Determination of optimal location for installation of symmetry facilities in 0.4 kV power supply systems with motor-drive load

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Abstract. This article considers the issue for creation of computer-aided program designed for determination of optimal location for installation of symmetry facilities in 0.4 kV power supply systems with motor-drive load in conditions of asymmetry of voltages. The developed program is implemented by means of C# programing language in Microsoft Visual Studio 2012 programming environment using the embedded cross-platform data base SQLite. The program is designed for making electrotechnical calculations during designing, modernization and operation of electrical grids with available motor drive load. It ensures plotting of schematic circuits for 0.4 kV power supply system sections with installed symmetry facilities. The program will enable quick and exact calculation of power capacity loss, determination of economic feasibility for taking special measures to eliminate the asymmetry of voltages, and to determine optimal application and location of symmetry facilities. Using the program in motor-drive load power supply systems will enhance the asynchronous motor reliability and efficiency.

1 Introduction

Consumers' operation under asymmetry of voltages is one of challenges faced in Russian electrical grids. The experimental investigations carried out in the current grids of of individual Russia regions [1,2] demonstrate that the levels of asymmetry of voltages exceed the established GOST 32144 – 2013 values [3]. Following performed investigations, there is sufficiently high level of asymmetry of voltages exceeding the value standardized by GOST 32144 – 2013by 2-3 times and is the permanent factor during operation of electrical grids. The voltage, which does not meet GOST 32144 – 2013 requirements, inflicts significant material damage, reduces technical and economical indicators of the electrical grid system operation on the whole. Different assignment types electrical grids widely use asynchronous electrical drive with large range of asynchronous motor (AM) rated power capacities. In AM field operation conditions, depending on various factors, there is significant deviation from the rated operation modes. The investigations [4-7], demonstrated that the asymmetry of voltages is one of causes for AM failures. The asymmetry of voltages results in accelerated ageing of insulation and breakdown of motors due to irreversible ionization processes. Approximately 75% of motors shut down due to insulation fault, and the economic damage can reach some tens of thousands of rubles [8].

Using of technical means and protection methods for motors against the emergency cases caused by reduction of quality and reliability of power supply systems, their efficient allocation in the power supply system is one of the options for solution of their reliable operation. The integrated solution of the specified problem is impossible without development and implementation of software computing facilities for power supply systems based on modern computer machines. Therefore, it is necessary to develop the procedure, the computing program for power supply systems, considering the allowable operation modes of the asynchronous motors in conditions of asymmetry of voltages.

The main objective of this research work is the development of the applied software program to determine the optimal installation location of symmetry facilities in 0.4 kV power supply systems (PSS) with the motor drive load.

The proposed software program is aimed at solution of practical tasks for enhancementof the asynchronous motor functional reliability by reducing the asymmetry of voltages. The above stated determines the problem relevance and implementation of the proposed software program.

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2 Task description

In accordance with the set objective, the task for development of the power supply system calculation procedure algorithm implementation will be based with account of using the the symmetry facilities and and their installation locations, on basis of which the software program for determining the optimal location of the symmetry facilities in 0.4 kV PSS with the motor drive load will be built.

Based on the data of experimental investigations of the main UPQI, the information on the power loss value in the elements of the power supply system under investigation, and besides, on the ground of consumers' allowable operation modes, it is possible to make selection of parameters for the symmetry facilities and determine optimal location of these devices in the power supply systems. Calculation of power capacity losses due to asymmetry of voltages will allow to justify the economical feasibility for the asymmetry elimination, to determine optimal location of the symmetry facilities.

