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PID Controller Design of an AVR System

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Research Article

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Abstract

Voltage control and reactive power management are two facets that enable the reliability of the transmission network. More reactive power demand causes a voltage drop at the generator terminal. Such reactive power demand may arise from some industries connected to the transmission line. Usually, this reactive power is of an inductive nature which causes the voltage drop. In this regard, automatic voltage regulation (AVR) is an important aspect that is responsible for the continuous adjustment of field excitation to maintain the generator terminal voltage constant. This is done by comparing the terminal voltage with a reference voltage and by changing the excitation voltage accordingly, usually through a PI/PID controller. The generator is normally the synchronous generator and the DC excitation may be through a variable voltage DC generator or an AC supply using a controlled rectifier. Proportional-Integral-Derivative (PID) controllers are very popular in a wide range of industries for rectifying errors in the output of a control system. These controllers are easy to design, simple to tune while in operation and require less maintenance. The designed AVR system with load disturbances and uncertainty of the model parameters are compared with some methods prevalent in the literature.

Keywords: Automatic Voltage Regulation (AVR), load-disturbance, PID Controller, set-point response, simulation

I. Introduction

Due to power flow in a power system, especially reactive power supply, the terminal voltage of alternators normally changes. For proper operation of the power system and to improve its stability, voltage regulation is necessary. On the generation side, this is done by controlling the excitation. An AVR does this control. The output voltage of the generator is compared with the reference voltage and the difference/error is taken by a PI/PID Controller to produce appropriate control action to operate the exciter for developing appropriate excitation to the alternator such that the alternator restores the desired terminal voltage. A typical excitation arrangement for an alternator is shown in Fig 1. The corresponding schematic diagram is shown in Fig 2.

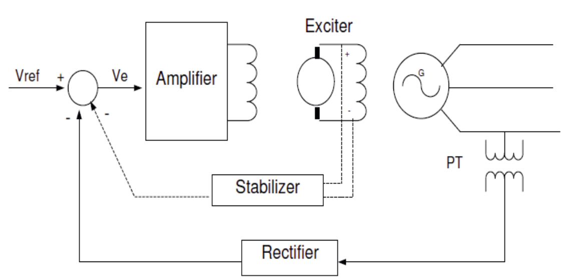

Fig 1: Excitation system of the AVR system

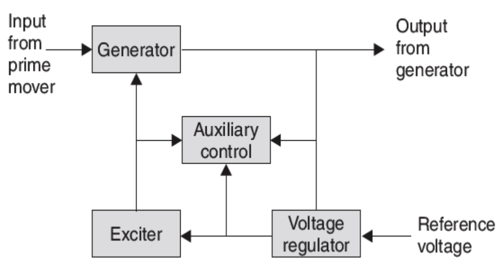

Fig 2: Schematic diagram of the AVR system showing the excitation

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II. Literature review

The proportional-integral-derivative (PID) controller with its variants is the most widely accepted controller for industrial applications due to its simple structure and ease of application. It provides solutions to a wide range of processes by improving transient and steady-state performance. The performance of the desired control system depends on the plant dynamics as well as the gains of the PID controller. The AVR systems continuously adjust the field excitation to maintain the generator terminal voltage at a specified level [1]. The PID controller design method for an AVR system using particle swarm optimization (PSO) was presented in [2], an intelligent PSO fuzzy PID controller in [3], Hybrid GA-BF-based intelligent PID controller tuning in [4], etc. in the category of optimization. Such methods require a good choice of initial guess and involve a huge computation.

On the other side, analytical methods demand comprehensive knowledge of control systems theory along with a detailed model of the system for achieving excellent performance. A semi-analytical method may require less derivation as well as less computation such as in [5] without noticeable degradation.

However, in an industrial environment, an easy-to-tune method that results in a good performance is preferable to the operators. Such a method with a trade-off between simplicity and performance has been indicated in Hackworth and Hackworth [6] which is named "Adjust and Observe" there. This has motivated authors to undertake the present work which is detailed in the following Sections.

III. Methodology

The basic block diagram in terms of the control system aspect is shown in Fig 3.

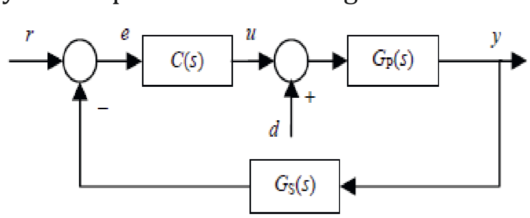


Fig 3: Basic block diagram of the AVR system

Where r is the input, e is the error, u is the controller output, d is the disturbance, y is the output to the plant, and $G_P(s)$ and $G_S(s)$ are the linearized model blocks of an AVR system. The detailed block diagram is shown in Fig 4.

