A Fuzzy Method of Distribution Energy Losses Calculation

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Abstract – **There are two main difficulties in calculating the distribution energy losses if, beside the total energy losses, knowledge of losses structure is required. First one is lack of input data for network node loads, and second one is large number of necessary load flow calculations. A method, based on the deterministic load estimation, which requires only one fuzzy load flow, is presented in this paper. The method is applied to calculate annual energy losses in the real distribution network. Accuracy of the presented method is tested comparing to a simulation results.**

Keywords – **Distribution losses, Fuzzy approach, Estimation, Consumer category.**

I. Introduction

Power and energy losses are inevitable consequence of energy transmission from generation points to consumers. The losses sometimes make ten or more percents. Therefore, it is important right assess losses, as well as find methods for their reduction. Basic items of mentioned problems are: dispense technical and non-technical losses, determine structure of losses (distribution of losses throughout the network elements), locate critical elements from aspect of losses, and select optimal methods for losses reduction.

Knowledge of load curves for each particular element is needed for exact calculation of energy losses. That is not possible, because of measurements are made only at some locations in network, so many different approaches to distribution losses assessment are developed. All these approaches can be classified in two basic groups deterministic and probabilistic.

As a result of the fact that loads are not exact known, it is developed fuzzy load flow methods [1,2], as well as the fuzzy method for estimation of node loads [3]. Fuzzy estimation method considers daily load profiles of different consumer categories. Based on that estimation method, distribution losses can be calculated. However, this approach requires large number of the fuzzy load flow calculations. That is why a new method for distribution losses calculation, which requires only one fuzzy load flow, is presented in this paper.

At the first, in this paper is described a method for distribution network simulation. After that, it is presented a method of forming fuzzy numbers that represent loads. The presented method is based on the deterministic load estimation. Annual energy losses of the test system are then obtained using the formed fuzzy loads.

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II. Simulation

Simulation of distribution network have been made under following assumptions:

- there are three consumer categories with specified daily load profiles,
- variation of maximal daily load during the year is different for different consumer categories,
- participations of any consumer category for each load node are known with accuracy within ±15%. Deviation is random and with normal probability distribution.
- annual peak demand of any load node is known with accuracy within ±15%. Deviation is random and with normal probability distribution.
- variation of root node voltage is known.

In Fig. 1 the possible forms of daily load profiles for three consumer categories are shown.

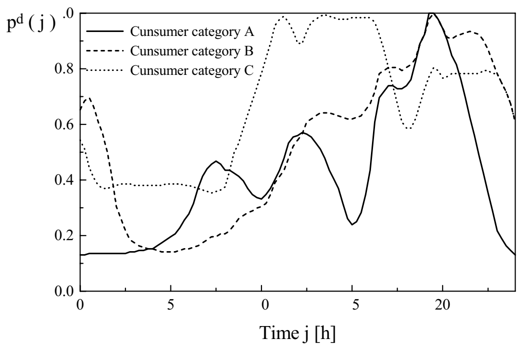

Fig. 1. Hourly load patterns for different consumer categories

Variation of relative daily peak load during the year for three consumer categories are shown in Figs. 2,3 and 4. Based on these curves it is possible to determine load of each node, for any hour during the year, as well as calculate the power and energy losses. Energy losses calculated in this way can be considered as the accurate ones, and they will be used for comparing the results obtained by estimation methods.

Since, in practice, the current of the first feeder section is usually known, the annual current curve of this branch is kept as result of the simulation.