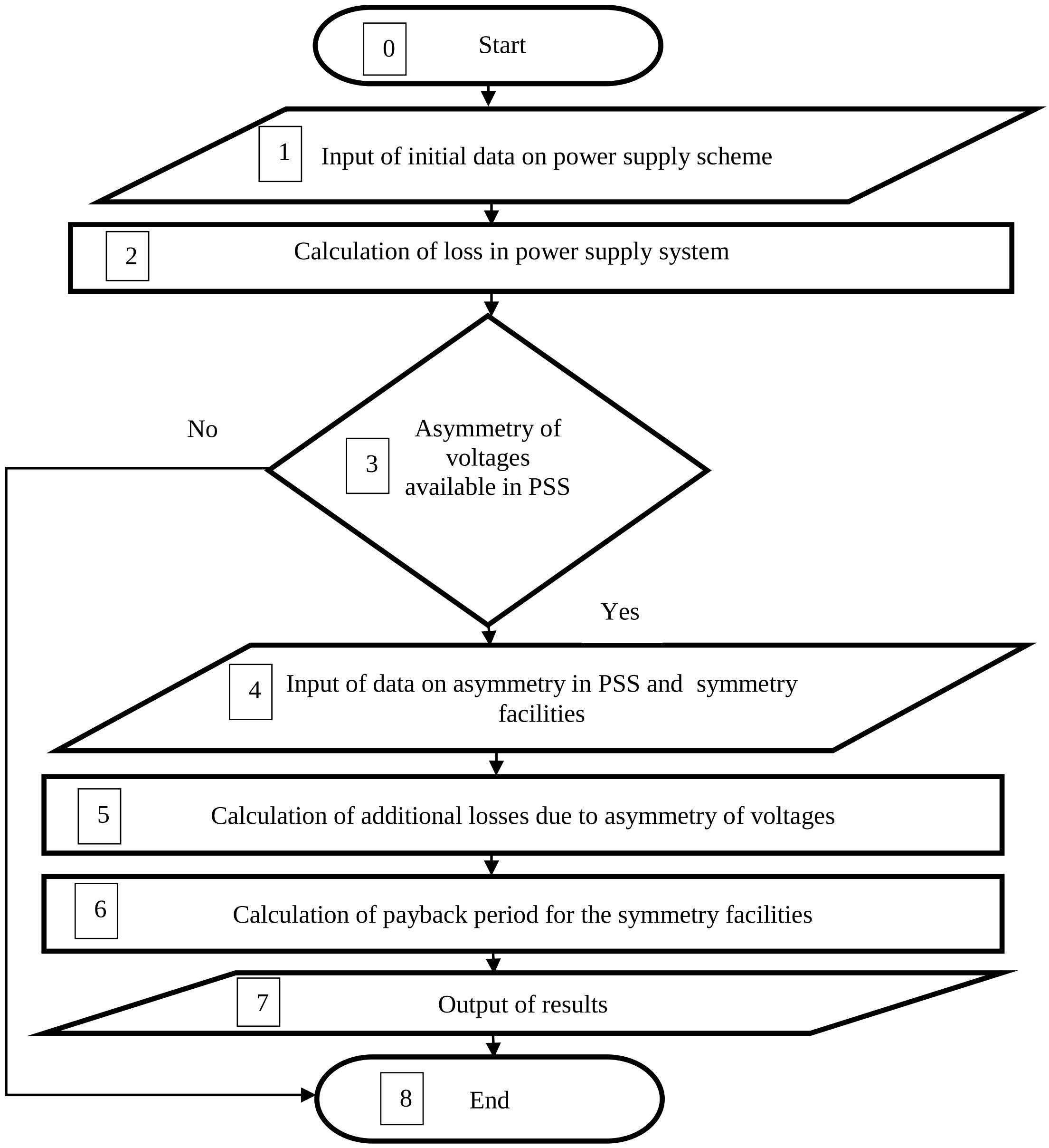

Fig. 1. Flow diagram for power supply system calculation algorithm with account of the symmetry facilities and and their installation locations.

3 Calculation procedure for power with account of the symmetry facilities and and their installation locations

The calculation procedure for power supply system calculation algorithm with account of the symmetry facilities and and their installation locations can be implemented according to the algorithm:

1) block 1 – input of initial data is performed in the software program.