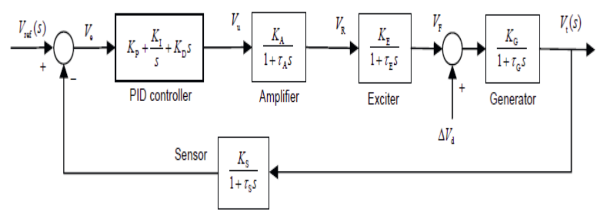


Fig 4: Detailed block diagram of the AVR system

$V_t(s)$ is the terminal voltage, $V_{ref}(s)$ is the reference voltage to be achieved by the AVR system, and ΔV_d is the disturbance due to the change of reactive power demand.

The parameters of the AVR model and the transfer function of each block are shown below:

Table 1. The Parameters of the AVR system

Component	Transfer function	Parameter limits
Amplifier	$G_A(s)=\frac{V_R(s)}{V_u(s)}=\frac{K_A}{1+\tau_A s}$	$10\le K_A\le 400$, $0.02\ \text{s}\le\tau_a\le 0.1\ \text{s}$
Exciter	$G_E(s)=\frac{V_F(s)}{V_R(s)}=\frac{K_E}{1+\tau_E s}$	$1\le K_E\le 10$, $0.4\ \text{s}\le\tau_E\le 1.0\ \text{s}$
Generator	$G_G(s)=\frac{V_t(s)}{V_F(s)}=\frac{K_G}{1+\tau_G s}$	K_G depends on load (0.7–1.0), $1.0\ \text{s}\le\tau_G\le 2.0\ \text{s}$
Sensor	$G_S(s)=\frac{V_S(s)}{V_t(s)}=\frac{K_S}{1+\tau_S s}$	$0.001\ \text{s}\le\tau_S\le 0.06\ \text{s}$ $K_S=1$

With typical values of different parameters, the Simulink diagram has been developed as shown in Fig 5.

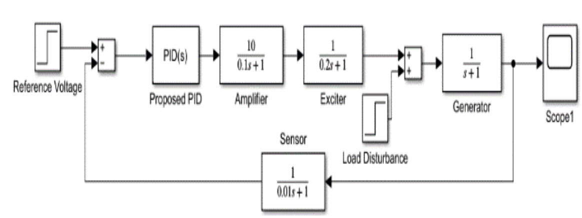
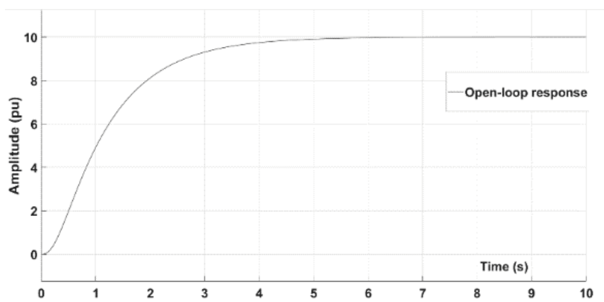


Fig 5: Simulink model of the AVR system

For the design of the PID controller, the following simulation-based procedure is followed which does not involve mathematical technique. In this procedure, the gains of the PID controller are adjusted one by one and the corresponding simulation responses are observed in terms of steady-state value, settling time, and percentage peak overshoot.



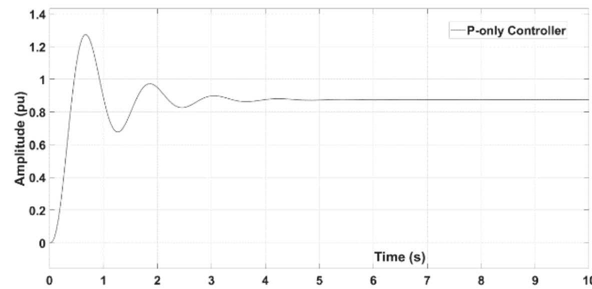
Graph-0: Open-loop response of the AVR system

The open-loop response of the AVR system has been shown above which shows the steady-state value as 10 pu instead of the required value of 1 pu.

