Development of an Adaptive Module for Control of Energy Supply of the Consumer in the Distributive Electrical Network 0,4 kV for Elimination of the Phase Load Unsymmetry

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Annotation. The paper considers the possibility of modeling the process of controlling the power supply of the consumer in the lower levels of network organizations to improve the quality indicators of electrical energy in the distribution electrical networks of 0.4 kV. The analysis of the process of control of indicators of the quality of electricity in the supply of energy to consumers. The block diagram of the adaptive power supply control module of the consumer and the algorithm of the control process are presented. A consumer power supply control module in 0.4 kV distribution networks is proposed.

Introduction

Improving production efficiency depends on the supply of energy resources to consumers in accordance with the requirements of the Laws of the Russian Federation [1], GOST [2,3], industry and other regulatory documents [4,5]. New scientific developments in this field of energy should be aimed at improving the network economy of energy suppliers [6,7], modernizing the technological equipment of electricity consumers [8,9].

The purpose of this work is to develop a model of the consumer's power supply control process in the adaptive system [10] of the power quality control and management complex [11,12] in the 10 / 0.4 kV power distribution network [13,14] and to solve the optimization problem [15] of the control technological process quality of electrical energy (EE) [16,17] by developing an algorithm for monitoring and control.
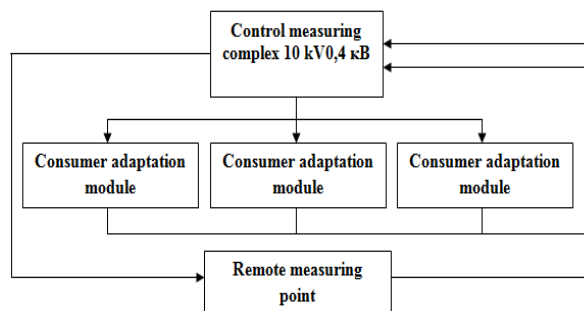
1 Adaptive control system.

An adaptive control system to eliminate the asymmetry of the phase load will be used in the concept of creating a complex for monitoring and managing the quality of the EE of a section of a 10 / 0.4 kV electrical distribution network (Fig. 1). The control complex for the section of the distribution network for monitoring and managing the quality of energy efficiency is a symbiosis of electrical and telecommunication networks, technological equipment, software and consists of a central management complex (CMC), control measuring complexes of 10 kV (CMC-10 kV) and 0.4 kV (CMC-0.4 kV), remote measuring points (RMP), adaptive power supply control modules of consumers (CAM) (Fig. 1).

The result of the use of the adaptive control system is the uniform distribution of the single-phase load over the phases of the three-phase network, increasing the energy characteristics of the network.

A diagram of a section of a 10 / 0.4 kV electrical distribution network using an adaptive control system is shown in Fig. 2.

The control system includes a CMC -0.4 kV, a RMP, CAM. CMC are located at 10 / 0.4 kV substations.
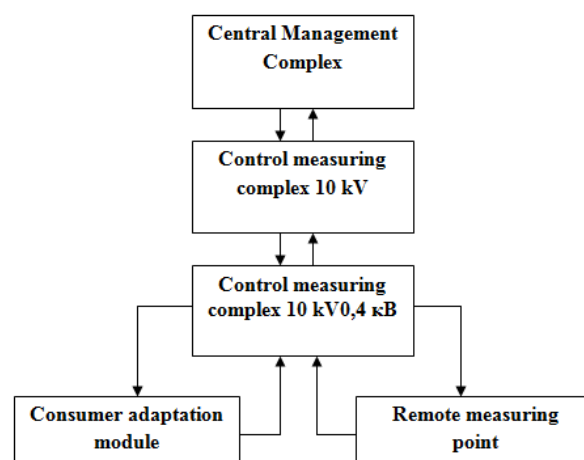
Fig. 1. Scheme of the complex for monitoring and managing the quality of electricity in the 10 / 0.4 kV electrical distribution network section.

Fig. 2. Diagram of an adaptive control system for eliminating phase asymmetry of a 10 / 0.4 kV electrical distribution network section.

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RMP is located on the end supports of the overhead line-0.4 kV. CMC, RMP and CAM perform the following main functions: monitoring EE parameters; collection, processing, transmission of data to the CMC.

