Information FUZZY-technologies in energy

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Abstract. The provisions for voltage mode group control using automatic control devices for the operation of power transformers with voltage regulation under load have been developed. This approach allows to select the rational voltage with minimal economic damage due to energy losses. The provisions are based on the use of fuzzy logic methods.

1. Introduction
When managing power engineering facilities the primary method of limiting power consumption to ensure minimization of impacts on the technological process while applying differentiated tariffs, is the voltage mode regulation [1, 2].

The most effective control of voltage mode at the load nodes is achieved by regulating the transformation ratio of power transformers at the substation, in which conditions voltage regulating effect is in the range between 1,002...1,415 depending on the operating parameters. The second to this method in terms of voltage control is voltage control in power supply centers (regulating effect between 0,969...1,270) and reactive power compensation (regulating effect between 0,076...0,325) [3-5]. It should be kept in mind that with a limited range of voltage mode variation, it is the reactive power in the mains that should be changed in the first place using compensating units (CU) synchronous machines (SM). In this case, adjustment actions shall not contradict requirements for reactive power compensation in a given node. The change in transformation ratios of the distribution substation power transformers and power provider is performed after application of technical capabilities aimed at adjustment of power lines reactive power and inductive reactance. For this purpose voltage regulator under load (RUL) limitations should be taken into account based on the number of switches [6-9].

The choice of voltage mode is a multifaceted task the solution of which requires detailed information on operating modes of the major part of an enterprise's electrical facilities. In this case, one should take into account the fact that a part of parameters change in functions of probabilistic characteristics. Famous FUZZY-technologies [10] are proposed to be used as an alternative with a possibility of adaptation to the solution of the task set of fuzzy logic theory and a system of expert opinions.

2. Fuzzy expert system based on FUZZY-technologies
To infer a solution, a fuzzy expert system uses a combination of fuzzy membership functions and rules instead of Boolean logic. Expert methods determine the term-sets of parameters that form the membership functions of all linguistic variables and the algorithms of FUZZY-modules that select devices. The solutions are implemented as per the following algorithm:

1. Actual values of input parameters are determined.
2. Values corresponding to the true value are determined at the output procedure.
3. Fuzzy sets generation is carried out with fuzzy sets corresponding output variables.
4. Quantitative forms of variables on the output devices are organized.

3. Implementation of informational FUZZY-technologies in the energy sector

The implementation of the automatic voltage control system using FUZZY-technologies in accordance with the steps considered is presented in the block schematic diagram in Figure 1.

![Block schematic diagram of the automatic voltage control system using FUZZY-technologies](image)

**Figure 1.** Block schematic diagram of the automatic voltage control system using FUZZY-technologies.

The FUZZY-regulator included in the block schematic diagram shown in Figure 1 consists of the following units:

- a rules base formation unit, in which each subinference is associated with a specific weight coefficient;
- fuzzification unit, in which the clear values of state variables obtained with a certain accuracy are translated into the language of fuzzy sets, and any degree of membership is further \( \mu_i \), determined by this fuzzy set. Thus, the extent is determined to which a measured or computed value of state variables has a quality or property determined by a certain fuzzy set;
- sub-conditions aggregation unit, where the degree of truth conditions for each rule of the fuzzy inference system is determined;
- subinferences activation unit, where the transition from conditions to sub-conditions occurs;
- inference accumulation unit, where fuzzy sets obtaining for each of the output variables is implemented taking into account the parameters of the electrical equipment operating mode;
- defuzzification unit, which is intended to convert the fuzzy recommendations on the selected conjunction into the quantitative value of a specific signal.

Expert on voltage modes control determines linguistic variables, and the range of their variations. The expert also estimates the degree of membership of term-sets according to the meaning of the considered array of variable parameters.

As a result of study conducted, it was established that the regime of outgoing conjunction, with certain assumptions, can be characterized by a set of four parameters: load power \((S)\), length of the line \((L)\), voltage regulating effects \((P(U))\), load distribution along the line \((R)\) and the category of the power facility subject to damage due to voltage deviations from a rational level \((K(U))\). This mode is described by five terms: very heavy mode (VH), heavy mode (H), medium mode (MM), light mode (L), very light mode (VL).

The intervals of possible load power variation and line length can be divided into five terms \((0; 0.25; 0.5; 0.75; 1.0)\), expressed in per-unit system (pu). The full maximum power and maximum conjunction
length respectively, are assumed as the basis. The load power of the outgoing lines can be obtained based on data from current and voltage primary sensors. Information on the length of all lines is entered into the database. The membership functions of the line length $\mu(L)$ and load power $\mu(S)$ are provided in Figures 2 and 3.

$$\mu(L)$$

**Figure 2.** Graph of the values membership function of the 'line length' linguistic variable.

$$\mu(S)$$

**Figure 3.** Graph of the values membership function of the 'load power' linguistic variable.

Damage arising due to voltage deviation from the rational level, is determined in advance for all considered damages when controlling assets. Damage zoning can be represented in three categories: small (1), medium (2), great (3), the functions of which are provided in Figure 4.

$$\mu(K(U))$$

**Figure 4.** The graph of the values membership function of a linguistic variable 'damage from voltage deviation from the rational level'.

