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PID controller for automatic voltage regulator using teaching–learning based optimization technique

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ABSTRACT

The present work presents teaching–learning based optimization (TLBO) algorithm as an optimization technique in the area of tuning of the classical controller installed in automatic voltage regulator (AVR). The proposed TLBO algorithm is applied with an aim to find out the optimum value of proportional integral derivative (PID) controller gains with first order low pass filter installed in the AVR. The voltage response of the AVR system, as obtained by using the proposed TLBO based PID controller with first order low pass filter, is compared to those offered by the other algorithms reported in the recent state-of-the-art literatures. The advantage of using this control strategy may be noted by providing good dynamic responses over a wide range of system parametric variations. For on-line, off-nominal operating conditions, fast acting Sugeno fuzzy logic technique is applied to obtain the on-line dynamic responses of the studied model. Furthermore, robustness analysis is also carried out to check the performance of the designed TLBO based PID controller. An analysis, based on voltage response profile, has been investigated with the variations of the model parameters. The simulation results show that the proposed TLBO based PID controller is a significant optimization tool in the subject area of the AVR system. The essence of the present work signifies that the proposed TLBO technique maybe, successfully, applied for the AVR of power system.

Introduction

An automatic voltage regulator (AVR) is a device that is designed to automatically control, adjust or maintain a constant voltage level of a synchronous generator. The main function of the AVR is to maintain the voltage of an alternator at a definite level. Thus, the security of the power system would be seriously affected by the stability of the AVR system.

General

In power system, one of the main control problem is to provide constancy and stability of the nominal voltage level in an electrical power network having all connected equipments, designed for a certain voltage level (called as rated or nameplate voltage). There may be decrease in the performance of these equipments and drop in their expectancy, if the nominal voltage level deviates from the rated one. Another vital reason for this control is that the real line loss depends on the real and reactive power flow. In fact, variation in terminal voltage changes the reactive power flow with a big margin. The AVR, which is used to maintain the terminal voltage of a synchronous generator at a specified level, is implemented in power system to overcome these control problems. It also controls the reactive power flow and ensures proper sharing of the reactive power amongst all the generators connected in parallel. With the variation of the exciter voltage of the alternator, the AVR maintains the consistency of the terminal voltage [1]. Stable and fast response of the regulator is difficult to achieve due to the high inductance of the alternator field windings and load variation. Hence, improvement of the AVR performance is very important. Insulation breakdown may occur in different parts of the power system due to high voltage which may damage the equipment. Thus, proper controlling mechanism is required for the AVR system to perform properly.

Literature survey

In the AVR system, so far, a number of different control strategies such as adaptive control, robust control and optimal control have been proposed by the researchers to analyze the system with an aim to gain better dynamic response. Self-tuning adaptive control technique is simple to apply than the other modern control

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Nomenclature

E_{SS}	steady state error, p.u.
K_A	gain constant of the amplifier
K_D	derivative gain of the controller
K_E	gain constant of the exciter
K_G	gain constant of the generator
K_I	integral gain of the controller
K_P	proportional gain of the controller
K_S	gain constant of the sensor
M_P	maximum overshoot, p.u.
N	filter co-efficient of the PID controller's filter
t	sample time, s
T	time constant of the PID controller's filter, s
T_R	rise time, s
T_S	settling time, s
β	parameter constant of figure of demerit
Δe	incremental change in error in terminal voltage, p.u.
Δe_i	incremental change in error in terminal voltage at time i, p.u.
Δe_{i-1}	incremental change in error in terminal voltage at time $(i-1)$, p.u.
$\Delta \dot{e}$	derivative of incremental change in error in terminal voltage, p.u.
$\Delta V_{ref}(s)$	incremental change in reference voltage, p.u.
$\Delta V_s(s)$	feedback voltage, p.u.
$\Delta V_t(s)$	incremental change in terminal voltage, p.u.
τ_A	time constant of amplifier, s
τ_E	time constant of exciter, s
τ_G	time constant of generator, s
τ_S	time constant of sensor, s

techniques and, with change in process parameters, it also makes the process less sensitive on being under control. This type of control mechanism is implemented in the AVR system. The presence of more mathematical computation may make the conventional self-tuning control techniques inadequate in some operating conditions because of intricacy of the power system such as variable operating points and non-linear load characteristics. Since 2000, the researchers prefer the usage of optimization techniques and artificial intelligence based self-tuning control strategy.