2 Adaptive power supply control module

The 0.22 kV consumer power management adaptation module (CAM) is part of an adaptive control system for eliminating the load asymmetry of the phases of the 0.4 kV power grid [18], which will be used in the concept of creating a complex for monitoring and controlling the quality of electric power in the 10/0 distribution network section , 4 kV. CAM is intended for uniform distribution of a single-phase load over the phases of a 0.4 kV three-phase network. AM contains input terminals L1, L2, L3, N for connecting the mains and output terminals L and N for connecting the load, and also includes a measuring device (MD), a device for selecting phases (switch) (PSD), a device control and data transmission (CDTD), communication device (CD) (Fig. 3).
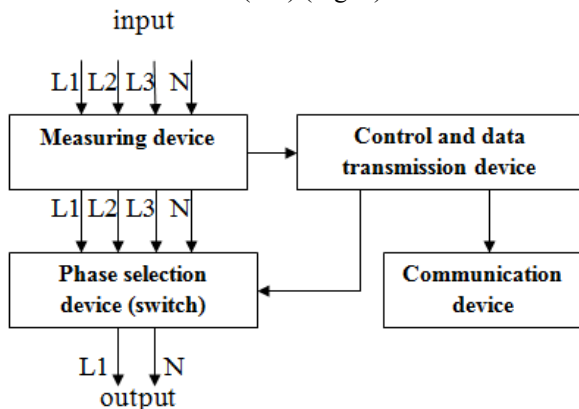

Fig. 3 Consumer power management adaptation module.

The task of the CAM device is to achieve balancing of phase currents (loads) of a three-phase distribution network of 0.4 kV, reducing the volume and cost of hardware, ensuring the realization of the goal of balancing phase currents (loads).

This CAM works as follows. Power supply to each consumer is carried out through the CAM, which is installed on the support of the power transmission line at the point of connection of the branch of the overhead line (OHL) of 0.4 kV. Power is supplied to the CAM input contacts in phases. The measuring device (MD) determines the magnitude of the parameters of the power grid for each of the phases: voltage, current load, power factor, electric power consumption of electricity (full, active, reactive) and others. The MD sends data on the state of the power grid to the CDTD for data analysis. The CDTD of each CAM transmits data on the state of the electric network at each specific point of the 0.4 kV overhead line through the CD to the measuring control complex to process the measurement data and decide on switching certain consumers to balance the loads along the phases of the power line, as well as sends control commands to a specific CAM for switching and load balancing. CDTD processes the received information,

makes a decision and sends a command to the PSD to switch a certain consumer to a phase that meets the specified requirements. Having received a command, the PSD switches the consumer's power supply to a predetermined phase and reports information on the switching performance to the control unit and the control unit.

The implementation of this device eliminates the use of additional hardware for regulating the asymmetry of the phase parameters of the 0.4 kV network.

3 Algorithm of the consumer energy supply control process

The block diagram of the algorithm of the process of managing the power supply of the electricity consumer to eliminate the phase voltage asymmetry and phase voltage deviations is shown in Fig. 4. The description of the operation of the algorithm is presented point by point.

1. Beginning of the algorithm.

2. Entering the technical characteristics of the power transmission line (PTL). The following technical characteristics are introduced: the total length of the power lines , the number of power line wires , the cross-sectional area of the power line wires , the distance from the starting point of the power line to the point of connection of each AM to the power line , the specific resistance of the power line conductors, maximum transmission capacity of power transmission lines , maximum power of electrical equipment of consumers connected to power lines.

3. Enter restriction parameters for the network. It is necessary to introduce the following basic restrictions: the tolerance for the maximum permissible deviations of the voltage value is not more than $\pm$ 10% of the nominal voltage , the tolerance for the value of the voltage unbalance factor between the phases of a three-phase four-wire electrical network is not more than $\pm$ 4% of the nominal voltage , tolerance to exceed the amount of power consumed by the consumer's electrical equipment relative to the declared maximum power determined by the terms of the power supply agreement.
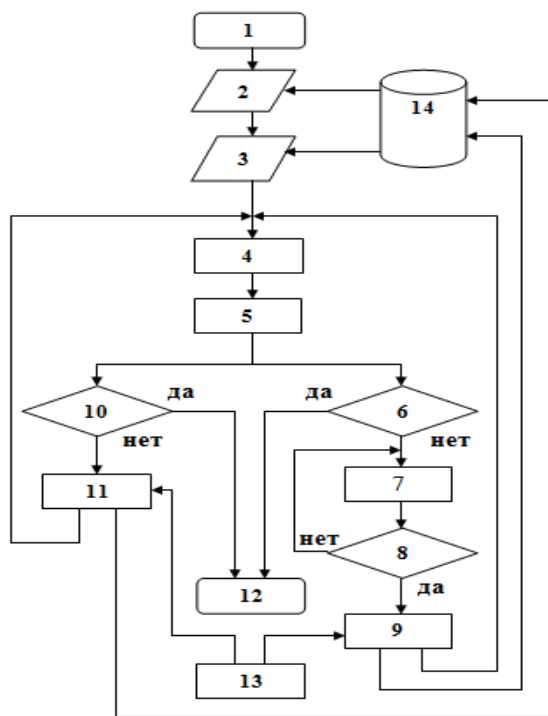
Fig. 4 Algorithm of the process of energy management of the consumer.

