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Development of energy-saving methods for minimization of power and load losses

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The article presents information on optimization of steady-state regimes in power supply systems in order to minimize power losses. The following tasks were formulated and solved: engine parameters were determined; the steady state of the power supply system was calculated. Statistical characteristics of power losses in asynchronous and synchronous motors and transformers were obtained. Investigations have been carried out for the ore mining and processing enterprise. On the basis of the obtained universal model, a software package has been designed to perform computational and experimental research in order to obtain static characteristics of power losses and loads in the power supply system and to determine the character of variation of these characteristics.

Keywords: power supply system, statistical characteristics; asynchronous and synchronous motor, transformer, load power; steady state; power loss; software package.

Introduction

It is well known that the power capacity of the national industry significantly exceeds the analogous indicators of the developed economies of Western Europe, the USA and Japan. Therefore, much attention is currently paid to energy saving in terms of optimizing power consumption of individual electrical receivers and electrical systems, as well as reducing losses in transmission, distribution and consumption of electricity [1]. At the same time, the efficiency of functioning of industrial enterprises is estimated, including the indicators of efficiency of the power supply system (PSS), which is especially important for significant electricity consumption and a high energy component in the structure of production costs [2]. In this regard, it is necessary to solve the problem of optimizing operating modes of power supply systems in order to minimize losses for power transfer from the power system to consumers.

It is reasonable to solve the problem of minimization of electric power losses in electric networks at the stage of designing an industrial facility, when the parameters of the main electrical equipment are selected. This task is no less important in the process of operation of the power supply system. However, in both cases, it is possible to solve the problems of analyzing, calculating and optimizing the PSS operating modes only using special methods and means of computer technology. Therefore, it is very important to develop methods of mathematical modeling aimed at solving these problems.

Development and operation of power supply schemes require solution of various problems characterized by increasing reliability of power supply to consumers and numerous parameters determining the state of interrelated and interacting processes in synchronous and asynchronous engines, individual elements of the power supply system and the power system. The problems of analysis, calculation and optimization of operating modes are solved on the basis of application of special methods and means of computer technology. The most widely used methods are the methods of mathematical modeling.

Despite a significant number of works in this field [1-6], methods for modeling and optimizing shop-floor power supply systems, algorithms for calculating the characteristics of the asynchronous motor (AD) and synchronous motor (SD), static load characteristics and power losses with respect to the calculation of normal operation of large PSSs and their practical implementation have not yet been properly developed. Most of the existing algorithms simplify complex in structure and configuration system of shop-floor networks, equalize a large part of the load to 380 V, not fully take into account changes in the parameters of AD and SD substitution schemes [7-11].

Metodology

Research includes a set of methods consisting of analysis and scientific generalization of scientific-technical and patent information, theoretical studies, methods of three-dimensional modeling and design. The reliability of the results of scientific research is confirmed by the development of models of the proposed devices [12]. To achieve this goal, the following theoretical and applied problems were solved in the work:

1. Development of a methodology and algorithms for calculating the parameters of replacement schemes for AD and SD with a massive smooth rotor and with laminated poles, according to the catalog data with reference to the determination of the static characteristics of power losses;

2. Investigation of the influence of the deviation of real data, standardized by the standards, for the engines from the catalogs on the spread of the values of the parameters of the replacement networks;

3. Completion of the program complex for calculating the steady-state PSS conditions with an electric motor load on the basis of the algorithms developed for determination of static characteristics of power losses;

4. Determination of static characteristics of loads and power losses for real industrial facilities and studying of the possibility of their use in developing energy-saving measures.

The quality of simulation of an industrial power supply system (IPSS) is largely determined by the method of mode simulation [13]. The method of mode modeling must allow us to display the whole variety of possible states of the IPSS at the optimal expenditure of computer time and computer resources for calculations [14].

To simplify calculations of IPSS modes, it is reasonable to distinguish three hierarchical levels [15]

Parameters of the IPSS modes at this level are determined by the equation:

$$\underline{U}_y = \underline{E}_c - \underline{Z}_y \underline{I}_y, \tag{1}$$

where $\underline{U}_y$ ($\underline{I}_y$) are m Matrices of nodal voltages (currents) corresponding to the sections of switchgears in the IPSS, i.e. nodes of industrial load; Z_y is the matrix of nodal resistances.

