cantons of the Federation of Bosnia and Herzegovina, Bosnia and Herzegovina. Canton is located in the northeastern part of Bosnia and Herzegovina headquartered in Tuzla. The area of canton is 2.649 km^2, accounting for 10.14% of the Federation of Bosnia and Herzegovina. Canton consists of 13 municipalities, namely: Banovići, Čelić, Doboj Istok, Gračanica, Gradačac, Kalesija, Kladanj, Lukavac, Sapna, Srebrenik, Teočak, Tuzla i Živinice. The position of the canton in B&H is shown in Fig. 1.

Fig. 1. Tuzla Canton

The area of Tuzla Canton has a population of about 500.000 inhabitants. The annual consumption of electrical energy is around 1.100 GWh. The average peak load consumption of ED Tuzla is about 220 MW. From the structure of delivered electrical energy in ED Tuzla can be seen that the most electrical energy delivered to households. For example, in 2015, industrial consumption at 35 kV voltage was 16,32%, and consumption on 10(20) kV voltage was 15,97% of total consumption of electrical energy. Electrical energy supplied on 0,4 kV voltage level amounted to 67,71% of the total electrical energy supplied in ED Tuzla. Electrical energy distribution at voltage level of 20 kV is represented only in the distribution areas of Sapna and Tečak. In the area of ED Tuzla is still significantly represented 35 kV network and transformations 35/10(20) kV. However, in the future it is planned to move to a one level of medium voltage (20 kV) and direct transformation. In the present circumstances, the jurisdiction of power distribution companies starts from medium voltage, and TS 110/x kV are under the jurisdiction of the transmission company. The total length of overhead power networks of ED Tuzla, which operates at voltage level 10 and 20 kV, is about 1.313 km, and cable network is about 366 km. The recorded overhead low-voltage network has length of 6.489 km and cable network is about 321 km. The models of MV network for estimation have satisfactory reliability and comply with the situation in the field, while the models of LV networks should be further developed.

2.2 Estimation of Total Losses

Electrical energy losses are estimated on a monthly and annual basis for all distribution parts of JP EP BiH. In composition of certain Branch, losses are calculated separately by respective business units of distribution (PJD). For example, in the case of ED Tuzla, the total losses and losses for each of the twelve PJD are calculated. Losses that are planned in the energy balance are the total losses incurred as the difference of taken electrical energy and supplied electrical energy to customers for a particular accounting period:

$$w_{loss}[\%] = \frac{W_{tak}[kWh] - W_{\sup}[kWh]}{W_{tak}[kWh]} \cdot 100[\%] \qquad (1)$$

where is:

- W_{tak}—taken electrical energy from supplier
- W_{sup}—supplied electrical energy to customers, for certain distribution area, i.e. for certain PJD

The losses of electrical energy estimated in this manner consist technical and all other losses, also called commercial. The locations where taken electrical energy W_{pr} are measured are installed on the locations of taking electrical energy from suppliers on 10 (20) kV or 35 kV voltage in tie or supplied transformer station (TS), and supplied electrical energy W_{isp} is measured by measuring devices installed at the locations of end customers on 35 kV, 10(20) kV i 0,4 kV voltage levels. Managing of electrical energy losses means systematic monitoring and analysis of the losses on a monthly and annual

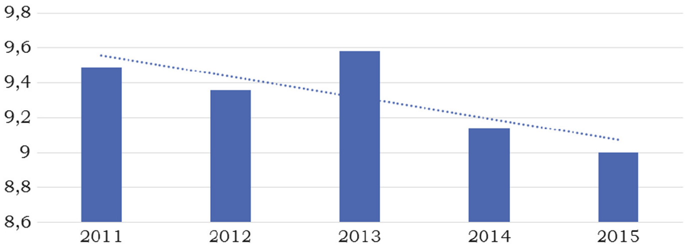

Fig. 2. Electrical energy losses (%) in JP Elektroprivreda BiH (2011–2015)

basis and take procedures to reduce them in order to achieve the planned objectives. The losses of electrical energy in JP EP BiH are shown in the Fig. 2 (2011–2015.).

