



PS2 – Poster-12



Optimization Principles of the Control Actions of the Emergency Control System

Nikolay V. KOROVKIN, Olga N. SOKOLOVA, Eugeny V. SOROKIN,
Oleg V. FROLOV

NIPT

Russia

sokolova.olga87@gmail.com

KEYWORDS

Emergency Control System, Optimization Algorithms, Power Supply Reliability and Quality

1 INTRODUCTION

Quick development of the computer engineering, on the one side, and toughening of requirements of the reliable power supply, on the other side, are caused the search of the new ways of the emergency control system algorithms determination. Inadmissible service conditions of the electrical devices operation can appear as a result of the disturbance or at the same time as a result of the dispatcher's mistake. Compliance with the requirements of the reliable power supply can be reached with the usage of the emergency control system optimization algorithms.

During the power system dispatching the multichoice analysis of the power system behavior for different sets of the control actions is impossible [1]. For example, dispatcher can operate with the seven control actions. Each control action has from 3 to 5 discrete values. General number which dispatcher has to review, will be quite large. Decision-making time is too short for full-scale analysis. It complicates the selection of the control actions. Time for the data set formation, which usually exceeds duration of the power systems calculation, should be also taken into account. This crude estimation shows the significance of the new optimization approach development.

The task of the control actions optimization is considered to be a problem of the online control actions choice. Chosen control actions should reduce the undersupply of energy, which is caused by the disturbance. The usage of the linear-fractional functions is proposed in this thesis.

2 MATHEMATICAL APPARATUS. ITS DEFINITION AND APPROVAL OF THE THEORY

Concerned control action can consist of:

- generator tripping;
- load shedding;
- usage of the flexible alternative current transmission systems (FACTS);
- changing of the network topology.

Additional complexity of the emergency control system algorithms determination is the variety of the states conditions and disturbances, which are defined the great amount of the emergency situations. These features should be taken into account. Proposed method allows to determine the optimal emergency control system algorithm. Power system state optimization can be carried out using different technical and economic criteria. Optimization criteria take into account control actions priority as well as their dosage.

Regularity of the power systems load conditions in the circuits' nodes will be shown further. Abstract load node can be represented as a node with static load with complex conductance Y , synchronous and asynchronous motors. It is widely known that asynchronous motors are sensitive to voltage level lowering below critical level.

Let indicate with index "0" parameters of the current state. Parameters of the mode are the following: complex conductance of the load Y_0 , current, voltage level in the circuits' nodes, power flows. Dependence of the complex voltage $\dot{U}$ and current $\dot{I}$ from complex conductance Y is described by the function [2]:

$$\begin{Bmatrix} \dot{U} \\ \dot{I} \end{Bmatrix} = \frac{a \cdot Y + b}{c \cdot Y + 1} \quad (1)$$

where: Y belongs to the ensemble W : $y_{\min} \leq |Y| \leq y_{\max}$, $y_{\min}$, $y_{\max}$ - minimally and maximum admissible complex conductance values; complex constants a , b , c - are defined from the calculation of the three power systems states: $Y = Y_0 = (y_{\min} + y_{\max})/2$, $Y = Y_1$, $|Y_1| \in [y_{\min}, y_{\max}]$, $Y = Y_2$, $|Y_2| \in [y_{\min}, y_{\max}]$.

Proportion (1) is correct for any branch current or node voltage. So it can be used for control actions' optimization purpose. Also it allows to solve inverse problems. For example, it is needed to estimate the complex conductance $Y_{var}^{(k)}$ of the k node, which ensure defined current $\dot{I}_{req}^{(p)}$ in the branch p . From (1) it is followed

$$Y_{var}^{(k)} = \frac{\dot{I}_{req}^{(p)} - b}{a - c \cdot \dot{I}_{req}^{(p)}} \quad (2)$$

Thus, to ensure the defined branch current $\dot{I}_{req}^{(p)}$, the complex conductance $Y^{(k)}$ should be changed from $Y_0^{(k)}$ value to $Y_{var}^{(k)}$ value, computed by usage of (2). Similarly we can calculate the complex conductance, which guarantees defined voltage level in the circuits' nodes.

$$\dot{U}^{(m)} = \frac{a \cdot Y_{var}^{(k)} + b}{c \cdot Y_{var}^{(k)} + 1} \quad (3)$$

Equations (2) and (3) can be solved together (for complex values). For active values calculation these equations should be used separately.

It is important that complex constants a , b , c , can be estimated beforehand for all or nearly all typical power systems states. Therefore calculations with the usage of (1)-(3) are utterly short (milliseconds). This allows to consider such approach as a prospective theoretical base for operative expert system, which plays the role of the dispatcher adviser.

