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USING OF FUZZY LOGIC IN THE STRUGGLE WITH THE UNAUTHORIZED CONSUMPTION OF THE ELECTRICAL ENERGY

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Abstract

The unusually high level of nontechnical losses of electrical energy in the public utility companies in Serbia demands a whole set of measures to be taken in order to reduce these losses. In this paper, a method based on fuzzy logic is presented, with aim to indicate a potentially unauthorized consumption of electrical energy.
The scope of this research is the consumers with the two tariff meters, categorized as households.
The method is tested on the actual database for considered category of consumers, and the results are presented in the paper.

1. INTRODUCTION

On the initiative of the Ministry of Mining and Energy of the Republic of Serbia, Electric Power of Serbia formed the coordination team and the task force for the realization of Integral Operative Program (IOP) for the reduction of non-technical losses of electric energy in Serbian distribution network.
The task force for the realization of IOP referred to following main reasons for the increase of non-technical losses:

- unfavorable rate of low voltage consumption toward the high voltage consumption (the low voltage consumption is three times higher)
- the increase of unauthorized consumption of electrical energy
- the increased number of unregistered consumers
- the increased number of incorrect and uncalibrated meters

Unfortunatey, the reasons mentioned above, and nominated as primary, are followed by insufficient activites in the field of detection and restrain of unauthorized consumption of electric energy, as a secondary reason. The presumtion made by compairing the losses structure form previous years (with more or less normal consumption), with recent period is folowing:

The share of nontechnical losses in the sum of all losses in the distribution network is of order of 40%. The estimated financial losses of EPS caused by unauthorized consumption are 43 270 000 US $.

One of the problem in the effectuation of IOP is inadequate choice of target group of consumers planned for inspection of their meters. The scope of this research is the consumers with the two tariff meters, categorized as households. This is the most represented group of consumers, and their number is 1 804 210 in all utilities in Serbia, and 47 690 in distribution utility in Leskovac. This reason makes them particularly interesting for the analyses, having in mind the predomination toward the unauthorized consumption of that group for the reason of high outspread of electric heating.
Most frequently, the inspection of unauthorized consumption is based on the level of realized consumption of electrical energy in the winter period (from October to May). and the differences and deviation of that consumption compared to the average consumer of similar level of electrification.

This way of determination of the target group of consumers chosen for inspection leads to idle, resulting in great number of inspected customers, compared to relatively small number of located cases of unauthorized consumption.

Greater or smaller predomination (or motivation) for unauthorized consumption can be expressed by appropriate “fuzzy” sets. Consequently, using the rules of “fuzzy” logic, the assessment of possibility of unauthorized consumption can be given.

2. SUSPICION OF UNAUTHORIZED CONSUMPTION ASSESSMENT

2.1. Criteria formulation

For two tariff consumers already registered in a financial data base, with regular cycles of meters reading, it is easy to access the data of energy consumed in higher or lower tariff period, and overall consumption for different periods, depending on a reading cycles (one or several months).
The level of electrification of households in rural and urban settlements is different, which results in tendency of increased consumption in urban area (due to the use of electric heating) in period from October to March. In rural area, the period demanding higher attention is summer (March trough October).
For that reason, following analysis will be referred to half -year periods or, to the “summer” and “winter” tariff season.

The most common way of stealing the electric energy is to remove one of all three voltage bridges, or to consume energy beyond the meter.

Having in mind this facts, it is possible to form criteria A, expressed by the coefficient K_a

$$K_a = \frac{W_s}{W} \cdot 100(\%) \qquad 1)$$

Ws - registered electric energy of one consumer in one season
W - average registered electric energy for one type of household

Average energy of one type of household W, can be determined for one specific location (area served by one distribution substation), extending that specific value to one settlement, or specific type of settlement. As an example of that determination, all rural settlements can be divided in plain-type and mountain-type rural settlements.
The unauthorized adjustment of tariff switching devices (mechanical or electronic clocks) undertaken by the consumers themselves, does not affect the sum of registered electric energy, and from that point of view, is not treated as steeling.

However, the money value of registered energy is decreased by readjustment of those devices, and that type of consumer’s actions is indirectly treated as stealing.