The initial data includes:

- section diagram description (section general information);
- parameters of electricity transmission lines, line length; type of line wires and cables; line load);
- parameters of motors connected to electricity transmission line (line number, where the motor is located; quantity of motors in the line, motor type);
- parameters of transformer (quantity of transformers and types);
- the value of factors asymmetry of voltages by reversible and zero-phase-sequence in the calculated power supply system;
- cost of electric power.

2) block 2 – calculation of losses for symmetrical operation mode in the main elements of the power supply system is performed.

Symmetrical operation mode current (positive-sequence current) is determined based on the expression:

$$I_1 = S/U \tag{1}$$

where S – substation full load.

Losses in electricity transmission lines are determined based on the expression:

$$\Delta P_{ETL} = 3I_1^2 R_{ph} \tag{2}$$

where I_1 – symmetrical operation mode current (positive-sequence current);

R_{ph} – phase conductor resistance.

Substation full load (total of loads for individual line) is determined based on the expression:

$$S = \sum_{i=1}^{n} P_i \tag{3}$$

where P_i – line load.

Losses of active $\Delta P'$ and reactive $\Delta Q'$ power capacities for double-winding transformers are determined based on the expression:

$$\Delta P' = \frac{\Delta P_k}{n}\left(\frac{S}{S_{rat}}\right)^2 \tag{4}$$

$$\Delta Q' = \frac{U_k}{100 \cdot n} \cdot \frac{S^2}{S_{rat}} \tag{5}$$

where $\Delta P_k, U_k, S_{rat}$ – passport certificate data of individual transformer [9];

S – substation full load;

n – number of one-type transformers in substation operating in parallel.

3) block 3 – let us proceed to condition "the available asymmetry of voltages in the power supply system".

If "NO", calculation termination.

If "YES", proceed to block 4.

4) block 4 – let us proceed to special measures for elimination of asymmetry of voltages, for determination of optimal application and location of these facilities.

supply system calculation algorithm

Input of data of factors for asymmetry of voltages by reversible and zero-phase-sequence according to two calculation options, as well as selection of suitable symmetry facilities from the database is carried out.

a) option 1 – consists in installation of the symmetry facilities in the common node of lines with the motor drive load;

b) option 2 – consists in installation of the symmetry facilities in each line of the scheme section with asynchronous motor.

5) block 5 – calculation of additional losses for asymmetrical operation mode in the main elements of the power supply system is performed.

Available amplitude and angular asymmetry in the grid, when estimating increase of additional losses as compared with symmetrical operation load shall be determined using the factor:

$$K_{asym} = 1 + K_{2I}^2 + K_{0I}^2 \cdot \left(1 + 3 \cdot \frac{R_r}{R_{ph}}\right) \tag{6}$$

where K_{2I}, K_{0I} – factors of the asymmetry currents by reversible and zero-phase-sequence.

Based on results of processing of data of main UPQI in 0.4 kV grid nodes of the considered object, let us accept the values of factors.

R_r, R_{ph}– resistances of neutral and phase conductors.

Accordingly, with account of (6), the expression (2) will look as follows:

$$\Delta P_{AD.ETL} = \Delta P_{ETL} K_{asym} \tag{7}$$

Additional losses of active power capacity in the asynchronous motor are determined based on the expression:

$$\Delta P_{AD.AM} = 2{,}41 K_{AM} K_{2U}^2 P_n \tag{8}$$

where K_{AM} – the factor considering the parameters of the particular motor (rated power capacity, copper losses in stator, starting current-to-rated current ratio);

K_{2U} – factor of asymmetry of voltages by reverse sequence;

P_n – motor rated active power capacity.

The value of factor for industrial load on the whole is recommended to accept as equal to 1.85 [10].

