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Performance Improvement of Automatic Voltage Regulator using Two Loop Configuration

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Abstract *- This paper has presented performance improvement of Automatic Voltage Regulator (AVR) using two loop configuration. It is required to improve the stability performance of an AVR to reduce error voltage. In order to achieve this, dynamic models of the components of an AVR system are obtained. Two loop structure was proposed and two compensators designed using Proportional Integral and Derivative tuning method and Nichols graphical tuning of the Control and Estimation Tool Manager (CETM) of MATLAB. Simulations were performed and the results obtained indicated that the proposed two loop structured for AVR system provided improved response performance.*

Keywords - *AVR, CETM, Compensator, PID tuning*

I. INTRODUCTION

The voltage of a generator is expected to be kept at a certain acceptable voltage level at all times. This applies also to large power distribution networks whose overall voltage profiles must be sustained at an appropriate level at all times [1]. Achieving this is a challenge in power system distribution network. This is because a particular problem in modern interconnected power system is the never steady and continuous varitions of active and reactive power occasioned by changes in load [2]. The resulting effect of the changes in load is imbalance between power generation and load consumption, which brings about instability problems in frequency and voltage [2]. The instability problem can be overcome using Automatic Voltage Regulator (AVR) [2, 3]. An AVR is a voltage regulator used to keep the terminal voltage of a generator at a setpoint (or referenced) voltage.

The working principle of AVR is based on error detection. The operational loop of AVR is in the form of a feedback control system in which the output is continuously measured by a feedback sensor and then transmits same to a comparator circuit that compares the setpoint voltage with the output voltage. The result is the difference between the sum of the setpoint voltage and the output voltage known as error voltage. The error voltage is detected by a compensator that manipulate on the error by means of computational algorithm to produce a correction signal known as control input (manipulated input). The manipulated input signal of the compensator is fed into the amplifier circuit, which strengthens the signal and then feeds same to an exciter and eventually to generator.

In this paper the focus is to design optimised two loop compensators for AVR system to improve the response tracking performance of generator output voltage based on PID tuning design method using robust response time tuning method of the MATLAB Control and Estimation Tool Manager (CETM).

The remaining parts this paper are sectioned into: literature review, methodology, results and discussion, and conclusion.

II. LITERATURE REVIEW

A. Control Terminology

In the control of physical systems –electrical, electronics, mechanical, or chemical systems, two configuration are readily available depending on the expectation of the designer. Biological and other systems which are not part of the engineering systems mentioned above can also be controlled. These configurations are: open-loop and closed-loop.

In open-loop control configuration, the output of the plant is not compared with the setpoint. That is, it is a control loop without feedback as shown in Fig.1.

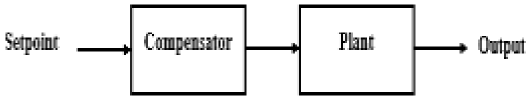

Fig. 1 Open loop configuration

In the closed-loop configuration, the network is characterised by a feedback measurment sensor and a summing point. That is, the output is compared with the setpoint as shown in Fig. 2. The result of the comparison at the summing point known as error e(t) signal is fed into the compensator.

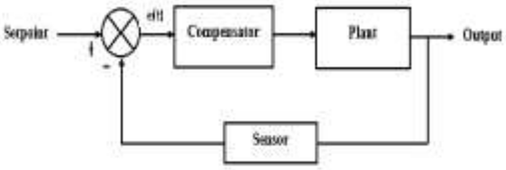

Fig. 2 Closed-loop configuration

B. Related Works

Venkatakrishnam et al [2] used Differential Evolution (DE) algorithm to perform optimal tuning of a Proportional-Integral-Derivative (PID) controller for AVR-Power System Stabilizer (PSS) system. In Andhare and Asati [4], a PID controller is designed for AVR with Load Frequency Control (LFC). The designed PID controller was designed using manual tuning technique to determine the optimized gain parameters so as to improve the dynamic response and steady state error of the AVR system. Odili et al, [5] employed Africa Buffalo Optimization (ABO) to carry out parameter tuning of PID controller to for effective AVR control loop. Wong et al [6] used a Real-valued Genetic Algorithm (RGA) and a Particle Swarm Optimization (PSO) algorithm combining fitness function technique to design a PID controller for AVR system. Adaptive Tabu Search (ATS) algorithm was employed to perform offline design of optimal PID parameters for AVR system in [7]. Bhatt and Bhongade [8] used evolutionary computational method based on PSO to optimally tune the parameters of PID for AVR system. To improve the performance of AVR, Salehinia et al [9] used a modified PSO called MOL algorithm to design a PID controller for improve AVR system. Also, Fractional Order PID (FOPID) controller designed in frequency domain using Chaotic Multi-objective Optimization for AVR system in (Indranil and Saptarshi).

