The use of fuzzy sets considering the operation of biogas plants under the conditions of voltage unbalance

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Abstract. A feature of problem solving of energy security in Russia at present time is environmentally friendly energy production. Numerous research works of the quality of electric energy reveal a significant discrepancy with the permissible standards. This will require not only an increase in the contribution of various energy sources to the overall energy balance, but also a more careful approach to the electric power quality. A significant part of the raw materials of agro-industrial facilities is used to generate electricity with an efficiency coefficient of 31%. Performance of electric power varies from 48 to 104 kWh per ton of feedstock, as a rule, organic waste. Disfunction of conversion units is accompanied by significant harm. The high harmonic of current and voltage adversely affect the operation of current-using equipment, electronic devices, distance control elements, relay protection, automatic equipment operation and protection tripping units.

1. Introduction
The consumption of electric power by individual single-phase current using equipment depends both on factors with a regular stable nature and those having irregular, random loads. In this case currents at feeders’ sections can be random variables at any time. We consider temporal variations of the load of biogas plants as the mathematical expectation of a random function described by the average load-time curve [1-7]. Taking into consideration uniformity of the phase-by-phase distribution of electrical receivers of plants, we exclude non-random asymmetry, taking into account the arbitrary distribution of the power of single-phase loads when switching on and off some part of consumers. Phase-wise equality of loads by duration does not exclude the presence of asymmetrical phase currents and currents in the neutral wire. The nature of unbalance will be static [8].

2. Materials and methods
With a large amount n of consumers in a group the distribution law of currents and voltages in rural networks could be considered as normal [9].

For a random independent sample \( y_1, ..., y_n \) of capacity size n of the general population with a normal distribution, the likelihood function is described by the dependence [10]:

\[
\lambda = \left(2\pi \cdot \sigma^2\right)^{-\frac{n}{2}} \exp^{-\frac{\sum_{i=1}^{n} (y_i - \mu)^2}{2\sigma^2}}
\]  (1)
Where $\bar{\xi} \pm \sigma^2$ - mean value and variance in the general population.

Estimates $\bar{\xi} \pm \sigma^2$ result from the equations:

$$\frac{\partial \ln L}{\partial \xi} = 0; \quad \frac{\partial \ln L}{\partial \sigma^2} = 0$$  \hspace{1cm} (2)

Or:

$$\frac{1}{\sigma^2} \sum_{i=1}^{n} (y_i - \bar{\xi}) = 0; \quad - \frac{n}{2\sigma^2} + \frac{1}{2(\sigma^2)^2} \sum_{i=1}^{n} (y_i - \bar{\xi})^2 = 0,$$

From which:

$$\bar{\xi} = \frac{1}{n} \sum_{i=1}^{n} y_i,$$  \hspace{1cm} (4)

$$\sigma^2 = \frac{1}{n} \sum_{i=1}^{n} (y_i - \bar{\xi})^2 = 0.$$  \hspace{1cm} (5)

The unbiased estimates of the parameters of the normal distribution are the sample mean:

$$\bar{\xi} = \frac{1}{n} \sum_{i=1}^{n} y_i,$$  \hspace{1cm} (6)

And sample variance:

$$\sigma^2 = \frac{1}{n} \sum_{i=1}^{n} (y_i - \bar{\xi})^2 = 0.$$  \hspace{1cm} (7)

Random variables $\bar{\xi} \pm \sigma^2$ are characterized by corresponding variances.

3. Results and discussion

On the base of statistical analysis, a histogram of the current irregularity coefficient was obtained for a sample of 1000 (figure 1). From the curve it follows that the irregularity coefficient, determined by formula:

$$k_n = \frac{I_{on}}{I_a + I_b + I_c},$$  \hspace{1cm} (8)

Conforms the mathematical expectation 0.46 at mean-square deviation 0.18.

Root-mean-square standard deviation $\sigma$ coincides with the distance from the mean value $k_n$ to the points of inflection. For a random variable $k_n$ with a normal probability distribution of observation, its value in the interval $-3 \sigma$ is 0.997.