Under long-term asymmetrical operation mode, due to running the reversible sequence currents in the power transformers, additional power capacity losses occur, which can be determined according to the following formula:

$$\Delta P_{AD.TR} = K_{2U}^2 \left(\Delta P_{i.r.} + \frac{\Delta P_{SHC}}{U_k^2}\right) \tag{9}$$

where K_{2U} – the factor of asymmetry of voltages by reverse sequence;

$\Delta P_{i.r.}$ – losses in the mode of idle running;

ΔP_{SHC} – losses in the mode of short-circuit;

U_k – short-circuit voltage.

Calculation of overall losses is performed.

The losses for symmetrical operation mode are determined based on the expression:

$$\Delta P_{sym} = \sum_{i=1}^{n\_line} \Delta P_{ETL} + \Delta P' \tag{10}$$

where n_lines – quantity of lines;

i – line number.

The losses for asymmetrical operation mode are determined based on the expression:

$$\Delta P_{asym} = \Delta P_{sym} + \sum_{i=1}^{n\_line} \Delta P_{AD.ETL} + \sum_{j=1}^{n\_dv} \Delta P_{AD.AM} + \Delta P_{AD.TR} \quad (11)$$

where j – motor number;

n_dv – quantity of motors in the electricity transmission line.

6) block 6 – calculation of payback period for each option of installation for symmetry facilities is carried out and the shortest period is selected.

Additional losses without the symmetry facilities are determined based on the expression:

$$S_{AD.W} = \Delta P_{AD.W} + \Delta Q_{AD.W} = \sum_{i=1}^{n\_line} \Delta P_{AD.ETL} + \sum_{i=1}^{n\_line} \sum_{j=1}^{n\_dv} \Delta P_{AD.AM} + \Delta P_{AD.TR} \quad (12)$$

with the initial factors of asymmetry of voltages by reversible and zero-phase-sequence.

Additional losses with the symmetry facility are determined based on the expression:

$$S_{AD} = \Delta P_{AD} + \Delta Q_{AD} = \sum_{i=1}^{n\_line} \Delta P_{AD.ETL} + \sum_{j=1}^{n\_dv} \Delta P_{AD.AM} + \Delta P_{AD.TR} \quad (13)$$

with the initial factors for symmetry facilities of asymmetry of voltages by reversible and zero-phase-sequence.

Selection of parameters for symmetry facilities is determined based on the following conditions:

a) option 1 – power capacity of the symmetry facilities shall be higher or equal to total loads in the lines outbound of the central node:

$$P_{sym} \geq S \quad (14)$$

b) option 2 – power capacity of the symmetry facilities shall be higher or equal to the load in each line with the motor:

$$P_{sym} \geq P_i \quad (15)$$

Calculation of the total cost of the symmetry facilities is determined based on the expression:

$$S = \sum_{k=1}^{k\_d} C\_d \quad (16)$$

where S – the total cost of installed symmetry facilities;

C_d – the cost of each symmetry facility;

k_d– quantity of installed symmetry facilities;

k – symmetry facility number.

Calculation of payback period for the symmetry facilities can be determined according to the following formula:

PP

(17)

where PP – the payback period;

S – total cost of installed symmetry facilities;

$(\Delta P_{AD.W} + \Delta Q_{AD.W})$ – additional losses without symmetry facilities;

$(\Delta P_{AD} + \Delta Q_{AD})$ – additional losses with the symmetry facility;

C – electric power cost.

7) block 7 – output of the total data is made.

The output data includes:

- losses for symmetrical operation mode;
- additional losses under asymmetrical operation mode (without symmetry facilities; with installation of the symmetry facilities in the common node of lines, including the motor drive load – option 1; with installation of the symmetry facilities in all lines with asynchronous motors – option 2);
- cost of the symmetry facilities (cost of symmetry facility; total cost of the symmetry facilities - option 1; total cost of the symmetry facilities - option 2; payback period - option 1; payback period - option 2).

The above stated procedure for power supply system calculation will be the basis for implementation of the task for creation of the software program on optimal location of the symmetry facilities in 0.4 kV PSS with the motor drive load.

For the software program implementation and testing, let us consider the power supply system section of Taptugary village, Mogochinsky region of Trans-Baikal district.

