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Influence of Excitation System’s Parameters to the Power System Stability

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Abstract: Excitation system is one of the significant elements affecting the dynamic performance of electric power systems. The power engineering as area of science and industry is subjected to rapid modernization, which is caused by technological progress. However, not all elements of the power system are developing simultaneously. The old type of elements sometimes is sufficient to adapt old system to the new operational conditions. The work developed and proposed in this paper deals with analysis of possible optimization of synchronous generator’s excitation system. Authors examined influence of excitation system’s parameters to the dynamics of transient processes in the power system. Authors investigated optimal parameters of excitation system of the Kegums hydro power plant. For optimization of parameters objective functions were used. The problem of the mutual influence of excitation systems of neighbor power plants was investigated. Investigation of transient processes using developed model proved that optimization of excitation parameters improves efficiency of regulation of excitation system, damping of active power oscillation and in some cases can prevent out-of-step condition.

Key words: Oscillation damping, stabilizer, optimization.

1. Introduction

The quality as well as reliability of electrical energy transmitted to consumers is one of the main parameters for successful operation of the power system. The problem of power oscillation damping in the power system is solved using PSS (power system stabilizer) as additional voltage regulation loops. The optimal PSS settings searching for constantly modernized power system are an important problem of the world power systems.

A lot of work has been dedicated to this problem [1-6]. Kegums HPP (hydro power plant) is one HPP creating cascade of the three HPP at the Daugava River. Modernization of equipment in the Latvian power system takes place during the last decades. Excitation system of the Kegums HPP is an old fashioned AVR+PSS excitation system with different stabilization parameters. Few other power plants are with modernized excitation systems. Hence, parameters of excitation system of the Kegums HPP are no more optimal. This paper deals with analysis of parameters of excitation system of Kegums HPP. Optimal parameters allow to improve power oscillation damping. Possible adaptive approach for more effective oscillation damping is suggested.

The given work presents the next step of investigation of the excitation system’s optimization and adaptation possibility to new Latvian power system operational conditions.

Investigation results of the previous studies showed that use of combinatorial analysis and objective functions’ methods allows to find optimal settings for Kegums HPP excitation system [7, 8].

However, the previous researches were done using simplified mathematical models, where the influence

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of only one neighbor power station was taken into account.

Major goal of the presented work is proof of possibility to select optimal parameters of Kegums HPP excitation system using mathematical model, which simulates real parameters of Latvian power system.

2. Description of Kegums HPP and Excitation System

The construction of Kegums HPP was finished in 1979. Since that time, three generators of 64 MW capacities are in service. Generator voltage is 13.8 kV. Excitation system is AVR+PSS type developed in the former USSR [9].

Transfer function of excitation system is:

$$U_{reg}(p) = \left(\Delta U(p)\left(K_U + pK_{U'}\right) + \Delta f(p)\left(\frac{pK_{\Delta f}}{Tp+1} + pK_{f'}\right) + \Delta I_f(p)\, pK_{I_f} \right) \times \frac{K}{T_y p + 1} \qquad (1)$$

where $T = 0.5$ s, $T_y = 0.2$ s, $K = 1$.

Fig. 1 presents block diagram of AVR+PSS excitation system.

3. Influence of PSS Parameters to Dynamic of Control Process

Simplified "machine-system" diagram (Kegums HPP and system) is presented in Fig. 2.

Model is equipped with block, simulating short circuit event. It simulates three-phase to ground short circuit. This type of short circuit is selected as the heaviest case to study transient process.

The dynamic of power system transient investigated for three phase to ground for different duration of short circuit simulation.

In this case duration of short circuit is 0.3 seconds. Increasing the duration causes out-of-step condition.

Maximal short circuit duration depends on the load value in the power system [7, 8].

For considered case load is represented by HPP auxiliaries.

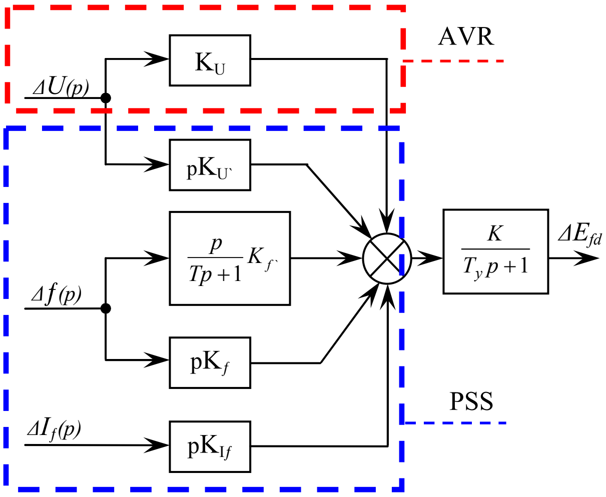

Fig. 1 Block diagram of AVR+PSS excitation.