It is found that the normal law of distribution is subject to the relative values of the direct sequence $U1$ negative sequence $U2$ and level of voltage unbalance $D_i$, percent.

This law satisfactorily describes continuous values of equal probability of symmetry with respect to the mathematical expectation of deviations, a large probability of small deviations from the mathematical expectation.
The operating conditions of the biogas plant are in large part determined by the reliability of the hardware components [11]. In this case, it is necessary that the units of grinders, pumps, blocks of shutoff and control valves have certain stability. Stability during calculation of the biogas plant should take into account changes in operating modes. The parameters of the elements of the load center of the biogas plant are determined for the maximum and minimum operating modes. The change-over from one mode of operation of the system to another significantly changes the parameters of the stability of feeding loads, therefore, the model describing this state of the rural power supply system must correspond to various modes of operation. In addition, protective devices installed at the biogas plant behind consumer transformers and adapted to one operating mode may have false alarms when the system switches to another mode, as well as when the conditions for regulating increases are met. In rural networks, the relationship between the parameters to be measured and the system modes is vague or ill-defined expressed. The qualitative characteristics of this relationship can be assessed by a set of conditions, for example, the system operates in a minimum mode at the load from low to medium. In this case, the voltage on the elements of the biogas plant will conform to an average or small value. If the system operates in maximum mode at the large or medium load, excluding a small one, then the voltage on the biogas plant elements will conform to the average or higher value. The specified voltage range is provided by devices for regulating of increasers of power supplies, in addition, discrepancies between voltage regulation and consumer load should be taken into account. Abnormalities affecting the operation of a biogas plant may be incorrect installation of adjustable taps on protective devices. So, in the minimum mode, the voltage of the source with a large load of the biogas plant elements will be the lowest, and with the maximum mode of setting of increasers and a low load, the voltage will be higher. The conditions just cited can be used to describe typical situations of minimum and maximum operating modes of a biogas plant using fuzzy logic methods.

Degrees of conformity of levels of fuzzy situations for $S_{\text{max}}$ and $S_{\text{min}}$ let us denote by index number [0.8…0.2], a value of 0.8 corresponds to good convergence, a value of 0.5 is an average convergence, a value of 0.4 is a low convergence, a range from 0.2 or less - unsatisfactory convergence. These criteria and their values were obtained on the basis of preliminary calculations for various parameters and operating modes of the biogas plant system.

Specified conditions conform to dependencies [12]:

$$S_{\text{min}} = \{0.8/T_{UF}, 0.5/T_{UM}, 0.2/T_{UB}\}$$

$$S_{\text{max}} = \{0.2/T_{UF}, 0.5/T_{UM}, 0.8/T_{UB}\} \bigcup \{0.2/T_{SF}, 0.4/T_{SM}, 0.5/T_{SB}\}$$

Figure 1. Histogram of the current irregularity coefficient.
Where $T_{UF}, T_{UM}, T_{UB}$ - the terms «small», «average» и «large» of the U feature (voltage);
$T_{SF}, T_{SM}, T_{SB}$ - the terms «small», «average» и «large» of the S feature (load).

If during the operation of a biogas plant are used modes with the parameters of load centers:

$$U_{(1)} = 0.6 \text{ and } S_{(1)} = 0.8$$ the first case,
$$U_{(2)} = 0.2 \text{ and } S_{(2)} = 0.1$$ the second case,

Then membership functions considered by the mode will define fuzzy situations:

$$S_{(1)} = \left\{ \left\{ 0/T_{UF}, 0.7/T_{UM}, 0.2/T_{UB} \right\}/U, \left\{ 0/T_{SF}, 0.4/T_{SM}, 0.3/T_{SB} \right\}/S \right\},$$
$$S_{(2)} = \left\{ \left\{ 0.6/T_{UF}, 0.1/T_{UM}, 0/T_{UB} \right\}/U, \left\{ 0.7/T_{SF}, 0.2/T_{SM}, 0/T_{SB} \right\}/S \right\}. \tag{13}$$

