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Application of New Emergency Control Principle in Power Systems

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Abstract—**Paper considers common issues of emergency automation preventing power system stability disturbance. Emergency automation operating on new principle during real emergency time calculates the value of necessary power impact dose on power system to prevent the stability disturbance. As a result improves the control efficiency of emergency conditions.**

In paper some examples of emergency conditions under different modes of disturbances and location of emergency control are performed.

Index Terms—**emergency automation, disturbance, power system stability control, power unbalance**

I. Introduction

Up-to-date power systems are large all-round automated systems provided with automation complexes, which are assigned to prevent the appearance and expansion of power system emergencies, as well as to localize and eliminate them. Emergency automation realizes its operation in a way of detection of emergency disturbances or deviation of operational condition parameters and control of emergency.

Each of automation complexes accomplishes a pre-requested task of emergency control and performing of determined operations.

Paper considers operation principle of automation preventing power system disturbance. Considered automation is entrusted with the task of providing power system stability that mainly is the aim to keep the parallel operation of interconnected power systems. Accomplishment of this task most frequently requires fast operation of automation to perform the generator start-up or tripping, load shedding [1].

This paper is devoted to the description of new operation principle of emergency automation preventing stability disturbance. Operation principle is based on continuous calculation of power deficiency or surplus (further called power unbalance) for separate power plant during real emergency state of power system, which allows determining the control impacts on power system to keep the stability. Paper covers some examples of disturbance distribution and impact dose determination in complex power systems.

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II. Operational Principle of Existing Emergency Automation

Each of automation arrangements uses dosed control actions, which are previously determined using power system models.

First, the structure scheme of control is selected, the location of starting units, which determine the disturbance, is appointed and location of execution units is defined. Further, the calculations of emergency conditions are fulfilled. On the basis of performed stability calculations, the list of emergency disturbances is determined, during which the emergency automation should operate. In that way the control impact doses on power system are determined for the specified emergency situations and fixed into the table of control impact doses [1].

Emergency automation during real emergency situation uses the data from table to select the appropriate control impact. However, not all emergency situations could be predicted in advance. In complicated power systems with bulk of power plants during cascade emergencies is very difficult to determine the impact doses.

Therefore, during eliminating the unpredicted emergencies the control efficiency decreases, as well it sometimes could cause the incorrect operation of automation and even lead to the system blackouts. Recently happened blackouts in United States, Italy, Sweden-Denmark, and in other countries showed that there is a need in new automatic control system, which is able to solve the stability problem during the emergency.

Obviously, the drawbacks of existing emergency automation are in the control principle, and exactly, in determination of control impact dose value and location in power system.

In order to solve the problem of successful preventing of power system stability disturbance, elaboration of new emergency control principle is required. Control system should determine not only the impact value, but also the location of provided impact. New control system should be adaptive during cascade emergencies as well.

III. Power unbalance value determination method

This section is devoted to the description of power unbalance determination method.

Power unbalance determination is illustrated by considering an isolated generating unit supplying a local load. A simplified block diagram representation of the speed control of a thermal-generating unit feeding an isolated load is shown in Fig. 1 [2,3].

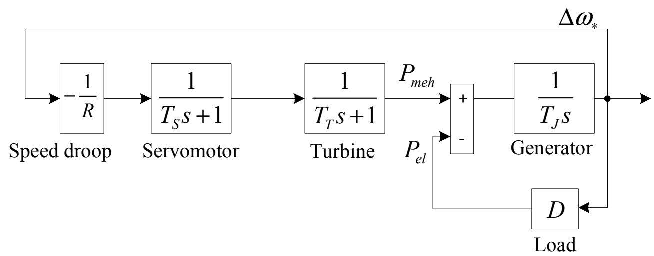

Fig. 1. Block diagram of a thermal-generating unit with speed governing system.

Equation of motion for the considered generator is expressed as follows:

$$T_J \frac{d\Delta\omega_*}{dt} = P_{meh} - P_{el}\,, \qquad (1)$$

where T_J - generator inertia time constant in seconds, $\Delta\omega_*$ - rotor speed deviation in per units, P_{meh} and P_{el} - mechanical and electrical power at current frequency in per units accordingly.

