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ACCOUNT OF ELECTRIC MODE PARAMETERS VARIATIONS FOR BALANCING THE LOADS

The paper proposes an approach to solving the engineering problem of balancing the loads, taking into account variations of the electric mode parameters. Efficiency criteria for adoption of engineering solutions are substantiated. Mathematical model for calculation of the balancing device with non-correctable parameters has been elaborated. A method for evaluating the efficiency of balancing the mode with time-variable parameters is suggested.

Keywords: *balancing the loads, mathematical model of balancing the loads, balancing device with non-correctable parameters.*

Introduction

Among electric energy quality indicators, which in many cases do not satisfy the Standard requirements (ГОСТ 13109-97), there are mode unbalance normalizing indicators [1, 2, 3].

Under certain conditions a balancing device (BD) with non-correctable parameters could be efficiently used, e.g. BD based on static reactive elements. As the mode changes, the parameters of such device should be determined taking into account this circumstance.

BD with non-correctable parameters could be calculated by mathematical programming methods if mathematical model is available and calculations are automated.

The paper aims at such mathematical setup of the problem, dealing with calculating the parameters of BD with non-correctable parameters, which takes into account parameter variations in the electric mode of unbalanced loads.

Efficiency criteria for adoption of engineering solutions

Variations of electrical mode unbalance parameters, occurring in real conditions, is a random process that could be considered to be a sequence of random values. Characteristic feature of alternating current modes is that their parameters are described by complexes or vectors.

Let us consider a vector (a complex) as a system of random values. On the complex plane of Fig. 1 a set of the ends of vectors of the inverse sequence currents $-\dot{I}_2$, obtained from observation results, is shown by dots. Point *A* has coordinates $\left[M(\operatorname{Re}\dot{I}_2);\, M(\operatorname{Im}\dot{I}_2)\right]$, and vector, the end of which is point A, we will consider to be mathematical expectation of the vector of the inverse sequence current: $M(\dot{I}_2) = M(\operatorname{Re}\dot{I}_2) + jM(\operatorname{Im}\dot{I}_2)$ [2], where

$$M(Re\,\dot{I}_2) = \frac{\sum\limits_i Re\,\dot{I}_{2_i}}{n};$$

$$M(\operatorname{Im}\dot{I}_2) = \frac{\sum\limits_i \operatorname{Im}\dot{I}_{2_i}}{n}.$$

For the case 1, a) a non-correctable engineering solution that provides full compensation of vector $M(\dot{I}_2)$, creating vector $\dot{I}_2^k$ ($\dot{I}_2^k = -M(\dot{I}_2)$), will effectively reduce the negative sequence currents in all cases observed.

In the case of Fig. 1, b) balancing efficiency is lower because for certain points (e. g. *i*; *i*+1) growth of the unbalance will occur.

Fig. 1 illustrates the case, when uncontrollable engineering solution for improving the electric network state does not exist, $M(\dot{I}_2) = 0$.

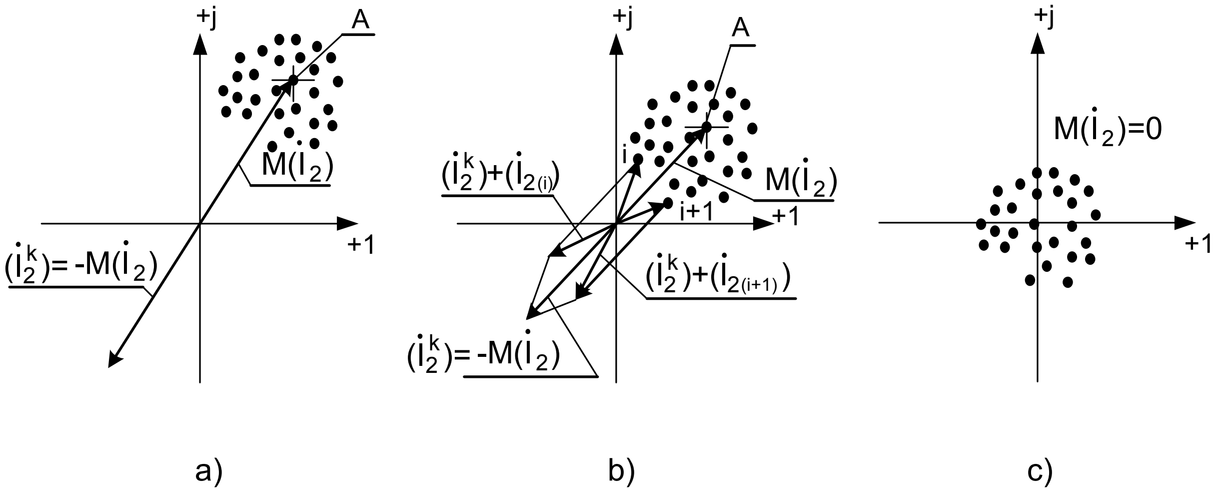

Fig. 1. Geometric interpretation of the dynamic mode balancing by means of balancing influence, which is not correctable in time
a) – the case of highly effective balancing;
b) – the case , where the mode is generally improved, although for certain time moments an increased unbalance is observed;
c) – the case, where it is impossible to improve the electric mode by balancing influence, which is not correctable in time

The value $\left|M(\dot{I}_2)\right|$ characterizes potential effect of the process of balancing through non-correctable engineering solution and its compensation influences the mode unbalance within the entire time range, for which statistical material has been collected.