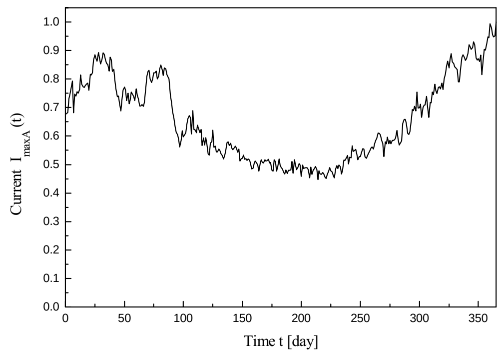

Fig. 2. Variation of daily peak load for A consumer category during the year

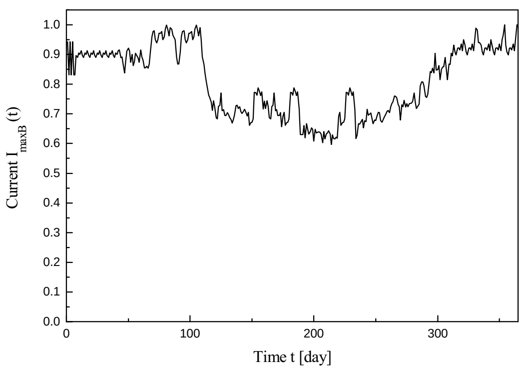

Fig. 3. Variation of daily peak load for B consumer category during the year

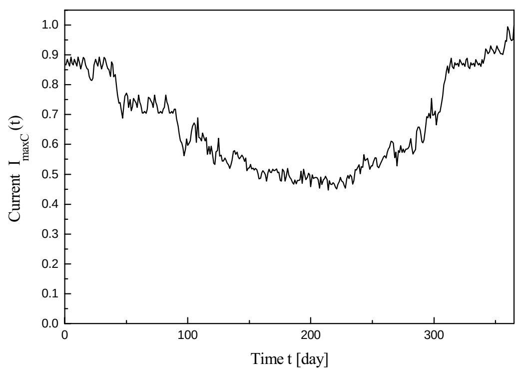

Fig. 4. Variation of daily peak load for C consumer category during the year

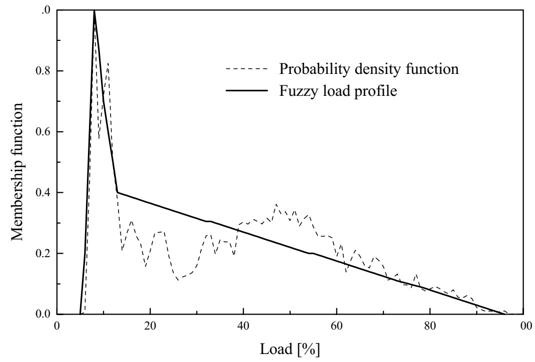

Fig. 5. Fuzzy load profile of A consumer category

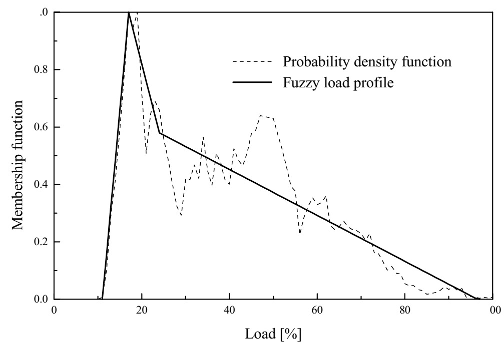

Fig. 6. Fuzzy load profile of B consumer category

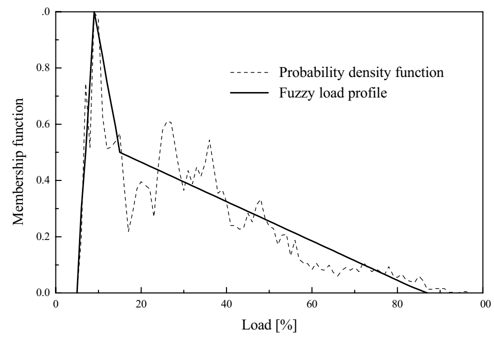

Fig. 7. Fuzzy load profile of C consumer category

III. Fuzzy Approach

Fuzzy approach starts from the real fact that loads (powers) for many load nodes are not complete known, but they are assessed in some way. This is the consequence of the fact that in distribution networks measurements are made only for industry consumers, and on the HV/MV substations. Since the loads (powers) are not strictly known, it is appropriate to consider their as fuzzy numbers.

In this paper the fuzzy numbers that represent the load are formed on the following way.

Firstly the values of relative powers $p_A^d(j)$, $p_B^d(j)$ and $p_C^d(j)$ are taken from Fig. 1, where j is hourofday. The current of i-th distribution transformer, for t-th hour-of-year (corresponds to j-th hour-of-day) can be estimated as:

$$I_i(t) = k(j) I_{fs}(t) k_i I_{ni}[k_{A_i} p_A^d(j) + k_{B_i} p_B^d(j) + k_{C_i} p_C^d(j)] \, , \quad (1)$$

where coefficient $k(j)$ is:

$$k(j) = \frac{1}{\sum\limits_{i \in \alpha_L} k_i I_{ni}[k_{A_i} p_A^d(j) + k_{B_i} p_B^d(j) + k_{C_i} p_C^d(j)]} \, , \quad (2)$$

and: α_L – set of load nodes, k_{A_i} – participation of A consumer categories in i-th node loads, k_{B_i} – participation of B consumer categories in ith node loads, k_{C_i} – participation of C consumer categories in ith node loads, $I_{fs}(t)$ – current of first feeder section at tth hour, $k_i I_{n_i}$ – maximal current of distribution transformer installed in i-th node.