Increase of the load will increase maximal duration of the short circuit, but it will not influence optimization process of excitation system.

4. Optimization of Excitation System

Results of research conducted by authors showed that existing parameters of excitation system are not optimal from the point of view of the power oscillation damping. The influence of excitation system parameters to power damping was considered.

The following equation as optimization criterion is suggested [3]:

$$\mathrm{A} = \alpha_1 \int_0^t \left| P_{\mathrm{G}}(t) - P_{\mathrm{ref}}(t) \right| dt + \alpha_2 \int_0^t \left| V_{\mathrm{G}}(t) - V_{\mathrm{ref}}(t) \right| dt + \alpha_3 \int_0^t \left| f_{\mathrm{G}}(t) - f_{\mathrm{ref}}(t) \right| dt \qquad (2)$$

where P_G denotes the active power, P_{ref} is its desired value; V_G and V_{ref} are the terminal voltage and its desired value, f_G denotes the frequency, f_{ref} is desired value, α_1, α_2, α_3 denote weighting factor.

The values of quantities used in equation (active power, voltage and frequency) are different. So, deviation of one parameter will always exceed others.

For unbiased estimation of optimization system it is possible to divide multi-objective equation into few simple equations and analyze each taken separately [10].

Comparison of simple equations can develop recommendations for optimization of the system.

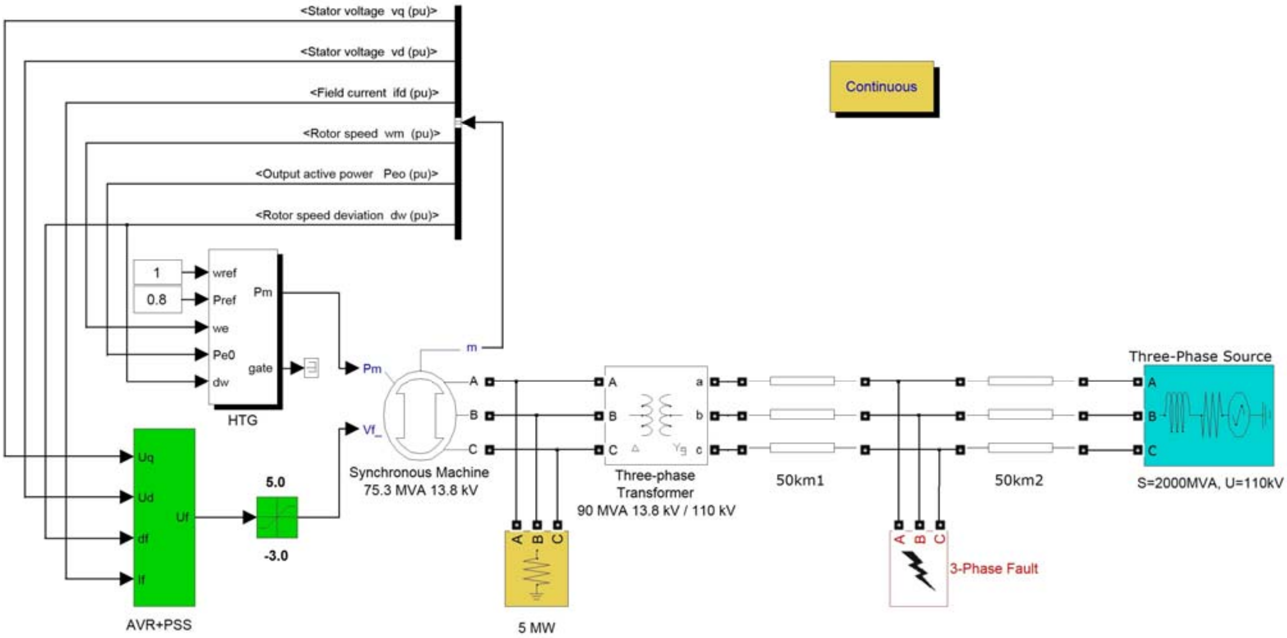

Fig. 2 Simulation model of Kegums HPP [6, 8].

