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An Automatic Voltage Regulator(AVR) System Control using a P-I-DD Controller

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Abstract — *In this paper a simple procedure is given to design a P-I-DD controller for an Automatic Voltage Regulator (AVR) system. The controller is designed such that it produces a dead-beat type output response of the AVR system. The design method is then applied to some typical numerical examples and time response simulation of the P-I-DD controlled system is done. A comparison of time domain specifications like peak overshoot, settling time, steady state value etc. for responses of AVR system with and without P-I-DD controller is made for the examples considered clearly indicate the superiority of the proposed procedure.*

Keywords*-voltage control; AVR system; P-I-D control; P-I-DD controller; dead-beat response*

I. INTRODUCTION

In electric power systems, automatic voltage regulator (AVR) is utilized to maintain the terminal voltage of a synchronous generator at a specified level. AVR basically controls the output voltage by controlling the exciter voltage of the synchronous generator. Variations in load and inductance of field windings of the generator may have an undesirable effect on the regulator response. To ensure stable, fast and efficient response to transient disturbances in terminal voltages, additional control mechanism may sometimes be necessary. PID is the most widely used control structure owing to its simplicity and wide range of operations. The P-I-D control mechanism involves the strategy of proper selection of proportional, integral and derivative gains. This process is often termed as '*tuning'* in the literature. Recently, many methods have been proposed which rely on some or the other intelligent optimization techniques. Such methods include particle swarm optimization (PSO)[5], artificial bee colony(ABC) algorithm [2], pattern search(PS) algorithm [8], chaotic optimization (CO) algorithm[4] . The application of FOPID controller [10] was also recently employed to control AVR system response. The main contribution of this paper is to propose an algorithm to tune the four term structure P-I-D plus second order derivative (P-I-DD) controller [1] for AVR system. The four gains of the controller are obtained using a simple procedure which produces dead-beat type response. The remainder of the paper is as follows: Section II deals with the block diagram model of an AVR system, dead-beat response and design with pre-filter is given in Section III, the proposed procedure is explained in section IV, Section V deals with the time response simulations of some typical numerical examples along with comparison of time-domain specifications.

II. AVR SYSTEM MODELING

The role of an AVR is to hold the terminal voltage magnitude of a synchronous generator at a specified level. A simple AVR system comprises four main components, namely amplifier, exciter, generator, and sensor. An AVR system with their components is shown in Fig.1. For mathematical modeling and transfer function of the four components, these components must be linearized, which takes into account the major time constant and ignores the saturation or other nonlinearities. The reasonable transfer function of these components may be represented, respectively, as follows

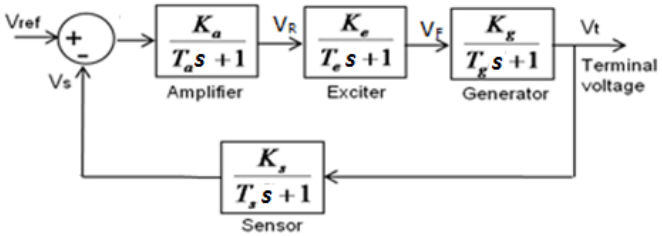

Fig.1. Block diagram of a typical AVR system

Amplifier model:
The excitation system amplifier may be a magnetic amplifier, rotating amplifier, or modern electronic amplifier. The amplifier is represented by a gain K_a and a time constant T_a and the transfer function is

$$\frac{V_r(s)}{V_e(s)} = \frac{K_a}{1+T_a s}$$

Exciter model:

There is a variety of different excitation types. However, modern excitation systems use ac power source through solid-state rectifiers such as SCR. The output voltage of exciter is a nonlinear function of the field voltage because of the saturation effects in the magnetic circuit. Thus, there is no simple relationship between the terminal voltage and the field voltage of the exciter. A reasonable model of a modern exciter is a linearized model, which takes into account the major time constant and ignores the saturation or other nonlinearities. In the simplest form, the transfer function of a modern exciter may be represented by a single time constant T_e and a gain K_e, i.e.,

$$\frac{V_f(s)}{V_r(s)} = \frac{K_e}{1+T_e s}$$

Generator model:

The synchronous machine generated emf is a function of the machine magnetization curve, and its terminal voltage is dependent on the generator load. 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, and the transfer function is

$$\frac{V_t(s)}{V_f(s)} = \frac{K_g}{1+T_g s}$$

Sensor model:

The voltage is sensed through a potential transformer and, in one form, it is rectified through a bridge rectifier. The sensor is modeled by a simple first order transfer function, given by a gain K_s and a time constant T_s will be

$\frac{V_s(s)}{V_t(s)} = \frac{K_s}{1+T_s s}$. The typical typical parameter limits are given in Table 1.

