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Research paper

Use of Generalized Regime Indicators when Evaluating Adaptive Reserve Coefficients by Active Power

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Abstract

To ensure the efficiency of the regime of electric power systems (EPS) most of the time should work near their physical limits, including the conditions of static aperiodic stability. To calculate the margin factors for active power corresponding to the existing scheme-operational situations (adaptive), when using the aggregate indicators of the mode in which the second derivatives are selected from the total active power losses in the network according to the controlled parameter. Safety factors allow you to separate the area "flow" modes, in which when equal to perturbing influences will have received a large response from areas of normal functioning.

Keywords: *Power System, Adaptive Safety Factors, Summary Measures of Regime*

1. Introduction

At present, the issues of electrical networks' efficiency are relevant both in Russia and in other countries. Technically, to ensure the efficiency of regime, electric power systems (EPS) should work most of the time near their physical boundaries, including the boundaries under the conditions of static aperiodic stability (SAS) [1]. This, in turn, can cause an increase of instability in non-standard or emergency situations, during EPS control.

Adaptive reserve coefficients, estimating the level of static aperiodic stability by active power K_p and obtained using generalized regime indicators - the second derivatives of the total active power losses in the network π'' by the controlled parameter [2] allows to evaluate the high risk zone in the coordinates of active powers. Analysis of changes' pattern of the second derivatives allows us to find the boundary value of active power, separating the zone of normal operation from the zone of near-boundary regimes, as well as to calculate the reserve coefficients by active power, corresponding to the existing scheme-regime situation, that is, adaptive. To do this, it is necessary to estimate changes π'' in the network for analyzing the regime and determining its static aperiodic stability, calculating the adaptive reserve coefficient K_p by active power.

In addition, in some electric power systems there is a high level of power loss and energy in the electrical networks, which is one of the most important indicators affecting the efficiency of power grid companies. Under such conditions, it seems relevant to develop new methods for analyzing energy systems in the conditions of electricity market, identifying generalized indicators of the regime, allowing at the same time:

to assess the possibility of operating an EPS with reserve coefficients by active power, lower than the normative ones, determined in each specific case by the characteristics of the regime;

to identify remoteness of the regime from the "flow" zone.

The theoretical significance of such results consists in the development of methods for assessing generalized indicators, development of methods for integrated assessment and building of algorithms for detecting and monitoring limit regimes.

Task of operational control of the steady-state regimes (SSM) in electric power systems (EPS) is to ensure reliable supply of consumers with electric power of the required quality at the lowest possible operating costs in the EPS within the considered period of time. In the new economic conditions, under contractual relations between energy facilities, there is a need for an integrated approach to the problem of regime management. For clarity, we can consider an example of the regimes' analysis with transit flows in deficit power systems [3].

Within the context of contractual relations, through transit flows can be organized in deficit power systems, which can lead to a noticeable change of the regime and even go beyond the boundaries of the zone of allowable regimes (AAR), therefore, it is important to assess the impact of transit flows on the regime reliability, efficiency and parameters of the existing regime. If we assume that in steady-state regime without transit flow, there is a basic power flow distribution with optimal voltage levels in the controlled nodes and with close to minimal losses of active power in the network, then in the presence of transit, it is possible to decrease the voltage along the transit path and in other network nodes, that in turn, can lead to dissatisfaction with electricity supplier, increase of active power losses in the network.

One of the indicators of reliable operation of electric power systems is regime reliability, which is determined taking into account the capacity of communications. It should be noted that with the growth of transit flows, the bandwidth of communications decreases.

This, in turn, can increase the risk of instability in non-standard or emergency situations, when optimizing the modes or when managing EPS power. The reserve coefficients, obtained using generalized parameters of the regime allow to estimate the zone of increased risk in the coordinates of active capacities $K_{зп}$ [4,5].

Technically, to ensure the efficiency of the regime, electric power systems (EPS) should work most of the time near their physical boundaries, including the boundaries under the conditions of static aperiodic stability [6]. It is impossible without taking into account the requirements for regime reliability. Determination of the limit regime of active power transfer is most often carried out by calculating a series of weighted (consistently degraded by any parameter) regimes. Weighting is carried out in such a way that the power flow changes most strongly through the controlled section (a separate power line) [7].