When there is a load change, it is reflected instantaneously as a change of electrical power of the generator. This causes a mismatch between the mechanical and the electrical power which in turn results in speed variations as determined by (1). System frequency varies depending on an active power [4].

However, use of (1) is not rational for determination of power unbalance, since the power balance between mechanical and electrical power can reinstate at frequency different from nominal value. Here, power system will be balanced, but at emergency deficient operational condition, reason of which is the dependence of values P_{meh} and P_{el} on frequency. In order to restore the power balance at nominal frequency, current parameters of (1) are to be reduced to nominal frequency, and then the power unbalance value could be determined at any level of frequency.

As it is known, the governor speed droop R characterizes the ratio of speed deviation ($\Delta\omega_*$) or frequency deviation (Δf) to change in power output (ΔP) [4]. From block diagram in Fig. 1 mechanical power change due to frequency deviation can be expressed as $\Delta P_{meh} = (-\Delta\omega_*/R)$. Also the power system load has the frequency sensitivity, which is characterized with the load damping constant D. From block diagram in Fig. 1 load change after frequency deviation can be expressed as $\Delta P_{el} = \Delta\omega_*\cdot D$ [4].

Equation of rotor motion in an extended way taking into account the effects of governor speed droop R and the frequency sensitivity of load D on the net frequency change can be expressed as:

$$T_J \frac{d\Delta\omega_*}{dt} = \left[P_{meh} - \frac{\Delta\omega_*}{R}\right] - \left[P_{el} + \Delta\omega_* \cdot D\right]. \qquad (2)$$

This means that an increase of system load results in a total generation increase due to governor action and a total system load reduction due to its frequency sensitive characteristic.

Consequently, from (2) the power unbalance value taking into account frequency change can be derived as

$$\Delta P = T_J \frac{d\Delta\omega_*}{dt} + \frac{\Delta\omega_*}{R} + \Delta\omega_* \cdot D\,. \qquad (3)$$

Expression (3) shows that power unbalance value is negative if the power system is deficient, i.e., frequency is less than nominal, and positive – if system is surplus with frequency above nominal.

Power unbalance value from (3) allows determining the exact power impact dose to the power system in order to restore the nominal frequency.

IV. Power unbalance determination in interconnected power systems

Applying the power unbalance value determination method in an interconnected power system with three or more power plants, the power unbalance distribution among power plants after some disturbance can be determined.

In case of interconnected power system power flows in tie lines should be taken into account. Considered method counts the power in tie lines as an electrical power.

Described power unbalance determination method can be applied to an emergency automation of power systems as an effective tool for providing power system stability during emergencies.

This section deals with the analysis of disturbance distribution along the interconnected power system.

Authors provided analysis of impact distribution for interconnected power system represented in Fig. 2. Interconnected power system could be assumed as an equivalent of Baltic power system operating in parallel with Russian and Byelorussian power systems forming an electrical ring. Simplified mathematical model was developed and simulations were performed using MATLAB software.

Equivalent power system consists of six thermal power plants (PP) feeding local load and connected with power transmission lines. Baltic equivalent power system can be represented with PP1-PP3 and Russian, Byelorussian power system – with PP4-PP6. Power balance and flows describing normal operational condition of power system in relative values (r.v.) on 1000 MVA base are represented in Fig. 2. Deficient power plants via tie lines receive the power from PP5, which is assumed as Russian Centre power system. Power angles in tie lines, as well as the inertia time constant of generators are displayed in Fig. 2.

