APPLICATION OF 'FUZZY' LOGIC IN DETECTION OF UNAUTHORIZED ELECTRICITY CONSUMPTION BY CUSTOMERS WITH SINGLE-RATE TARIFF METERS

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SUMMARY

This report sums up the method of detection of unauthorized electricity consumption by applying ''FUZZY' logic'. The subject matter is customers categorized as households with single-rate meters.

INTRODUCION

[L.1] shows the method of detection of unauthorized electricity consumption by customers categorized as households with two-part tariff meters.
In the 'households' tariff group, customers with single-rate meters make ED Leskovac which accounts for 33,92 % of the distributed electricity. This is a good reason to apply the concept of the method shown in [L.1] to the aforementioned category of electricity consumers.
The observation of unauthorized electricity consumption is based on indicators such as: low rate electricity consumption in a particular period, illogical discrepancy regarding the consumption in the previous years, discrepancy between the consumption of the observed customer and the average consumption of approximate electrification of households in urban settlements or compared to the average consumption in inner localities of rural areas.
This selection of target customers bound to be observed leads to a gap, thereby resulting in a large number of observed customers and a small number of those caught out in unauthorized electricity consumption.
Low or high inclination or an incentive for unauthorized consumption can be linguistically formulated by means of adequate “FUZZY” groups, and eventually estimated by applying “FUZZY” logic.

ESTIMATE OF ASSUMED UNAUTHORIZED ELECTRICITY CONSUMPTION

Setting the criteria

For the registered customers with single-rate meters regularly read out, there is a data bank which contains the data on consumption on a monthly, quarterly, half-yearly or yearly basis

Bigger discrepancies in electrification of households is more evident in urban areas. There is an evident tendency of higher level of consumption in the colder period of October – March. This particularly goes for households with electric heating systems.
In rural areas, more attention should be drawn to the warmer period of March – October.
The hypothesis that customers with single-rate meters should, on average, have consumption rate lower than those ones with two-part tariff meters seems highly plausible. However, it does not disengage us from analyzing and eventually rechecking on them.
We are going to adopt two criteria: Ə
Criterion A is expressed by means of the co-efficient Ka

$$K_{Ə} = \frac{W_H}{\underline{W}_H} \cdot 100 \ (\%) \qquad (1)$$

with Wh denoting 3he recorded electricity consumption in the colder term of October – March
and <u>Wh</u> denoting the average recorded electricity consumption for determined electrification of a household in the same observed period.
Bearing in mind specific features of the area in which the customer is located, <u>Wh</u> is related to a certain locality, primarily determined by the distance from the substation area, and expanding over a residential area, that is, a type of the settlement, where rural areas, for example, can be divided into flat and hilly-mountainous ones.
Criterion B is expressed by means of co-efficient Kb

$$K_B = \frac{W_T}{\underline{W}_T} \cdot 100 \ (\%) \qquad (2)$$

Where:
Wt - denotes recorded electricity consumption of the customer in the warmer period of March – October.
<u>Wt</u> - denotes the average recorded electricity consumption of particular electrification of a household in the same surveyed period.
The logic of determining <u>Wt</u> is the same as that for <u>Wh .</u>

Establishing the Function of Inclusion in a 'FUZZY' Group

In the classical theory of groups, the inclusion of elements x in group A is represented by the function of inclusion of µA (x) in the following way:

$$\mu A(x) = \begin{cases} 1, \text{ when x is included in A} \\ 0, \text{ when x is not included in A} \end{cases} \qquad (3)$$

As for 'FUZZY' (scattered) groups, the function of inclusion can take on any value at segment [0,1]. 'FUZZY' group A is defined by means of a group of arranged pairs of x and µA (x), with µA (x) representing the degree of inclusion of elements x in group A .
The µA (x) value denotes the degree to which the statement that element x belongs to group A is true.
Let us form 'FUZZY' groups on the basis of both criterion A and B regarding highly suspected customers, fairly suspected and least suspected customers.
Let us represent all of the three 'FUZZY' groups in a coordinate system according to criterion A highly suspected fairly suspected least suspected