2.3 Technical Losses in Distribution MV Network

Technical losses in the distribution system components are divided into losses dependent on the voltage and losses dependent on the current. Losses dependent on voltage are called idle running losses. Idle running losses are constant losses and due to maintaining power network in station of continuing operation ability for supplying customers with electrical energy. Idle running losses are consisted from losses in the transformer cores and dielectric losses in cables and capacitors. Losses which depend on the current are subsequent of current passing through the components of the power system and they are dependent on the current squared or on the amount of transmitted electrical energy. Losses in transmission networks are smaller than the losses in distribution networks and technical losses in transmission networks can be precisely determined in relation to the losses in distribution networks. Technical losses depend on the length and cross section in the network. Calculation of technical losses of electrical power and electrical energy can be made only if a model of the network and certain values of distributed loads are available. The results of calculation of power flows, which are presented in this paper have been calculated in the software package PowerCad. Stationary power flow calculation was made according to the method of peak load [6–10]. Calculations are performed separately for each PJD and calculated losses are technical losses of electrical power in: 10(20) kV network, transformers 10 (20)/0,4 kV, transformers in TS 35/10(20) kV and in 35 kV feeders. The values of distributed loads are set at 0.4 kV side of TS 10(20)/0,4 kV. For a reliable calculation of the power losses, in addition to the so-called passive network model (drawn all lines and transformers) it is very important to specify the correct input on the average peak load. Based on the calculation results of electric power losses, the approximate calculation of electrical energy losses has been done on the annual level. For operating conditions, corresponding to the measurements of the load diagram on 10(20) kV feeders and transformers in TS, the constant losses (P_0) are separated, which create annual losses of electrical energy W_0:

$$W_0 = P_0 \cdot 8760 \tag{2}$$

For the calculation of user time and annual losses of energy, it can be used the next relation:

$$T_{loss} = \frac{W_{\mathrm{var}}}{P_{\mathrm{var}}} = \left[a \cdot T_{up} + (1 - a) \cdot \frac{T_{up}^2}{8760}\right] \tag{3}$$

where is:

- T_{loss}—time of losses duration or estimated user time
- W_{var}—annual losses of electrical energy dependent on loads
- $P_{var} = P_{loss} - P_o$—losses of electrical power dependent on loads

- $T_{up} = \frac{W_{ukg}}{P_{\max}}$—user time
- $P_{\max}$—peak power in the reporting period
- W_{ukg}—total annual electrical energy supply
- A—constant that is in distribution networks, depending on the shape of load duration curve, usually ranges from 0.15 to 0.2. This calculation assumed the amount of constant a = 0.17.

Based on the calculated user time for all 10(20) kV feeders of certain distribution area it is possible to make the annual estimation of electrical energy losses. During estimation, idle running losses and variable losses dependent on the loads are calculated for all 10(20) kV feeders grouped according to the corresponding TS and PJD [11, 12]. In general, the results obtained from the steady state load flow, most are used in the planning of network development (building of new substations and parts of the network, the transition to the voltage level of 20 kV) and checking of operating conditions. Due to lack of measurements on TS 10(20)/0,4 kV, the data obtained accordind to the method of peak loads are also used when checking the possibilities of connection new customers to the existing TS 10(20)/0,4 kV. The percentage of technical losses of electrical energy can be considered as an indicator of network development and representation of the cable network in relation to the network with Al–Fe conductors. To achieve as small as possible losses it is necessary to plan operation conditions with optimal power flow and minimal flow of reactive power. Additionally, it is needed to plan appropriate cross sections of conductors and transformer schedules in accordance with the actual needs of consumers.