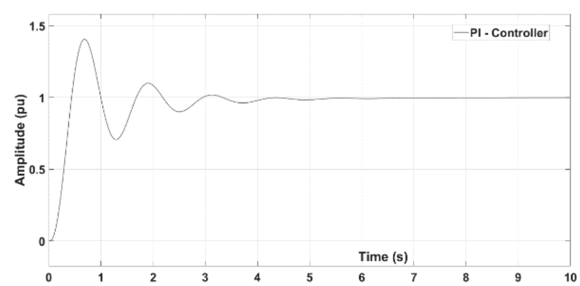
At this point, the steps for the design of the PID controller through "adjust and observe" are stated as follows:

- First, the proportional gain, *P* is chosen as 1, and the simulation response is observed. Then, *P* is increased and the simulation shows worse performance. Hence, *P* is decreased till improvement is observed up to *P*=0.7 (Sl. No. 6 of Table II). However, an offset is observed with a *P*-only controller (Graph-1).
- Next, with this *P*=0.7, the integral gain, *I* is increased from 0 to see that further improvement occurred up to *I*=0.3 (Sl. No. 8 of Table II). The PI controller shows no offset (Graph-2).
- Then, for further improvement, the derivative gain is introduced and observed that up to *D*=0.2, the performance is improving. Thus, the most improved performance is obtained for the PID controller with the gains *P*=0.7, *I*=0.3, and *D*=0.2 (Sl. No. 11 of Table II) (Graph-3).

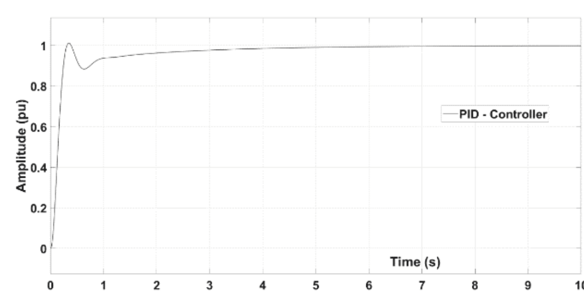
Thus, the PID controller has been designed with which further simulation and analysis are carried.



Graph-1: Set-point response with P-only controller



Graph-2: Set-point response with PI controller



Graph-3: Set-point response with PID controller

Table 2. Tuning the P, PI, and PID controllers

Sl. No.	Parameters			Performances				Remark
	K_p	K_i	K_d	y_{ss}	M_p	$M_p\%$	t_p (s)	
1	1	0	0	0.909	1.506	65.68	0.75	Highly oscillatory with large offset
2	2	0	0					Large oscillation leading to instability
3	1.5	0	0					Stable but highly oscillatory
4	1.1	0	0	0.914	1.556	70.24	0.711	Oscillatory with large offset
5	0.8	0	0	0.889	1.384	55.69	0.836	Less oscillatory with considerable offset
6	**0.7**	**0**	**0**	**0.875**	**1.315**	**50.29**	**0.860**	**Oscillatory with considerable offset**

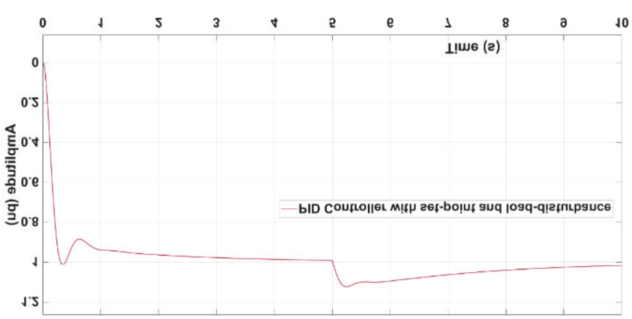
Sl. No.	Parameters			Performances				Remark
	K_p	K_i	K_d	y_{ss}	M_p	$M_p\%$	t_p (s)	
7	0.7	0.1	0	0.977	1.374	40.63	0.884	Oscillatory with reduced offset
8	**0.7**	**0.2**	**0**	**0.996**	**1.432**	**43.77**	**0.884**	**Oscillatory with zero offset**
9	0.7	0.2	0.1	0.996	1.14	14.46	0.719	No oscillation with almost zero offset
10	0.7	0.3	0.1	1	1.17	17	0.734	Settling fast at 3.232s
11	**0.7**	**0.3**	**0.2**	**1**	**1.042**	**4.2**	**0.562**	**Settling fast at 3.035s**
12	0.7	0.3	0.3	1	1.012	1.2	0.412	Settling fast at 3.075s

IV. Results and analysis

With the above setting of the PID controller (Sl. No. 11 of Table II), further study is carried out with a unit step load-disturbance applied to the AVR system at time $t = 5s$. The simulation response is given in Graph 4 and the performance is tabulated in Table III. It is observed for the load-disturbance response that the settling time is increased slightly whereas the peak overshoot increases considerably, however, the system remains stable with no offset at steady-state.