Table 1. Parameters of AVR with transfer function and parameter limits

	Transfer function	Parameter limits
Amplifier	$TF_{amplifier} = \frac{K_a}{1+T_a s}$	$10 \le K_a \le 40$; $0.02 \le T_a \le 0.1$
Exciter	$TF_{exciter} = \frac{K_e}{1+T_e s}$	$1 \le K_e \le 10$; $0.4 \le T_e \le 1$
Generator	$TF_{generator} = \frac{K_g}{1+T_g s}$	$0.7 \le K_g \le 1$; $1 \le T_g \le 2$
Sensor	$TF_{sensor} = \frac{K_s}{1+T_s s}$	$K_s = 1$; $0.001 \le T_s \le 0.06$

III. DEAD-BEAT CONTROL AND PRE-FILTER DESIGN

The characteristics of a dead-beat response [12] is as follows:

- steady state error is zero
- fast response with minimum rise time and settling time
- percent peak overshoot in the range of $0.1\% \le M_p \le 2\%$ percent under shoot $\le 2\%$

A controller for any unity feedback closed loop system (no zeros) (Fig.2) can be designed such that the overall closed loop system is expected to give a dead-beat response. Consider the transfer function of the closed loop system as T(s). The coefficients of T(s) that yield dead beat response can be chosen from the table 2. for some considered ω_n value. An example of 4^{rth} order closed loop system transfer function be

$$T(s) = \frac{\omega_n^4}{s^4 + \alpha\omega_n s^3 + \beta\omega_n^2 s^2 \gamma\omega_n^3 + \omega_n^4}$$

A value of ω_n is first chosen from the required settling time T_s as , α, β, γ values are chosen from the Table2.

Table2. Coefficients and response measurement of a deadbeat response system

Sys. order	α	β	γ	δ	ε	% peak over shoot	%under shoot	Rise time (90%)	Rise time (100%)	Settling time
2nd	1.82					0.1	0.0	3.47	6.58	4.82
3rd	1.9	2.2				1.65	1.36	3.48	4.32	4.04
4th	2.2	3.5	2.8			0.89	0.95	4.16	5.29	4.81
5th	2.7	4.9	5.4	3.4		1.29	0.37	4.84	5.73	5.43
6th	3.15	6.5	8.7	7.55	4.05	1.63	0.94	5.49	6.31	6.04

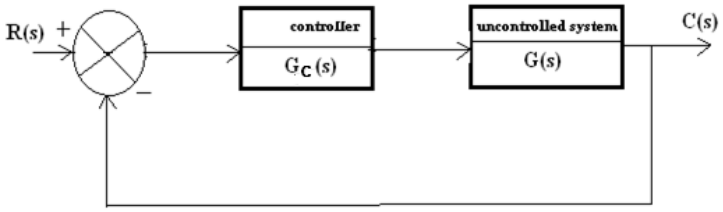

Fig.2. A unity feedback closed loop system with controller

Sometimes the dynamics of the closed loop controlled system due to unwanted zeros and poles may affect the performance of the system forcing the control engineer to somehow get rid of their effect. It is done by pole-zero cancellation using what is called as a pre-filter. The closed loop system with a controller (compensator) along with a pre-filter is shown in the Fig.3.

