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METHOD FOR THE DETERMINATION OF CONTROLLING ACTIONS TO ENHANCE POWER SYSTEM STABILITY

VADĪBAS IEDARBJU NOTEIKŠANAS METODE ENERGOSISTĒMAS STABILITĀTES PAAUGSTINĀŠANAI

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Introduction

This paper provides the description of power system control during emergency situations applying new stability control method, which is based on determination of controlling actions using real emergency state of power system.
Development of power systems, appearance of large interconnected power systems with thermal and hydro power plants of large capacity, as well as loaded power transmission lines complicates control tasks of operational conditions.
Effective tools for providing power system stability are the anti-emergency automation, which contains various numbers of arrangements preventing expansion of emergency disturbances and their spreading out to neighbouring regions of power system [1]. Existing anti-emergency automation prevents power system stability disturbance using pre-calculated emergency situations and providing dosed control impacts on power system generation and load in order to restore power balances and prevent dangerous overloading of transmission lines. However, not all emergencies can be foreseen in advance. Therefore, there is a need in development of control automation adaptive to any possible emergency situation.

Existing anti-emergency automation system

This section briefly describes the operational principle of anti-emergency automation at present operated in many power systems.
Existing anti-emergency automation represents a complex of arrangements providing the functions to recognize and prevent the disturbance. The function of determining impact dosing on power system during emergency situation is realized by the automatic dosage arrangement (dozer). This arrangement encloses the data table of calculations “disturbance – control impact value”. Table is formed of calculation results of emergency state previously made on mathematical models for different impact conditions. Depending on type of dozer arrangement the table can be presented in the form of “scheme – operational condition – disturbance – control impact”. Table is formed in a way of impact dose determination for each selected emergency situation.
The simplest arrangements of anti-emergency automation operate in accordance with action of one of starting arrangements (for example, block contacts of circuit-breaker) from the list of several arrangements, each of which corresponds to one of the

accounting impact types. Impact dose has been determined before the emergency. Results of calculations are formed into the table, which is set inside the memory storage of anti-emergency automation.
The basic drawbacks of existing anti-emergency automation are:

- after disturbance in the power system automation is not operating according real emergency impact, but selects nearest emergency situation from the table;
- system of emergency condition control by preventing stability disturbance has no adaptability for complex character of disturbance;
- automation does not provide rearranging after emergency condition of power system into normal operational condition, this operation is provided manually.

In order to enhance the efficiency and quality of power system emergency control new method is required for the determination of impact doses and providing the restoration of normal operational condition during control process without unnecessary shedding of load or generators.

Impact dose determination method

In this section the mathematical description of suggested impact dose determination method is given.
Method is based on using of dynamic equation of rotor movement. Dynamic equation of power system, which consists of single turbo unit and load on its busbars is expressed as follows:

$$J_{\Sigma} \cdot \omega \cdot d\omega / dt = P_{meh}(f) - P_{el}(f) \qquad (1)$$

where J_{Σ} - total inertia moment of gyrating mass of turbo unit and load; ω - angular velocity; $P_{meh}(f)$ - mechanical power on turbine's shaft at any frequency value; $P_{el}(f)$ - electrical load power on generator's busbars at any frequency value.
Equation (1) is true for both transient and steady states.
In order to restore the power balance at nominal frequency after some disturbance, current parameters of equation (1) are to be reduced to nominal frequency, and then the power deficiency value could be determined at any level of frequency.
Equation of turbine's mechanical power dependence on frequency:

$$P_{meh}(f) = P_{meh\,n} \frac{2f_n \cdot f - f^2}{f_n^2} = P_{meh\,n} \cdot F_1(f) \qquad (2)$$

where $P_{meh\,n}$ - mechanical power on turbine's shaft at nominal frequency; f; f_n - current and nominal frequency values.
Equation of power load dependence on frequency:

$$P_{el}(f) = P_{el\,n}\left(\alpha_0 + \alpha_1 f/f_n + \alpha_2 f^2/f_n^2 + \alpha_3 f^3/f_n^3\right) = P_{el\,n} \cdot F_2(f) \qquad (3)$$

where $\alpha_0 \div \alpha_3$ - coefficients of frequency dependent load ($\sum_0^3 \alpha_n = 1$).
Available expression of total inertia moment:

$$J_{\Sigma} = J_G + J_L = \tau_G \cdot P_{meh\,n} / \omega_n^2 + \tau_L \cdot P_{el\,n} / \omega_n^2 \qquad (4)$$

where τ_G; τ_L - time constants of generator and load.
Dynamics equation of mechanical power of turbo unit, expressed using derived values:

$$P_{meh\,n} = -P_{el\,n} \frac{f_n^2 \cdot \left(\alpha_0 + \alpha_1 f/f_n + \alpha_2 f^2/f_n^2 + \alpha_3 f^3/f_n^3\right) + f \cdot df/dt \cdot \tau_L}{f \cdot df/dt \cdot \tau_G - \left(2 \cdot f_n \cdot f - f^2\right)} \qquad (5)$$