2.3.1 Structure of Losses in 10(20) kV Network

The amount of calculated technical losses in 10(20) kV network is very different for different distribution areas. In order to control and planning to reduce losses the structure of technical losses in terms of how many losses relate to network elements is considered. The value of losses by network elements is observed and the basic separation is transformer losses and conductor losses. It can also be viewed as a separation in idle running losses and losses dependent of load (variable losses). For example, to give an idea about specific distribution area in connect to technical losses, the following indicators can be calculated [11].

$$Efekt.\_TR\_10(20)/0,4kV = \frac{Losses\_in\_TR\_10(20)/0,4kV\_[kWh]}{Number\_TR\_10(20)/0,4kV} \quad (4)$$

$$Build.\_network = \frac{Losses\_in\_network\_10(20)kV\_[kWh]}{Length\_network\_10(20)kV\_[m]} \quad (5)$$

The above indicators are used to assess 10(20) kV network construction and proper scheduling capacity of transformers 10(20)/0,4 kV (avoid substantial underloaded transformers and eliminate overloaded). In principle certain distribution areas has a favorable status with regard to energy losses if the value of these indicators are less. In the case of considered the one electrodistribution unit (e.g. Branch ED Tuzla), the average value of the indicators is calculated. For certain distribution areas within the observed ED, whose indicators calculated according to (4) and (5) deviate from the average values, specified corrections in the network should be planned in order to reduce losses. The most common corrections are: optimizing of operating conditions, changes in cross section, cabling of overhead feeders, replacing of overloaded and significantly underloaded transformer, transition to 20 kV voltage level or planning a new supply point of 110/10(20) kV. Separated electrical energy losses by network elements are calculated as a percentage level in relation to the total taken electrical energy, in order to be comparable with the total realized losses on a monthly basis.

2.4 Estimation of Losses in 0.4 kV Network

For the low voltage networks, which include the main lines and house connections, determination of energy losses dependent of loads is very difficult. A set of variable data which are used in calculations represents the main problem, in making analysis of electrical power and energy losses in 0.4 kV network. Namely, the losses are dependent on: the length of lines, resistance of lines, density of the connected customers, the intensity of demand for power of individual customers as well as the simultaneously of loads of individual customers, coefficient of symmetry in the network and other factors. Changing of certain parameters causes a change in electrical power losses in specified time unit, i.e. electrical energy losses for specified time period. In the literature we can find the proposed methods for determination of active power and energy losses in three phase LV networks, which are asymmetrically loaded. However, from the aspect of exploitation of 0.4 kV network, it is possible to conclude that in practice rarely, almost never, are found lines with concentrated load at the end of lines, or loads that are usually distributed along the feeder (distributed loads). In addition, the simultaneous measurement of currents in power lines with distributed loads, in several places along the feeder, if very difficult and sometimes impossible [6]. For example, in JP EP BiH, as well as in most other electric power company there is a problem about modeling complete 0.4 kV network. Calculations in 0.4 kV network are obtained for the purpose of verifying the interpolation of the new TS or checking of time response of fuses. However, these are individual cases when analyzing only a part of the transformer area or certain 0.4 kV feeder at which it is necessary to check or conclude something. For the analysis of losses in the LV network for specific distribution areas it is necessary to have model which includes a complete 0.4 kV network, displacement of all customers connected to 0.4 kV voltage and appropriate load measurements. This can not be expected any time soon and it is unlikely that there are distribution organisation with models of complete 0.4 kV network, displacement and loads of each terminal. Therefore, for estimation of the total value of losses in 0.4 kV it is practically to make combination of measured and calculated data as described below. Realized losses according to PJD are total loses, including losses in 0.4 kV network also. Technical losses, which are calculated, including losses in the 10(20) kV network and transformers 10(20)/0,4 kV of certain PJD. Thus, the difference between total electrical energy losses and calculated technical losses of electrical energy refers to the losses in the 0.4 kV network. To illustrate, the method of assessing the losses in the 0.4 kV network is given in Fig. 3. To make it possible to perform the calculation of the realized losses of PJD, taken electrical energy on 10(20) kV buses of supply transformer station is estimated (‘$W_{taken\ on\ 10(20)\ kV}$’). In this way, all the PJD are observed in the same manner and from losses estimation are removed customers at 35 kV voltage level. The data ‘$W_{supplied\ on\ 10(20)\ kV}$’ is obtained as the sum of supplied electrical energy to customers on 10(20) kV i 0,4 kV voltage levels. With respect to relation (1) electrical energy supplied at 35 kV voltage level is removed.