Table. 3 Set-point and load-disturbance responses with the proposed PID controller

K_p	K_i	K_d	Set-point response					Load-disturbance		
			y_{ss}	M_p	$M_p\%$	t_p (s)	t_s (s)	$M_p\%$	t_s (s)	y_{ss}
0.7	0.3	0.2	1	1.042	4.2	0.562	3.035	17.3	4.434	1



Graph-4: Set-point and load-disturbance responses with PID controller

At this point, we consider the parameter uncertainty of the generator model. For this, +50% changes in the gain and time constant of the generator have been made in the Simulink model (Fig 7) to see the responses as in Graph-5 and Table IV. It is observed that peak overshoot is increased but the settling time is decreased for the set-point response. For load-disturbance response, both the peak overshoot and the setting time are increased. However, the system remains in stable condition with no offset at steady-state.

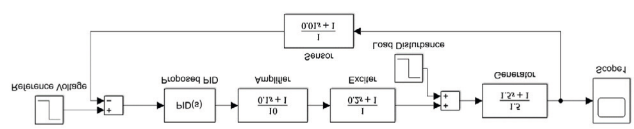
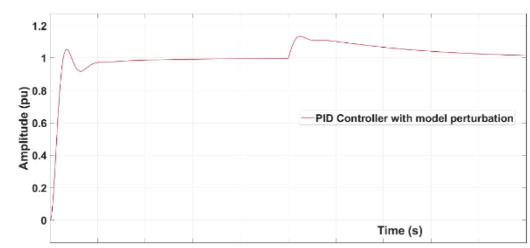


Fig 7: Simulink model of the perturbed AVR system

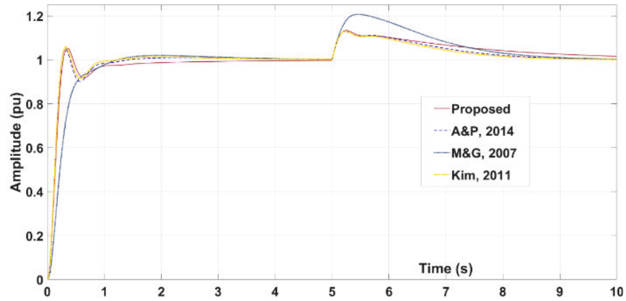


Graph-5: Set-point and load-disturbance responses for perturbed AVR system

Table 4. Set-point and load-disturbance responses for perturbed AVR system

K_p	K_i	K_d	Set point response					Load disturbance		
			y_{ss}	M_p	$M_p\%$	t_p (s)	t_s (s)	$M_p\%$	t_s (s)	y_{ss}
0.7	0.3	0.2	1	1.10	10	0.556	1.263	18.2	4.247	1

Finally, a comparison is studied with some methods prevalent in the literature. For this study, a perturbed AVR model has been taken and the disturbance has been applied at $t = 5s$. It is observed from Table V and Graph-6 that the proposed PID controller offers performance comparable to the controllers designed by various methods (3-5) taken from the literature.



Graph-6: Comparison of various methods of set-point and load-disturbance responses for perturbed AVR system

Table 5. Comparison of various methods

Method	K_p	K_i	K_d	Set-point response					Load-disturbance		
				y_{ss}	M_p	$M_p\%$	$t_p(s)$	$t_s(s)$	$M_p\%$	$t_s(s)$	y_{ss}
Proposed	0.7	0.3	0.2	1	1.051	5.1	0.350	1.482	13.3	4.499	1
A&P	0.652	0.434	0.236	1	1.044	4.4	0.337	0.920	12.8	2.988	1
M&G	0.374	0.268	0.1	1	1.020	2.0	1.940	1.999	20.7	3.348	1
Kim	0.672	0.478	0.229	1	1.055	5.5	0.337	0.841	12.9	2.752	1

A&P: Anwar & Pan 2014 [5], M&G: Mukherjee & Ghoshal 2007 [3], Kim: Kim 2011 [4]

V. Conclusion

A PID-controlled AVR system has been developed in Simulink. A step-by-step “Adjust and Observe” method [6] has been employed which is in practice in the industry where the system under consideration is not very complex. The performance has been compared with some formal design methods prevalent in the literature that involve rigorous mathematics as well as computations. In the present method, first, the gain P is adjusted to obtain the best performances. Then, gains I and D are adjusted sequentially to improve further. It is to be noted that as P sets the speed of response, gain I eliminates offset in the response, and D smooths out oscillation. It is observed from the graphs and tables that the present method shows results that are comparable with that of the other methods considered.

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