Calculated function of mechanical power at nominal frequency:

$$P_{meh\,n} = -P_{el\,n} \cdot F_3(f; f') = -\frac{P_{el}(f)}{F_2(f)} \cdot F_3(f; f') \qquad (6)$$

Calculated power impact value on turbine unit:

$$\Delta P = P_{meh\,n} - P_{el\,n} = -\frac{P_{el}(f)}{F_2(f)} \cdot F_3(f; f') - \frac{P_{el}(f)}{F_2(f)} = -\frac{P_{el}(f)}{F_2(f)} \cdot \left[1 + F_3(f; f')\right] \qquad (7)$$

Equations (5) and (7) show that equality of powers $P_{meh\,n}$ and $P_{el\,n}$ can reinstate when function $F_3(f; f' ...) = -1$. Using estimated function F_3 it is possible to determine the state of a power system for any current frequency and its rate of change value.
Only at normal operational condition, when the frequency is equal to nominal value and rate of change of frequency is zero, the calculated power balance is equal to balance of current powers.

Operating principle of suggested automation

Operating principle of automation preventing stability disturbance is based on calculation of power deficiency or surplus for separate power station during real emergency state.
Disturbance appeared in one location of power system spreads out in short time interval to another electrical power stations. Electrical power stations have sufficient information about disturbance value in power system. If, for example, the power deficiency will be calculated on each power station and eliminated in a way of load shedding with dose equal to this calculated deficiency, then there will be restored the normal post-emergency operational condition in power system.
Impact dose is determined by real time calculations, not by the comparison with pre-calculated emergencies.
Anti-emergency automation operating on new principle is decentralized automation solving separate problem of power deficiency or surplus elimination on examined power station and stability disturbance prevention. However, restoring normal post-emergency operational condition on one power station, restoration process takes place also in other non-controlled power stations.

Analysis of emergency condition in case of tripping parallel power transmission line

This section is devoted to observance of emergency conditions, caused by the tripping of parallel power transmission line in power system.
Stability analysis during emergency situation was provided for power system consisting of three thermal power plants interconnected via power transmission lines. Principle electrical scheme and parameters of normal operational condition in relative values are showed in Figure 1.

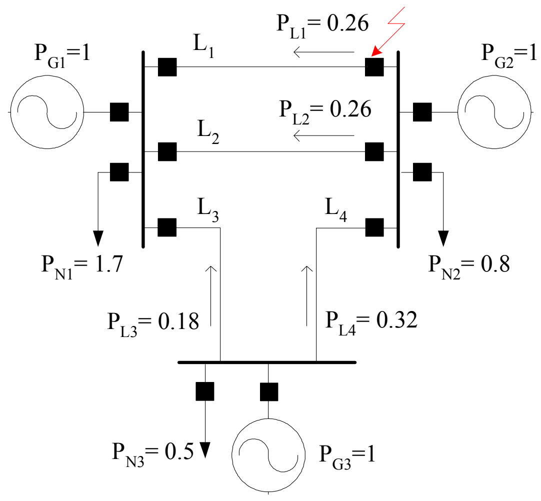
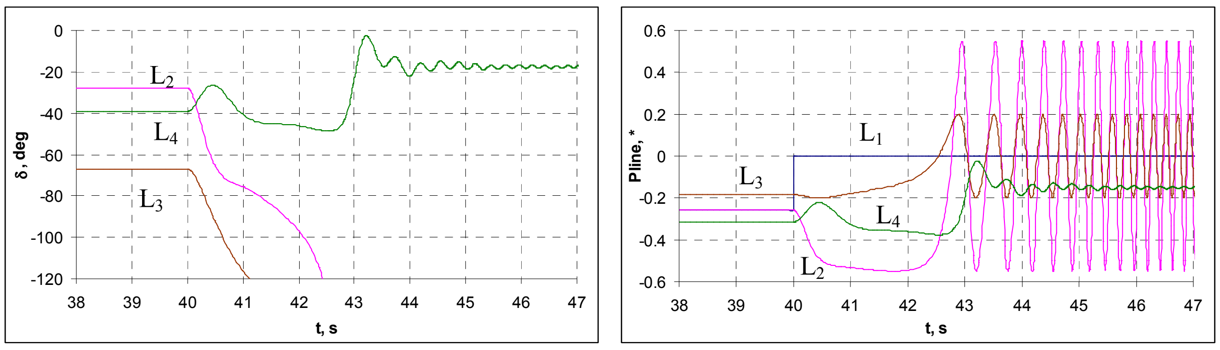


