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OPTIMIZED PARAMETERS CONTROLLER OF SYNCHRONOUS GENERATOR USING INTELLIGENT COMPUTING TECHNIQUES

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Abstract- In this work the power system (PS) transient voltage response enhancements have been investigated and studied in details through the following: A complete and modified model of Synchronous Generator (SG) has been introduced, where this model is suitable in studying the transient voltage response of SG. Enhancing the responses of the transient voltage profiles through using a modified novel approach, with new technique (Particle Swarm Optimizing) for the Synchronous Generator Voltage Controller. Hence, instead of using conventional controllers (PID controllers) as an auxiliary voltage controller with the Automatic Voltage Regulator (AVR) to enhance the transient voltage response, the proposed approach using particle swarm optimization is used to optimize the parameters values of the PID controller (PSO-PIDC). The obtained results give remarkable enhancements in the terminal voltage transient response. The obtained result for the Integral Square of Errors (ISEs) (which had been taken as measures for the terminal voltage transient response enhancements) of the second order of (SG) model had been reduced from 22,25 (withoutcontroller) to 1,109 with the novel proposed (PSO-PIDC). The choice was set on using Matlab-Simulink to design the models, while all the programs have been written in MATLAB programming.

Keywords: Automatic Voltage Regulator (AVR), PID Controllers, Partical Swarm Optimization (PSO).

I. INTRODUCTION

The transient voltage stability in electric power systems is regarded as an important problem. Voltage stability phenomena can be divided into transient voltage stability and long-term voltage stability. The transient stability is primarily concerned with maintenance of synchronism for large disturbances. An important problem associated with severe faults, where the voltage at the terminals of the synchronous generator can drop significantly [1]. The generator's Automatic Voltage Regulator (AVR) works through the excitation system to maintain constant generator terminal voltage. Thus the AVR plays a crucial role with respect to transient stability, by attempting to maintain terminal volt sunder fault conditions. It ensures also a fast terminal voltage recovery profile after the fault is cleare dunder transient conditions [2]. The modern power systems are non-linear and highly complex with continuous variations in the inoperating conditions over a wide range. Synchronous machines are the main parts of these systems, so in order to study and improve their performance; it must be known that, the overall accuracy of the system is primarily decided by how correctly the synchronous machines with in the system are modeled [3]. The problems of the most widely applied controller in power system control which is the well-known (PID) controller is that; the parameters tuning is a complex exercise because it depends mainly on the classical techniques which are always time consuming and manually done depending on the classical and Ziegler–Nichols method and sometimes on the human experts of the operators [4]. Particle swarm optimization (PSO), first introduced by Kennedy and Eberhart, is one of the modern heuristic algorithms. It was developed through simulation of a simplified social system, and has been found to be robust in solving continuous nonlinear optimization problems [5]–[6]. The PSO technique can generate a high-quality solution within shorter calculation time and stable convergence characteristic than other stochastic methods [7]–[8]. Because the PSO method is an excellent optimization methodology and a promising approach for solving the optimal PID controller parameters problem; therefore, this study develops the PSO-PID controller to search optimal PID parameters. This controller is called the PSO-PID controller. The generator excitation system maintains generator voltage and controls there active power flow using an automatic voltage regulator (AVR) [9]. The role of an AVR is to hold the terminal voltage magnitude of a synchronous generator at a specified level. Hence, the stability of the AVR system would seriously affect the security of the power system. In this paper, a practical high-order AVR system with a PID controller is adopted to test the performance of the proposed PSO-PID controller [10].

II. SIMULATION MODEL DESIGN

There are two ways in Simulink to design the machine model, these are:

1. Using power system blockset which is a set of ready-made [11].

2. Using blocks of transfer functions of the machine to manipulate the design model.

However, using blocks of the transfer function to represent the components in the power system is capable of having first and second order machine time constants as inputs. This can be achieved by the illustration shown in Figure 1.

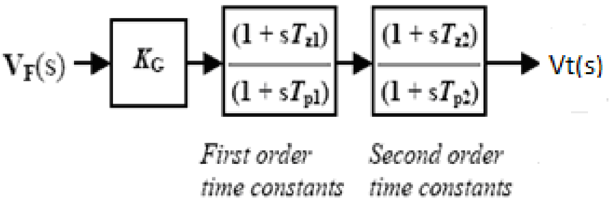

Figure 1. Block diagram representing a first and second order time constants model Synchronous Generator

where:

K_G = Gain of the generator
T_z = Time constant of the zero
T_p = Time constant of the pole
V_F = Field voltage of the synchronous generator
V_t = Terminal voltage of the synchronous generator

A. Generator Model

In the linearized model, the transfer function relating the generator terminal voltage to its field voltage can be represented by a gain K_G and a time constant T_G:

$$\frac{V_t(s)}{V_f(s)} = \frac{K_G}{1+sT_G} \tag{1}$$

Typical values of are in the range of K_E 10 to 400. The time constant T_E is in the range of 0.5 to 1.0 s.