Mathematical models of calculation of BD with non-correctable parameters

In order to determine non-correctable parameters of BD for electric mode balancing in a three-phase electrical network with isolated neutral, taking into account its variations, one of the mathematical models could be used:

$$\begin{cases} \left|M\left[\dot{I}_2^P(\boldsymbol{x})\right]\right| \to min; \\ Q^{BD}(\boldsymbol{x}) \le Q_{ad}; \\ U^P(\boldsymbol{x}) \le U_{max.ad}; \end{cases} \quad (1)$$

$$\begin{cases} \left|M\left[\dot{I}_2^P(\boldsymbol{x})\right]\right| \to min; \\ Q^{BD}(\boldsymbol{x}) \le Q_{ad}; \end{cases} \quad (2)$$

$$\left|M\left[\dot{I}_2^P(\boldsymbol{x})\right]\right| \to \min, \quad (3)$$

where $\boldsymbol{x}$ – vector of the variables (vector of non-correctable BD parameters); $M\left[\dot{I}_2^P(\boldsymbol{x})\right] = M(\dot{I}_2) + M(\dot{I}_2^{BD})$; $\dot{I}_2^{BD}$ – negative sequence current, generated by BD; Q^{BD} – reactive power of BD; Q_{ad} – maximal time-invariant power component of the graph of reactive loads;

BDU^P – voltage at BD coupling node after it is connected; $U_{мax.ad}$ – voltage value corresponding to the maximum permissible deviation, regulated by the Standard (ГОСТ 13109-97).

Mathematical model (1) is used when BD parameters must be determined under conditions, where as a result of BD connection, reactive power generation from the network of consumer in the network of the power supply company is possible as well as emergence of the voltages with impermissible values.

Mathematical model (2) is intended for the case, when BD parameters should be determined under conditions of possible reactive power generation in the power supply network.

Mathematical model (3) is a local optimization model intended for the cases when negative consequences of BD connection are absent.

Fig. 2 presents results of balancing (dependence 2) of the real mode (dependence 1), using BD in the form of asymmetrical triangle of the banks of static capacitors with non-correctable parameters, calculated by the model (3). According to the calculation results, reactive powers of BD per phases are as follows: $Q_{AB} = 116\,kVar$; $Q_{BC} = 5{,}8\,kVar$.

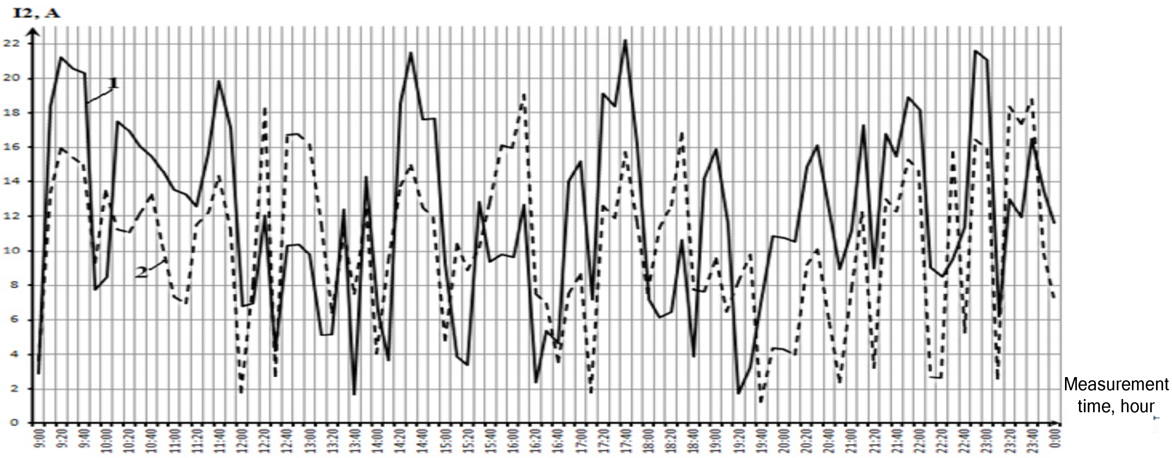

Fig. 2. Results of balancing the time-variable electric mode by means of BD with non-correctable parameters:
1 – initial mode;
2 – optimized mode

The example of variable mode, shown in Fig. 2, refers to the case when strengthening of asymmetry is observed for certain time moments. In such cases there is a necessity of quantitative evaluation of BD efficiency for the entire time interval.

Evaluation of the efficiency of the variable mode balancing

Since BD with non-correctable parameters exerts a targeted influence, which aims at changing one of the power supply system parameters (which, in fact, is a control), then for evaluation of the obtained results a control quality indicator could be employed. This indicator is used in the optimal control theory to evaluate the efficiency of the obtained results within a certain time interval [3].

For the case of electric mode balancing the following functional could be used as a control quality indicator:

$$J = \int_{t_1}^{t_2} \left[I_2^P(\boldsymbol{x}, t) \right]^2 dt\,, \tag{4}$$

where t_1 – the initial time moment; t_2 – final (not fixed) time moment.

Physical content of the functional (4) is a value, proportional to the additional energy losses, determined by the mode unbalance in a three-wire network.

Evaluation of the obtained balancing results by expression (4) for the case under consideration gives the following values:

– initial mode $J_{in} = 15594\ A^2 \cdot hour$;

– optimized mode $J_{opt} = 11695\ A^2 \cdot hour$.

Therefore, the obtained balancing results in the presented example are positive.

Conclusions

1. Calculation of the parameters of non-correctable BD should be performed by the criterion of minimum mathematical expectation of the negative sequence current module, which will make it possible to adopt a solution, taking into account variations of the electric mode parameters.
2. Under conditions, where the variation range of unbalanced mode parameters is small, a positive balancing result could be achieved by application of BD with non-correctable parameters.
3. End effect from the application of BD with non-correctable parameters could be evaluated using the control quality indicator, physical content of which is a value, proportional to the additional electric energy losses caused by the mode unbalance.

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