Figure 1. Principle electrical scheme of power system

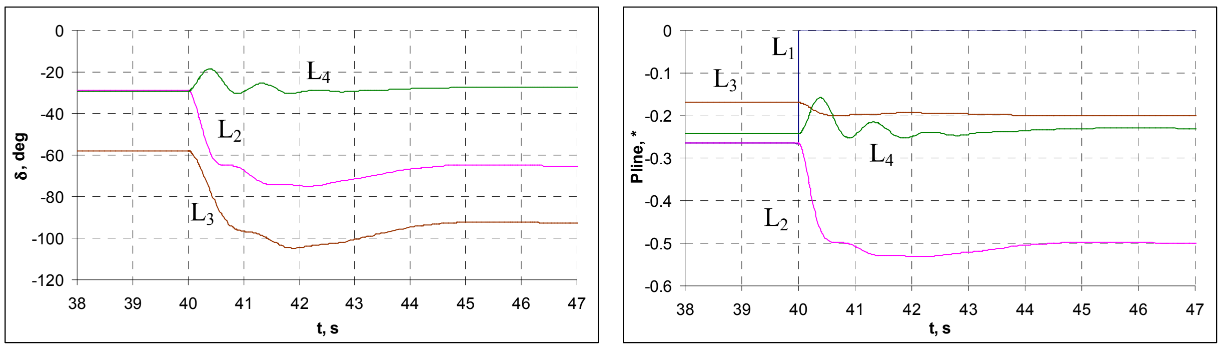
For such configuration power systems and in case of large amount of power exchange between three regions, it is very substantially to keep the parallel operation, i.e., maintain system stability in case of emergency trip of one power line.
Here as an example is examined situation, when power region G_1 is deficient and receives power via transmission lines from second and third - the surplus one regions G_2 and G_3.
Emergency tripping of one power line leads to the disturbance of power balance on generators, as well as sudden load drop on power lines, which are left in operation.
Power system stability is dependent on transmission capacity of power lines and adaptive anti-emergency operation. For power lines with sufficient transmission capacity system stability is not disturbed and transient process stabilizes rapidly. However, very often total amount of transferred power via transmission lines exceeds the transmission capacity of one line and emergency can disturb the system stability. Anti-emergency automation should prevent stability disturbance in a way of increasing generated power or load shedding in deficient part of power system (in this case it is G_1) and decrease generated power in surplus power regions to avoid overloading of the lines.
For evaluation of operation efficiency of anti-emergency automation calculation results of dynamical process is compared in non-controlled power system and in power system controlled by new automation.
Disturbance is assumed as tripping of one parallel line L_1, which connects power plants G_1 and G_2.
In this case the weakest power line is L_3 with transmission capacity P_{max} = 0.2 relative values. Transfer capacity for lines L_1 and L_2 is assumed 0.55 relative values and for line L_4 maximal transfer capacity is 0.5 relative values.
Figure 2 a) shows that power angle in line L_3 in case of non-controlled power system at pre-emergency state already comes up to 70^0 due to the large power flow from surplus region G_3 and after emergency trip of line L_2 system stability is disturbed. Figure 2 b) represents power flows in transmission lines.
Non-controlled power system cannot maintain stability for such power exchange scenario. Power flow to deficient region G_1 should be decreased in order to provide power system stability at normal and emergency conditions.
Figure 3 a) and b) represent calculation results of emergency condition for the same structure power system as in Figure 1, which has generators G_1, G_2 and G_3 applied with rotation speed governors and load shedding system affected by power deficiency (surplus) calculating arrangements of new principle.



a) b)

Figure 2. Transient processes after disturbance in non-controlled power system: a) – power angle in lines L_1, L_2 and L_3; b) – power flows in lines L_1, L_2, L_3 and L_4

During emergency time these arrangements control all the system characterizing parameters, as well as line loading and actuate load shedding in first region at the same time impacting executive mechanisms of turbo units to decrease the generated power in the second and third regions.
Accuracy of determined value of necessary load shedding and generated power decrease allows fast preventing of line out-of-step condition and providing system parallel operation at power exchange between regions. This condition is characterized with operation of governors on generated power sources and load shedding, which compensate the disturbance on generator busbars. This shows that calculations during real emergency time determine minimal necessary power value dose on power system to provide the stability.
By elimination of power deficiency on one generator and power surplus on another, frequency in power system is restored to nominal value, which could not be realized for system with existing anti-emergency automation selecting improper impact dose, consequently which could lead to the over-frequency situation in power system and stabilizing process would take more time and less efficiency.



a) b)

Figure 3. Transient processes in controlled power system: a) – change of power angle in lines L_2, L_3, L_4; b) – power flows in lines L_1, L_2, L_3 and L_4

From calculation results in Figure 3 a) and b) it can be seen that power flow and angle in line L_3 at pre-emergency operational state is less than values detected in non-controlled system, but power flows and therefore power angles in lines L_2 and L_4 is larger. Power system stability disturbance is efficiently prevented by operation of calculating arrangements affecting governors of thermal power plants.