As a method of weighting in the absence of self-oscillation, one usually chooses an increase of the generation (load) or decrease of the voltage in the specified nodes of the system, redistribution of the load generating nodes or combination of these methods. Often, instead of estimating the stability limits, one determines the existence limit regimes and reserve coefficients relative to such limits. Simplified evaluation of static stability in some cases can be carried out using the signs of free term of the characteristic equation a_n, the determinant of the synchronizing powers of the system generators *S*, the determinant of the Jacobi matrix **J** of the SSM equations, written in a certain way [8,9]. When these values are equal to zero, the limit regime with positive value will have a margin for stability. Having negative value, the mode will be unstable.

In [10-12] it is shown that under certain conditions [13] a_n coincides with determinant of the Jacobi matrix of the steady-state regime equations completely or with an accuracy of a constant factor. The positions are valid in polar and Cartesian coordinate systems.

In [14,15] it is shown that there is a relationship between the determinant of the Jacobi matrix and the derivative of the total active power losses in the network π with respect to the variable parameter of regime P:

$$J \equiv \frac{1}{\sigma},$$

Where $\sigma = \frac{\partial \pi}{\sigma \Pi}$.

When the Jacobian approaches zero, the derivative increases, approaching infinity. Far from the limit $\sigma\,(\Pi)$, it is linear in existence, and becomes significantly nonlinear and increasing in the zone of near-boundary regimes [16]. Then it is acceptable to use any of these values for analyzing the regimes. As the generalized indicators of the regime, one can use the second derivatives from the considered values according to the controlled (weighted) parameter. Generalized indicators have opposite signs, which change when regime goes beyond the limit values. They determine the presence of an inflection point and allow us to separate the "flow" zone of regimes, in which, with equal disturbing influences, a large response of the system will be obtained from the zone of normal functioning. Thus, the generalized indicators of the regime allow us to separate the zone of normal functioning from unstable regimes.

In the Russian practice of regime calculations, reserve coefficients by active power K_p, are considered upon receipt of which no less than the normative mode is considered acceptable by static stability. The current standards provide for a margin of power transmission stability, not less than 20% in normal regime and 8% for a short-term post-accident [2]:

$$K_p = \frac{P_{пр} - (P + \Delta P_{нк})}{P_{пр}} 100\%,$$

Where *P* and $P_{пр}$- the current and limit values of the transmitted power in the considered section;

$\Delta P_{нк}$ is the amplitude of irregular oscillations of active power in this section (it is assumed that under the action of irregular oscillations the flow changes in the range $P \pm \Delta P_{нк}$).

The amplitude value of irregular oscillations of active power is set for each section of the power system (including partial) according to the measurement data. In the absence of such data, the calculated amplitude of irregular oscillations of the active power of the cross section can be determined [2]. The amplitude of irregular oscillations found for the cross section can be distributed over partial cross sections in accordance with the power distribution coefficients in this cross section.

The normative reserve coefficients obtained in the traditional way are regulated separately for normal steady-state and post-emergency operating conditions by constant values that do not determine degree of "severity" of the current scheme-regime situation in the system. Therefore, it is of interest to analyze the generalized indicators of the regime, allowing determination of the reserve coefficients associated with both, the existing situation and the method of weighting the regime.

In the process of dispatching control of normal and post-emergency SSM, it is necessary to determine the zones of allowable regimes (AAR) and areas of the EPS regimes' existence (ARE) for each of the control subtasks. The boundary regimes for ARE are the limit regimes, and AAR is located within ARE at some distance from the boundaries, which determines the reserves. In general case, the problem of searching for limit regime is formulated as a search for existence limit of steady - state regime on a given trajectory of weighting with physically realizable independent variables [7]. In this case, the assessment of reserves is reduced to determining the distance to the boundary zone of the regime.

When choosing a single indicator of the reserves, it is necessary to take into account its compliance with a number of requirements, such as universality, accessibility, possibility to obtain information based on EPS regime, the ability to characterize the regime [9]. It is possible to identify representative characteristics of regimes that simultaneously meet the requirements for the reserve indicator. It is function that can correctly assess the degree of approximation to the limit and allows to assess the level of reliability and efficiency of the electric regime existing in the EPS.