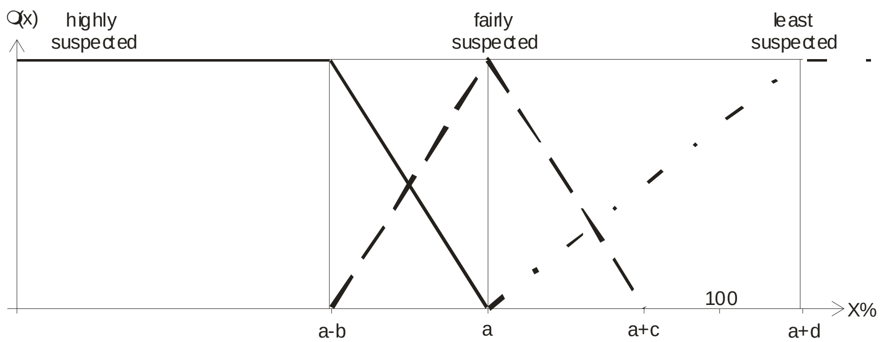

Fig. 1. Functions of inclusion in the groups on the basis of criterion A

Functions of inclusion which define the groups shown above:
highly suspected customer is represented by a continuous line

$$\mu(x)=\begin{cases} 1, & x<a-b \\ \frac{a-x}{b}, & a\leq x \leq a-b \\ 0, & x>a \end{cases} \tag{4}$$

fairly suspected customer is represented by a dashed line

$$\mu(x)=\begin{cases} \frac{x-(a-b)}{b}, & (a-b)\leq x\leq a \\ \frac{(a+c)-x}{c}, & a \leq x \leq (a+c) \\ 0, & x<a-b \text{ i } x>a+c \end{cases} \tag{5}$$

least suspected customer is represented by a ***dot – dash line***

$$\mu(x)=\begin{cases} 0, & x< a \\ \frac{x-a}{d}, & a\leq x\leq a+d \\ 1, & x>a+d \end{cases} \tag{6}$$

In the same way, we could present 'FUZZY' groups based on criterion B, but the co-efficient values of a, b, c and d might be different. Thus, 'fuzzy' groups based on criterion A can be defined as a_A , b_A, c_A, and d whereas 'FUZZY' groups based on criterion B can be determined by a_B, b_B, c_B and d_B.
It is important to emphasize that the shape of the diagram in Figure 2 depends on the electrification of a household.

Application of 'Fuzzy' Logic for an Estimate of the Assumed Unauthorized Electricity Consumption of Customers

In the discussed cases, the input variables are the so called linguistic variables - as for example, highly suspected customers on the basis of criterion A and fairly suspected customers on the basis of criterion B. The output variable should be ' the estimate of the assumed unauthorized consumption (hereinafter referred as suspicion estimate).

'FUZZY' logic is successfully applied for determining the output variable, although it is difficult to determine the interdependence which exists between the input variables. The model based on 'fuzzy logic' consists of the " if - then " rules.
Let us denote the inner variables: criterion A (highly suspected, fairly suspected and least suspected) and criterion B (highly suspected, fairly suspected and least suspected).
Let us mark the output variable with ίρ which denotes the suspicion estimate and which takes values ranged from 0 to 100%. Also, this estimate can be linguistically expressed by means of 'FUZZY' groups as little suspicion, a bit higher suspicion, fair suspicion, considerable suspicion and high suspicion.