B. Amplifier Model

The amplifier model is represented by a gain K_A and a time constant; the transfer function is:

$$\frac{V_R(s)}{V_e(s)} = \frac{K_A}{1+sT_A} \tag{2}$$

Typical values of $K_A$are in the range of 10 to 400. The amplifier time constant T_A is very small ranging from 0.02 to 0.1s.

C. Sensor Model

The sensor is modeled by a simple first-order transfer function, given by:

$$\frac{V_S(s)}{V_t(s)} = \frac{K_R}{1+sT_R} \tag{3}$$

T_R is very small, ranging from of 0.001 to 0.06 s.

D. Automatic Voltage Regulator (AVR) Model

By combining the previous models, a simple Automatic Voltage Regulator (AVR) is created with the combination of a first order model of synchronous generator without PID controller as shown in the Figure 2 below:

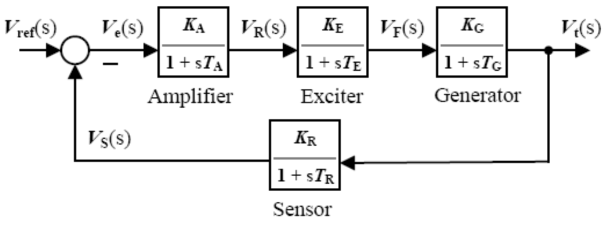

Figure 2. Block diagram of a simple Automatic Voltage Regulator (AVR) [11]

From this block diagram, the closed-loop transfer function relating the generator terminal voltage $V_t(s)$ to the reference voltage $V_{ref}(s)$ can be written as follow.

$$\frac{V_t(s)}{V_{ref}(s)} = \frac{K_A K_E K_G K_R (1+sT_R)}{(1+sT_A)(1+sT_E)(1+sT_G)(1+sT_R)+K_A K_E K_G K_R} \tag{4}$$

E. AVR Control System Simulation Model

In this section the obtained simulation model for AVR will be examined without controller. The results of these simulation 1^{st} and 2^{nd} orders considering step response, error signals, and corresponding models are illustrated in Figures 3 and Figure 4.

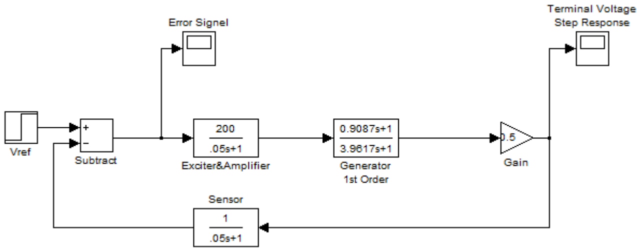

Figure 3. First order SG model without controller represented by Matlab – Simulink

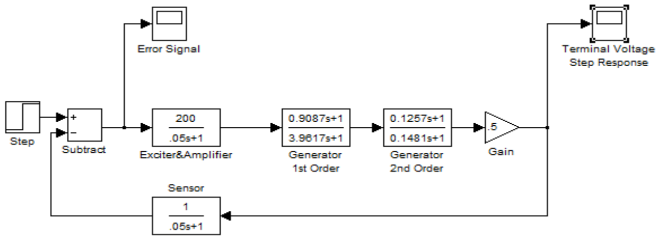

Figure 4. Second order SG model without controller represented by Matlab – Simulink

This model is examined here without PID controller to make a good reference results for comparison with the new suggested controllers which had been developed in the next section for enhancement of the power system transient voltage stability response.

III. AVR WITH PID CONTROLLER

A three term controllers of proportional-integral-derivative action (PID) controller, is introduced to the excitation system. It improves the dynamic response and also reduces or eliminates the steady state error. However, the use of a high derivative gain will result in excessive oscillation and instability when the generators are strongly connected to an interconnected system. Therefore an appropriate control of derivative gain is required. The proportional and integral gains can be chosen to result in the desired temporary droop and reset time [13, 14]. Figure 5 and Figure 6 illustrate the Matlab – Simulink First and Second orders simulation model of SG-AVR with PID controller.