When solving problems, values of the determinant of the Jacobian matrix, written for the equations of node voltages (ENV) are often analyzed in the form of voltages' balances J_u (or currents balances, capacities). The derivative of the active power losses in the network for some regime parameter D_i is equal to [13]:

$$\frac{\partial \pi}{\partial D_i} = \frac{\overline{\partial \pi}}{\partial D_i} - \begin{pmatrix} \frac{\partial \pi}{\partial U'} & \frac{\partial \pi}{\partial U''} \end{pmatrix} \begin{pmatrix} \frac{\partial U'}{\partial D_i} \\ \frac{\partial U''}{\partial D_i} \end{pmatrix} = \frac{\overline{\partial \pi}}{\partial D_i} - \begin{pmatrix} \frac{\partial \pi}{\partial U'} & \frac{\partial \pi}{\partial U''} \end{pmatrix} \times \begin{pmatrix} \frac{\partial W'}{\partial U'} & \frac{\partial W'}{\partial U''} \\ \frac{\partial W''}{\partial U'} & \frac{\partial W''}{\partial U''} \end{pmatrix}^{-1} \begin{pmatrix} \frac{\partial W'}{\partial D_i} \\ \frac{\partial W''}{\partial D_i} \end{pmatrix},$$

where

$$\begin{pmatrix} \frac{\partial U'}{\partial D_i} \\ \frac{\partial U''}{\partial D_i} \end{pmatrix} = \begin{pmatrix} \frac{\partial W'}{\partial U'} & \frac{\partial W'}{\partial U''} \\ \frac{\partial W''}{\partial U'} & \frac{\partial W''}{\partial U''} \end{pmatrix}^{-1} \begin{pmatrix} \frac{\partial W'}{\partial D_i} \\ \frac{\partial W''}{\partial D_i} \end{pmatrix} = J_u^{-1} \begin{pmatrix} \frac{\partial W'}{\partial D_i} \\ \frac{\partial W''}{\partial D_i} \end{pmatrix}.$$

when

$$\frac{\partial \pi}{\partial D_i} = \frac{\overline{\partial \pi}}{\partial D_i} - \left(\frac{\partial \pi}{\partial U'} \; \frac{\partial \pi}{\partial U''} \right) J_u^{-1} \begin{pmatrix} \frac{\partial W'}{\partial D_i} \\ \frac{\partial W''}{\partial D_i} \end{pmatrix}.$$

Here, π is the total losses of active power in the network; U', U'' are active and reactive components of the voltage in the nodes; D_i is variable parameter; $W'W''$ are active and reactive components of unbalances in nodes; J_u is Jacobi matrix of nodal equations.

The condition for existence of the derivative $\frac{\partial \pi}{\partial D_i}$ will be in this case $\det[J_u] \neq 0$. If $\det[J_u] = 0$, then at this point $\frac{\partial \pi}{\partial D_i} = \infty$.

Thus, the steady - state regime of the system will be limiting to the deviation of any parameter *D*, if small changes in this parameter cause infinitely large changes of the total power losses in the network. In other words, if the system of equations of the SSR for certain values of independent variables has a solution and at the point of solution the Jacobians are non-zero [10], then with a small change in the parameters, the system will have a well-defined solution. If, at the point of solving the Jacobian equations SSR is equal to or close to zero, then an insignificant change of the parameters in the direction of the weighting of the regime will determine the absence of a real solution.

Accounting of active power losses of the electrical network (network factors σ_i) is an integral part of the methodology for planning EPS regimes. The existing approaches to the accounting of network factors [17] are based on their simplified representation, therefore the mode of the electric network is reflected quite adequately. If necessary, it is possible to clarify these factors, that can be approximately calculated using linearized expressions [17], which makes it possible to calculate σ_i и P_l if the generation capacities of power plants and the loads of consumers in all nodes are known. In [17], the expression for the first derivatives σ_i for the controlled cross section is also presented, which consists of several links forming a group of controlled lines. In this case, the coefficients of the expression for the total load of lines group are equal to the sum of the corresponding coefficients for the individual VL groups.

The second derivatives of the total active power losses in the network π, which initially slightly decreases with increasing *P*, but in the zone of regimes close to the limiting, even with a small *P* change, changes dramatically, are of greater interest. The boundary point during the transition to the zone of a sharp increase according to the absolute value may serve as a characteristic, indicating that the regime is approaching the boundary.

It is already more convenient to use the method of numerical differentiation for estimating calculations in the scheme, containing two generator and one load nodes. The criterion for the correctness of the choice of the differentiation step (also known as the weighting step ΔP) is the stabilization of the values of the first (second) derivatives when decreasing ΔP. Smoothing the characteristics of the first derivatives makes it possible to calculate π'' by small steps of differentiation.

