Journal of Energy and Power Engineering 8 (2014) 724-728

The Application of the Combined Method for Selection of Optimal Excitation Parameters

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Received: November 06, 2013 / Accepted: January 02, 2014 / Published: April 30, 2014.

Abstract: The quality as well as reliability of electrical energy transmitted to consumers is one of the main parameters of successful operation of the power system. The searching of optimal coefficient's combination of PSS (power system stabilizer) is the main goal of this article. The possibility of application of the new combined approach for the optimal excitation's settings search is presented. MC (Monte Carlo) method, in order to search and select the optimal combination of excitation system, was applied. The proposed method has been researched with a mathematical model of the power system. This model has been built using Matlab/Simulink software. Paper shows advantages and disadvantages of the proposed methods.

Key words: Power systems stabilizer, excitation parameters, Monte Carlo method.

1. Introduction

In the last few years, factor of human dependence on electricity has grown. For this reason and also because of ever-tightening legal requirements for electrical power utilities which are given by the opening of the electricity market, safe and reliable power system operation requires increased attention. Insufficient immunity against system failures and other transient disturbances, and also the occurrence of bottlenecks in the system, can cause failures in power supply, or cascading failures which may lead to black-out [1, 2].

Therefore, for the power system operator, it is important to ensure that power system will be operated safely and reliably, even during and after faults.

Since time when power system stability issues were discovered, a great effort was dedicated to research of power system behavior during and after faults, and to possibilities of oscillation damping in power system. Some design and operation arrangements were invented, to improve oscillation damping, and also some devices were introduced, like PSS (power system stabilizer). Usage of this device, which is a supplement to synchronous generator excitation system, together with optimal settings, can have very positive influence to power system stability after severe faults in power system.

The aim of this paper is to propose methods, which can be used to obtain optimal PSS settings, and to show their use to optimize settings of excitation system of specific generator, and to verify, if these settings are optimal, using computer model of generator [3, 4].

2. Power System Model

In Latvian power system, most part of the electric power comes, especially during the spring, from HPP (hydro power plants). Kegums HPP is one of the HPP on Daugava river, which creates cascade of totally three HPP, and was put into operation in 1979. Three generators with 64 MW capacity, and 13.8 kV generator

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voltage are in service. Fig. 1 shows the simplified diagram of connected Kegums HPP to power system. Most of equipment in Latvian power system undergoes some modernization, but not every device has been modernized yet. In Kegums HPP, one of generators still uses old fashioned Automatic voltage regulator plus power system stabilizer (AVR + PSS) excitation system, developed in former USSR, with different input variables. Some power plants have now modernized excitation systems. Therefore, excitation system parameters at Kegums HPP are no longer optimal [5].

Transfer function of excitation system can be written for block diagram presented at Fig. 2 as follows:

$$U_{REG}(p) = \big(\Delta U(p)(K_U + pK_{U'}) + \Delta f(p)\Big(\frac{pK_{\Delta f}}{Tp+1} + pK_{f'}\Big) + \Delta I_f(p)pK_{I_f}\big).\frac{K}{T_y p+1} \quad (1)$$

where, U_{REG}—excitation voltage, ΔU—generator out voltage deviance from the nominal value, K_U and $K_{U'}$—excitation coefficients of the generator deviance and derivative out voltage, Δf—frequency deviance from the nominal value, $K_{\Delta f}$ and K_f—excitation coefficients of the frequency deviance and derivative respectively, ΔI_f—rotor current deviance from the nominal value, K_{If}—excitation coefficient of the rotor current deviance. Constants: $K = 1$, $T_y = 0.2$ s, $T = 0.5$ s.

In computer model, generator is equipped with standard governor, and is connected to infinite bus through three-phase transformer and transmission line. Simulation model was created in Matlab/Simulink environment [6].