$$w_{loss}[\%] = \frac{W_{tak10(20)\,kV}[kWh] - W_{\sup 10(20)\,kV}[kWh]}{W_{tak10(20)\,kV}[kWh]} \cdot 100[\%] \tag{6}$$

If we take into account the assumption that the situation with measurement on 10 (20) kV are a lot ‘clean’ in terms of illegal consumption or errors in measurements, then it can be concluded that the calculated technical losses is equal to the realized (or total) losses in 10(20) kV network. This means that, when estimation losses in 0.4 kV network of concerned distribution area is observed in presented way, it should take into account both technical and commercial aspects. Respectively, the estimated losses in the 0.4 kV network are the total realized losses in the observed part of the distribution system.

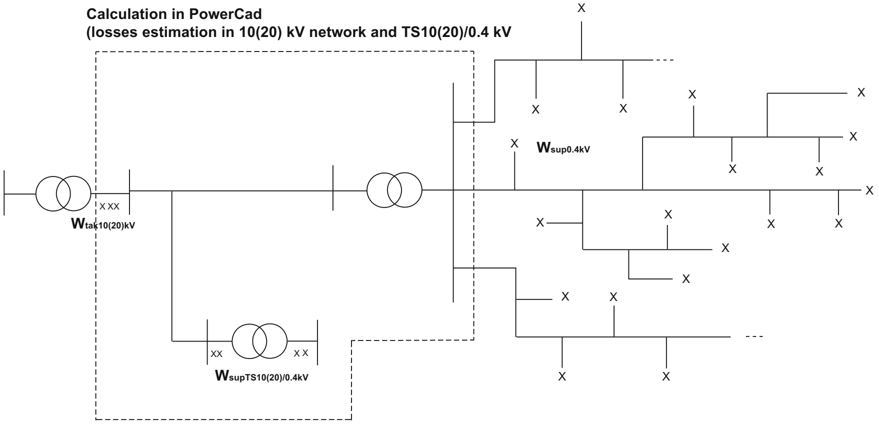

Fig. 3. Estimation of annual electrical energy losses according to voltage levels

If the preceding considerations are translated into relations, it follows:

$$W_{loss} = W_{tak10(20)\,kV} - \left(W_{\sup TS10(20)/0{,}4\,kV} + W_{\sup 0{,}4\,kV}\right) \tag{7}$$

$$W_{loss} = W_{lossPowerCad} + W_{loss0{,}4\,kV} \tag{8}$$

where is:

- W_{loss} [kWh]—Total electrical energy losses from place of taking on 10(20) kV voltage to place of delivering on 10(20) kV and 0.4 kV voltage

- $\mathrm{W}_{\mathrm{tak10kV}}$ [kWh]—Taken electrical energy on 10(20) kV side of transformers in supply TS (measurement—accounting measurement place)
- $\mathrm{W}_{\mathrm{supTS10/0,4\ kV}}$ [kWh]—Supplied electrical energy to customers that have measurements on TS 10(20)/0,4 kV (on 10(20) kV or 0,4 kV side)
- $\mathrm{W}_{\mathrm{sup0,4\ kV}}$ [kWh]—Supplied electrical energy to customers on 0.4 kV (households and other consumtion with measurements that are not directly on the TS)
- $\mathrm{W}_{\mathrm{lossPowerCad}}$ [kWh]—Estimation of electrical energy losses for the part of the network that was created in PowerCad and included load flow (10(20) kV network and transformations 10(20)/0,4 kV)
- $\mathrm{W}_{\mathrm{loss0,4\ kV}}$ [kWh]—Estimation of losses in 0,4 kV network

It follows that the assessment of losses in 0.4 kV network can be made on the basis of the relation:

$$W_{loss0,4\,kV} = W_{tak10(20)\,kV} - \left(W_{\sup TS10(20)/0,4kV} + W_{\sup 0,4\,kV}\right) - W_{lossPowerCad} \tag{9}$$

