TECHNIQUE OF OPTIMUM CONTROL OF THE VOLTAGE IN NETWORKS OF THE POWER SUPPLY SYSTEM WITH HELP REGRESSION MODELS

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ABSTRACT

The technique of a choice of optimum turn ratio of transformers in high-voltage networks from a condition of maintenance of the best level of a voltage in all units of loading and minimization of active power losses in a network is considered. The technique of achievement of an object in view is provided with the help preliminary made regression mathematical models, based on methods of planning of multifactorial experiments. On the basis of the suggested method optimum the turn ratio of transformers and laws of their regulation in high-voltage networks of separate regions of the Azerbaijan power supply system are determined.

Keywords: transformers, transformers, network, methods, mathematical models.

I. INTRODUCTION

One of the major problems of management of an operating mode of high-voltage networks is continuous definition of the current values of transformation ratio of transformers with regulation under loading. Thus the level of a voltage in units of loading improves, the active power losses decrease (sometimes the reactive power losses decrease too) in a network, in non-uniform networks the flows improve, bringing to unloading the overloaded sites of an electric network, etc.

The considered problem is multifactorial, as the mode of a voltage of each unit depends on voltage of all used transformers with regulation under loading. This dependence is complex, as it is by loadings of units, circuits of a network and their parameters. For the purposes of operative management, and also for short-term forecasting a mode it can effectively be used regression analysis [1]. In the present work the method based on the theory of planning of experiment [2] which is characterized by use of the limited number of machine experiments is used. Fractional factorial experiments with very much limited number of experiments when the number of experiments is determined as $N=2^{k-p}$ where k - number of factors, and p - number of factors, replaced with interaction of the major factors.

II. MAIN PART

In a considered problem the factors are transformation ratio of transformers adjustable under loading. Sometimes total loading of a power supply system or even loading of separate power stations can be included in number of factors also. Target parameters (parameters) are voltage of all units or some most important units, active power losses in a network.

Considering, that is desirable to achieve as a result of management also improvement of a voltage not only in separate units, but also as a whole in a network, i.e. achievements of the least rejection of voltage from nominal (or desirable), it is possible to use as target size mean square deviation of voltage of all units from nominal.

The regression models have the following kind:

$$y_i = a_{0_i} a_{1_i} x_1^n + a_{2_i} x_2^n + \dots a_{n_i} x_n^n + a_{12_i} x_1^n x_2^n + $$
$$+ a_{13_i} x_1^n x_3^n + \dots a_{1,2,3\dots,n_i} x_1^n x_2^n x_3^n \dots x_n^n +$$
$$+ a_{11_i} (x_1^n)^2 + a_{22_i} (x_2^n)^2 + \dots + a_{nn_i} (x_n^n)^2$$

y_i – value of target parameter

a_j – factors of regress which are determined by a method of the least squares.

For example, for a three-factorial problem at full factorial experiment we have the following matrix of planning:

In the table $x_1^n = T_{r1}$, $x_2^n = T_{r2}$, $x_3^n = T_{r3}$, - turn ratios of transformers, $U_1, U_2, \dots U_n$ - settlement values of the central voltage received usually from computer calculation of the steady state, $(U_i - U_{nom})$ - a voltage fluctuation from nominal, δU_m - mean square deviation of voltage fluctuation of all observable units determined as

$$\delta U_m = \frac{\sqrt{\sum_{i=1}^{n} (U_i - U_{nom})^2}}{n}$$

ΔP - settlement values of active power losses in a network.
Adequacy of the received models is checked on root-mean-square errors.
Factors of regress show a share of influence of each factor on target size. If factors of regress in comparison with constant factor do not render essential influence on target size these factors are excluded from consideration, and the equation becomes simpler. For construction of the linear models which are taking into account also interaction of factors it is used orthogonal central composite plans [2], and for square-law models rotatability plans. The regression models for ΔP and δU_m are used for optimization of a mode by achievement of their minimal values, and models U_i of central voltage are used for management of a mode of controllable voltage of units.

