Electric Power Systems Research 144 (2017) 175–184

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Techniques of control, analysis and visualization of automatic exciter controller functioning in synchronous machine

J.L. Artsyshevsky, T.G. Klimova*, B.K. Maximov, O.O. Nikolaeva

National Research University "MPEI", Russian Federation

ARTICLE INFO

Article history:
Received 29 May 2016
Received in revised form
26 November 2016
Accepted 6 December 2016

Keywords:
Electrical power systems
Quality of the transition processes
Automatic exciter controller
Optimal settings
Visualization of parameters information

ABSTRACT

In operation, expansion, complication and modernization of electrical power systems one of the important task is stability provisioning. Automatic exciter controller (AEC) functioning in synchronous machine (SM), is one of the devices, allowing to perform this task. The article defines and illustrates the variety of tasks that is necessary to solve by the development of AEC algorithms, analysis of functioning and setting their parameters. New techniques, designed for solution of these tasks are presented. These techniques allow when setting the regulators:

1. Take into account the working conditions of SM.
2. Determine the region of stability for given sets of AEC channel coefficients.
3. Determine the optimal AEC parameters settings, providing the best damping of transient processes under various disturbances.
4. Visually present regulation setting results. Solutions of all the tasks are demonstrated by the example of the analysis of the functioning and the setting up DECS-400 controller operating in a test scheme, assembled with real-time simulator RTDS.

1. Introduction

Operational stability is one of the main requirements what is necessary to provide during technical maintenance, enlargement, complication and modernization of electrical power systems (EPS). It is important to provide acceptable characteristics of transition processes (TP) of the synchronous machine (SM) regime parameters that is required quality of control under various disturbances. Automatic exciter controller (AEC) of the SM is one of the possible devices for solution of this task. In order to obtain, it's necessary to calculate optimal values of the parameters of AECs for all variations of circuits and conditions and select the final settings, ensuring the best quality of the TP in all situations under small perturbations of the system at any point [1,2].

The subject of article is the techniques, developed at department of "Relay protection and automation of power supply systems" of National Research University "Moscow Power Engineering Institute"(NRU MPEI) for research and settings the AEC SM of various types according to requirements of the Russian Federation Standard [1]. In addition, the techniques of information visualization and examples of their use at the choice of the AEC parameter settings for SM of concrete power plant are given. For the solution of a problem of optimization of the AEC parameters, the following techniques, based on well-known principles of the automatic control theory [3] are developed and checked:

1. Experimental determination of frequency characteristics of the SM, working in various schemes [4]. The technique, based on spectral method investigation of dynamic systems, is applicable to real and model networks.
2. The definitions of the regions of stability for the specified set of channels parameters AEC [5]. The technique is developed with usage the frequency Nyquist criterion for experimental frequency responses and could be used for any types AEC with different stabilization channels.
3. Quality of functioning AEC devices estimates are given. In this technique, the various ways of TP parameter quantification are considered [6]: duration (the time, during that the dominant component of TP will decrease by 95%), the logarithmic damping decrement and overshoot (the maximum deviation oscillatory component from steady-state value). The estimation of functioning quality AEC is possible by: (a) integration of TP curves

* Corresponding author.
E-mail address: KlimovaTG@mpei.ru (T.G. Klimova).

http://dx.doi.org/10.1016/j.epsr.2016.12.007
0378-7796/

(in time domain, integral criterion estimation of control quality [3]); (b) determination TP parameters (in time domain, root criterion estimation of control quality [3]); (c) spectral analysis of TP (the frequency criterion estimation of control quality [3]).
4. Determination of the optimal settings AEC, providing the best damping of TP for given regime parameters during test and standard emergency perturbations [5]. This technique is consequence of p.3, because we determine the settings of AEC parameters for required quality of regulation process.
5. A quantitative assessment of the impact the structure and parameters of AEC on the parameters of TP in EPS [7]. In p.3 and 4 we give quantitate results. They allow to determine influence of structure and parameters AEC on TP parameters.
6. Visualization of different AEC operation characteristics for clear graphical representation of the regulation quality [5]. The technique shows different ways of graphical representation the quantitate parameters of regulation quality and allow to compare the results of AEC settings.

Presented in this article techniques aimed at provisioning the maximal damping of TP in all frequency range and allow to investigate AEC functioning with comprehensive visualization.

The developed techniques for selection AEC parameters allow to determine stability regions and optimal parameter settings for particular EPS in accordance with requirements of Standard [1] and estimate AEC operation under different parameters of automatic voltage regulator (AVR) and stabilization channels.