Conclusions

Results of fulfilled investigations allow revealing following statements:

- Principle is based on determination of the deficiency or surplus value on power station continuously during transient and steady state conditions, and it considerably improves power system stability and allows adapt operation of automation on conditions of cascade emergencies.
- Automation operates on power system with doses equal to calculated deficiency or surplus, what allows efficient preventing power system stability disturbance.
- After preventing of power system disturbance anti-emergency automation restores normal post-emergency condition without unnecessary load or generator switching.
- Great interest on further research work raises power system emergency control with impact doses distributed by settings in equal time intervals, where the power of each next setting is equal to left deficiency (surplus).

Still lot of work have to be done in the area of investigations for more complicated power systems and types of disturbances.

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Gurovs N., Čuvičins V., Ķiene S. Vadības iedarbju noteikšanas metode energosistēmas stabilitātes paaugstināšanai

Rakstā ir pievērsta uzmanība energosistēmas pretavāriju vadības un stabilitātes uzturēšanas problēmām.

Autori, atklājot vairākus eksistējošās pretavāriju automātikas trūkumus, piedāvā jaunu pretavārijas vadības iedarbju noteikšanas metodi, lai paaugstinātu energosistēmas stabilitāti, atjaunojot jaudu bilances un novēršot bīstamas elektropārvades līniju pārslodzes.

Kā tika analizēts, esošā pretavāriju automātikas sistēma, kas paredzēta energosistēmas stabilitātes traucējumu novēršanai, izmanto vadības iedarbes uz ģenerāciju un slodzi, kas iepriekš aprēķināta dažādām avārijas situācijām. Taču ne visas avārijas situācijas var paredzēt iepriekš, tāpēc rodas nepieciešamība attīstīt pretavāriju vadības automātiku, lai tā būtu adaptīva jebkurās avārijas situācijās.

Piedāvātā metode balstās uz nepārtrauktu ģenerējamās un patērējamās jaudu starpības noteikšanu pie nominālās frekvences uz elektrostacijas kopnēm. Šī metode ļauj noteikt vadības iedarbes lielumu pie jebkuras frekvences vērtības, kas atšķiras no nominālās.

Rakstā ir parādīti modelēšanas rezultāti, izmantojot jauno iedarbju noteikšanas metodi stabilitātes traucējumu novēršanai vienkāršā energosistēmā.

Gurov N., Chuvychin V., Kiene S. Method for the determination of controlling actions to enhance power system stability

Authors, revealing some drawbacks of existing anti-emergency automation, suggest new method for the determination of controlling actions in order to enhance power system stability by the means of restoring power balances and preventing dangerous overloading of power transmission lines.

As it was analyzed, existing anti-emergency automation system provided for preventing power system stability disturbances uses pre-calculated control actions to generation and load for different emergency situations. However, not all emergencies can be foreseen in advance. Therefore, there is a need in development of control automation adaptive to any possible emergency situation.

Suggested method is based on continuous metering of difference between generated and consumed powers on power station busbars at nominal frequency value. This method allows defining the controlling actions to the power system at any frequency value different from the nominal level.

Paper presents the results of stability disturbance prevention in simple power system using the method of determination of controlling actions.

Гуров Н., Чувычин В., Киене С. Метод определения управляющих воздействий для повышения устойчивости энергосистемы

В статье рассматриваются проблемы противоаварийного управления и поддержания устойчивости энергосистемы.

Авторы, указывая на некоторые существенные недостатки существующей системы противоаварийного управления, предлогают новый метод определения противоаварийных воздействий для повышения устойчивости энергосистемы путем восстановления балансов мощностей и предотвращения опасных перегрузок линий электропередачи.

Из проведенного анализа следует что существующая система противоаварийной автоматики предназначенная для предотврощения нарушения устойчивости энергосистемы использует управляющее воздействие на генерацию и нагрузку уже прежде рассчитанную для различных аварийных ситуаций. Однако, не все аварийные ситуации могут быть предсказанны заранее, поэтому необходимо развитие противоаварийной автоматики чтобы та была адаптивна при любых аварийных ситуациях.

Предложенный метод основывается на непрерывном замере разности генерирующей и потребляемой мощностей при номинальной частоте на шинах электростанции. Этот метод позволяет определить дозу управляющего воздействия при любой частоте отличной от номинального значения.

В статье показанны результаты моделирования предотвращения нарушения устойчивости несложной энергосистемы новым методом определения управляющих воздействий.