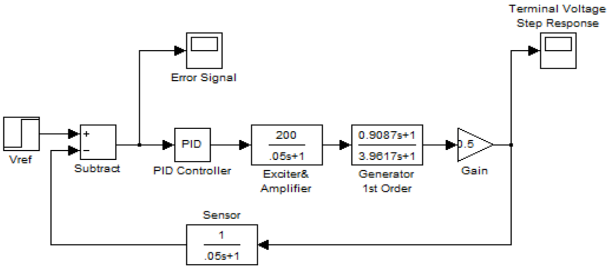

Figure 5. First order SG model with PID controller represented by Matlab-Simulink

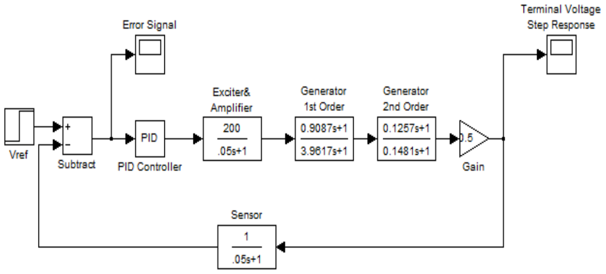

Figure 6. Second order SG model with PID controller repersented by Matlab-Simulink

IV. PERFORMANCE ESTIMATION OF PID CONTROLLER

In general, the PID controller design method using the integrated absolute error (IAE), or the integral of squared-error (ISE), or the integrated of time-weighted-squared-error (ITSE) is often employed in control system design because it can be evaluated analytically in the frequency domain. The three integral performance criteria in the frequency domain have their own advantages and disadvantages. For example, a disadvantage of the IAE and ISE criteria is that its minimization can result in a response with relatively small overshoot but a long settling time because the ISE performance criterion weights all errors equally independent of time.

Although the ITSE performance criterion can overcome the disadvantage of the ISE criterion, the derivation processes of the analytical formula are complex and time-consuming. The IAE, ISE, and ITSE performance criterion formulas are as follows;

$$IAE = \int_0^\infty |r(t) - y(t)|\,dt = \int_0^\infty |e(t)|\,dt \tag{5}$$

$$ISE = \int_0^\infty e^2(t)\,dt \tag{6}$$

$$ISTE = \int_0^\infty te^2(t)\,dt \tag{7}$$

In this paper, a new performance criterion in the time domain is proposed for evaluating the PID controller. A set of good control parameters kp,ki , and kd can yield a good step response that will result in performance criteria minimization in the time domain. These performance criteria in the time domain include the overshoot Mp, rise time tr, settling time ts and steady-state error Ess. Therefore, a new performance criterion w(k) is defined as follows

$$W(k) = (1 - e^{-\beta})(M_p + E_{ss}) + e^{-\beta}(t_s + t_r) \tag{8}$$

where k is [kp, kp, kd] and β is the weighting factor. The performance criterion W(k) can satisfy the designer requirements using the weighting factor β value. We can set β to be larger than 0.7 to reduce the overshoot and steady-state error. On the other hand, we can set β to be smaller than 0.7 to reduce the rise time and settling time. In this paper, β is set in the range of 0.8to 1.5 [15].

In this simulation, the objective is to minimize the cost function. For this reason the objective function is chosen as the Integral Square Error (ISE). The ISE squares the error to remove negative error components [8].

$$ISE = \sum_{k=1}^{q} e^2(k) \tag{9}$$

Particle Swarm Optimization (PSO) minimize the fitness function, the minimization objective function is transformed to be as fitness function as follows,

$$f = \frac{1}{ISE} \tag{10}$$

V. PSO-PID CONTROLLER

The optimizations of the controller's PID parameters using PSO algorithms will be compared to that of a standard method for designing PID controllers (Ziegler-Nicholas tuning method). Figure 7 illustrates the method of the PID parameters tuning using the ISE criteria as an index. The PSO algorithm is used here to find the optimum PID values for the AVR system for power system transient voltage stability enhancements of the terminal voltages of the first and second order Synchronous Generator model [17].

The results of the performance indexes (ISEs) and the transient responses for this case are illustrated in the Figure 8 and Figure 9 for the 1st and 2nd order models with their corresponding error signals. Table 1 illustrate the performance index and its enhancements percentage of the Terminal Voltages Responses for various order models of synchronous generator without controller, with PIDs tuned through using conventional method (Ziegler-Nichols Method), and with PID Controllers tuned by PSO algorithm.

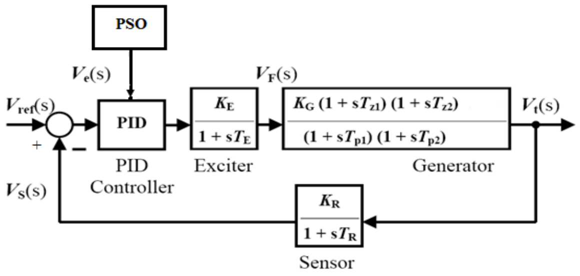

Figure 7. Second order SG model with PSO-PID controller

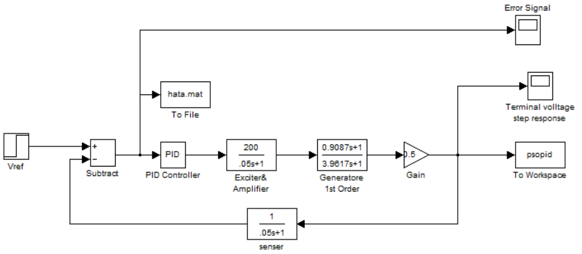

Figure 8. First order SG model with PSO-PID controller represented by MATLAB- Simulink

