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Control of Automatic Voltage Regulator Using Hybrid Optimization Techniques

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Abstract The present work studies the modelling and PID controller tuning aspects of an automatic voltage regulator. The PID controller is tuned using a hybrid optimization algorithm. This paper tunes the controller using the BF-PSO hybrid optimization algorithm. Simulation results and comparative analysis have been provided to validate the algorithm. Time-domain as well as frequency domain analysis has been carried out. In order to keep the voltage at the terminals, the VAR has a fixed set of operational parameters. Different electrical devices will degrade significantly if the terminal voltage is too low or too high. AVRs, which are controlled by a computer, are a key component in power system operation and control. A controller is used by AVR to regulate the terminal voltage. AVR is controlled using a proportional-integral-derivative (PID) controller, one of the most common control systems. The AVR's PID controller must be properly tuned in order for it to function properly. PID controller tuning approaches have been compared in a comparative analysis.

Keywords. PID controller, AVR, Optimization, Voltage Regulator.

1. Introduction

Automatic Voltage Regulator (AVR) is an electronic regulating device which adjusts the terminal voltage of synchronous generator under varying load and operating conditions [1-3]. The VAR maintains the terminal voltage and has hard constraints regarding its operating limits. Too low or too high terminal voltage will have significant deteriorating effect on different electrical equipment. Computer controlled AVR is one of the fundamental building blocks in power system operation and control [4-7]. AVR controls the terminal voltage with the help of a controller. Proportional-integral-derivative (PID) controller is one of the old war horses of control system and it is used to control AVR. Proper tuning of PID controller is required for satisfactory control of AVR. Comparative analysis of different classical tuning methods of PID controller has been discussed in [2, 8]. Comparative analysis of different control strategy has been discussed in [9-14]. Different swarm optimization based tuning methods for PID controller have been discussed in control literature. PID controller as well as fractional order PID controller and 2-DOF PID controller are widely used in control literature. PSO tuned fractional-order PID controller for AVR has been discussed in [6, 14]. Whale optimization-based tuning of PID and PIDA controller for AVR has been discussed in [7]. Excitation system and transient stability analysis of synchronous generator has been discussed in [8, 12]. Loss of excitation in synchronous generator has been reported in [10-18].

This paper provides a hybrid optimization method i.e. (BF-PSO) based tuning of PID controller for AVR unit. Simulation results have been provided for the same.

2. Automatic Voltage Regulator

Figure 1 shows the schematic diagram of automatic voltage regulator where Exciter is one of the most important components. There are two types of exciters such as DC exciter as shown in Fig.2 (a) and AC exciter as shown in Fig. 2(b). Figure 3 shows the mathematical model of governor and all transfer functions are given in Equs. from (1) to (4), the transfer function for amplifier is denoted as

$$G_a = \frac{K_a}{sT_a + 1} \tag{1}$$

Transfer function of exciter is denoted as

$$G_e = \frac{K_e}{sT_e + 1} \tag{2}$$

Transfer function of generator is represented as

$$G_g = \frac{K_g}{sT_g + 1} \tag{3}$$

and transfer function of sensor is denoted as

$$G_s = \frac{K_s}{sT_s + 1} \tag{4}$$

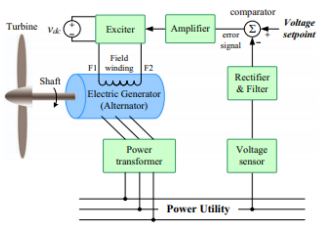
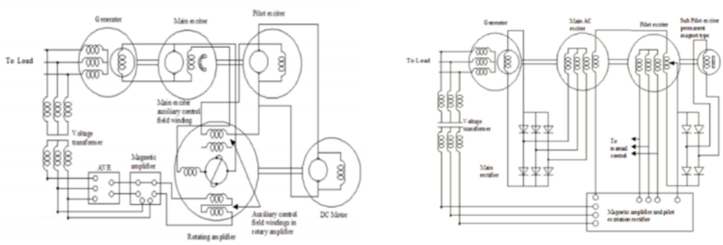


Figure 1. Schematic diagram of automatic voltage regulator



(a) (b)

Figure 2. Synchronous generator excitation system (a) DC excitation, (b) AC excitation

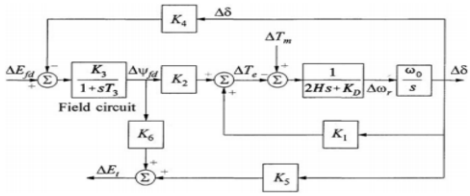


Figure 3. Mathematical model of generator

3. Swarm Optimization based controller tuning

Objective function of hybrid optimization algorithm can be represented as

$$\min_{(K_p K_i K_d)} W(K) = \left(1 - e^{-\beta}\right)\left(M_p + e_{ss}\right) + e^{-\beta}\left(t_s - t_r\right) \quad (5)$$

$$\text{Subject to, } \begin{cases} 0 \le K_p \le K_{p(\max)} \\ 0 \le K_d \le K_{d(\max)} \\ 0 \le K_i \le K_{i(\max)} \end{cases} \quad (6)$$

The flow chart of BFO is shown in Figure 4.