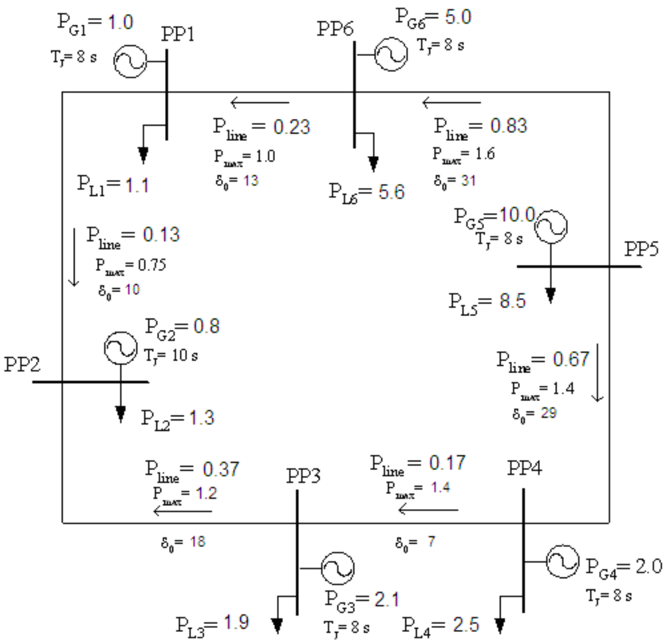

Fig. 2. Principle electrical scheme of complex structure power system.

Interconnections between PP4 and PP5, and PP5 and PP6 are the most loaded and require the most attention. Speed governors at PP1-PP4 provide the primary speed control function with droop R = 10%, speed governors at PP5 and PP6 provide the primary speed control function with droop R = 6% and R = 7% accordingly. Load damping factor D in whole power system is equal to 1.6.

To perform the simple simulations we assumed that the electromotive force of generators and respectively the voltage on their busbars remains constant during dynamic processes.

For considered operational condition of power system two the most dangerous disturbances can be accented – the loss of large generating unit in PP3 (assumed as Ignalina NPP in Lithuania with 1.5 relative values of active power) or the emergency trip of loaded cross section lines PP5-PP6 or PP5-PP4. Below we have examined the behavior of power system after mentioned two severe disturbances.

A. Loss of large generating unit

After loss of generating unit of 1.5 relative values in PP3 active power balance in power system is disrupted, system is deficient.

Each power plant is provided with power unbalance calculating equipment, which calculates the power deficiency or surplus values on power plant busbars using the above described principle.

The frequency of a system is dependent on active power balance. As frequency is a common factor throughout the system, a change in active power at one point is reflected throughout the system by a change in frequency.

Depending on the values of T_J, R and D of each power plant, power unbalance distributes in accordance with (2).

Transient process and character of distribution of this disturbance as power deficiency for all power plants is showed in Fig. 3 (curves 1-6). Deficiency on third power plant at first time moment increases up to the occurred power deficiency value in power system. Then it starts to decrease along the curve 3 in Fig. 3. Dynamic process appearance and subsequent change of deficiency on generator PP3 differs markedly from processes on other power plants. After short time interval power deficiency distributes along the other power plants.

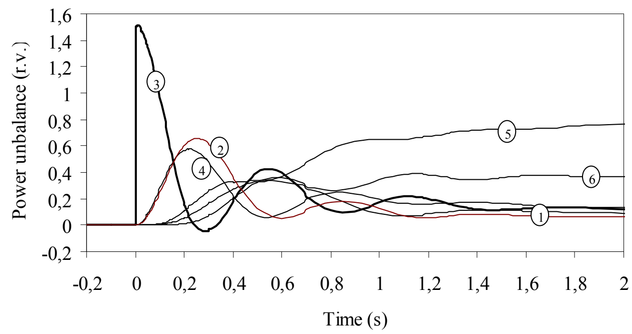

Fig. 3. Power unbalance distribution on power plants after tripping of generating unit at PP3.

Total power deficiency at any time moment is equal to the initial disturbance, respectively, 1.5 relative values. The character of power unbalance change defines the power plants to be controlled at first.

Operational condition does not stabilize, but due to the increased generation in PP5 by rotor speed governors after some seconds loading of cross-section between PP4 and PP5 increases, and the out-of-step condition takes place.

Conventionally, power system would be split across the unstable cross-section PP5-PP6. However, our concerns are to keep the parallel operation of interconnected power systems.

If power deficiency on every power plant will be eliminated with the control amount appropriate to the calculated deficiency value, then the normal operational condition with nominal frequency and power balances will be restored in power system.