The study of the nodes' sensitivity is one of the areas of structural analysis of electric power systems (EPS), using an assessment of the reactions of node voltages to changes of loads in them.

To analyze and control the regimes of electric power systems, the sensitivity (sensor) of the nodes, i.e. reaction of their voltages to changes of reactive power load, was evaluated.

Elements of the network scheme, the regime parameters which change the most with random changes in the topology of the network scheme and loads, were called [17] sensor, and others were called rigid.

EPS heterogeneity, which leads to the appearance of sensors, is largely determined by the EPS scheme and its parameters, and in principle, it is possible to single out such EPS elements, changes in the parameters of which to the greatest extent affect the response of the EPS to disturbances. It is with the help of these parameters it is possible to improve (or worsen) the properties of EPS most quickly.

Such elements will be called weak points.

Installation of stationary means of power quality control in the network may be appropriate in the nodes with the highest sensitivity at the fundamental frequency and higher harmonics. The most indicative in the assessment of voltage deviations are, for example, rigid and sensor nodes with specific properties [18,19]. The electric network is considered homogeneous if for all its sections the ratio is : $\frac{X}{R} = const$. In order to be fulfilled for the specified condition, the nominal voltages of the network sections, sites and the location of the wires on the supports must be the same [20]. All substations should have transformers with the same ratio $\frac{X}{R}$. In real networks this is not possible, therefore real networks are heterogeneous. A homogeneous network is characterized by lower losses of active power in the network compared to real networks. It is of interest to analyze the heterogeneity and its effect on the change of losses in the network. In this regard, the heterogeneity of the network, expressed in the presence of rigid and sensor nodes, and generalized indicators of the regime are considered.

Test example

For example, the IEEE test circuit is considered (Fig. 1), for which intermediate, sensor and rigid nodes are defined and calculated. It makes possible to obtain reserve coefficients by active power given in Table 1. For the test circuit, these are respectively 2.7.4 nodes.

Table 1: Calculation results of reserve coefficients by active power

	Intermediate	Sensor	Rigid
Node No.	2	4	7
K_p	0,21	0,29	0,13

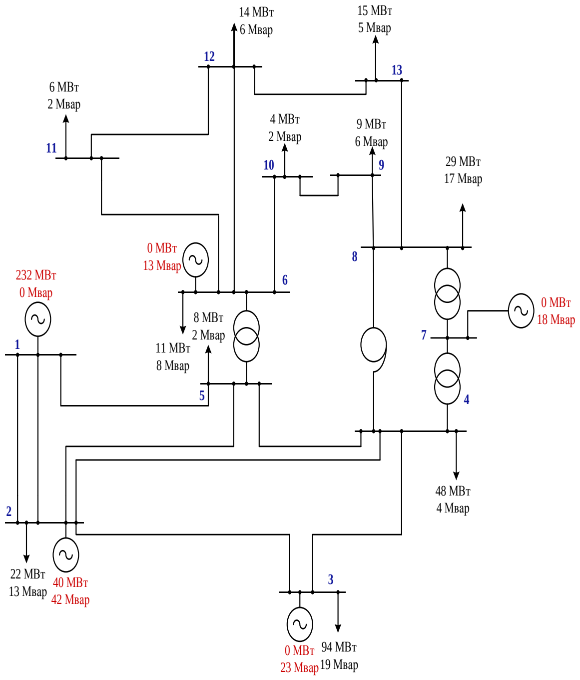

Fig. 1: Test scheme for calculations

The dependence of the generalized regime indicator on the power varied during the calculation in the 4th node is shown in Fig. 2. The coefficient is determined by the break point of characteristics.

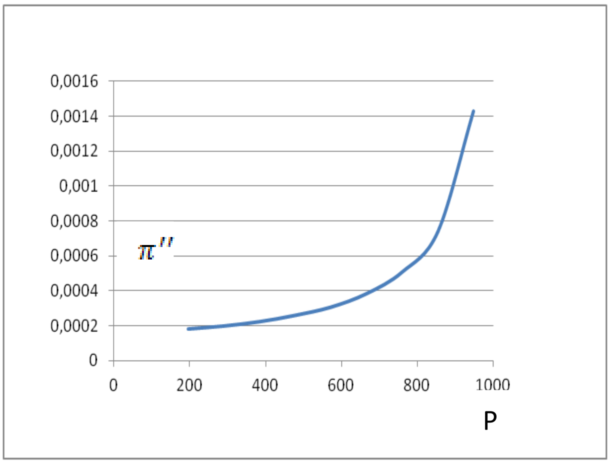

Fig.2: Dependence of the generalized regime parameter on R in the 4th node

As follows from the data in the table, the smallest margin is required when changing the regime in a rigid node, the largest for the sensor node.