For this reason, current of all consumers that belong to x

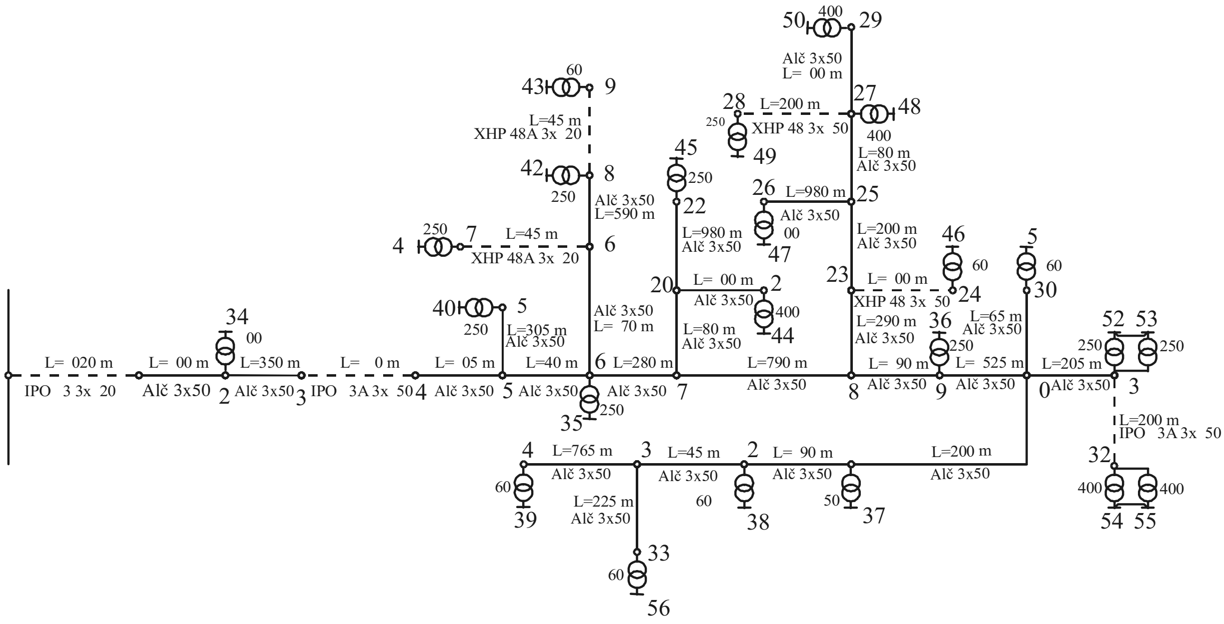

Fig. 8. Test network

consumer category, for t-th hour-of-year is:

$$I_x(t)=k(j)\, I_{fs}(t)\, p_x^d(j) \sum_{i\in\alpha_L} k_{x_i} k_i I_{ni},\ x\in\{A,B,C\}. \quad (3)$$

Obtained current curves are then normalised using equation:

$$I'_x(t) = \frac{I_x(t)}{\max\limits_t I_x(t)}, \qquad x \in \{A,B,C\}. \quad (4)$$

Based on normalised curves, probability distribution of consumer category current is obtained and converted to fuzzy membership function according to a possibility-probability consistency principle. Fuzzy numbers that represent load for each consumer categories with three lines ($\tilde{I}_A(t)$, $\tilde{I}_B(t)$ and $\tilde{I}_C(t)$) are shown on Figs. 5, 6 and 7.

This is not the only way for fuzzy numbers determination but that has been the way chosen by authors.

Current of each node, as fuzzy number, can be determined using relation:

$$\tilde{I}_i = [\tilde{I}_A\, k_{A_i} + \tilde{I}_B\, k_{B_i} + \tilde{I}_C\, k_{C_i}]\, k_i\, I_{ni}\ . \quad (5)$$

Root node voltage is considered as triangular fuzzy number. Power flow calculation is then made on the way presented in [2], and according to fuzzy arithmetic lows [4].