The input parameters of the first level are the node currents I_y, which reflect the influence of the second and third levels; the output parameters are nodal voltages U_y characterizing the influence of the first level on the other levels.

For the second hierarchical level of the IPSS, the following equations can be written:

$$\underline{U}_{VD} = \underline{U}_y - \underline{Z}_{VD} \underline{I}_D, \tag{2}$$

$$\underline{I}_y = \underline{I}_{PR} + \underline{M}_D \underline{I}_D, \tag{3}$$

where $\underline{U}_{VD}$ is the matrix of voltages at the motor terminals; $\underline{Z}_{VD}$ is the matrix of resistances of the electric network elements in the circuit from the load node to the motor terminals; M_D is the matrix for connecting motors to the load nodes; $\underline{I}_D$ is the matrix of motor currents.

The input parameters of the second level with respect to the first are the node voltages U_y; in relation to the third, the currents of the motors $\underline{I}_D$. Output parameters of the second level with respect to the first will be the node currents I_y, with respect to the third - the voltage $\underline{U}_{VD}$ at the terminals of the engines.

At the third hierarchical PSS level, the parameters of the regime are determined by the system of equations of steady-state regimes of SM and AM. In this case, the input parameters for the SM are the voltages at the motor output $\underline{U}_{VCD}$, the excitation winding U_f and the moment of resistance of the mechanism M_{MEX} and for the asynchronous motor – it is the voltage at the motor terminals $\underline{U}_{VAD}$ and the moment of resistance of the mechanism M_{MEX}. The output parameters of the SM and AM, through which they affect the mode of other PSS levels, are the currents of the motors $\underline{I}_{CD}$ and $\underline{I}_{AD}$.

The workshop networks, in contrast to the supply networks of the external power supply and distribution networks of the internal power supply, have the following specific features, reflected in the mathematical model of power supply systems with voltage up to 1 kV:

1. The range of elements of the workshop network is much wider than in high-voltage electrical networks (to the above listed elements it is necessary to add current transformers, fuses, circuit breakers (automatons), contactors, starters, circuit breakers). The type of the element in the mathematical model is set by analogy with high-voltage networks with a type (JE) with numbers from 10 to 16 (JE = 10 - current transformer, JE = 11 - automat, etc.).

2. Though many low-voltage elements of the electric network are switching devices, they have a finite value of electrical resistance, which is determined by the nominal parameters of the device (rated current and voltage). Resistance of current transformers is determined from the data on the rated current of the primary winding and the precision class.

3. In low-voltage electrical networks, it is necessary to take into account the value of contact resistances between the elements, which is added to the resistance of the underlying network element.

Results

For the normal operation of consumers it is necessary to maintain a certain voltage level on the substation buses. In electrical networks, different methods are used for voltage regulation, one of which is the change in the transformer transformation ratio.

It is known that the coefficient of transformation is defined as the ratio of the primary voltage to the secondary one.

The transformation coefficient is changed by means of additional branches provided in the windings of the transformers.

The developed universal mathematical model of power supply systems and industrial load nodes enabled us to perform a comprehensive simultaneous assessment of power losses for each element in the entire system on the basis of a detailed account of the nature of power loss dependences on voltage levels. On the basis of the obtained universal model, a software package has been created, which uses computational and experimental methods to obtain static characteristics of power losses and loads in the PSS and to establish the patterns of variation of these characteristics.

For computational and experimental studies of the steady-state PSS regimes, the software complex SEZAM, developed at the Department of Electricity Supply of Industrial Enterprises of the National Research University MPEI, was used. With reference to the purposes and tasks of the work, modernization of the complex consisted in:

- modernization of the program for calculating parameters of replacement circuits for high-voltage and low-voltage induction motors;
- modernization of the program for calculating parameters of replacement circuits for high-voltage and low-voltage synchronous motors of various types;
- development of an algorithm for calculating power losses in motors, taking into account the effect of current displacement in the damping AM and SM windings;
- development of a program for determining the static characteristics of power losses in both individual electric motors and in the entire power supply system;
- change of the interface of the software complex for the tasks of studying of static characteristics of power losses.