Optimization criteria can be:

$$A_1 = \int_0^t \left| P_G(t) - P_{ref}(t) \right| dt \to \min \tag{3}$$

$$A_2 = \int_0^t \left| V_G(t) - V_{ref}(t) \right| dt \to \min \tag{4}$$

$$A_3 = \int_0^t \left| f_G(t) - f_{ref}(t) \right| dt \to \min \tag{5}$$

From the transfer Eq. (1) it is seen that for different coefficients character of control is different. The real diapason of coefficients is:

$$K_{\Delta U} = 15, 25, 50\ (p.u.);$$

$$K_{U'} = from\ 6\ to\ 8.5\ (p.u.);$$

$$K_{\Delta f} = from\ 11\ to\ 14.4\ (p.u.);$$

$$K_{\Delta f'} = from\ 4\ to\ 5.5\ (p.u.);$$

$$K_{I'_f} = from\ 2\ to\ 3\ (p.u.)$$

Table 1 illustrates combination of coefficients used for the study of optimization the excitation system. Figs. 3 and 4 illustrate optimization results for excitation system when optimization criteria are A_2 and A_3. When criteria A_1 and A_3 are selected the most optimal variant is for parameters of variant 6 and criterion A_2 gives best result with parameters of variant 10. There is need in selection priority of variant for coefficients P, f and U or to select compromise version.

Table 1 Variants of coefficients used for the study of optimization the excitation system of Kegums HPP.

Nr	ΔU	$\Delta U'$	Δf	$\Delta f'$	$\Delta I'f$
1	15	6	11	4	2
2	25	8.5	11	4	2
3	15	8.5	14.4	4	2
4	50	6	11	5.5	2
5	25	6	14.4	5.5	2
6	15	6	11	4	3
7	50	8.5	11	4	3
8	15	8.5	14.4	4	3
9	25	8.5	14.4	4	3
10	15	8.5	11	5.5	3
11	50	6	14.4	5.5	3
12	50	8.5	14.4	5.5	3

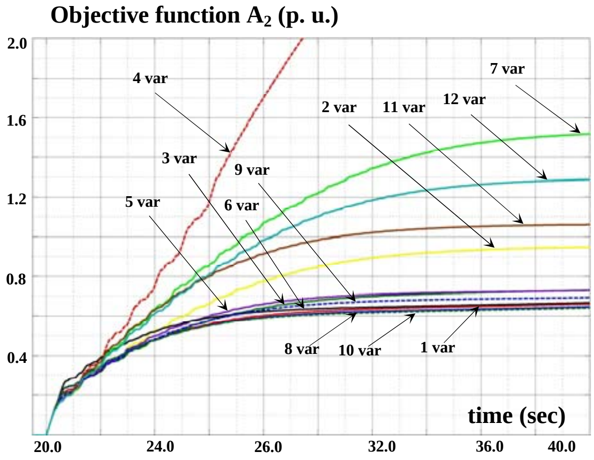

Fig. 3 Variations of objective function A_2 for different variants of coefficients during short circuit.

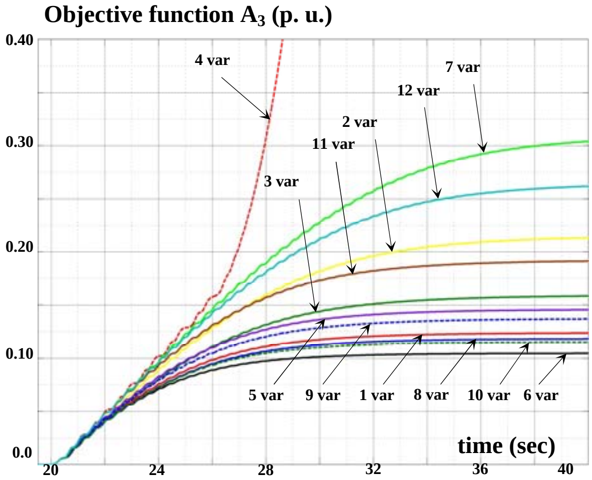

Fig. 4 Variations of objective function A_3 for different variants of coefficients during short circuit.

Figs. 5 and 6 illustrate results of parameters' optimization. Transient processes for voltage and frequency variations are shown for different optimization parameters.