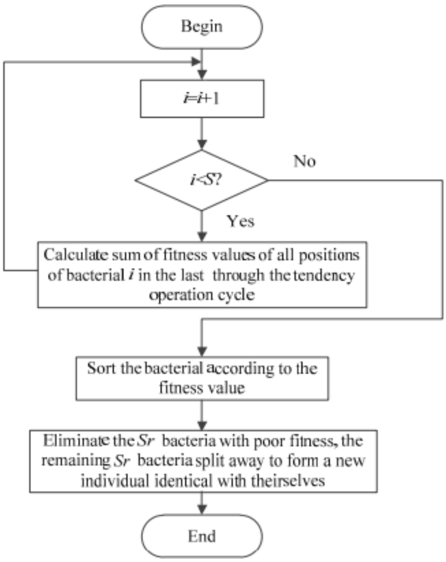


Figure 4. Flow chart of BFO

4. Simulation Results

Simulation analysis of closed-loop control of AVR has been shown in this section. Figure 5 shows the closed loop control using hybrid optimization algorithm. Figure 5(a) shows the step response analysis of controlled AVR and Figure 5(b) depicts controlled and uncontrolled frequency response

Table. 1: Parameters of PSO

Population size	100
Velocity constant,c_1	1.8
Velocity constant,c_2	1.8
Inertia weight factor, W	0.5

Table. 2: Parameters of BFO-PSO

Dimension of search space	P = 3
Number of bacteria	S =10
Inertia weight factor.	W= 0.5
Limits the length of a swim	$N_s = 4$
Number of chemo tactic steps	$N_c = 10$
Acceleration Constant.	C_1, $C_2 = 1.8$

Table. 3: Controller tuning using hybrid BF-PSO

Parameters	**Hybrid Optimization**	**IAE**	**ISE**
K_p	2.7200	3.4400	3.8438
K_i	0.0703	0.0796	0.0915
Kd	18.2497	25.3049	31.5727

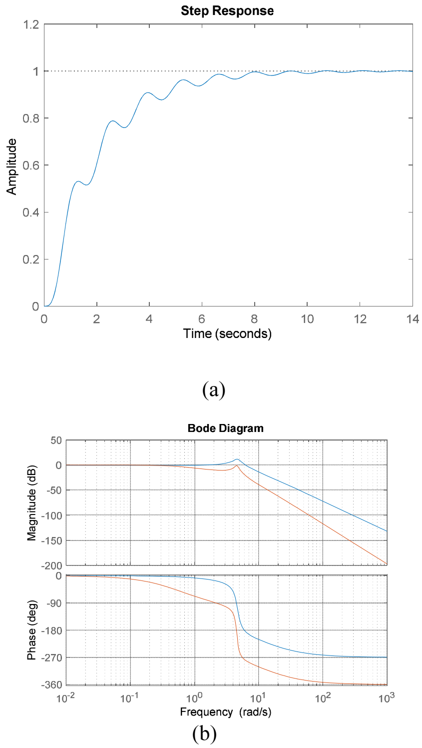


Figure 5. (a) Unit step response of PID controlled AVR, (b) frequency response analysis of uncontrolled and controlled AVR

5. Conclusions

This paper provides a swarm optimization based PID controller tuning scheme for AVR system. A hybrid optimization algorithm is used for the purpose of PID tuning. Mathematical modelling of AVR scheme and PID controller tuning has been discussed in this paper. Simulation results have been provided which illustrates the superiority of the tuning methods. The VAR is responsible for maintaining the terminal voltage and is subject to strict limitations in terms of its working limits. A terminal voltage that is either too low or too high will have a substantial negative impact on the performance of various electrical equipment. The AVR, which is controlled by a computer, is a basic building block in the operation and control of power systems. With the help of a controller, AVR is able to manage the terminal voltage. The proportional-integral-derivative (PID) controller is an old war horse in the world of control systems, and it is used to regulate the automatic valve regulator (AVR). Effective control of the AVR is dependent on the PID controller being properly configured. Different classical tuning approaches for PID controllers have been compared and contrasted in this paper.

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