Proportional integral derivative (PID) controller is the most preferable controller amongst all the proposed ones. Robust performance over a wide-range of operating conditions and simplicity of structure design makes the PID controller different from other types of controllers [2]. PID controller is designed with three control parameters *i.e.* proportional, integral and derivative gains. For improving the voltage response of the AVR system, different types of heuristic optimization algorithms have been evolved. These methods have become popular across the world and acceptable to the researchers' pool. PID controller gains are being tuned by many soft computing techniques for the AVR system. In 2004, Gaing [3] proposed a particle swarm optimization (PSO) technique based self-tuning PID controller for the AVR system and presented a comparison between PSO based method and genetic algorithm (GA) based method. In order to improve the performance of the self-tuning PID controller for the AVR system, Kim and Cho [4] have developed a hybrid method containing GA and bacterial foraging optimization technique. Mukherjee and Ghoshal have presented Sugeno fuzzy logic (SFL) based self-tuning algorithm for PID controller employing crazy PSO (CRPSO) [5]. In 2008, Kashki et al., based on reinforcement learning automata (RLA), have proposed continuous action RLA optimization method in order to optimize the parameters of the PID controller for the AVR system of synchronous generator and further they have also compared their results with PSO and GA based controller [6]. In the year of 2009, Zhu et al. proposed a chaotic ant swarm algorithm to optimize the gains of the PID controller for the AVR system [7]. In the same year, Coelho proposed chaotic optimization approach, based on lozi map, for the tuning of the PID controller gains of the AVR system [8]. Later on, Chatterjee et al. [9] have carried out a comparison between the optimization response of CRPSO based optimization technique and velocity relaxed PSO based optimization technique for the AVR system. Gozde and Taplamacioglu [10] have suggested artificial bee colony (ABC) algorithm to obtain optimum control for the AVR system and have carried out a comparison between their obtained results with the PSO and differential evolution algorithm (DEA) based results for the AVR system. Panda et al. have proposed a simplified version of PSO, called many optimizing liaisons (MOL), to have optimum PID controller gains for the AVR system and further a comparative analysis of their obtained results with the ABC, PSO and DEA based results has been reported in [11]. Mohanty et al. have used local unimodal sampling (LUS) optimization algorithm to tune the gains of the PID controller for the AVR system [12]. ABC-based obtained results were also compared to PSO and DEA based results in [12].

Motivation for the present work

Literature survey reveals that most of the previous researchers have used evolutionary optimization algorithms to tune the parameters of the PID controller for controlling the AVR system. The simulation results of the existing research works have some deficiencies of their own which may be overcome for having the most appropriate and desirable response. The responses, presented in the earlier works, require lesser value of rise time (T_R), settling time (T_S), overshoot (M_P) and steady state error (E_{SS}). Thus, the values of T_R, T_S, M_P and E_{SS} may even become optimum than those offered by the reported algorithms *viz.* PSO [10,11], MOL [11], GA [3], LUS [12], ABC [10] and DEA [10] for the PID controlled AVR system. PID controller, tuned by modern optimization technique, may overcome this drawback of the AVR system by reducing the values of T_R, T_S, M_P and E_{SS} which may lead to decrease in overall objective function value and, in turn, optimizing the system performance. Thus, it may be expected that the transient response of the AVR system may be closer to the optimal one.

Some studied optimization techniques, as per the literature survey, have a number of limitations and problems of their own. The notified limitations in GA are (a) requirement of more overall execution time, (b) exposition of premature convergence *i.e.* ambush in local minima and (c) involvement of lots of crossover and mutation operations in each iteration cycle. PSO uses the concept of simulation of bird flocking in multi-dimensional search spaces. PSO undergoes various pragmatic studies which show that the particle may still diverge *i.e.* may go to infinity (a phenomenon known as "explosion" of the swarm) even on currently defining the maximum velocity and acceleration constants [13]. ABC has also some inherent deficiencies such as (a) improvement of performance requires new fitness tests on the new algorithm parameters, (b) chance of losing pertinent information on the behavior of the function to be optimized, (c) large number of objective function calculations, (d) on usage of sequential processing, it slows down, (e) increment of computational cost occurs due to slowdown which may further lead to the requirement of more iterations