The sum $W_{\sup TS10(20)/0,4\,kV} + W_{\sup 0,4\,kV}$ is delivered electrical energy to customers on 10(20) kV and 0,4 kV. By applying of the above procedure, the total losses of Branches, certain PJD or TS are devided to the losses in: 10(20) kV network, transformers 10(20)/0,4 kV and losses in 0,4 kV network. From the variables in the relations (7), (8) i (9), the most difficult is to obtain information $\mathrm{W}_{\mathrm{lossPowerCad}}$. This information includes: model of complete 10(20) kV network, view all transformers 10(20)/0,4 kV, affiliated average peak loads and load flow.

In the present circumstances, for the purpose of analysis and reduction of losses in the 0.4 kV network, it can be treated in two ways. It is necessary to record the areas where the voltage drops on 0.4 kV higher than required at the time of peak load and make voltage measurement at the end points of LV feeders. For further analysis the area with measured voltage values at the places of delivering that are lower than required are taken. By bringing the voltage at the end customers within the prescribed limits it will be significantly reduced technical losses in the 0.4 kV network too. Another way, in terms of location of losses, is control of measurement and possibly illegal consumption of electrical energy.

Considering the existing concept of electrical energy measurement in electrodistribution, it can be seen that the separation of losses in the 0.4 kV network can be made according to 10(20) feeders too. Compared with complete supplied TS, in this way the area where it is needed to conduct a detail control of consumption and connection places is precisely defined. It should be in mind that improperly downloading and use of electrical energy, except losses, can cause a greater risk to humans and objects. It should be noted that the process of separation losses according to 10(20) kV feeders can be applied to radial feeders where there was no change in the operation state during the period under consideration. If the operation states changed, then should have accurate indication about it.

3 Results and Discussion (Tuzla Canton Case Study)

In this part of the paper, the analysis and structure of losses in the Branch ED Tuzla is in short term presented. The distribution network of ED Tuzla is observed separated by individual PJD (twelve PJD). 35 kV network and losses in transformers in supply TS 110/35/10(20) kV and 35/10(20) kV was excepted from the discussion. The volume of consumption of industrial customers at 35 kV is considerably reduced compared to the amount in the period before 1991. Operating condition of 35 kV network is usually optimal and at this voltage level is not possible to reduce losses. Also in JP EP BiH systematically transition to direct transformation and one level of medium voltage (20 kV) is planned, and therefore the work on the construction or expansion of 35 kV network is not considered. The Fig. 4 shows the structure of losses in distribution network ED Tuzla for the year of 2015 [11]. Distribution network considered for analysis starts from taking place of energy at 10 and 20 kV voltage. It can be seen that the largest losses occurring in the 0.4 kV network. A small delivering electrical energy at 10(20) kV voltage affects to this relation in losses, which in 2015 accounted for only 15.97% of the total supplied electrical energy. Losses in 10(20) kV network and transformers 10(20)/0,4 kV have amount of 28,14%, while losses in 0,4 kV network are 71,86% of the total losses.