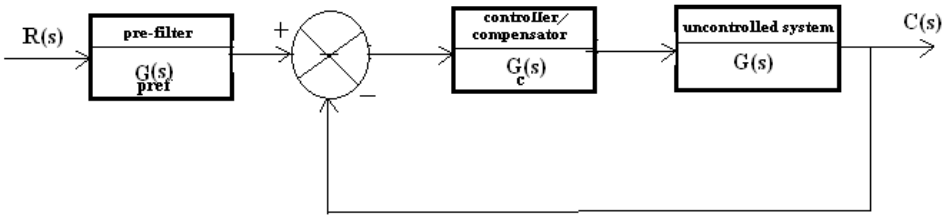

Fig.3. A unity feedback closed loop system with controller and pre-filter

The new closed loop transfer function with pre-filter now becomes

$$G_{clpref} = \left(\frac{G_c G}{1+G_c G}\right) G_{pref} = G_{cl} G_{pref}$$

.

The pre-filter can be modeled such that it eliminates the unwanted poles and zeros of G_{cl} and improve the response.

IV. PROPOSED P-I-DD CONTROL PROCEDURE

The P-I-DD (double derivative PID controller) is proposed here for the control of an AVR system such that the output of the controlled system (Fig.4) exhibits dead-beat response. In general, P-I-DD controller alone makes the response faster with shorter rise and settling times but may produce unwanted high peak over/undershoots in the transient part. The reason is due to the dynamics of zeros present in the closed loop system. If this effect of the zeros arises in the output response, then it can be nullified or cancelled by using a pre-filter as shown in Fig.5.

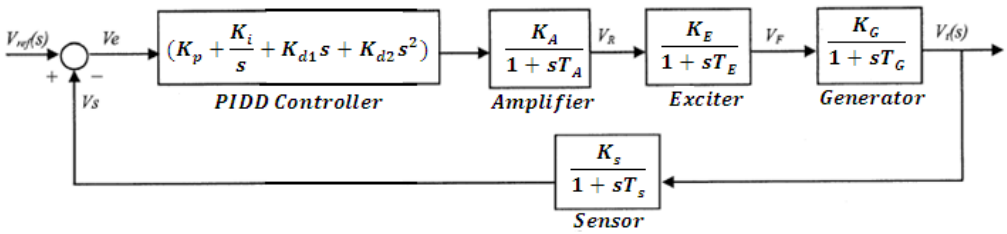

Fig.4. Block diagram of the PIDD controlled AVR system

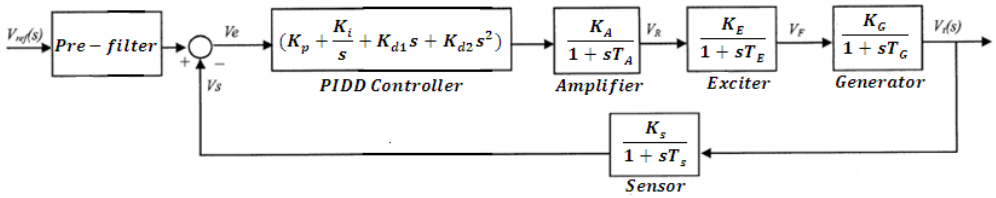

Fig.5 Block diagram of the PIDD controlled AVR system with pre-filter

The *step-wise* procedure for the proposed design method of P-I-DD controller is given below:

Step 1: Consider a P-I-DD controller with transfer function
$G_{PIDD} = (K_p + \frac{K_i}{s} + K_{d1}s + K_{d2}s^2) = \frac{As^3+Bs^2+Cs+D}{s}$ in the forward path of the AVR system as shown in Fig.4.1

Step 2: The closed loop Transfer function $G_{AVRPIDD} = \frac{\Omega(s)}{\Delta(s)}$ in unknown parameters of the PIDD controller is obtained.

Step 3: The denominator polynomial of $G_{AVRPIDD}$,$\Delta(s)$ is made a monic polynomial $\tilde{\Delta}(s)$ by dividing the entire polynomial $\Delta(s)$ with highest power of s co-efficient.