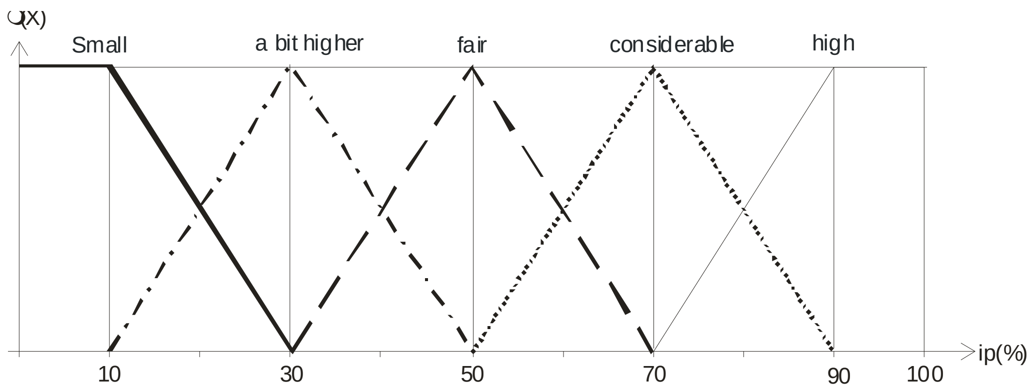

Fig. 2 The functions of inclusion in the groups of suspicion estimate

By combining input variables determined by criteria A and B, we can set nine rules for suspicion estimate:
Rule 1
If the customer is highly suspected on the basis of criterion A and highly suspected on the basis of criterion B then the IP is high
Rule 2
If the customer is highly suspected on the basis of criterion A and fairly suspected on the basis of criterion B, then IP is considerable
Rule 3
If the customer is highly suspected on the basis of criterion A and less suspected on the basis of criterion B, then IP is considerable
Rule 4
If the customer is fairly suspected on the basis of criterion A and highly suspected on the basis of criterion B, then IP is considerable
Rule 5
If the customer is medium suspected on the basis of criterion A and fairly suspected on the basis of criterion B, then TP is fair
Rule 6
If the customer is fairly suspected on the basis of criterion A and less suspected on the basis of criterion B, then IP is a bit higher
Rule 7
If the customer is less suspected on the basis of criterion A and highly suspected on the basis of criterion B, then IP is considerable
Rule 8
If the customer is less suspected on the basis of criterion A and fairly suspected on the basis of criterion B, then IP is a bit higher
Rule 9
If the customer is less suspected on the basis of criterion A and less suspected on the basis of criterion B, then IP is small
Since the rules account for all the possible relations of the variables, they are proportionally connected with the term ' or '. Each of these rules represents the 'FUZZY' relation between criterion A, criterion B and estimated IP. In each of the above mentioned rules 'FUZZY' relations depict imprecise relations

between the examined values. In each rule, the combination of the variables 'a' from group A and variables 'b' from group B represents 'FUZZY' phrase M defined in the A x B group .
For example, the function of inclusion of 'FUZZY' phrase related to Rule 4 is determined by:

$$\mu_{M4}(a,b)=\min\{\mu_{\text{medium suspected}}(a),\ \mu_{\text{highly suspected}}(b)\} \quad (7)$$

Each of the rules represents a 'FUZZY' implication which connects 'FUZZY' phrase M to the estimate IP. It is at the same time the 'FUZZY' phrase defined in A x B x IP group. As for Rule 4, the function of inclusion of 'FUZZY' phrase M equals

$$\mu_{N4}(a,b,\text{ίρ})=\min\{\mu_{M4}(a,b),\ \mu_{\text{important}}(\text{ίρ})\} \quad (8)$$

This or several 'FUZZY' phrases, if connected with the term 'or', represent 'FUZZY' clause Z. The rules set as 1,2,...7,8,9 represent the N1, N2 ..... N7, N8 'FUZZY' phrases with the functions of inclusion corresponding to them.

$$\mu_{n1}(a,b,\text{ίρ}),\ \mu_{n2}(a,b,\text{ίρ}),\ \ldots\ \mu_{n9}(a,b,\text{ίρ}) \quad (9)$$

The function of inclusion of 'FUZZY' clause Z is calculated as

$$\mu_{Z}(a,b,\text{ίρ})=\max\{\mu_{n1}(a,b,\text{ίρ}),\ \mu_{n2}(a,b,\text{ίρ}),\ \ldots\ \mu_{n9}(a,b,\text{ίρ})\} \quad (10)$$

Let us determine the estimated suspicion for the customer for whom,
a_A = 60%; b_A = 30%; c_A = 20%; d_A = 70% and x_A = 40% on the basis of criterion A and
a_B = 70%; b_B = 30%; c_B = 20% ;d_B =50% and x_B= 55% on the basis of criterion B.
9 rules have already been set for estimating suspicion. Therefore, it is essential that each rule be accompanied by the design of a sequence of corresponding functions of inclusion where $\mu_ί$ (a), $\mu_ί$ (b), $\mu_ί$ (ίρ) where ί = 1,2,....,7,8,9.
Each of the rules has a corresponding function of inclusion. $\mu_{nί}$ (a, b, ίρ) is depicted by a **sloping** diagram of the corresponding group of adopted estimate, and according to relation (8).
The result of the procedure according to relation (9) is the function of inclusion μz (a, b, ίρ) which is derived graphically by taking into account the highest values of μi (ίρ) on the entire range, that is, from 0 to 100! (Fig. 3). The function of inclusion μ_Z (a, b, ίρ) is the representative of 'FUZZY' estimated suspicion of unauthorized electricity consumption of the given customer.