The term aggregation of the electrical load dependence on the voltage level $P(U)$ consists of three separate terms: weak 0.3, medium 0.6, strong - 0.9 (Figure 5).
medium strong weak

Figure 5. The graph of the values membership function of a linguistic variable ‘dependence of the electrical load on the voltage level’.

Load distribution along the line (R) is represented by three terms: the load is concentrated in the start of line (S), and is distributed along the line (D), concentrated in the end (E) (Figure 6).

Figure 6. The graph of the values membership function of a linguistic variable ‘load distribution along the line’

In the process of FUZZY-logical transformations, we obtain the initial data in the form of parameters, membership functions, and degrees of membership of parameter elements. Based on logical rules, the basic FUZZY-logic calculations are performed, which results in a line selection with the voltage mode determining it. Initial information about the management strategy is stored as a rule base. Expert methods should determine the terms aggregates and membership functions of all linguistic variables and the algorithms of FUZZY-control devices. The population of rules and the mechanism for processing FUZZY-information in a fuzzy expert system form a knowledge base.

The rule base is formed from conventional logical inferences of the type ‘IF<condition ...>, THEN<result ...>’ using the necessary logical operations AND, OR, etc. The first part of the rule is a statement about the fuzzy (linguistic) value of the input parameters characterizing the voltage mode in the i-th line (S, L, K(U), P(U), and R). The second part of the rule is a statement about the appropriate mode severity. For example: ‘IF the power of the current receiver (S) is maximum (1 pu) AND line length (L) is maximum (1 pu), AND the ‘heavy damage’ power facility category was assigned (3) due to voltage deviation from a rational level, (K(U)), AND the dependences of the electric load on the voltage (P(U)) strong level (0.9), AND the load is concentrated at the end of line, (E), THEN it is decided that the mode is very heavy (VH). Then, a mechanism for processing FUZZY-information is established – the execution of logical operations in preconditions. Since it is necessary to consider the entire population of the mode parameters, with respect to this problem under solution, the AND
operation is used as a minimum operator.

Using the membership functions defined for the input variables, their actual values for each $i$-th conjunction $\mu(S_i), \mu(L_i), \mu(K_i), \mu(P_i), \mu(R_i)$, are calculated, and the degree of confidence for each rule premise with respect to all linguistic terms is determined. Based on logical rules, the basic FUZZY-logical calculations are performed, as a result of which problems are resolved in the fuzzy logic categories.

To find the membership functions of the $i$-th conjunction, $\mu_i(S_i, L_i, K_i, P_i, R_i)$ characterizing the $V$-th rule of fuzzy conditional logical inference, the Mamdani rule is used:

$$\mu_i(S_i, L_i, K_i, P_i, R_i) = \min \{\mu(S_i), \mu(L_i), \mu(K_i), \mu(P_i), \mu(R_i)\}.$$  

(1)

The resulting membership function of conjunction, $\mu_{res}(S_i, L_i, K_i, P_i, R_i)$, which characterizes the whole population of $V$-th rules for $i$-th joining, connected by the THEN union, is defined as the maximum among all membership functions:

$$\mu_{res}(S_i, L_i, K_i, P_i, R_i) = \max \{\mu_i(S_i, L_i, K_i, P_i, R_i)\};$$  

(2)

Each $i$-th conjunction $(C_i)$ in accordance with a certain logical rule is assigned the mode severity degree $(M_{S_i})$. According to the maximum of the determined resulting membership degrees, $\mu_{c_{\text{res}}}(S_i, L_i, K_i, P_i, R_i)$ a conjunction is selected that determines the voltage mode in the distribution mains $(C_{\text{det}})$:

$$\mu_{c_{\text{res}}}(S_i, L_i, K_i, P_i, R_i) = \max \{\mu_{res}(S_i, L_i, K_i, P_i, R_i)\}.$$  

(3)

4. Conclusion

Based on the stated logical rules, the basic FUZZY-logic calculations are performed, resulting in the lines selection and determining their voltage mode.

The presented provisions for voltage mode group control using automatic control devices during operation of power transformers with voltage regulation under load, allow the selection of rational voltage in power supply centers. When implementing this algorithm, the following is taken into account: the technical condition of the regulation means, the mode parameters in the controlled power lines, the ability to perform FUZZY-logical operations and determining the rational voltage level, with minimal economic damage caused by electricity losses.

Using the fuzzy logic methods in the developed algorithm allows to automate the selection of the line that determines the voltage mode in the conditions of a large number of input parameters variation. The algorithm corresponding to these provisions, embedded in the FUZZY-regulator, ensures the integration of local regulators of transformer automatic voltage control devices, adjustable compensating units, and automatic excitation controllers (AEC) of synchronous machines (SM) into the automated power supply control system and supervisory control and data acquisition (SCADA) system.

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