Step 4: This polynomial $\tilde{\Delta}(s) = s^5 + as^4 + bs^3 + cs^2 + ds + e$ is now compared with the fifth order 'dead-beat polynomial $\Omega(s)$ as $\tilde{\Delta}(s) = \Omega(s)$
where $\Omega(s) = s^5 + \alpha\omega_n s^4 + \beta\omega_n^2 s^3 + \gamma\omega_n^3 s^2 + \delta\omega_n^4 s + \omega_n^5$, $\alpha = 2.7, \beta = 4.9,\ \gamma = 5.4, \delta = 3.4.$

Step 5: Obtain the undamped natural frequency ω_n as $\omega_n = \frac{a}{\alpha} = \frac{a}{2.7}$

Step 6: The unknown P-I-DD parameters A, B, C, D *and hence* k_p, k_i, k_{d1}, k_{d2} can be obtained by solving the following set of equations
$b = 4.9\omega_n^2;\ c = 5.4\omega_n^3; d = 3.4\omega_n^4; e = \omega_n^5$

Step 7: The P-I-DD controller thus obtained is considered in the closed loop.

Step 8: Obtain the unit step response of closed loop system $G_{AVRPIDD}$

Step 9: If the time response is not satisfactory, design a pre-filter G_{PREF} such that the zeros of the closed loop system are cancelled with the poles of the pre-filter without changing the steady state value.

Step 10: Obtain a closed loop system $G_{AVRPIDD\,1}$ with both controller and pre-filter considered as shown in Fig.4.2.

Step 11: Obtain the unit step response of closed loop system $G_{AVRPIDD\,1}$

V. EXAMPLE AND RESULTS

EXAMPLE 1[4]: Consider the parameters of an AVR system with the following gain and time constants and reference input 1.0 (p.u.)

Amplifier:		
Amplifier gain (K_a)	=	10
Amplifier time constant (T_a)	=	0.1
Exciter:		
Exciter gain (K_e)	=	1
Exciter time constant (T_e)	=	0.4
Generator:		
Generator gain (K_g)	=	0.7
Generator time constant (T_g)	=	1
Sensor:		
Sensor gain (K_s)	=	1
Sensor time constant (T_s)	=	0.01

The PIDD parameters are
$k_{d2} = 0.4155, k_{d1} = 22.7063, k_i = 7501.1, k_p = 606.55$

The PIDD controller Transfer function is

$$G_{PIDD} = \frac{0.4155s^3 + 22.7063s^2 + 606.55s + 7501.1}{s}$$

Transfer function of pre-filter is

$$G_{PREF} = \frac{52510}{0.02909s^4 + 4.498s^3 + 201.4s^2 + 4771s + 52510}$$

The unit step response for PIDD+pre-filter controlled AVR system for example1 is shown in Fig.6.

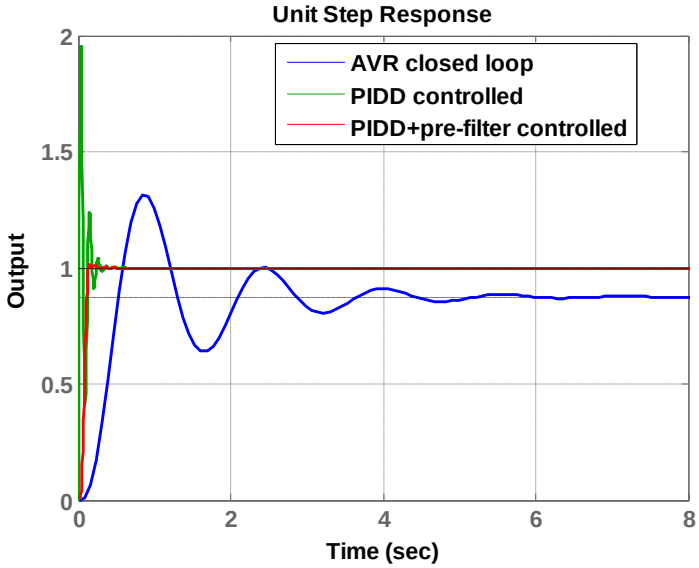

Fig. 6 Step response of AVR system with PIDD controller with pre-filter

The comparison of time response characteristics of AVR system for uncontrolled and controlled cases is shown in Table3.