The data include the number of branches in the replacement circuit, synchronous and asynchronous motors, transformers, cable lines, overhead lines, current conductors, reactors, switches, sections, electrical systems, the value of the base power and the rated voltage of the EMF stage of the system.

To determine the location of the elements (transformer, cable line, overhead line, reactor, etc.) of the electrical network precisely, the substitution circuit has nodes or points, each of which has its own number. It is necessary to use these numbers when inserting the coordinates of the power network element, for the program to see what the given network element is attached to and what element in the electrical network it is connected with. The elements that are not present in this replacement scheme do not have their number, i.e. 0. The elements of the network at each node, the connection of asynchronous motors, sections, as well as the types and conditions of the switches are indicated.

The electric system has the code of element 1, the beginning of branch node is 0, and the end of branch node is 1. It is very important to specify the beginning and the end of the branch, otherwise the program will not be able to understand what the element is attached to. The second system has the same number for the beginning of the branch node as the first system, i.e. 0.

The initial data on the configuration of the circuit breakers also include the method of filling the cells, and it is necessary to indicate the type of the circuit breaker and its state, otherwise the program will not calculate.

The numbering of the nodes corresponding to the place of connection of the asynchronous motor is indicated by its connection node.

All the data of the system elements must be indicated in the same order as it was indicated in the network structure.

In two-winding transformers, the following parameters are indicated: rated power, short-circuit voltage, active short-circuit power losses, winding voltage for HV and LV, voltage regulation step and number of adjusting taps. Technical data were taken from the reference [16].

The following parameters are specified in the overhead transmission lines: inductive resistance, cross-section, length, network voltage at the location of the gasket, inductive residual resistance of the zero sequence.

The following parameters are specified in the cable transmission lines: inductive resistance, cross-section, length, number of cables, mains voltage at the location of the gasket and inductive resistance of the zero sequence.

The initial data on nodal loads contain the following parameters: active power, reactive power, active power index of the other load on the voltage, reactive power index of the other load on the voltage, power of capacitors connected to the load node, nominal node voltage.

In the voltage level, the desired voltage level in the first section in the initial mode is indicated.

If the data are entered correctly, a new window "calculation results" will appear, where the calculations of parameters of the loading node mode, asynchronous motors, losses in the electrical power supply system are made, and power loss graphs are constructed.

Figure 1 shows the results of calculation and parameters of the load mode for nodes, their active power, reactive power, load node current, voltage on the section of the reactor, the angle between the voltage vectors in the section and the EMF of the electrical system, the angle between the current and voltage vectors of the load node.

The parameters of the mode of the elements of the electrical network show the results of calculating the voltage in the initial node, the voltage in the final node, the active and reactive power at the beginning of the branch, the active and reactive power at the end of the path.

Figure 1 shows the parameters for the asynchronous motor mode: active power, reactive power, EMF current, output voltage and slip.

The losses of active power in the power supply system were calculated: total active power losses, total active power losses in the electric network, total active power losses in asynchronous and synchronous motors.

The graphs of power losses are presented. The graph is based on the data in the table. To do this, you must click the button "draw a graph for all voltages", and then a graph of the dependence of the active power losses on voltage and a graph of the dependence of the reactive power loss on voltage will appear.