Model is equipped with block, which is used to simulate different types of short circuit, in this case, three-phase to ground short circuit was used, with duration of 0.3 s, in the middle of transmission line. Longer duration time causes out-of-step condition. As it is stated in Ref. [7], maximal short circuit duration in this system mostly depends on the load value in power system.

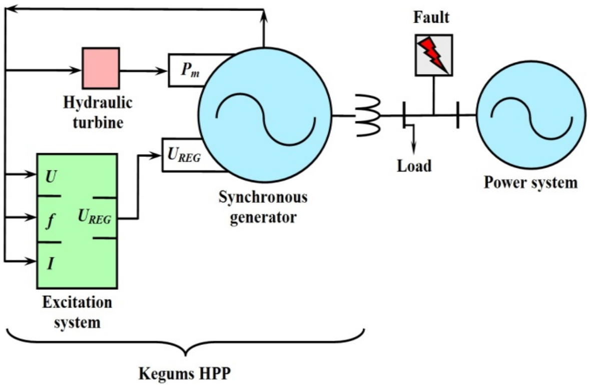

Fig. 1 Simplified diagram of Kegums HPP.

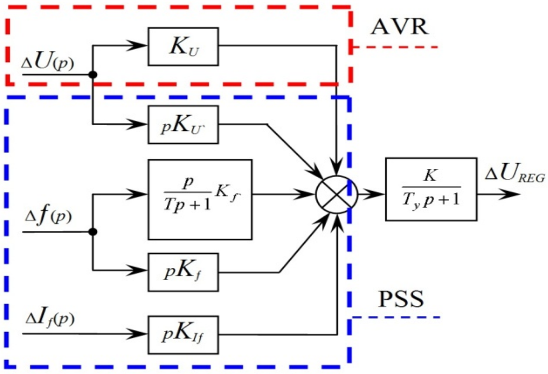

Fig. 2 Excitation system block diagram.

3. Optimization Methods

As mentioned before, previous research performed by Chuvychin et al. [8] proved that excitation system parameters for Kegums HPP are not optimal from view of the power oscillation damping.

In Ref. [9], use of objective function as optimization criterion was proposed. The basic tools of objective function in Ref. [9] are random changes in properties of individuals, which are objects of optimization, and to prefer more successful individuals at the expense of the less successful ones, with high computational effort [9].

Using this method, as optimization criterion, a following objective function can be suggested:

$$A = \alpha_1 \int_0^t \left| P_G(t) - P_{ref}(t) \right| dt + \alpha_2 \int_0^t \left| V_G(t) - V_{ref}(t) \right| dt + \alpha_3 \int_0^t \left| f_G(t) - f_{ref}(t) \right| dt \quad (2)$$

where, P denotes active power, V denotes voltage, f denotes frequency, P_{ref}, V_{ref}, f_{ref} denotes desired values, and P_g, V_g, f_g denotes actual values, α_1, α_2, α_3 are weight factors emphasizing the effect of active power and frequency oscillation damping to the terminal voltage control optimization.

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

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

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

For unconstrained optimization, multi-objective equation can be divided to simpler equations. After this division, every equation can be analyzed separately [10]. It can be convenient, because usually it is a problem to find right values of weight factors α. Using these simpler equations, it is possible to develop some recommendations for system optimization easier. So, in this case, instead of one criteria, three criteria will be obtained, one from the view of real power by Eq. (3), one from view of voltage by Eq. (4) and one from view of frequency by Eq. (5).

As other optimization method, MC (Monte Carlo) method can be used, which received name from Monte Carlo casinos. This name has its origin in specific nature of this method, which consists in use of random numbers in scientific computing. In other words, it does mean to use random numbers to compute something, what is not random. Let's suppose that X be a random variable, and write its expected value as $A = E(X)$. If a n—independent random variables with same distribution, X_1, X_n can be generated, then approximation can be made as follows:

$$A \approx \hat{A}_n = \frac{1}{n} \sum_{k=1}^{n} X_k \quad (6)$$

The strong law of large numbers states that $A_n \rightarrow A$ as $n \rightarrow \infty$. The X_k and A_n are random and could be different each time the program will be ran. Still, the target number A is not random.