Table 1

№	x_1^n	x_2^n	x_3^n		U_1	U_2	...	U_n	$U_i - U_{nom}$	$(U_i - U_{nom})^2$	δU	ΔP
1	+	+	+									
2	-	+	+									
3	+	-	+									
4	-	-	+									
5	+	+	-									
6	-	+	-									
7	+	-	-									
8	-	-	-									
+1	$T_{r_{1max}}$	$T_{r_{2max}}$	$T_{r_{3max}}$									
-1	$T_{r_{1min}}$	$T_{r_{2min}}$	$T_{r_{3min}}$									

Sharing of all models represents a challenge and should be carried out by one of methods of optimization (linear programming, gradient method, dynamic programming, etc.).
For practical purposes at a choice of rational turn rations the following algorithm of definition of optimum turn rations of transformers on regression models can be used.
The initial data is the complex regression models under factors - T_r - turn rations adjustable transformers:

- regression models of voltage of characteristic units of loading:

$$U_i = a_{0_i} + a_{1_i} x_1 + a_{2_i} x_2 + \ldots + a_{12_i} x_1 x_2 + \ldots$$

- regression model of total losses of active capacity in a network:

$$\Delta P = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_{12} x_1 x_2 + \ldots$$

- regression model of a root-mean-square deviation voltage of units from nominal:

$$\delta\Delta U = c_0 + c_1 x_1 + c_2 x_2 + \ldots + c_{12} x_1 x_2 + \ldots$$

The purpose of optimization is maintenance of voltage in all units in the field of allowable $U_{i\,nom,max} > U_i > U_{i\,nom,min}$, thus the condition, that $\delta U \rightarrow \min$ and also $_d\Delta P_n \rightarrow \min$ should satisfy.
Realization of this position is carried out as follows:

1) In an electric network from among characteristic units the unit with the least voltage in the maximal regime ($U_{k\,min}$) gets out
2) It is determined (gets out) the range of desirable change of voltage in this unit ($U^d_{i_{max}}, U^d_{i_{min}}$). At absence of any installations it is possible to accept ±5 % from rated voltage of a network.
3) On items 1, 2 the additive of voltage in the considered examined unit, as is determined

$$U^d_{i_{min}} - U_{i_{min}} = U_{i_a}$$

4) For each adjustable transformer the size of voltage of one step of the adjusting device of the transformer is defined

$$U_{i_s} = \frac{U^T_{i_{max}} - U^T_{i_{min}}}{N_{max}}$$

Where N - number of steps of regulation
5) On the equation of regress of voltage of the considered unit the adjustable transformer (on the maximal value of factor of regress) for the given unit gets out and the normalized value of factor of transformation of this transformer is defined as:

$$T^n_{r_i} = \frac{U_{i_a}}{b_{i_{max}}}$$

where - $b_{i_{max}}$ the maximal values of factor of regress

6) On regression models voltage in all controllable units U_i , and also value δU and ΔP are checked at accepted one transformer $T_{r_i}^n$
7) If voltage in all units appear in an allowable range the problem regarding maintenance of levels of voltage in a network is solved
8) If in any voltage of units will leave for an allowable range, the new unit with the least voltage gets out and the problem is solved since item 1
9) After choice T_r of all (or parts) transformers on voltage of units, on the equation of regress ΔP it is defined T_r having the greatest influence on d ΔP and at presence of a reserve in T_r, change of it T_r up to a maximum (minimum) is carried out at which losses decrease
10) The problem is considered solved when, voltage in all units are within the limits of allowable, and due to additional change T_r of all possible transformers is achieved minimization of active power losses and a deviation of voltage from nominal
11) Position of the adjusting device of the transformer (number of branches) on found $T_{r_i}^n$ is determined as follows:

$$N_{branch} = \frac{N_{max} - 1}{2}\left(1 + T_r^n\right)$$

where N_{max} - the maximal number of branches of the transformer, T_r^n -normalized value of the transformer (from-1 up to +1)

For example, at number of steps of regulation N_{max} =13 with numbers from 0 up to 12 we have:

$$T_r^n = +1 \qquad N_{branch} = \frac{13-1}{2}(1+1) = 12$$

$$T_r^n = 0 \qquad N_{branch} = \frac{13-1}{2}(1+0) = 6$$

$$T_r^n = -1 \qquad N_{branch} = \frac{13-1}{2}(1-1) = 0$$

$$T_r^n = 0{,}5 \qquad N_{branch} = \frac{13-1}{2}(1+0{,}5) = 9$$

III. CONCLUSIONS

The suggested algorithm is easily realized on computer. On the basis of the algorithm the choice of optimum factors of transformation of transformers for separate regions of the Azerbaijan power supply system is executed and laws of regulation of voltage on substations are offered. By comparison of the received optimum factors with put into practice factors economic efficiency of management on the suggested method is appreciated.

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