For that reason, the second criteria B is composed, expressed by the coefficient K_b:

$$K_b = \frac{W_{nt}}{W} \qquad 2)$$

Wnt - energy of one consumer in the low tariff period, for one season
W - the sum of registered electric energy for one consumer in both tariff periods

2.2. The creation of membership functions of fuzzy sets

The membership function of one element x, in fuzzy set theory (unlike the classical set theory) can take any value in the segment [0,1]. Fuzzy set A is defined by the set of arranged couples x and $\mu_A(x)$. The value μ_A determines the measure of truth in the statement that element x is member of set A.
For criteria A, we can compose three fuzzy sets: the great, the medium, and the low suspicion of steeling. The set of consumers with "high suspicion" is represented by a triangle, with zero value for of membership function for values of X=50% and X=110%. The set of "medium suspicion" has a form of trapezoid, and for the set of "low suspicion" customers, the vale of membership function has a value of one for all values of x which are greater then 130%.

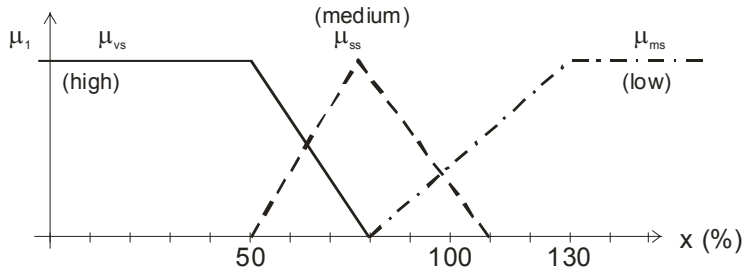

Fig. 1. Membership functions composed form criteria A

Following the criteria B, (the ratio of energy in low tariff and the sum of energy in both tariffs), we are forming three similar fuzzy sets: the great, the medium, and the low suspicion of steeling.

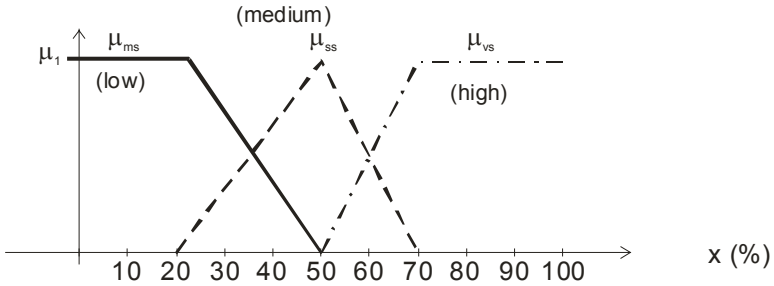

Fig. 2. Membership functions composed form criteria B

It is important to notice that the form of fuzzy sets in figure 2 depends on the level of electrification of one household. The presented figure is referring to consumers with partial electric heating.

2.3. The application of fuzzy logic for the assessment of suspicion of unauthorized consumption

In this paper, the six months period is analyzed for two reasons. First, two six month's periods (summer and winter) are very distinct by the level of consumption. The second reason of this choice is to avoid some disproportion in consumption that might emerge if the consumption on the monthly basis is analyzed.
In our case, the input variables are of linguistic type: for both criteria A and B, the consumers might be of low, medium or high suspicion. The output is suspicion assessment expressed in percentage.

Fuzzy logic is successfully applied if it is difficult to determine correlation between input variables. The model based on fuzzy logic is composed of several "if / then" rules. The output is

suspicion assessment expressed also by linguistic variables and represented by five fuzzy sets: low, greater, medium, significant and high suspicion.

By defuzzification, we get the output variable, denoted by IP (Index of Preferences) by witch the suspicion assessment is expressed. This variable can take values from 0 - 100%.

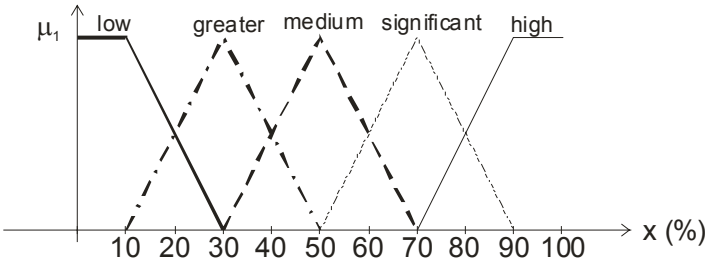

Fig. 3. Membership functions for fuzzy sets representing the suspicion assessment

Combining the input variable for both criteria A and B, the nine rules for suspicion assessment can be set out:

Rule one
IF consumer is of high suspicion by criteria A AND of high suspicion by criteria B THEN IP is high