The following initial information was used during this publication performance:

1) results of processing of data of main UPQI in 0.4 kV grid nodes in Mogochinsky region of Trans-Baikal district,

2) configuration of the power supply system of Taptugary village, description of electric power consumers.

Power supply system, where the software program was approbated, is given in (Fig.2).

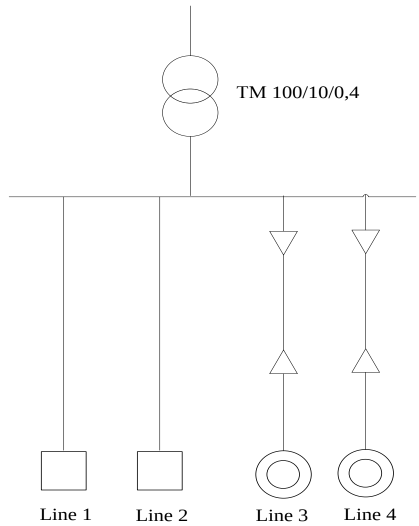

Fig.2. Scheme of Taptugary village power supply system section.

Scheme of power supply system section includes:

1) line 1 – is routed with conductor AS-25, line distance - 350 metres, feeds 7 private houses with the furnace heating,

2) line 2 – is routed with conductor AS-25, line distance - 50 metres, line distance double-storeyed house, the primary school, the kinder garden, the administration building, the library,

3) line 3 – is routed with conductor AVVshv 4*50, line distance - 70 metres, feeds the boiler house of two boilers with the electrical motors: type 4A132S4Y3 with Pn = 7.5 kW with 2 pieces, flue gas fan Pn = 3 kW, fan blower

Pn =1.4 kW,
4) line 4 – is routed with conductor SIP 4*25, line distance - 150 metres, feeds two band saws type AI132M4
Pn = 11 kW.

Table 1. Taptugary village grid section initial data.

Parameter	Line 1	Line 2	Line 3	Line 4	TS
Power capacity, kVA	30.4	49.4	20.9	25	100
Current, A	80	130	55	65.7	330.7

4 Program implementation

The software program is implemented by means of C# programing language in Microsoft Visual Studio 2012 programming environment using the embedded cross-platform data base SQLite [11-14].

The software program main functional capabilities:

1) input, editing of the initial parameters of the power supply system elements;

2) input, editing of the reference data of the power supply system elements;

3) input of additional data for calculation of option with installation the symmetry facilities;

4) plotting of power supply system section with the initial data entered into database;

5) calculation of options with installation of the power supply system symmetry facilities;

6) graphic presentation of schemes for options of calculations with particular location specification of the symmetry facilities in PSS.

The software program consists of the database storing all required information for calculation and designing of 0.4 kV power supply systems with the motor drive load; the computational calculation module with the algorithm for calculation of power capacity losses in the power supply system elements; the module for data input and output of 0.4 kV power supply system design calculation results. The software program carries out the required calculations automatically based on the set initial data. The initial data includes the data on 0.4 kV power supply system section with the motor drive load. The data is developed into data base (DB). Its structure allows for handling the data; it is flexible and eliminates superabundance and non-conforming dependences.

The data base includes the tables of the following nature: reference parameters of the power supply system elements, Table the symmetry facilities, tables of the power supply system input data, tables of tables of the power supply system output calculations. Each BD table has its unique attributes and its own designation in the system.

The most important specificity of the software program consists in plotting of the power supply system calculation model. At that, the accuracy of calculations will be mainly determined by the fact, how fully the calculation model plotted by means of special instrument set, the parameters of the designed or operated – real power supply system are considered. The software program interface is well understood and plain (Fig.3–4). The software program interface presents and displays the power supply system initial information, the output of the summary information on calculation results.