Table 3: Comparison of time response characteristics of an AVR system

System	%Peak overshoot	Rise time(s)	Settling time(s)	Steady state
AVR Closed loop	50.2	0.322	4.89	0.875
PIDD	95.5	0.0099	0.282	1
PIDD + pre-filter	1.27	0.066	0.129	1

EXAMPLE 2[7]:
Consider an AVR system with the following parameters with 1.0 (p.u.) reference input.
Amplifier:
Amplifier gain (K_a) = 400
Amplifier time constant (T_a) = 0.01
Exciter:
Exciter gain (K_e) = 0.2
Exciter time constant (T_e) = 4
Generator:
Generator gain (K_g) = 1
Generator time constant (T_g) = 1
Sensor:
Sensor gain (K_s) = 1
Sensor time constant (T_s) = 0.001
The PIDD parameters are
$k_{d2} = 0.3569, k_{d1} = 183.1394, k_i = 5.6439 * 10^6, k_p = 47048$
The PIDD controller Transfer function is

$$G_{PIDD} = \frac{0.3569s^3 + 183.1394s^2 + 5.6439 * 10^6 s + 47048}{s}$$

The unit step response for PIDD+pre-filter controlled AVR system for example 2 is shown in Fig.7.

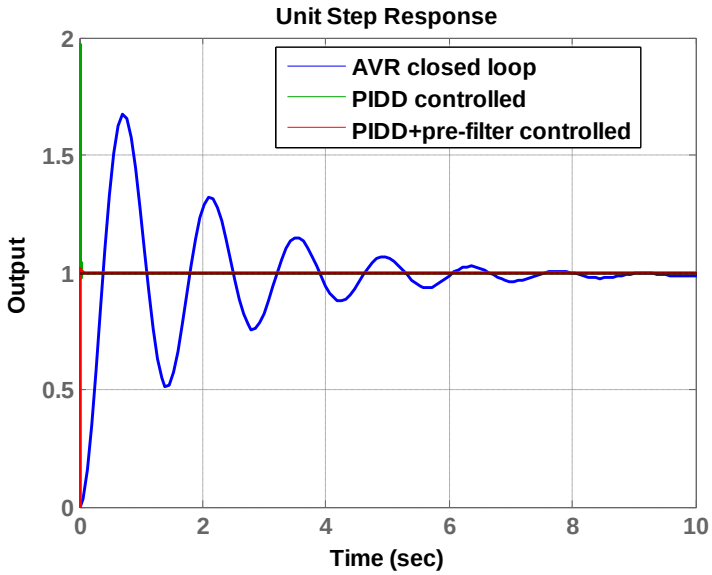

Fig.7 Step response of AVR system with PIDD controller with pre-filter

The comparison of time response characteristics of AVR system for uncontrolled and controlled cases is shown in Table4.

Table 4: Comparison of time response characteristics of an AVR system

System	%Peak overshoot	Rise time(s)	Settling time(s)	Steady state
AVR Closed loop	69.4	0.255	7.21	0.988
PIDD	97.2	0.007	0.029	1
PIDD + pre-filter	1.27	0.0068	0.013	1

EXAMPLE 3: Consider an AVR system with the following gain and time constants
Amplifier:
Amplifier gain (K_a) = 40
Amplifier time constant (T_a) = 0.05
Exciter:
Exciter gain (K_e) = 1
Exciter time constant (T_e) = 0.5
Generator:
Generator gain (K_g) = 0.8
Generator time constant (T_g) = 1
Sensor:
Sensor gain (K_s) = 1
Sensor time constant (T_s) = 0.001
The PIDD parameters are
$k_{d2} = 0.5315, k_{d1} = 229.4181, k_i = 6.1 * 10^6, k_p = 54741$
The PIDD controller Transfer function is

$$G_{PIDD} = \frac{0.5315s^3 + 229.4181s^2 + 6.1 * 10^6 s + 54741}{s}$$

The unit step response for PIDD+pre-filter controlled AVR system for example 3 is shown in Fig.8.