4. Measurement of the electrical parameters of the network at the points of CAM connection to the power transmission line. To calculate the symmetry of electrical loads and voltages in phases of a three-phase electrical network, the following parameters are recorded: electric current flowing in the circuit I, electric voltage U , active power factor , reactive power factor, electric active power P, electric reactive power Q.

5. Calculation and analysis of asymmetry of phase voltages and values of maximum deviations of phase voltages and values of power consumption. This is necessary to determine the configuration of the distribution of the connection of CAM consumers in the phases of power lines. The values of phase voltages should be equal to each other, i.e. it is necessary to fulfill the relation

$$U_1 = U_2 = U_3 \quad , \qquad (1)$$

where, U1, U2, U3 - electric voltages of phases L1, L2, L3 respectively.

The deviation of the voltage levels of the phases of the three-phase four-wire electrical network should be no more than ± 10% according to paragraph "3" of the algorithm:

$$U_{MIN} < U_i < U_{MAX} \quad , \qquad (2)$$

where, U_i - is the voltage value of phase *i; U_{MIN} , U_{MAX}* - minimum and maximum voltage values.

Next, we check the ratios of the phase voltage deviations among themselves:

$$|U_1 - U_2| < \Delta ?; |U_2 - U_3| < \Delta ?; |U_3 - U_1| < \Delta ? \quad (3)$$

If relation (3) is not satisfied, then the transition to step "6" of the algorithm occurs. To determine the correspondence between the consumed and allowed capacities, the average active power consumed by the electrical equipment at the point of connection of the consumer CAM to the power transmission line is calculated:

$$P_{потреб} = U_i \cdot I_i \cdot cos\varphi_i \quad , \qquad (4)$$

where, $P_{потреб}$ - active power consumption; U_i, I_i, $cos\varphi_i$ - network parameters of the i phase.

The condition for matching the capacities is checked when moving to paragraph "10" of the algorithm.

6. The choice of the algorithm action based on the analysis of the asymmetry of the mains phase voltages and the maximum deviations of the mains phase voltages. If the voltages U1, U2, U3 have equal values in phases L1, L2, L3 of the network according to the tolerance requirement for voltage unbalance and maximum voltage deviations specified in paragraph "3" and the condition:

$$(|U_1 - U_2| < \Delta) \wedge (|U_2 - U_3| < \Delta) \wedge$$
$$(|U_3 - U_1| < \Delta) \qquad (5)$$

then, no actions are taken to switch the load on the phases of the power transmission line and the transition to point "12" "End of the algorithm" is performed. If the voltages U1, U2, U3 have unequal values in phases L1, L2, L3 of the network in accordance with the tolerance requirement for voltage unbalance and maximum voltage deviations specified in paragraph "3" and condition (2) and (5) is not met, then actions are taken to switch the consumer load to the power transmission line phase, which meets the requirements specified in paragraph "3" and proceeds to paragraph "7" of the algorithm.

7. Determination of the configuration of the optimal connection of the consumer's CAM to the phases of the transmission line. The voltage regulation method can be carried out by distributing the power of consumers over the phases of the network to equalize the voltage level and switching the load of the consumer to the phase of the network, which meets the requirements of relation (5).

8. Decision-making on the distribution of the connection of CAM consumers taking into account the indicators of electric voltage at the points of connection to the power transmission line. the decision is made on the basis of determining the most optimal variant of the distribution of CAM consumers by phases.

9. Automatic switching of CAM consumers to selected network phases. Switching selected CAM consumers to other phases of power lines is carried out in compliance with relation (2).

10. The choice of the algorithm based on an analysis of the comparison of power consumption with the allowed (declared). If the condition for limiting the permitted power for the consumer is met and the power consumed by the electrical equipment does not exceed or equal to the allowed:

$$P_{потреб} \le P_{разреш} \qquad (6)$$

then, you go to "12" "End of algorithm". If the condition for limiting the permitted power for the consumer is not met and the power consumed by the electrical equipment exceeds the permitted:

$$P_{потреб} > P_{разреш} \qquad (7)$$

then proceeds to step "11".

11. Temporary limitation of the consumption of electrical energy through the consumer's CAM. At present, exceeding the maximum power is a violation of consumer obligations under an electricity supply agreement, for which a restriction on the consumption regime is introduced [14].

12. End of the algorithm execution.
13. Controlling influence of the adaptive control system. An adaptive system for controlling electrical loads as part of a control measuring complex and an adaptive module for controlling energy supply of a consumer eliminates uneven distribution of electrical loads in phases, asymmetry of currents and phase voltages for monitoring and controlling the quality of electricity in a section of a distribution electrical network.
14. Database for receiving, storing transmission of information.