Results of calculation are node voltages and power/current flows as fuzzy numbers. Using the calculated current values, the power losses as fuzzy numbers can be obtained. Defuzzification gives the deterministic value of power losses that multiplied with number of hours for observed period gives energy losses. There are several defuzzification strategies, but authors suggest the bisector method.

IV. Test Example

The presented procedure is used for determining annual energy losses of the test network shown in Fig. 8. In this figure are also shown data needed for calculation, while data about maximum powers of load nodes and participation of any customer categories in each load node are shown on Table 1.

Table 1. Maximum powers and participation of any customer categories

Node number	A (%)	B (%)	C (%)	S_{max} [MVAr]	cos φ
34	70	30	0	0.090	0.96
35	60	20	20	0.220	0.96
36	00	0	0	0.240	0.95
37	20	20	60	0.020	0.97
38	20	0	80	0. 70	0.98
39	0	20	80	0. 70	0.96
40	20	50	30	0. 80	0.94
4	30	70	0	0. 80	0.93
42	80	20	0	0.200	0.95
43	0	80	20	0.200	0.98
44	60	40	0	0.300	0.96
45	90	0	0	0. 80	0.95
46	0	90	0	0. 70	0.99
47	0	20	70	0.05	0.99
48	0	0	80	0.350	0.96
49	0	20	80	0.230	0.97
50	20	30	50	0.380	0.95
5	20	20	60	0. 60	0.96
52	20	0	80	0.270	0.94
53	20	0	80	0.270	0.94
54	20	20	60	0.380	0.97
55	20	20	60	0.380	0.97
56	0	50	40	0. 60	0.96

In Table 2 the results have following meaning:

- Simulation – Results of simulation described on Section II.
- Estimation 1 – Estimation based on relations (1) and (2).
- Estimation 2 – Estimation based on relations presented in [5]. This estimation assumes that consumer of any load node have been put into consumer category with

Table 2. Results obtained by simulation, estimations and fuzzy

	Total losses		Lines losses		Transformers losses		Line 4-5 losses		Line 9-10 losses		Transformer 30-51 losses	
	MWh	MVArh	MWh	MVArh	MWh	MVArh	MWh	MVArh	MWh	MVArh	MWh	MVArh
Simulation	795.1	716.1	546.5	330.2	248.7	385.9	30.87	18.43	81.75	48.8	9.916	15.61
Estimation 1	780.2	709.2	530.9	321	249.3	388.2	30.98	18.5	75.4	45.02	9.795	15.3
Estimation 2	823.5	749.9	569.2	343.9	254.4	406	31.12	18.58	84.51	50.45	9.637	14.93
Estimation 3	752.5	673.4	511	309.1	241.4	364.3	31.09	18.56	65.87	39.33	8.036	10.82
Fuzzy approach	794.1	735.3	560.7	339.1	255	396.2	33.2	19.8	70.1	41.9	7.8	10.3

the highest percent participation. The consumers in nodes 34, 35, 36, 42, 44 and 45 are A category, in nodes 40, 41, 43, 46 and 56 B category, while other consumers are C category.

- Estimation 3 – Estimation that supposes distribution of first feeder section current proportionally to rated power of distribution transformers.

Comparing the results from Table 2, the following statement can be established. Results obtained using the estimation method presented in this paper are better then ones given by other two estimation methods. However, the usage of this method requires knowledge the participation of different consumer categories in the total load of each node. This requirement is of course weakness of the presented estimation method.

The accuracy of results obtained by the fuzzy approach is satisfying for engineering applications. The accuracy should be obtained comparing with results of estimation presented in this paper. In our test example the error made by the estimation is nullified by the error of the fuzzy approach. For some cases, these errors can be of course summed.

It should be emphasized on the end that required time for fuzzy approach calculation is very short, because of only one load flow calculation is made.

V. Conclusion

The method for distribution losses calculation, based on the fuzzy approach, is presented in this paper. Presented method enables the total energy losses determination as well as determination energy losses of each network element (structural losses analysis). Simulations that have been made by the authors show that satisfying results for energy losses (total and by network elements) are obtained using fuzzy approach. Computation time for this approach is significant smaller comparing to other methods. This statement, as well as not well knowledge of the input data are reasons for using the presented fuzzy approach.

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