Considered above control actions' set consisted of the single parameter of one type - complex conductance $Y_{var}^{(k)}$ of the k node. On the assumption of FACTS usage the proportion format won't be changed. In this case controlled parameter of the FACTS will be taken into account instead of the complex conductance $Y_{var}^{(k)}$. If we additionally take into account the electromotive difference of the generators $E_{var}^{(n)}$ in the circuits' nodes $n = \overline{1, N}$, the proportion connecting branch current $\dot{I}$ and voltage level $\dot{U}$ with the control action is changed to the following form

$$\begin{Bmatrix} \dot{U} \\ \dot{I} \end{Bmatrix} = \sum_{n=1}^N E_{var}^{(n)} \frac{a_n \cdot Y_{var}^{(k)} + b_n}{c \cdot Y_{var}^{(k)} + 1} \quad (4)$$

Quantity of the coefficients, which enter in to the expression (4), is $2N+1$. Thus the possibility of its usage supposes the calculation of the $2N+1$ power systems states.

Changing of the network topology as a control action can be taken into account by the instrumentality of logical variable X_{nm} . Value of the logical variable X_{nm} , equal to one, corresponds to the state, when connection between n and m nodes exists; equal to zero ($\bar{X}_{nm} = 1 - X_{nm} = 1$) - the nodes are not connected. If two network elements X_{nm} and X_{pq} and complex conductance $Y^{(k)}$ are taken into

account together, the proportion between branch current $\dot{I}$ or line (load) voltage $\dot{U}$ and control action transforms to the following form:

$$\begin{aligned} \begin{Bmatrix} \dot{U} \\ \dot{I} \end{Bmatrix} = & X_{nm} X_{pq} \frac{a_1 Y_{var}^{(k)} + b_1}{c_1 Y_{var}^{(k)} + 1} + X_{nm} \bar{X}_{pq} \frac{a_2 Y_{var}^{(k)} + b_2}{c_2 Y_{var}^{(k)} + 1} + \\ & + \bar{X}_{nm} X_{pq} \frac{a_3 Y_{var}^{(k)} + b_3}{c_3 Y_{var}^{(k)} + 1} + \bar{X}_{nm} \bar{X}_{pq} \frac{a_4 Y_{var}^{(k)} + b_4}{c_4 Y_{var}^{(k)} + 1}. \end{aligned} \quad (5)$$

The expression (5) has four sets of the coefficients $a_s, b_s, c_s, s = \overline{1,4}$, which have to be determined. Thus the usage of the proportion (5) supposes preliminary analysis of 12 power system states.

In the case of accounting the complex conductances $Y_{var}^{(k)}$ and $Y_{var}^{(\ell)}$ of the k and ℓ nodes accordingly as the control action, the proportion for complex current $\dot{I}$ or voltage $\dot{U}$ and control action becomes the following (6). The usage of the proportion (6) requires calculation of the 7 power system states.

For compact and universal description of the power systems' voltages and currents it is convenient to use contracted notations shown in (6): function B is voltage or current; upper indexes (0,0) of the function B show quantity of the variable generator voltages (zero in the given case) and the quantity of the controlled network elements (also zero in the given case); lower index m indicates the number of the controlled branch; control actions are specified in the brackets. Thus, the function $B_m^{(3,3)}(E^{(1)}, E^{(2)}, E^{(3)}, X_{nm}, X_{pq}, Y^{(k)}, Y^{(\ell)}, Y^{(f)})$, expresses the dependence of the current (voltage) in the branch m from 8 control action: three generator voltages, state control of the two lines, changing of the complex conductance of k, f and ℓ nodes. The quantity of the analyzable states does not depend on the type of the control action within the usage of the modern approaches for the emergency control system algorithms determination. The usage of the proposed method allows to reduce the number of the analyzable states. Thus for the mentioned above set of the control actions the analysis of the 80 power system states is required. Comparison of this number with the number $10^3 - 10^5$, which is equal to computational complexity in the case of the combinatorial method, shows the significance of proposed approach. Thus the proposed method is considered to be promising one.