Amount of control impacts at any time instant can be determined as calculated deficiency on power plants and imposed on power governors or load shedding by the controllers, which realize the continuous switching of impact amount by settings, power value of which is determined by law of decreasing geometrical progression with denominator less than one. Time interval between settings is selected 0.2 seconds.

Impact on power system is provided using following algorithm. Controller determines an initial impact dose P_{i0} in relative values. After that it defines power of dose for first setting as:

$$N_1 = P_{i0} \cdot k\,, \qquad (4)$$

where k – coefficient of proportionality, which remains constant during determination of next power settings.

The initial amount of impact is determined by selection of value k. The closer value k is to one, the more effective is impact on power system, since the first impact dose is the biggest, and after impact transient process slows down. The less is k, the less probability that after the tripping of first setting overcorrection will take place. The value of k is selected 0.8 for considered case [5].

Distribution of impact amounts to the settings of controller is performed automatically during emergency conditions. Impact on deficient power system with first setting, forming the most part of impact as load shedding, slows down the transient process. This allows operating next settings of impact before stability disturbs. At the same time after operation of each setting there is no overcorrection during control [5].

Considered impact dosing method allows decreasing possible control errors, since the parameters of T_J, D and R can differ from real values.

Calculated control impact values, which are imposed to the load shedding of nearest to the disturbance power plants (PP2-PP4) are represented in Fig. 4. At time moment $t = 2s$ automation of power plants 2-4 performed load shedding in total amount of 1.06 relative values. However, load shedding process still continues until the frequency is restored to the rated value of 50 Hz. Power system stability disturbance is eliminated successfully.

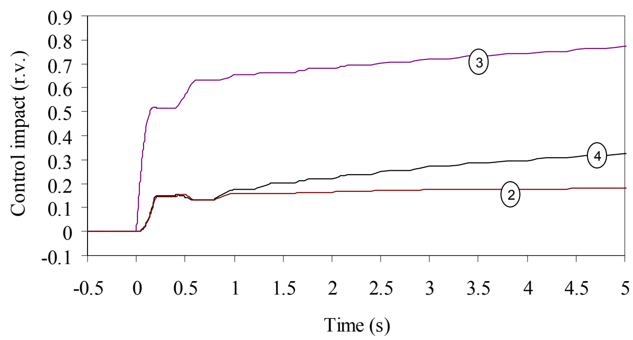

Fig. 4. Calculated control impact values applied on load shedding of PP2-PP4.

Fig. 5 describes the character of power unbalance change during operation of load shedding automation providing disturbance elimination.

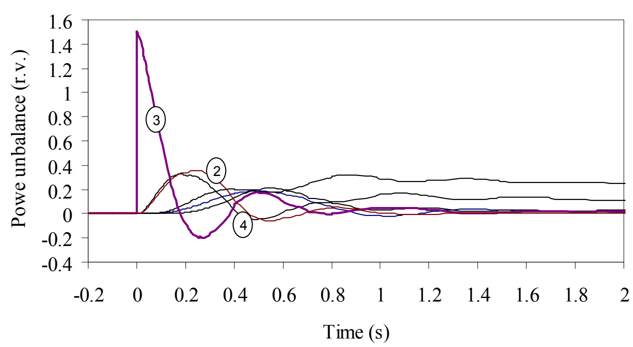

Fig. 5. Power unbalance on power plants during operation of load shedding automation on PP2-PP4.

Power unbalance value after disturbance in interconnected power system is decreased, but not eliminated. At time moment $t = 2s$ power deficiency still comprises about 0.4 relative values of active power, which corresponds to 49.9Hz of frequency in power system. Fig. 6 shows the character of frequency change in power system during control actions.

Control impact doses of emergency automation on every power plant are calculated continuously until the balance of mechanical and electrical power at nominal frequency is restored.

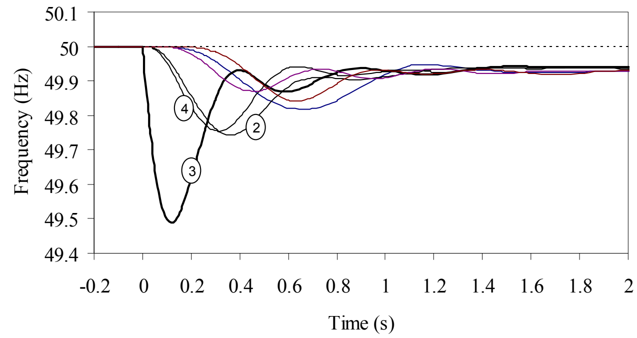

Fig. 6. Frequency change on power plants after operation of load shedding automation.