Rule two
IF consumer is of high suspicion by criteria A AND of medium suspicion by criteria B THEN IP is significant

Rule three
IF consumer is of high suspicion by criteria A AND of low suspicion by criteria B THEN IP is significant

Rule four
IF consumer is of medium suspicion by criteria A AND of high suspicion by criteria B THEN IP is significant

Rule five
IF consumer is of medium suspicion by criteria A AND of high suspicion by criteria B THEN IP is medium

Rule six
IF consumer is of medium suspicion by criteria A AND of low suspicion by criteria B THEN IP is greater

Rule seven
IF consumer is of low suspicion by criteria A AND of high suspicion by criteria B THEN IP is significant

Rule eight
IF consumer is of low suspicion by criteria A AND of medium suspicion by criteria B THEN IP is greater.

Rule nine
IF consumer is of low suspicion by criteria A AND of low suspicion by criteria B THEN IP is low.

All of these nine rules represent a fuzzy relation between criteria A, criteria B and assessment IP. The combination of variable “a” from the set A, and variable “b” from the set B is fuzzy proposition M, defined on A x B. For example, membership function of fuzzy proposition from rule four is determined as:

$$\mu_{M4}(a,b) = \min\left\{\mu_{low}(a), \mu_{high}(b)\right\} \qquad 3)$$

Every rule represents a fuzzy implication, connecting the fuzzy proposition M with assessment IP. It is a fuzzy proposition N defined on set A x B x Ip. For rule four, for example, membership function of fuzzy proposition M equals:

$$\mu_{N4}(a,b,ip) = \min\left\{\mu_{M4}(a,b), \mu_{important}(ip)\right\} \qquad 4)$$

One or more fuzzy propositions, related with “OR” form, represent fuzzy relation Z. Rules form 1 to 9 represent fuzzy relations N1, N2, ..., N9, with adequate membership values. The value of membership function of fuzzy relation Z is calculated as:

$$\mu_Z(a,b,ip) = \max\left\{\mu_{n1}(a,b,ip), \mu_{n2}(a,b,ip),..., \mu_{n9}(a,b,ip)\right\} \qquad 5)$$

As an illustrative example, let determine the suspicion assessment for the consumer with following data: Ka= 65%, and Kb = 55%. The graphical technique of determination of suspicion assessment is given on figure 4.

The last stage in a process of fuzzy reasoning is defuzzification, witch turns one fuzzy conclusion into a real number. In this paper, the defuzzyfication is performed by the center of gravity method. The consumers with highest rate of index of preference (ip) in percents should be the first group planned for inspection.

3. TEST EXAMPLE

The technique represented in a paper is applied on several thousands consumers of distribution public utility “Elektrodistribucija” Leskovac. As an example, results for one group of customers (300 households) living in urban residential sectors are given. The main characteristic of these households is partially electric heating. The results are given for winter season. The average value of the total amount of energy consumed in winter season by one household for a month is W_{av}=727 kWh, and the average ratio of energy consumed in low tariff and the total consumed energy is K = 0,58. The results of assessment of suspicion for top 10 consumers with highest indexes of preferences (highest suspicion) are given in table 1.

As can be seen from the table 1, the dominating parameter for the determination of suspicion is the index K_b. By choosing some other rules, the more weight can be given to the index K_a (the ratio of consumed energy and average energy of analyzed area), or the weight of these indexes can be balanced.

More accurate assessment of suspicion can be performed with taking into acount the patterns of behavior of consumers already caught in the unauthorized consumption. The future research of authors of this paper will be oriented in that direction.