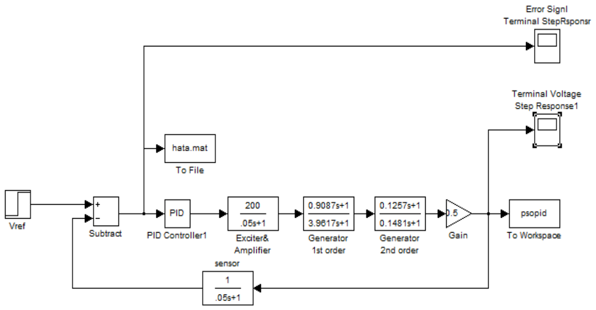

Figure 9. Second order SG model with PSO-PID controller represented by MATLAB- Simulink

Table 1. Performance indexes of the terminal voltage response for various order models of SG with and without controller

Generator Order	Controller Type	ISE	Over Shoot	Setting Time
First Order	Without	25.86	4.107	0.195
	Ziegler Nichols PID	4.53	2.018	0.9899
	PSO - PID	1.8821	1.166	0.1265
Second Order	Without	22.25	3.916	0.211
	Ziegler Nichols PID	3.70	1.576	0.7984
	PSO-PID	1.1090	0.9609	0.1299

From this table we notes that ISE in first order have been reduced from 25.86 without controller to 4.53 with PID and by using PSO-PIDC with ISE reduced to 1.8821 and ISE in second order have been reduced from 22.25 without controller to 3.70 with PID and by using PSO-PIDC with ISE reduced to 1.1090.

The enhancements of the transient responses are obviously appeared in the Figure 10 and Figure 11 which illustrates the terminal voltages transient responses of the first and second orders SG model with different types of controllers.

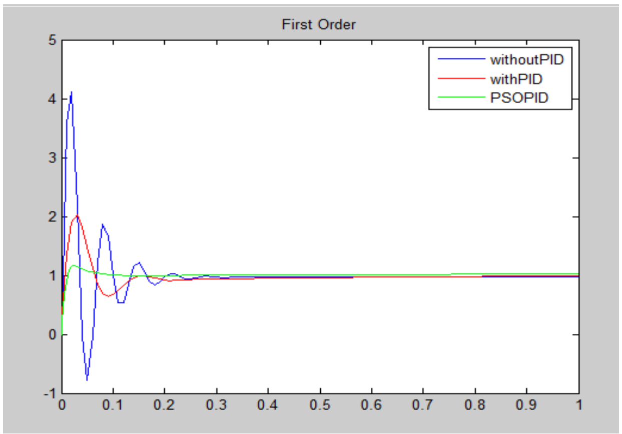

Figure 10. Terminal voltage transient responses of the first order SG model with different types of controller

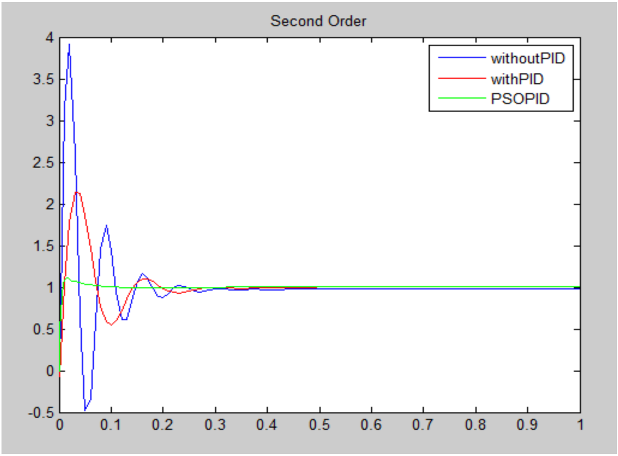

Figure 11. Terminal voltage transient responses of the second order SG model with different types of controller

VI. CONCLUSIONS

In this study, using PSO for tuning the PID parameters (Kp, Ki, Kd) enhanced the terminal voltages transient response when this controller (PSOPIDC) used as an auxiliary voltage regulator in the excitation control system with the AVR instead of the conventional PID controller tuned by Z-N method. A novel design method for determining the PID controller parameters using the PSO method. The proposed method integrates the PSO algorithm with the new time-domain performance criterion into a PSO-PID controller. Through the simulation of a practical AVR system, the results show that the proposed controller can perform an efficient search for the optimal PID controller parameters. The overall enhancements results of the performance Indexes or the optimization criteria (ISEs), overshoot and setting time which being a measures for the terminals voltage transient stability enhancements through all the works in this study.

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BIOGRAPHIES

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