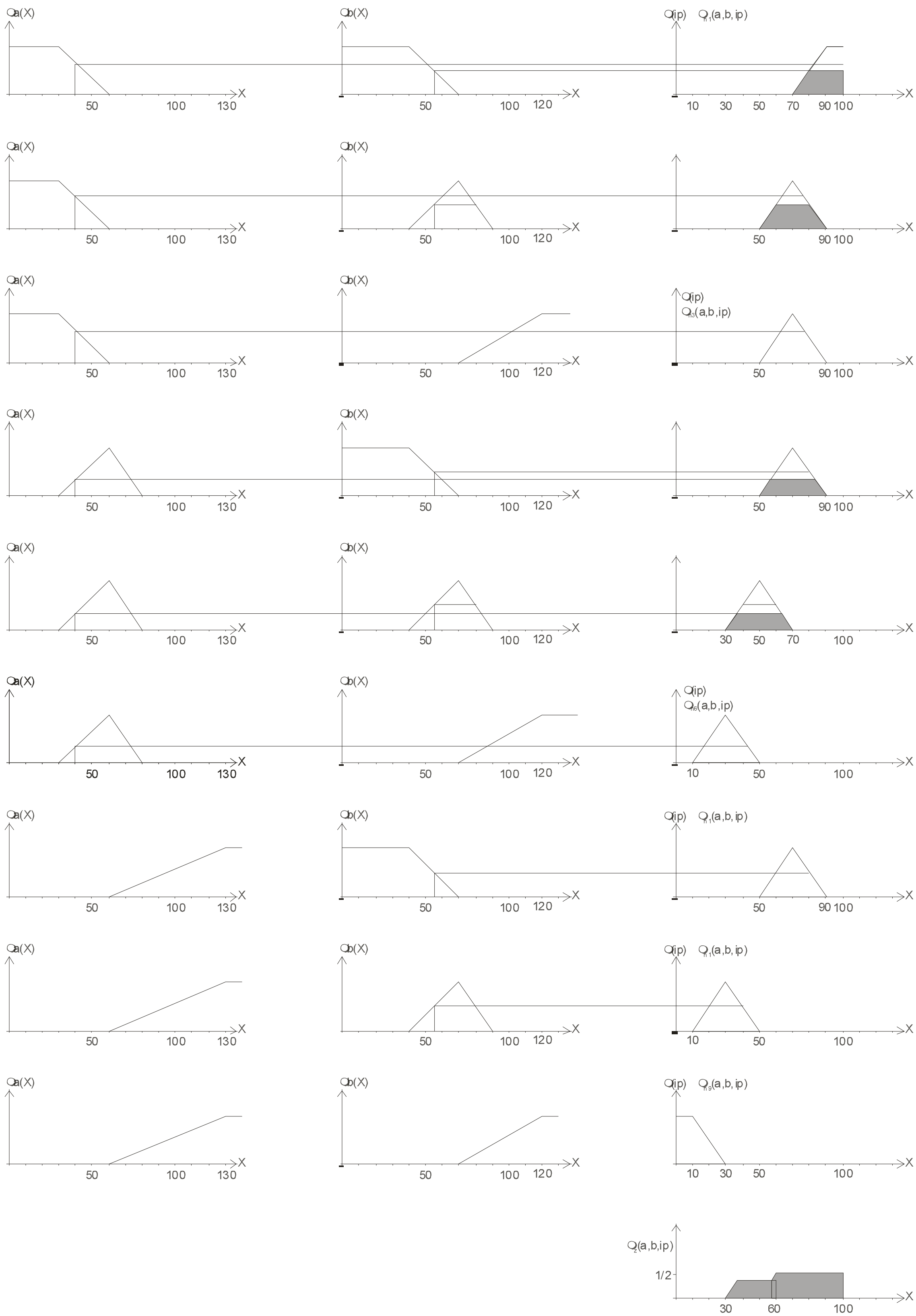

Figure 3. Graph presentation of the estimate of suspected unauthorized electricity consumption

The final phase in the process of 'FUZZY' deduction is defuzzification **.** Through defuzzification**,** the 'FUZZY' conclusion is transformed into a real number whose unit is percentage. There are several approaches to the method of defining that number, in our case, of estimated Ip.
We think that the most favourable way to reach the 'FUZZY' conclusion is by using the centroid of the function of inclusion μz (a,b,ip) where S is the surface formed by μ_z (a, b, ίρ) with x and x_1 and x_2 borders.

$$ί\rho^* = \int_{x_1}^{x_2} \frac{\mu_z(a,b,\iota_p)\cdot x dx}{S} \qquad (11)$$

Customers with the highest index value of ip (%) preference should be subject to observation.
In the given example: ίρ* = 69,6%

CONCLUSION

Functions of inclusion in the groups based on criteria A and B should be carefully defined.
The greater the variety of diagram types in Fig. 1, depending on electrification of the households and their population density, the more regular conclusions could be drawn, that is, the more precise the result of estimated suspicion will be expressed in percentages.
The previously detected unauthorized electricity consumption should be used for drawing diagrams in Fig.1.
The rules set in the work are the result of the authors' views based on the acquired experience and preferences, though it is possible to set the other rules as well.
We can reach the final rules by means of iteration due to the possible occurrence of some illogical assumptions for close values of input variables. Therefore, the analysis of output estimates is required and, if necessary, the correction of some rules should be made.
Formation of 'FUZZY' groups for input parameters and groups for the purpose of estimation can definitely be various, depending on the electricity company.

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