It is necessary to distinguish between simulations, using which a set of random numbers with specific distribution is produced, with just simple purpose of just to look at them, and usage of MC method, by which quantitative questions about obtained random variables are to be answered [11].

Other explanation of MC method can be obtained using Buffon's needle experiment. This experiment was based on dropping needle randomly on the table with equally spaced lines with distance δ between them. Using this experiment, Buffon was able to estimate value of Π. MC method became more popular with introduction of digital computers, for example the first scientists, which have successfully used this method together with digital computer were scientists from project Manhattan [12].

4. Optimization of Excitation System

In this part, utilization of combined method will be shown. From Eq. (1) can be observed, that for different coefficients, character of the control is different. For start, twelve different combinations of coefficients (gains) were obtained, with dissipation as follows:

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

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

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

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

$K_{I'f}$ = 2; 3 (p. u.).

These combinations were produced randomly, and they are shown in Table 1. Using MC method, by randomly creating 20 combinations of coefficients (excitation system gains), using principle of "Buffon's needle", from previously shown dissipation, and then, by picking from these 20 combinations of gain values, which in these 20 "droppings" appeared most frequently, a final combination was produced. This final coefficient combination is denoted in last row of Table 1.

As a final step, for every coefficient combination, a simulation was performed, with observation of every one of three optimization criteria.

In Figs. 3-5, the integral curves of objective functions A_2, A_1, and A_3 are displayed, respectively, for

Table 1 Coefficient variants used in process of Kegums HPP excitation system optimization.

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
MC	15	6	14.4	5.5	2

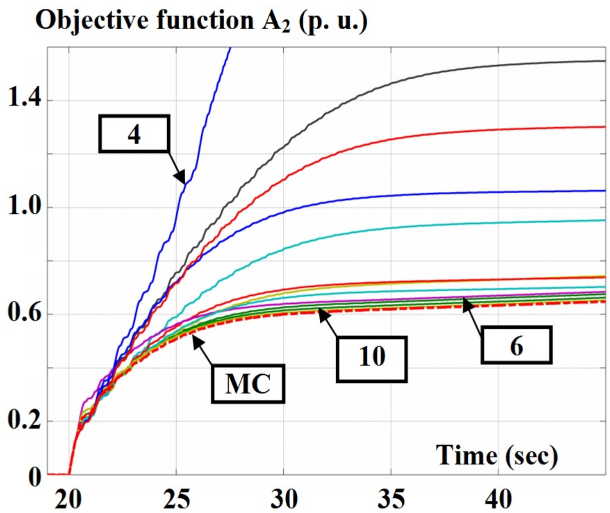

Fig. 3 Variations of objective function A_2 for different coefficient combinations of coefficients during short circuit.

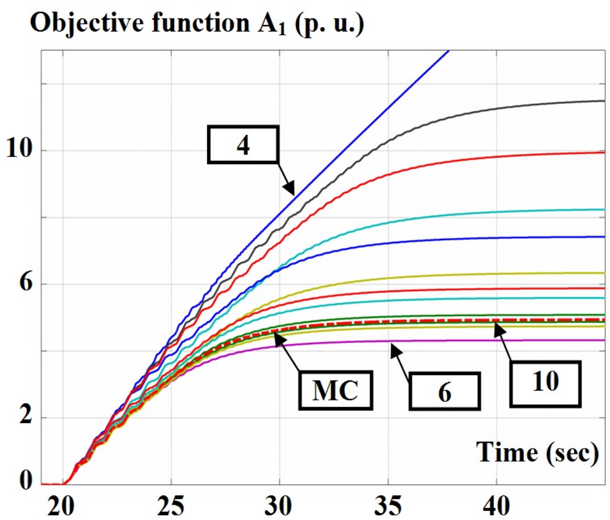

Fig. 4 Variations of objective function $A1$ for different coefficient combinations of coefficients during short circuit.