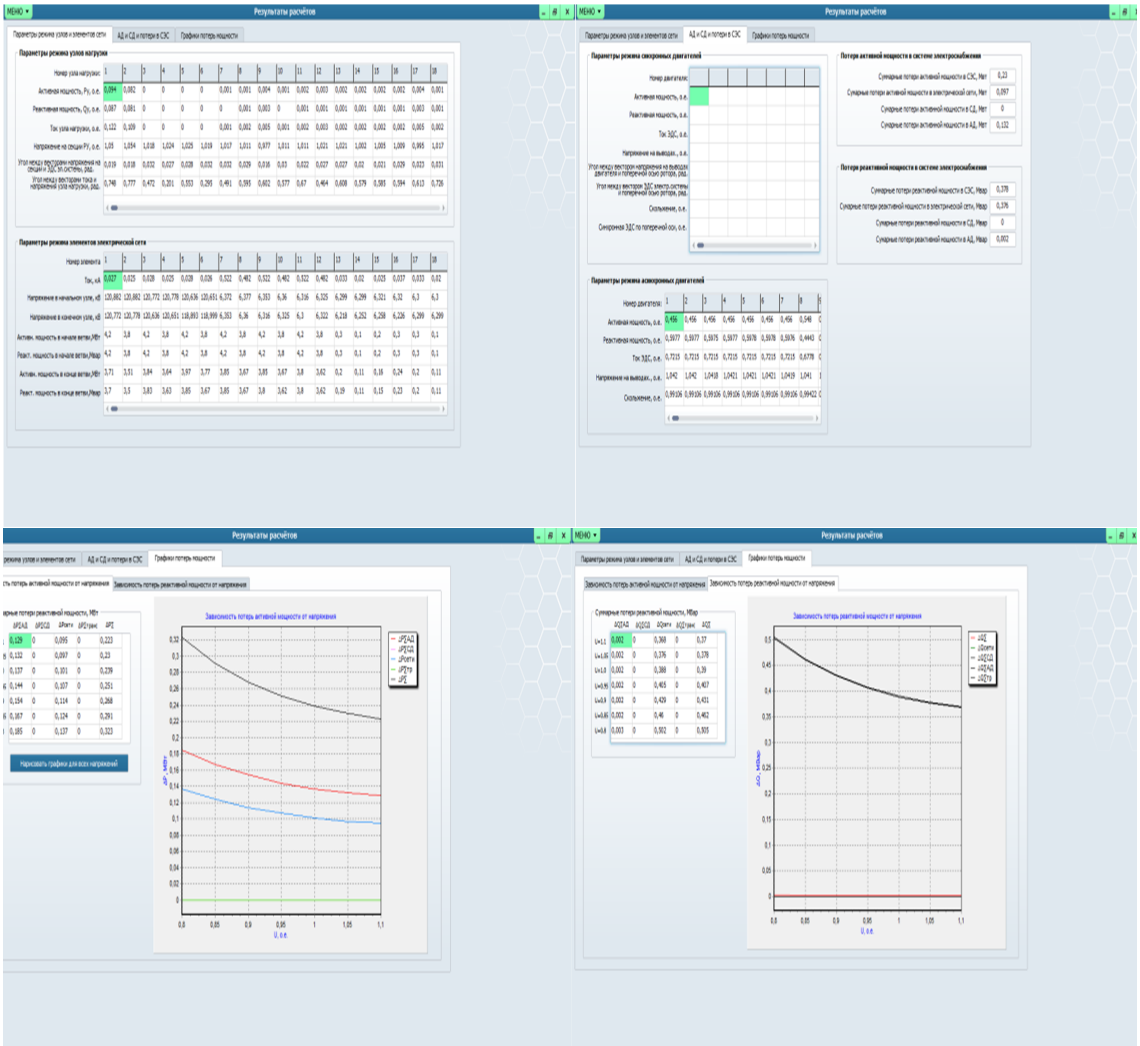

Figure 1. Output data of the software package.

The program for calculating PSS parameters determined the parameters of the mode of nodes and electric network elements, the mode of asynchronous motors, the loss of active and reactive power in the power supply system, and plotted the graphs of voltage dependence of active and reactive power losses.

Conclusion

Power-efficient policy should include measures on modernization of economic sectors, improvement of the quality of management and skills of production personnel, attraction of large-scale investments, and teaching people the methods of economic power consumption. The necessary condition for its implementation is the use of scientific and technical potential and new innovative thinking, higher investment attractiveness of energy efficiency as an attractive business sector.

The developed software package for calculating steady-state PSS regimes is designed for performing a complex evaluation of the influence of voltage regulation on the substation buses on the level of total power losses in all elements of the power supply system for enterprises of any industry.

The software package was used for performing energy saving works for industrial enterprises by determining the optimal voltage levels in order to minimize power and load losses up to 5 %.

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