2. Discussion.

To confirm the data obtained, calculations were performed in the real energy system for the retrospective scheme of the power system of Kazakhstan. Sensor and rigid nodes are defined respectively 485, 31401 nodes. Similar calculations are carried out. Fragments of the scheme with highlighted sections are shown in Fig. 3, 4. The results are shown in table 2.

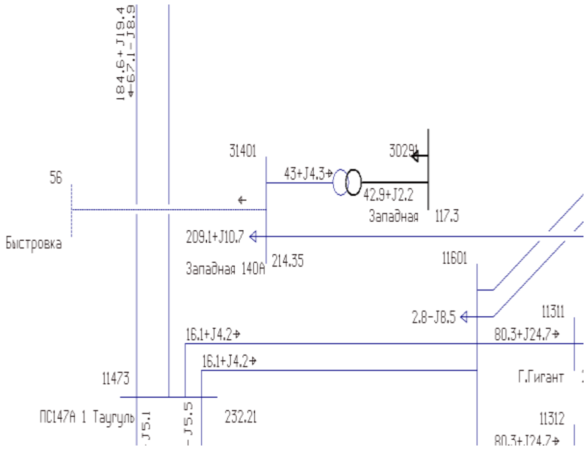

Fig.3. The real scheme for calculations in node No. 31401

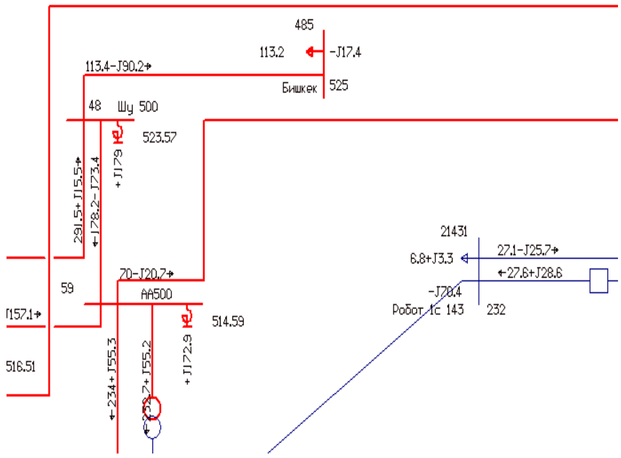

Fig.4: The real scheme for calculations in node No.485.

Table 2: Calculation results of reserve coefficients by active power

	Sensor		Rigid	
Node No.	485		31401	
	winter	summer	winter	summer
K_p	0,27	0,25	0,10	0,14

From the result presented in Table 2, it becomes clear that the same ratios are observed in the real scheme and generalized indicators of the regime can be useful in determining adaptive reserve coefficients that will allow working with reduced reserves during regime changes in rigid nodes and normative for sensor nodes.

3. Conclusion

The analysis of the relationship between the elements of the Jacobi matrix with unbalance of currents in the Cartesian coordinate system and unbalances of power in the polar coordinate system is carried out. According to the analysis, the interrelation between the determinant of the Jacobi matrix and the derivative of the total active power losses in the network with respect to the variable parameter of regime P. is determined.

It is acceptable for analyzing the regimes, as well as the generalized indicators of the regime, to use the second derivatives of the considered values according to the controlled (weighted) parameter, which allow to separate the "flow" zone of regimes, in which, with equal disturbing influences, a large system response will be obtained from the zone of normal functioning.

It is proposed to use the second derivatives of the total active power losses in the network as generalized indicators of the regime.

The second derivatives of the total active power losses in the network are almost constant in the zone of EPS normal operation and quickly grow in the zone of hazardous near the limit regimes [2,3], so they are convenient to use when changing regime along a trajectory (weighting). Here, it is possible to determine the boundary value of the active power, separating the two zones and calculate the reserve coefficients by active power corresponding to the existing situation.

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