Application the coefficients of variant 4 will cause out-of-step condition. The best damping case is observed for application of variant 6.

5. Adaptive Approach for Control of Excitation System

The next step of research was verification of optimal parameters' selection when influence of a neighbor power plant is investigated. The design diagram of the Latvian power supply system represents the mathematical model which is constructed with PSS/E software.

The excitation system presented in Fig. 1, was integrated into simulation model of the Latvian power system.

Fig. 7 represents investigated network of the Latvian power system. For practical analysis of dynamic behavior during disturbances in the power system each plant is represented by an equivalent generator.

Optimization criteria search was determinated at three-phase to ground short circuit, with duration 0.3 seconds.

The fault location was chosen the same distance to Kegums HPP as represented in Fig. 2. Short circuit's location is at 110 kV substation (Ķekava).

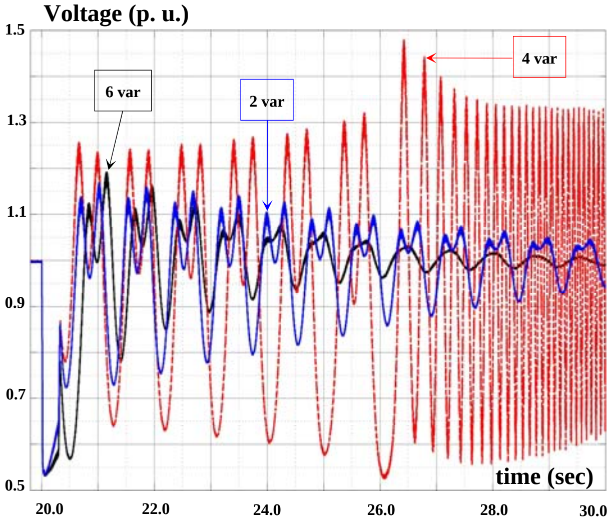

Fig. 5 Variation of Kegums HPP generator's voltage depending on combination of control coefficients.

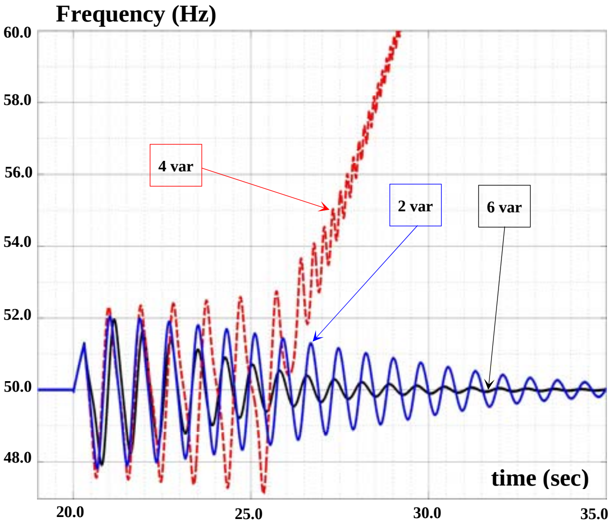

Fig. 6 Variation of Kegums HPP generator's frequency depending on combination of control coefficients.

Variations of objective function A_2 for different variants of coefficients are illustrated in Fig. 8.

Fig. 8 shows that parameters of variant 3 are the most optimal. Two worst parameters of transient process are for variants 6 and 11.

Results of voltage investigation on the bus of the Kegums HPP's synchronous generator at transient process moment (Fig. 9), show that at parameters of variant 6 there is a significant voltage drop.

As it can be observed from Fig. 9a visible overshoot occurs for parameters of variant 11 at the moment of voltage recovery.

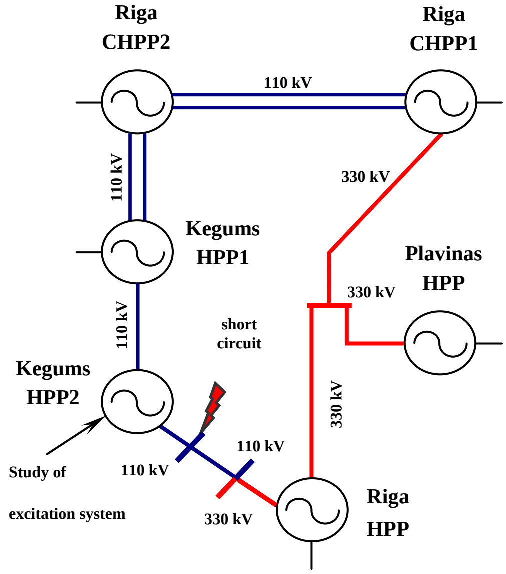

Fig. 7 Simplified diagram of interconnected power plants.