To perform more efficient elimination of power system disturbance, we suggest providing control impacts on load shedding in PP2-PP4 simultaneously with control impacts on generation increasing in PP5 and PP6. Fig. 7 shows the control impacts on load shedding in PP2-PP4 and control impacts on generation increasing on PP5-PP6. This method allows avoiding of unnecessary load shedding. At time moment $t = 2s$ automation of power plants 2-4 performed load shedding in total amount of 0.89 relative values, and automation of power plants 5 and 6 performed fast generation increase in total amount of about 0.72 relative values. As it is seen from Fig. 7, automatically load reconnection is provided by the same power unbalance controller described above. Therefore, this method allows automatically reconnecting the load, which was shed excessively during control process in order to slow down the transient process.

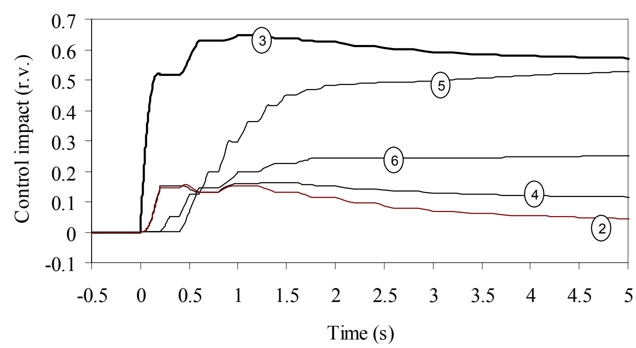

Fig. 7. Calculated control impact values applied on load shedding at PP2-PP4 and generation increasing at PP5-PP6.

Fig. 8 describes the character of power unbalance change during operation of load shedding simultaneously with generation increasing automation. Power deficiency value after disturbance in interconnected power system is decreased close to zero in 2 seconds. Respectively, in short time interval frequency is restored to allowable limits.

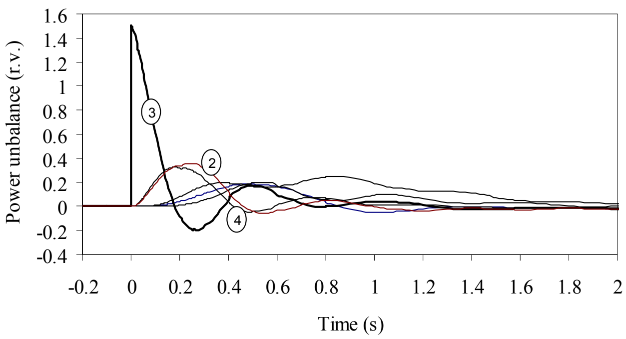

Fig. 8. Power unbalance distribution on power plants during operation of load shedding automation on PP2-PP4 and generation increasing on PP5-PP6.

Fig. 9 shows the character of frequency change in power system during control actions. Frequency after 2 seconds is close to nominal value.

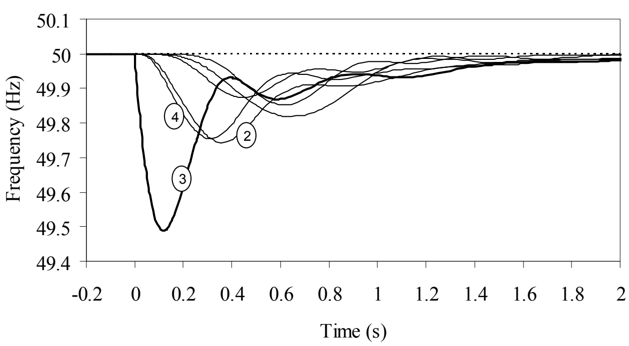

Fig. 9. Frequency change on power plants after operation of load shedding and generation increasing automation.