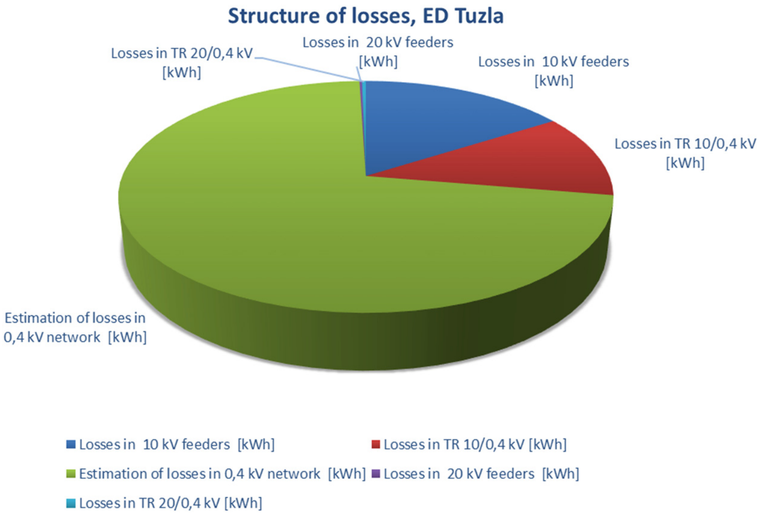

Fig. 4. Structure of losses in ED Tuzla in 2015

Table 1 shows the structure of losses in network part for which calculation of load flow was done [11]. It can be noted that the constant losses are significant and in some PJD are greater than the losses dependent on the load. This is partly result of a large number of undervoltage transformers, which produce significant idle running losses. Reduction of losses in the MV network can be achieved by transition to the voltage level of 20 kV.

In the case of ED Tuzla, losses in 0.4 kV network are about 2,55 times larger than the losses in 10(20) kV network and transformers 10(20)/0,4 kV. However, for each PJD, composed of ED Tuzla, it can be noticed big differences. Table 2 shows the estimated losses in the 0.4 kV network separated according to PJD [11]. In percentage terms, these losses are counted in relation to the taken electrical energy at 10(20) and 0,4 kV of certain PJD. Compared to delivered electrical energy at 0.4 kV voltage, these losses ranges from 3.91% for the area of PJD Teočak to 12.22% for the area of PJD Tuzla. In relation to the electrical energy taken at 10(20) kV voltage (electrical energy which 'enters' in the system at 10(20) kV voltage and consume at 10(20) and 0.4 kV voltage) losses range from 3,52% for the PJD Teočak to 9,46% for the PJD Tuzla. For the total estimated losses in the 0.4 kV network of ED Tuzla, it was made separation according to PJD. The most part of losses relates to the PJD Tuzla (37,19%) and the lowest to the PJD Teočak (0,38%). The diagram in Fig. 5 shows the participation of individual PJD in the total losses at 0.4 kV network of ED Tuzla.

Table 1. Losses in 10(20) kV network, in 2015, ED Tuzla

PJD	Wtaken [kWh]	wo [%]	wvar [%]	wloss [%]	Length of 10(20) network [km]	Number of TR [kom]	Build. of network [kWh/m]	Efekt. TR [kWh/TR]
Banovići	81,414,926	58.79	41.21	1.27	82.67	108	5.97	4,991
Čelić	14,253,297	45.12	54.88	3.34	55.42	58	4.91	3,511
Gračanica	145,403,035	19.66	80.34	3.87	216.34	312	20.60	3,756
Gradačac	116,084,903	35.70	64.30	2.32	174.29	213	9.54	4,814
Kalesija	62,004,623	42.66	57.34	2.29	105.64	128	7.25	5,116
Kladanj	24,460,140	50.81	49.19	2.69	99.73	83	3.85	3,310
Lukavac	186,009,050	51.69	48.31	1.37	219.76	264	5.93	4,737
Sapna	10,431,039	59.50	40.50	2.01	35.68	35	1.47	4,477
Srebrenik	75,788,083	35.95	64.05	3.40	149.40	194	11.15	4,712
Teočak	7,547,605	49.68	50.32	3.63	44.25	38	3.17	3,518
Tuzla	305,441,434	65.47	34.53	1.64	261.04	448	4.94	8,311
Živinice	178,227,497	38.49	61.51	2.84	199.67	283	16.87	5,957
Total PJD:	**1,207,065,633**	**41.92**	**58.08**	**2.29**	**1,643.89**	**2,164**	**9.65**	**5,422**

The symbols in the table are: Wpr—total of taken energy including customers at 35 kV, wo—idle running losses, wvar—losses dependent on loads, wgub—estimated (technical) losses in 10(20) kV network and TR 10(20)/0,4 kV

In the Fig. 6 the structure of losses of certain distribution areas in ED Tuzla was shown. The results show that it is necessary to work at first on reducing losses in LV network of distribution areas Tuzla and Živinice, and then in LV networks of distribution areas Lukavac, Kladanj, Srebrenik. In order to reduce technical losses in the low voltage network there are proposed activities to: increase cross section of lines, reconstruction of low voltage network, optimization of supplying customers at 0.4 kV, reducing unbalanced loads, compensation of reactive power along the LV feeders.