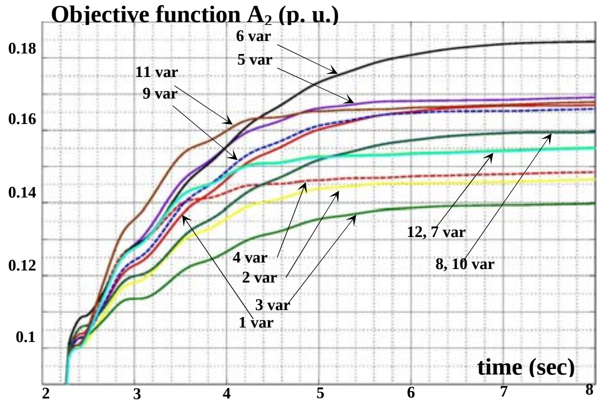

Fig. 8 Variations of objective function A_2 for different variants of coefficients during short circuit.

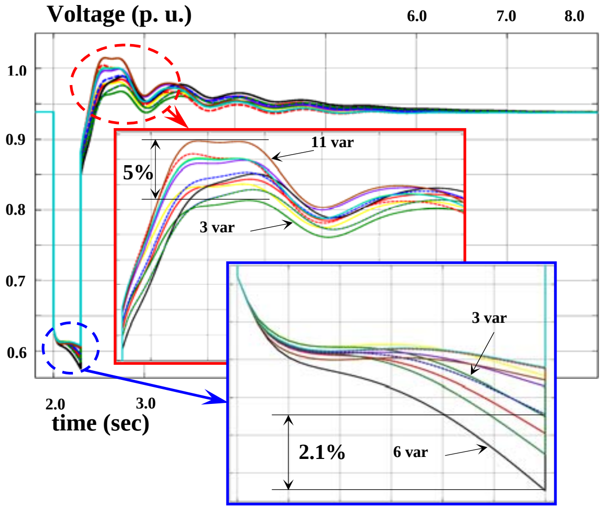

Fig. 9 Variation of Kegums HPP generator's voltage depending on combination of control coefficients.

In turn, comparing voltage raise at parameters of variants 3 and 11, it is possible to reduce overshoot by 5%.

Using objective function A_1 (Fig. 10) parameters of variant 10 are most optimal, but the worst is variant 11. Active power's characteristics for different variants of coefficients are illustrated in Fig. 11.

Comparing variant 10 with variant 11 is visible that deviations from nominal value can be reduced by 14.7% (the top value) and 27.0% (the bottom value).

Last objective function is shown in Fig. 12. Like the criterion A_2, parameters of variant 10 are most optimal, but the worst is variant 11.

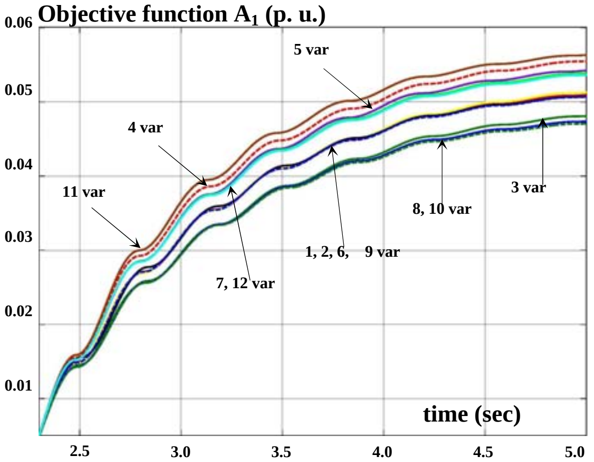

Fig. 10 Variations of objective function A_1 for different variants of coefficients during short circuit.