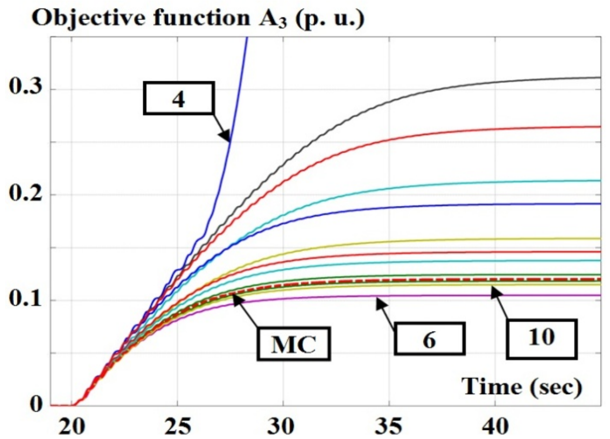

Fig. 5 Variations of objective function $A3$ for different coefficient combinations of coefficients during short circuit.

each coefficient combination, where dashed line is for MC combination. From Eqs. (3)-(5), it can be seen that most optimal damping case for particular variable will be obtained using coefficient combination, for which the curve is most parallel and closest to X axis. Therefore, for voltage is most optimal MC combination, next one is variant 10, and then nr. 6. For the real power, most optimal is combination 6, MC is the third after variant 10, and for the frequency, situation is almost the same as for real power. In all cases, variant 4 was considered as improper, because usage of this coefficient combination will cause out-of-step condition. From this also can be seen, that improper selection of coefficient combination can cause deterioration of stability.

In Fig. 6, generator's frequency variations are displayed, for different coefficient variants. Worst case is, of course, for variant 4, best case is observed for variant 6, which is just slightly better than MC variant (dashed curve). Almost the same conditions can be observed for other variables, i.e., voltage and real power.

From this investigation, it can be seen that MC variant can be used as compromise variant between variants 6 and 10, because it provide satisfactory damping of oscillations from view of all variables. According to this, a conclusion can be made, that using that use of MC method provided optimal combination of excitation system coefficients.

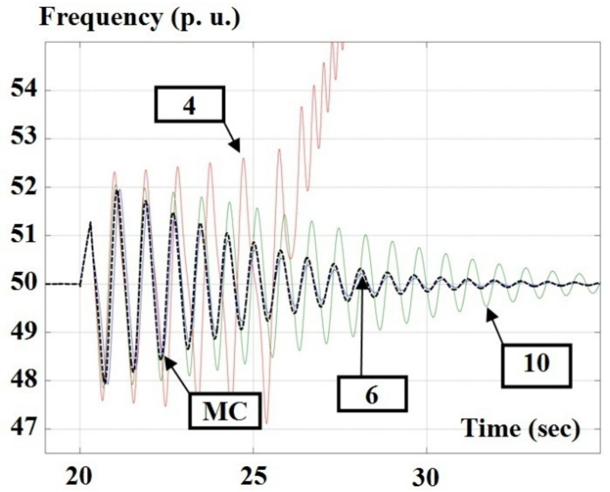

Fig. 6 Variations of generator real power depending on combination of control coefficient's.

5. Conclusions

In this paper, an influence of PSS parameters to power system transient behavior was investigated. Optimal PSS parameters for Kegums HPP were found, using MC method and multi-objective function. Simulation results shown, that using MC method, optimal excitation settings can be easily obtained, which was proved by verification of fulfilling optimization criteria (Figs. 3-5).

The presented research can continue by investigation of influence of coefficients selected using MC method in interaction with neighboring generators in power system.

Acknowledgments

Presented paper is combined work with Riga Technical University and Technical University of Košice.

This work was supported by Slovak Research and Development Agency under the contact No. APVV-0385-07 and VEGA 1/0166/10 and VEGA 1/0388/13 projects.

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