The proposed software essence consists in the fact, that, based on the obtained investigation results of of K_{2U} permissible values for AM [15] entered in the software program algorithm, the data of K_{2U} power supply system calculation experimental investigation, selection of parameters for the symmetry facilities and the optimal location of these devices in the power supply system are determined.

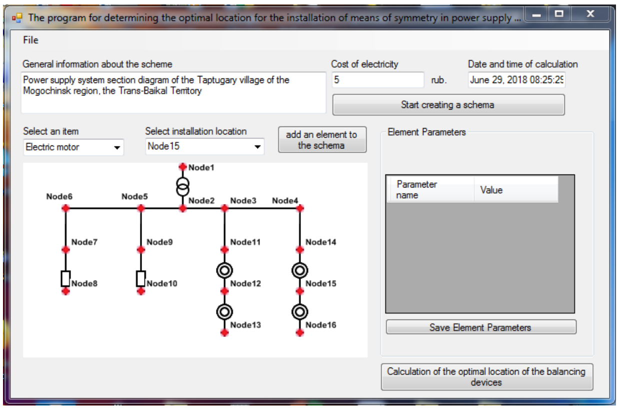

Fig. 3. Software program interface: addition of scheme elements by means of designing.

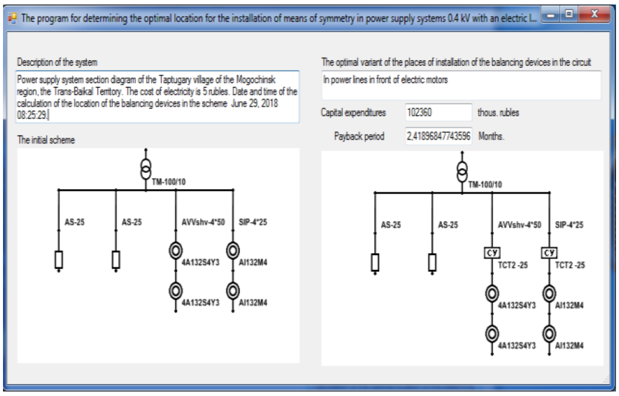

Fig.4. Software program interface: window for calculation results output.

When changing the calculation scheme parameters (for example, replacing the symmetry facilities and their quantity), it is possible to match them in such way that the sustainable and fail-free operation of asynchronous motors is ensured in the whole power supply system. The use of the software program will allow of significant increase of AM and the whole power supply system operation reliability and efficiency due to using the symmetry facilities (balance-unbalance transformers, frequency converters and filter-balancing devices) [16,17].

Based on the results of the software program operation according to the considered scheme (Fig.2), it is much in evidence that it is economically feasible to install the balance-unbalance transformers type TCT2 with power capacity 25 kW on line 3,4 having the motor drive load.

The necessity for using the symmetry devices for the industrial consumers in the investigated scheme was detected as a result of the software program implementation. Based on the capital expenditures and the payback period of actions aimed at asymmetry reduction, the most economically advantageous location of the symmetry facilities PSS was determined.

The proposed software program allows for the power supply system calculation procedure simplification without significant increase of labor costs due to using computer equipment. The software program operability was tested on different 0.4 kV PSS sections.

5 Conclusion

The program is designed for making electrotechnical calculations during designing, modernization and operation of power supply systems with available motor drive load. It ensures plotting of schematic circuits for 0.4 kV power supply system sections with installed symmetry facilities.

The software program provides for calculation of different symmetry options and for selection of the most economically feasible option. Such user options are provided for during the software program operation: replenishment, changing and removal of the reference parameters for the elements included in the power supply system; input of initial data in the power supply system section, and besides, input of additional data for procedure of the symmetry optimal option calculation and for payback period for each of them.

Practical significance of the developed software program consists in the fact that implementation of new research solutions in designing and operational practice ensures suppression of asymmetry of voltages in 0.4 kV PSS, and, at that, it improves the operation reliability of asynchronous motors. The developed software program is intended for the regions with available non-linear loads, where the actions directed for support of electric energy quality in the power grids are of the most priority.

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