Table 2. Estimation of losses in LV network, in 2015, ED Tuzla

PJD	Wtak on 10 (20) kV [kWh]	Realized losses without customers at 35 kV [%]	Estimated losses in 10 (20) kV network and TR 10/0,4 kV [kWh]	Losses in 0.4 kV related to Wtak on 10 (20) kV [%]	Losses in 0.4 kV related to Wtak on 0,4 kV [%]	Part. of PJD in total losses on 0.4 kV ED Tuzla [%]
Banovići	49,326,903	6.12	1,032,916	4.03	5.80	2.82
Čelić	14,253,297	8.02	475,803	4.69	5.12	0.95
Gračanica	145,403,035	8.33	5,628,557	4.46	6.71	9.21
Gradačac	116,084,903	7.69	2,688,587	5.38	8.98	8.86
Kalesija	62,004,623	6.84	1,421,093	4.55	6.41	4.00
Kladanj	24,460,140	8.70	658,736	6.00	7.67	2.08
Lukavac	91,295,311	10.48	2,553,790	7.68	9.19	9.96
Sapna	10,431,039	7.95	209,196	5.95	6.46	0.88
Srebrenik	75,788,083	9.58	2,580,183	6.18	7.32	6.65
Teočak	7,547,605	7.15	274,174	3.52	3.91	0.38
Tuzla	277,003,597	11.27	5,013,406	9.46	12.22	37.19
Živinice	151,942,691	11.21	5,054,566	7.89	11.68	17.01
Total ED:	**1,025,541,227**	**9.56**	**27,591,007**			

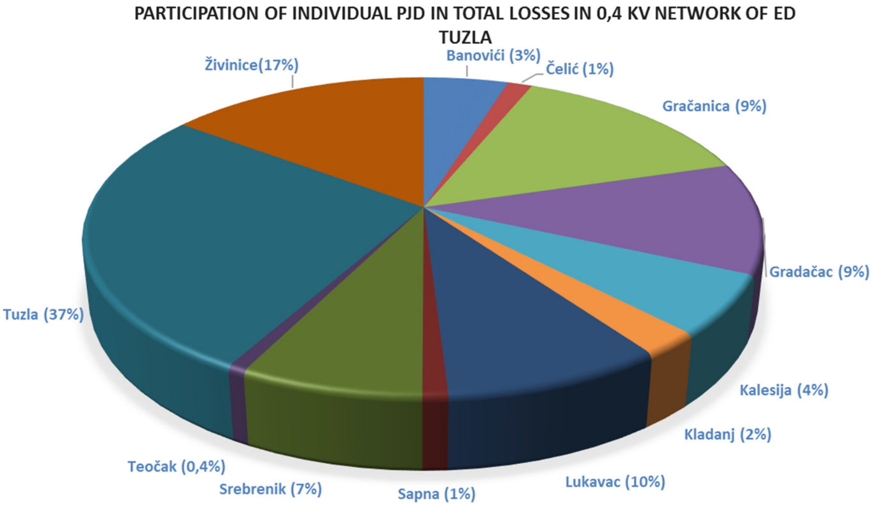

Fig. 5. Participation of individual PJD in total estimated losses in 0.4 kV network, ED Tuzla