Simulation results showed that the most efficient operation of automation is in case the control impact on load shedding is provided simultaneously with generation increasing on other power plants. In addition, the presence of rotating active power reserves in power system should be taken into account.

Efficiency of emergency operation preventing power system stability disturbance can be determined with deficiency elimination time in whole interconnected power system.

Comparing the power system operation efficiency using different quantity of controlling equipments (with suggested control principle) the simulation results showed the obvious advantages of applying the maximal number of power plants with emergency automation operating by new principle.

B. *Loss of cross-section lines*

In case of tripping loaded tie line between PP5 and PP6 in electrical ring of Fig. 2 it is clear that out-of-step condition takes place with electrical swing centre in cross-section between PP5 and PP4, since it is hardly loaded at an initial state of power system.

Fig. 10 shows the character of power unbalance distribution on power plants after considered disturbance. Identically to case *A*, due to the increased generation in PP5 by rotor speed governors after some seconds loading of cross-section between PP4 and PP5 increases and the out-of-step condition takes place. From Fig. 10 it can be seen that power plants PP1, PP6 and PP5 with the power plants PP2, PP3 and PP4 are on the opposite sides of electrical swings. This means that power deficiency in one region and power surplus in another occurs. Power unbalance value and sign allows defining the value and sign, as well as the location of necessary impact dose to keep the synchronous operation of interconnected power system.

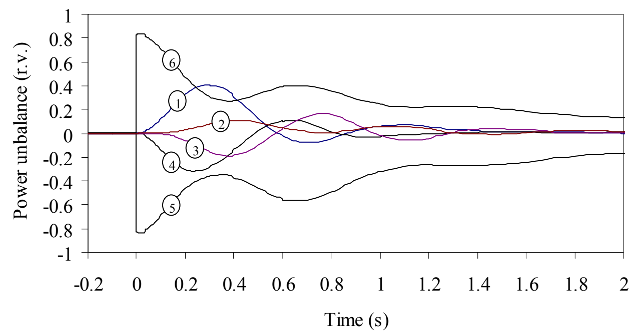

Fig. 10. Power unbalance distribution on power plants after tripping power transmission line between PP5 and PP6.

Impact dose distribution to the power plants as increase or decrease of power output of generating units is showed in Fig. 11.

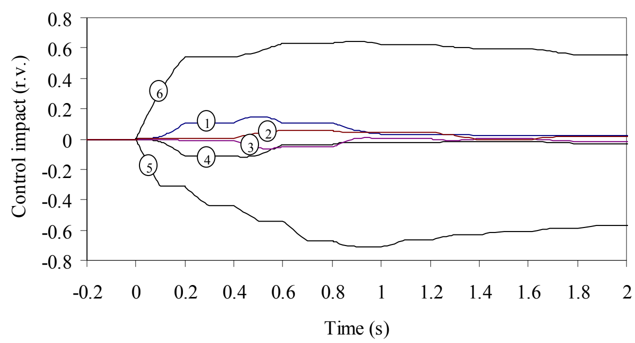

Fig. 11. Calculated control impact values on every power plant.

After imposing the calculated impact dose to all the power plants system stability is maintained and disturbance is eliminated.

V. Conclusion

Simulation results of application of new emergency control principle revealed following conclusions:

– Active power unbalance after some disturbance distributes along the power system in a defined manner. Development and implementation of power unbalance calculation arrangement at power plant would allow determining power unbalance value at every time moment.

- Use of the calculated power unbalance value in emergency automation would allow efficient preventing of power system stability disturbance.
- Suggested control principle considerably improves power system stability and allows adapt operation of automation on conditions of cascade emergencies.
- Effective use of new control principle in power systems can prevent the bulk consumer shedding, as well as avoid of operation of out-of-step automation and consequently system separation.
- Suggested control principle can be applied as a secondary frequency control in power systems, since the operation of such governors restores the frequency to nominal value.

Further researches have to be done in development of common algorithm of new control principle application, i.e., proper impact dose selection depending on types of power plants, presence of spinning reserves, types of disturbances, as well as taking into account the specific of power generating units, excitation system operation and control of transmission line loadings.

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