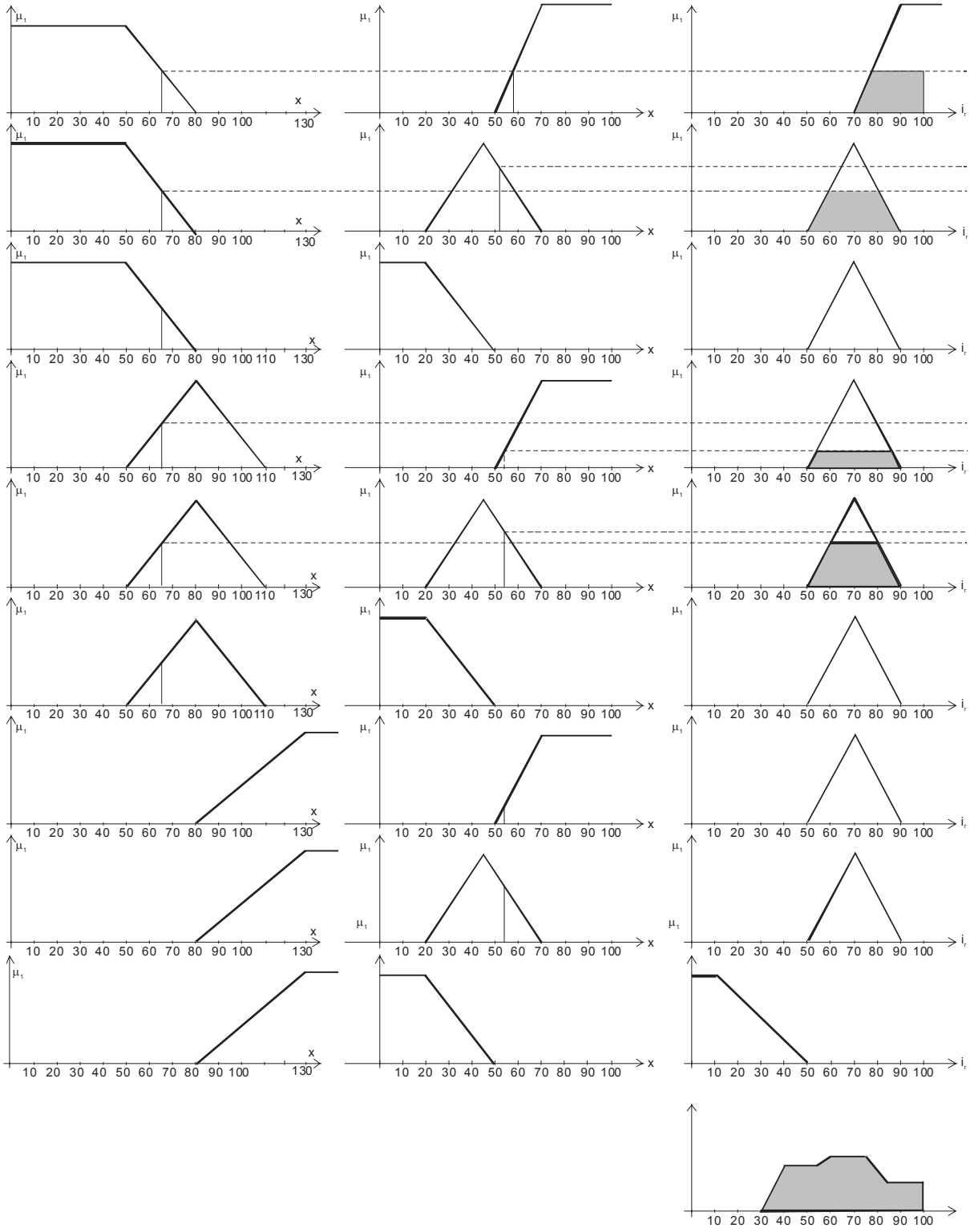

Figure 4. Graphical determination of suspicion assessment of unauthorized consumption

TABLE 1. Results of suspicion assessment for 10 consumers with highest suspicion

K_a	K_b	ip(%)
0,2	0,55	85,29
0,28	0,05	82,64
0,27	0,32	83,41
0,22	0,32	87,74
0,19	0,44	89,44
0,29	0,5	81,90
0,29	0,16	81,90
0,28	0,27	82,64
0,17	0,43	89,44
0,29	0,44	81,90
0,25	0,23	85,03

4. CONCLUSION

- The membership function of sets defining criteria A and B should be composed very carefully, having in mind the characteristics of supplied area, the habits of the consumers and the level of electrification.
- The greater the number of various types of diagrams like fig. 1 and fig. 2, the results of suspicion assessment would be more accurate.
- The process of composure of diagrams from figures 1 and 2 should involve the data for consumed energy from the database of registered cases of unauthorized consumption.
- The rules set in this paper are results of author's view, and depending on past experience and preferences, it is possible to compose some other rules.
- The final set of rules is formed ina iterative way, because of possible inconsistencies for close values of input variables. The analysis of output assessments is therefore performed, and, if it is necessary, the rules are corrected. The composure of fuzzy sets for input variables, and sets for their assessment should be different for different public utility.

5. LITERATURE

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