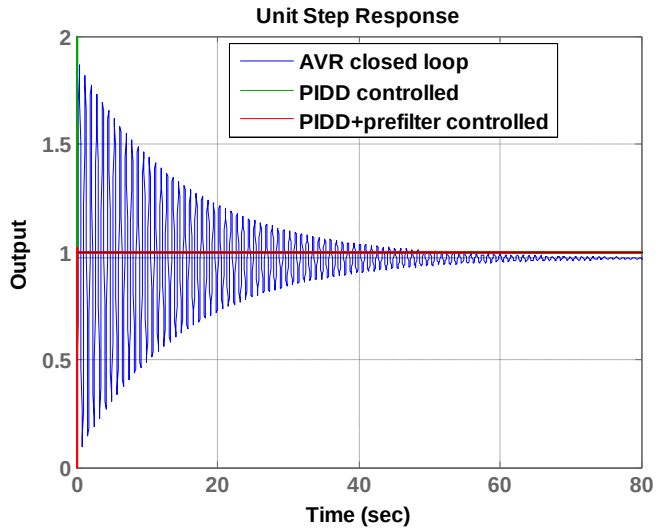

Fig. 8. Step response of AVR system with PIDD controller with pre-filter

The comparison of time response characteristics of AVR system for uncontrolled and controlled cases is shown in Table5.

Table 5: Comparison of time response characteristics of an AVR system

System	%Peak overshoot	Rise time(s)	Settling time(s)	Steady state
AVR Closed loop	92.3	0.148	58.8	0.97
PIDD	99.7	0.0001	0.0356	1
PIDD + pre-filter	1.27	0.00732	0.0143	1

IV. CONCLUSIONS

A P-I-DD controller design method is proposed for an AVR system which is based on deadbeat response. The method is applied for some typical AVR problems and verified successfully. The transient response specifications are compared for systems with and without P-I-DD controller. It can be concluded that the designed P-I-DD controller gives a better transient as well as steady state response.

REFERENCES

[1] Mouayad A. Sahib "A novel optimal PID plus second order derivative controller for AVR system" Engineering Science and Technology, an Intr. Journal, Vol. 18, pp.194-206, 2015.

[2] H. Gozde et.al. "Comparative performance analysis of artificial bee colony algorithm for automatic voltage regulator (AVR) system", Jr. Franklin Inst., Vol. 348 (8), pp.1927-1946, 2011.

[3] S. Panda et.al. "Design and performance analysis of PID controller for an automatic voltage regulator system using simplified particle swarm optimization", J. Franklin Inst., Vol. 349 (8), pp.2609-2625, 2012.

[4] Leandro dos Santos Coelho, " Tuning of PID controller for an automatic regulator voltage system using chaotic optimization approach" Chaos, Solitons and Fractals, Vol. 39, pp.1504-1514, 2009.

[5] G. Zwe-Lee, "A particle swarm optimization approach for optimum design of PID controller in AVR system", IEEE Trans. Energy Convers., Vol. 19 (2), pp.384-391, 2004.

[6] Supol Kansit et.al. "Optimization of PID Controller based on PSOGSA for an Automatic Voltage Regulator System", Procedia Computer Science, Vol.86, pp.87-90, 2016.

[7] G.Shabib et.al. "Optimal Tuning of PID Controller for AVR System using Modified Particle Swarm Optimization", Proc. of the 14th Intr. Middle East Power Systems Conf. (MEPCON'10), Cairo University, Egypt, pp. 305-310, 2010.

[8] Binod Kumar Sahu, "Robust analysis and design of PID controlled AVR system using Pattern Search algorithm", 2012 IEEE Intr. Conf. on Power Electronics, Drives and Energy Systems, Bengaluru, India, 2012.

[9] Apurva Tripathi et.al. "Design of Ziegler Nichols tuning controller for AVR System", Intr. Jr. of Research in Electronics & Communication Technology, Vol. 1, Issue 2, pp. 154-158, 2013.

[10] N. Aguila-Camacho, M.A. Duarte-Mermoud, Fractional adaptive control for an automatic voltage regulator, ISA Trans. 52 (6) , pp. 807-815, 2013.

[11] Haadi Saadat, Power System Analysis, Tata McGraw Hill Publishing, sixth re-print,2005.

[12] Richar Dorf and Robert Bishop , Modern Control Systems, 13th edition, Pearson eduztion,2016 .