Proximity measure of current situations $\tilde{S}_{(1)}$ and $\tilde{S}_{(2)}$ in relation to $\tilde{S}_{\text{max}}$ and $\tilde{S}_{\text{min}}$ will be the degree of fuzzy equality from the expression [13]:

$$\mu(\tilde{S}(i), \tilde{S}(j)) = \nu(\tilde{S}(i), \tilde{S}(j)) \land \nu(\tilde{S}(j), \tilde{S}(i)) \tag{15}$$

Where $\nu(\tilde{S}(i), \tilde{S}(j))$ - fuzzy set inclusion degree $\tilde{S}(i)$ into a fuzzy set $\tilde{S}(j)$;
$\nu(\tilde{S}(j), \tilde{S}(i))$ - fuzzy set inclusion degree $\tilde{S}(j)$ into a fuzzy set $\tilde{S}(i)$;
$\land$ - conjunction operations of fuzzy statements.

Herewith the degree of introduction of the fuzzy set $\tilde{S}(i)$ into a fuzzy set $\tilde{S}(j)$ is determined by the relation:

$$\nu(\tilde{S}(i), \tilde{S}(j)) = \land(\mu\tilde{S}(i)(x) \rightarrow \mu\tilde{S}(j)(x)) x \in X, \tag{16}$$

Where $\mu\tilde{S}(i)(x), \mu\tilde{S}(j)(x)$ - fuzzy prepositional variables;
$\rightarrow$ - operation of implication of fuzzy statements;
$\land$ - operation of conjunction which is taken over all $x \in X$.

An illustration of fuzzy statements A, B can be a fuzzy supposition $A \rightarrow B$, defined by the expressions:

$$A \rightarrow B = \max(1 - A, B) \tag{17}$$

The result of these statements is an expression $A \land B$, which is defined by:

$$A \land B = \min(A, B) \tag{18}$$

The fuzzy set inclusion degree $\tilde{S}_{(1)}$ into a fuzzy set $\tilde{S}_{\text{max}}$ is defined by the relation (14) and represents as:

$$\nu(\tilde{S}_{(1)}, \tilde{S}_{\text{max}}) = (0 \rightarrow 0.2) \land (0.7 \rightarrow 0.5) \land (0.2 \rightarrow 0.5) \land (0 \rightarrow 0.2) \land (0.4 \rightarrow 0.4) \land (0.3 \rightarrow 0.5) = 1 \land 0.5 \land 0.8 \land 1 \land 0.6 \land 0.7 = 0.5. \tag{19}$$

Situations $\tilde{S}_{(1)}$ and $\tilde{S}_{(j)}$ can be fuzzy equal if:
\[ \mu \tilde{S}_{(1)}(t) \cap \tilde{S}_{(j)}(t) \geq t, \quad (20) \]

Where \( t \in [0.5;1] \) - conforms to the stated threshold of fuzzy equality of situations.

This provides a possibility to define the inclusion of fuzzy set \( S_{\text{max}} \) into the fuzzy set \( S_{(1)} \): \( \forall \ (S_{\text{max}}, S_{(i)}) = 0.5 \).

In this case the fuzzy equality degree \( \mu(S_{(1)}, \tilde{S}_{(\text{max})}) \) of the fuzzy sets \( S_{(1)} \) and \( S_{(\text{max})} \) will be 0.5.

The evaluation findings of the fuzzy equality degrees of current situations \( S(1) \) and \( S(2) \) for systems of biogas plant of rural power supply under model situations can be reflected by the following criteria (table 1):

| Criteria | \( S_{\text{max}} \) | \( S_{\text{min}} \) |
|----------|-----------------|-----------------|
| \( S_{(1)} \), current situation | 0.5 | 0.2 |
| \( S_{(2)} \), current situation | 0.3 | 0.5 |

### 4. Conclusion

The proposed adaptation system of the biogas plant to a change of electrical load is built on the basis of the fuzzy logic method, which allows increasing the stability margin of the biogas plant, reducing the number of shutdowns of electrical equipment, increasing the reliability of the biogas plant system as an element of rural power supply while ensuring operational safety.

From the above material it follows that fuzzy logic is a promising direction in the algorithms of biogas plant systems of rural networks, both in working and emergency modes of power supply.

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