4 Results of modeling the operation of the algorithm of the consumer's power supply control process

The adaptive power supply control module of the consumer, using the operation of the control process algorithm, analyzes the parameters of the network phases according to the magnitude of the voltage level [18,19]. When the voltages U1, U2, U3 have equal values in phases L1, L2, L3 of the network according to the tolerance requirement meets the specified limitation conditions, the action of the algorithm is performed to move from point "6" to point "12" of the algorithm and the optimization process is not performed. If the voltage value exceeds the limits of the limits, a transition is made to point "7" of the algorithm, then the optimization process is performed on the choice of the electric phase for powering electrical appliances, which corresponds to the specified conditions of the limits [20] .

Let us consider an example of calculating the problem of optimizing the operation of an adaptation module using linear programming when the voltage in the supply phase of the network drops below a given level under the conditions of restrictions.

Let the consumer's electrical equipment through the adaptation module be powered from phase A of the electrical network. The voltage values of the phases of the network L1, L2, L3 are 190 V, 200 V, 230 V, respectively. The voltage value of phase A is lower than the level specified by the condition-limitation of item "3" and the conditions (2) and (5) of the algorithm are not met.

Let us solve this problem using the dual simplex - the method [21] of linear programming using a simplex table.

The objective function is as follows:

$$F(X) = 190x_1 + 220x_2 + 230x_3 \qquad (8)$$

Let us determine the minimum value of the objective function under the following constraint conditions:

$$190x_1 + 220x_2 + 230x_3 \leq 242 \qquad (9)$$
$$-190x_1 - 220x_2 - 230x_3 \leq -198 \qquad (10)$$

To construct the first reference plan, the system of inequalities is reduced to a system of equations by introducing additional variables [22]. We introduce the basic variables X4, X5.

The coefficient matrix A = a (ij) of this system of equations has the form:

$$A =$$

190	220	230	1	0
-190	-220	-230	0	1

Let's solve the system of equations for the basic variables: X4, X5.

The initial version of the simplex table is shown in able 1.

Table 1

Basis	B	x_1	x_2	x_3	x_4	x_5
x_4	242	190	220	230	1	0
x_5	-198	-190	-220	-230	0	1
F(X0)	0	-190	-220	-230	0	0

After performing the transformations, the simplex table acquires the final version (table 2).
The optimal plan can be written as follows:

$$x_1 = 0, x_2 = 0, x_3 = {}^{99}/_{115} \qquad (11)$$
$$F(X) = 190*0 + 220*0 + 230*{}^{99}/_{115} = 198 \qquad (12)$$

Table 2

Basis	B	x_1	x_2	x_3	x_4	x_5
x_4	44	0	0	0	1	1
x_3	${}^{99}/_{115}$	${}^{19}/_{23}$	${}^{22}/_{23}$	1	0	${}^{-1}/_{230}$
F(X1)	198	0	0	0	0	-1

The optimal plan can be written as follows:

$$x_1 = 0, x_2 = 0, x_3 = {}^{99}/_{115} \qquad (11)$$
$$F(X) = 190*0 + 220*0 + 230*{}^{99}/_{115} = 198 \qquad (12)$$

We will also determine the maximum value of the objective function (8) under the above conditions-constraints (9).

The initial version of the simplex table is shown in Table 1. After performing the transformations, the simplex table acquires the final version (Table 3).

Table 3

Basis	B	x_1	x_2	x_3	x_4	x_5
x_5	44	0	0	0	1	1
x_3	$121/115$	$19/23$	$22/23$	1	$1/230$	0
F(X2)	242	0	0	0	1	0

The optimal plan can be written as follows:

$$x_1 = 0, x_2 = 0, x_3 = 1^6/115 \qquad (13)$$
$$F(X) = 190*0 + 220*0 + 230*1^6/115 = 242 \qquad (14)$$

We see that the condition for limiting the voltage value in phase A of 198 V was not met. To fulfill this condition, it is necessary for CAM to switch the power supply to phase B or C, which satisfy the condition for limiting the voltage value in the range of variation of the objective function from 198 V to 242 V according to expressions (12), (14). That is, as a result of solving the optimization problem, the control process is carried out for the selection of the supply phase for the power supply of the consumer.

Conclusion

The presented article discusses the issues of modeling the process of managing the energy supply of the consumer. As a result, a structural diagram of the adaptive module for controlling the consumer's power supply, an algorithm for the process of controlling electrical loads in a three-phase 0.4 kV electrical distribution network was developed. Also, a study was carried out to simulate the operation of the algorithm for the control process of electrical loads based on the use of the dual simplex method of linear programming. As a result, simulation modeling of the state of the network and the operation of the algorithm for changing the configuration of the consumer's connection was carried out to achieve a uniform distribution of power over the phases of the network and the magnitude of permissible voltage deviations.

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