Illustration of these techniques is carried out at control and research of the ST4B + PSS2B regulator (firm Basler, GE, etc.) [8–12], working in the Feedback Power Control System (FPCS). In this, network ST4B is AVR and PSS2B is system stabilizer, where input parameters are rotor rotation speed and electrical power of generator.

Settings of the AVR done by selecting parameters under the condition fulfilling requirements given in [12], providing a maximum rate of change of regime parameters at an acceptable quality of TP.

Under the traditional setup of channels of stabilization, it is necessary to provide zero value of a phase of complex transformation of a deviation of a setting ΔUref at the electric moment of a shaft of the synchronous generator at a frequency of the dominating oscillations in the considered range of frequencies [12]. However, in Ref. [13] it is shown that the AEC setup for damping of one frequency can lead to essential deterioration in damping of frequencies in other range, for example, at the PSS setup for damping of $f = 0.8$ Hz (widespread resonant frequency in a network) there can be a strengthening of frequency of $f \approx 0.4$ Hz (possible frequency of interzonal oscillations).

For determination optimal AEC settings the objective function formed providing choice of AEC channel parameters (Figs. 2 and 3) with minimal oscillations of frequency and amplitude of *the voltage on the generator buses* for various disturbances. The type of objective function depends upon applied criteria of quality estimation for regulation process, but we will have the same result using any criterion (root, integral or frequency) for solution the same task for provisioning required quality of regulation.

Root criterion of quality estimation for regulation process required limitation for placement the roots of characteristic equation end zeros of transfer function on the complex plane. The migration of the roots and zeros traced by the changes of AEC parameters in the specified range.

The estimation of position characteristic equation roots on the complex plane can be obtained by usage of experimental frequency characteristics.

By usage of integral criterion quality estimation for regulation process it is necessary to minimize the integral of square of time domain realization TP in the range of changing parameters of AEC.

Frequency criterion of quality estimation for regulation process is the most convenient with usage experimental frequency characteristics. For forming objective function for optimization it is advisable in this case to use parameters of complex frequency characteristics of feedback control system [3,17].

Objective function for any type of criteria has the numerical value. Next, we will use the symbols P_f and P_u, numerically characterize the quality of the damping of the oscillations frequency and amplitude of the voltage on the generator buses. Minimum values of these characteristics correspond to the minimal objective function, that is optimal setting of AEC with specified range of its parameters.

In this article the main way of checking the results of analysis functioning of AEC and their settings is research of work (real and mathematical model) in digital model of the power supply system realized with usage of the hardware and software system RTDS (Real-Time Digital Simulator). RTDS has allowed to do necessary researches in real time with physical connection of AEC in the conditions close to real.

2. Configuration object description

AVR (type ST4B) has three channels: proportion, integral and differential. In Ref. [11] it is noted that in static system of excitement the differential channel AVR is not used. This situation is shown in Fig. 1.

The voltage regulator provides the realization of a prescribed value of the output voltage amplitude. Thus FPCS is realized with output parameter deviation from the prescribed value. The coefficients of proportional and integrated channels in equivalent mathematical model (Fig. 1) consider coefficients of all links through which the operating signal passes. The last link has time constant Ta and describes generator exciter.

Standard stabilizer PSS2A (B) uses two input signals: frequency of rotor rotation (input A) and the power (input B). The signal of rotor speed is transformed to the signal proportional to changing of speed of shaft rotation. The high-pass filter of the input signal eliminates the signal of the average level of speed and forms a signal of oscillation of speed. Thus the stabilizer reacts only to change of speed.

Similarly, a signal is generated proportional to the change in the output electric power generator (input B). As a result, the signal of integrated mechanical power (p. G) is created. When setting PSS, the parameters of phase compensation units (time constants T1 $\div$ T4, T10, T11), providing the best damping TP [9,11] are calculated. The values of these parameters depend on the network circuit where this generator runs, coefficient Ks1 determines the depth of the phase compensation.

For analytical study of such systems is necessary to know an exact description of all parts of FPCS (AEC and SM, running on a distributed network). AEC is described above, and to describe the synchronous machine running on a distributed network, we use the experimentally obtained by the method [4] frequency characteristics of the SM operating in test scheme of EPS, modelled with RTDS. Further we will use abbreviation AFR for Amplitude Frequency Response, PFR for Phase Frequency Response and APR for Amplitude-Phase Response. Fig. 3 presents AFR of the conversion excitation voltage UF on channels of regime parameters used for work of AEC to: voltage amplitude on the buses of generator Wu, generated active power Wpe and to frequency of rotor speed. All this figures calculated for test circuit.

The task is to define the optimum settings for the AEC channels giving the best quality of transition process in chosen circuits and regimes with AFR presented in Fig. 3. Under the best quality of TP we understand the minimum duration, minimum overshoot and