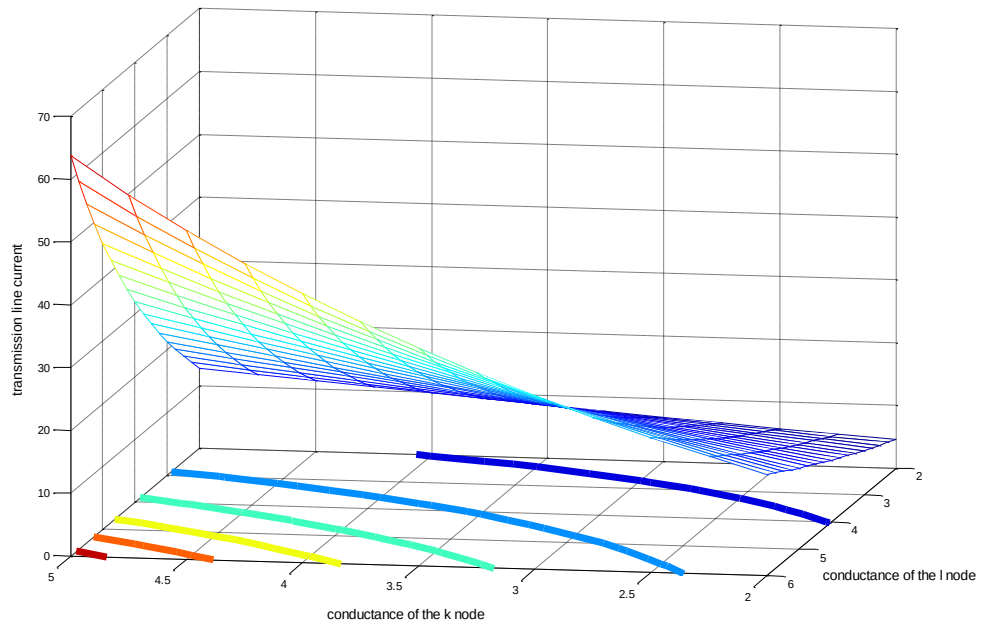


Fig. 1: Dependences between transmission line current and k and l nodes conductance

Developed mathematical apparatus testing showed its high effectiveness as on the test tests circuits as on the real power systems. Initial data for coefficients determination were defined using power systems states calculation software (EuroStag, RastrWin, etc.). Real nonlinear power system characteristics are taken into account in such software. Development of the calibration error shows its applicability.

Approval of the theory was made by the example of the power system of Primorye territory. Optimal control algorithm of the inadmissible transmission line 500 kV current overload abandonment was needed to be defined (fig.1).

Analytic dependence of the transmission line current from load parameters is shown on the fig.1, which was obtained using proportion (6). Load parameters sets equal to one or another transmission line current value are shown on the figure using level curves. As a control action was used load shedding, which is directly connected with the undersupply of energy. Comparison between developed and used algorithm shows the effectiveness of the first one. Undersupply of energy reduces up to 17%. Approximate benefits assessment of the developed algorithm usage on Unified Energy System of Russia shows that undersupply of energy decrease will be sizeable.

Finding capability of the rotations between complex currents or voltages and control actions makes possible to obtain analytic forms for effective quantities. Expressions for active and reactive power and loss power can be determined. Coefficients in (1) are following: $a=Ar+jAk$, $b=Br+jBk$, $c=Cr+jCk$. The expression for the root-mean square voltage is shown below:

$$U = \left| \frac{(yAr + jyAk + Br + jBk)^2}{(yCr + jyCk + 1)^2} \right| \quad (7)$$

Similar expressions can be found out for the brunch current. Denominator in (7) and (8) is equal. Denominator is determined only by the network topology.

$$I = \left| \frac{(yAr_i + jyAk_i + Br_i + jBk_i)^2}{(yCr + jyCk + 1)^2} \right| \quad (8)$$

Dispatcher controls during supervising the power flows over the transmission lines. Expressions (7,8) allows to find out the linear-fractional rotations for the power flows. Therefore analytical dependences between power flow and nodes conductance is shown below:

$$\dot{S} = \frac{\sum_{i=1}^n E_i \cdot (A + Br \cdot y + jy \cdot Bk) \cdot \frac{(Ai + Br_i \cdot y + jy \cdot Bk_i)^2}{(yCr + jyCk + 1)^2}}{(yCr + jyCk + 1)^2} \quad (9)$$

Thus quantity of the control actions influencing on the power system state is rather small, even if the power system consists of the thousands branches and nodes. This allows to create the data base of the analytical dependences for power systems state under disturbance without sizeable difficulties. Therefore dispatcher may solve optimization problems in the real time.

3 CONCLUSION

Every regime of the power system should provide reliable and high quality power supply. At the same time each regime of the power system has several limits which determine admissibility conditions. Several regimes could comply with the admissibility conditions. Thus it is very important to study different optimization methods in order to find the most optimal regimes. Power flows' reaction to power system topologie and parametres changing are taken in to account in the developed algorithm.

Approval of the developed algorithm on the power system of Far East of Russia allows to reduce undersupply of energy up to 17%.

REFERENCES

- [1] Frolov O. V., Korovkin N.V., Sokolova O.N., Sorokin E.V., Volokov A.I. Principles of the control actions optimization in the postemergency state of the power system. // Power plants 2010 №12 P. 33-35.
- [2] Demirchan K. S., Korovkin N. V. Neiman L.R. Theoretical basis of electrical engineering. Vol. 1. St. Petersburg, 2008.