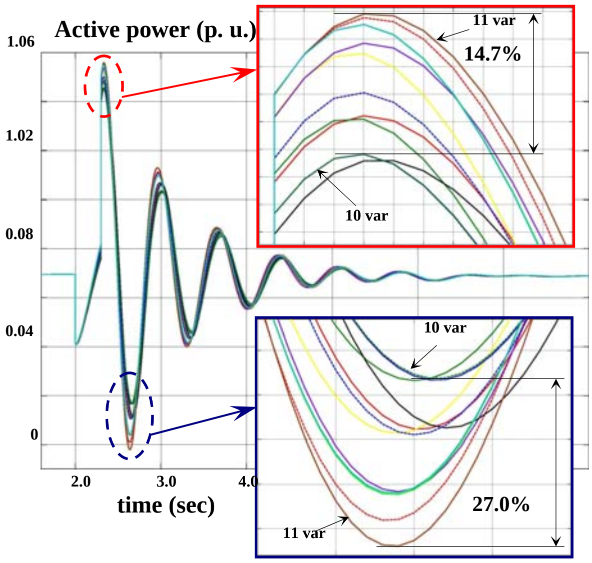

Fig. 11 Variation of Kegums HPP generator's active power depending on combination of control coefficients.

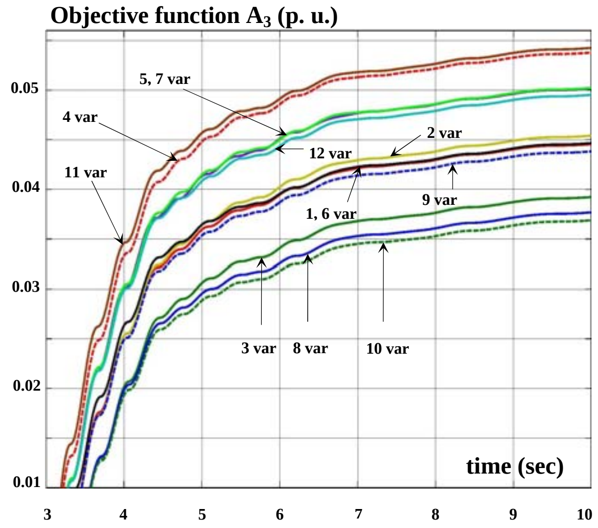

Fig. 12 Variations of objective function A_3 for different variants of coefficients during short circuit.

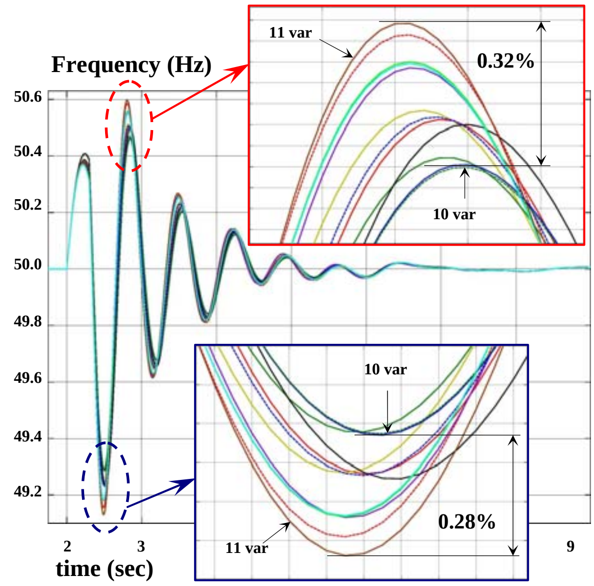

Fig. 13 Variation of Kegums HPP generator's frequency depending on combination of control coefficients.

Frequency's characteristics for different variants of coefficients are illustrated in Fig. 13.

Using variant 10 in comparison with variant 11, allows to reduce frequency's deviation from nominal value (raises damping).

6. Conclusions

In this paper the influence of excitation system's parameters on the power system stability is observed. The main investigations of the paper are:

(1) Influence of PSS parameters on control process dynamic was investigated;

(2) Optimal parameters for Kegums HPP were selected using objective functions;

The investigations done using simplified scheme Fig. 2 shows that criteria (3), (4), (5) are possible to improve synchronous generator's output parameters' damping and in some cases can prevent out-of-step condition in Figs. 4 and 6.

(3) Influence of neighbor operating power plants' parameters was considered from the point of view of stability of excitation control.

Influence of neighbor power plant's parameters is significant. The results of investigations which are done using simulation model of the Latvian power supply system, show that optimization of Kegums HPP's excitation system's parameters can increase stability and efficiency. Possibility of damping increasing of synchronous generator's output parameters is illustrated in the paper. For example, active power's amplitude is reducing by 14.7% and by 27.0% in the first period (Fig. 11).

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