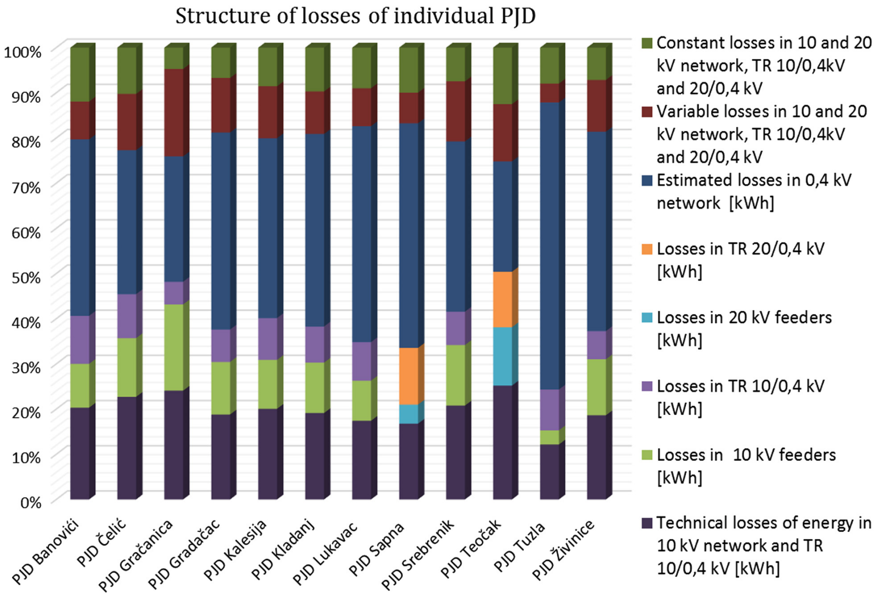

Fig. 6. Structure of energy losses according to certain PJD

When replacing conductors in MV and LV feeders it should be noted that due to losses dependent on the load, the best results achieved by increasing the cross sections in the initial lines. In order to reduce technical losses in the LV network it is proposed to shorten the LV feeders and optimum supplying from the nearest TS 10(20)/0,4 kV. It should be noted that the LV feeders can be burdened with asymmetric power flows due to the large number of single phase customers, causing additional losses in distribution of electrical energy. It is necessary to work on balancing the load on the entire length of the LV feeders based on the results of measurements and calculations.

In order to reduce losses in the LV network it should be planned procedures to reduce non-technical or commercial losses too. Due to the large number of customers and connection places it is proposed to separate priority areas for controlling connections and accounting metering points (protected measuring devices and equipment by appropriate seal, wiring correctness, correctness of accounting constants, failures of measuring and auxiliary equipment, etc.). It is recommended to install in TS 10(20)/0,4 kV measuring devices to measure the total consumption of transformer area, which is compared with the amount of delivered electrical energy to all customers connected to the concerned TS plus the estimated value of technical losses.

4 Conclusion

The total losses in the distribution system of JP EP BiH amounts to 9%. The negative impact on the total amount of losses has a relatively low consumption of industrial customers. Almost two-thirds of the total electrical energy supply is carried out on

0.4 kV voltage level. To implement effective procedures for the management of the losses it is necessary to reliable determine the structure of electrical energy losses by voltage level and by type. By applying the methods of estimation of electrical energy losses by voltage levels it can be concluded that the highest losses of electrical energy are in 0.4 kV network. These findings have been known before, but the estimates were flat and never worked assessment of losses by voltage levels for smaller distribution areas (PJD, TS or 10(20) kV feeders) in a way that takes into account the assessment of technical losses in 10(20) kV network and transformers 10(20)/0,4 kV based on calculation. In addition to insights into the structure of the total losses of ED Tuzla, a special benefit from the application of this method, is the knowledge about structure losses for parts of distribution areas. Data for Branch ED Tuzla, losses in the 0.4 kV network, for the period under consideration is 2.55 times higher than the losses in 10 (20) kV network and transformers 10(20)/0,4 kV, clearly indicate in which area should be to act in order to achieve the greatest effect in reducing losses in the network. Separated losses at 0.4 kV voltage level according to the presented method are the total losses (technical and commercial together). By precise analysis of the situation in the area with identified significant losses of electrical energy it can be concluded that:

- parts of network with the largest estimated losses have the worst network in terms of structure, dimensioning and length of LV feeders.
- parts of the network with losses above the average may have the highest concentration of faulty measurements and illegal consumption of electrical energy.

Finally, the application of that method to the business decision makers clearly shows what to do and on which aspect need to pay attention in order to reduce the total realised losses on certain distribution area i.e. in particular distribution network.

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