III. METHODOLOGY

A. Automatic Voltage Regulator Circuit and Modelling

Figure 3 is a basic circuit diagram of a typical Automatic Voltage Regulator (AVR) system. The entire circuit operation of the AVR is minimize the error signal to acceptable value or zero.

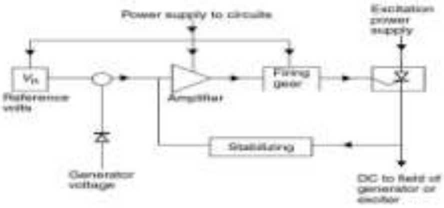

Fig. 3 Circuit diagram of a typical AVR system [10]

The circuit diagram is represented in block diagram form as shown in Fig. 4. The figure shows that the AVR composed basically of four elements. These are: amplifier, exciter, generator and sensor. The fifth element is the compensator (or controller).

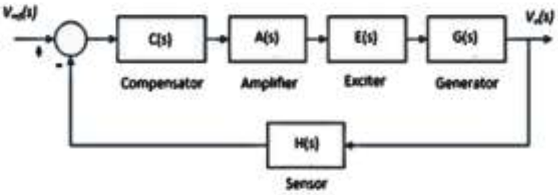

Fig. 4 Closed-loop block diagram of AVR system

The definitions and values of the AVR components gain parameters are defined in Table 1. The mathematical representations of the various elements of the AVR system are expressed in the form of transfer function (block gains) as given by:

$$A(s) = \frac{K_A}{1+\tau_A s} \qquad (1)$$

$$E(s) = \frac{K_E}{1+\tau_E s} \qquad (2)$$

$$G(s) = \frac{K_G}{1+\tau_G s} \qquad (3)$$

$$H(s) = \frac{K_S}{1+\tau_S s} \qquad (4)$$

Table 1 Definition of AVR components parameters

S/N	Definition	Symbol	Range of Value
1	Amplifier gain, time constant	K_A, τ_A	10 to 40, 0.02 to 0.1s
2	Exciter gain, time constant	K_E, τ_E	1 to 10, 0.4 to 1.0s
3	Generator gain, time constant	K_G, τ_G	0.7 to 1.0 (depends on load), 1.0 to 2.0s
4	Sensor gain, time constant	$K_s\ \tau_s$	1, 0.001 to 0.06s

Generally, the closed loop transfer function of a negative feedback control system for a given plant without the compensator (or Controller) is given by:

$$G_{close}(s) = \frac{G_p(s)}{1+G_p(s)H(s)} \qquad (5)$$

where $G_p(s)$, $H(s)$ is the plant transfer function, feedback transfer function respectively.

The closed loop transfer functions considering the extreme limit values of the parameters (Tables 2 and 3) without compensator is given by:

$$G_1(s) = \frac{0.007s+7}{8e^{-6}s^4 + 8.428e^{-3}s^3 + 0.429s^2 + 1.421s + 8} \qquad \text{.... (6)}$$

$$G_2(s) = \frac{24s+400}{0.012s^4 + 0.338s^3 + 2.486^2 + 3.16s + 401} \qquad \text{.... (7)}$$

Table 2 Definition of AVR components parameters for $G_1(s)$

S/N	Definition	Symbol	Range of Value
1	Amplifier gain, time constant	K_A, τ_A	10 , 0.02s
2	Exciter gain, time constant	K_E, τ_E	1 , 0.4s
3	Generator gain, time constant	K_G, τ_G	0.7), 1s
4	Sensor gain, time constant	$K_s\ \tau_s$	1, 0.001s

Table 1 Definition of AVR components parameters for $G_2(s)$

S/N	Definition	Symbol	Range of Value
1	Amplifier gain, time constant	K_A, τ_A	40, 0.1s
2	Exciter gain, time constant	K_E, τ_E	10, 1.0s
3	Generator gain, time constant	K_G, τ_G	1.0, 2.0s
4	Sensor gain, time constant	$K_s\ \tau_s$	1, 0.06s

B. Compensator Design

Two compensators were designed in this paper for two loop control configuration (Fig. 5) proposed to improve the response tracking performance of an AVR system of a generator. The MATLAB Control and Estimation Tools Manager is used for the design based on PID tuning and Nichols tuning. The designed compensators are given by:

$$C_1(s) = 170 \times \frac{(1+0.14s)(1+1.2s)}{s} \qquad (8)$$

$$C_2(s) = 4 \times \frac{(1+0.052s)(1+s)(1+0.5s)}{(1+0.1s)} \qquad (9)$$

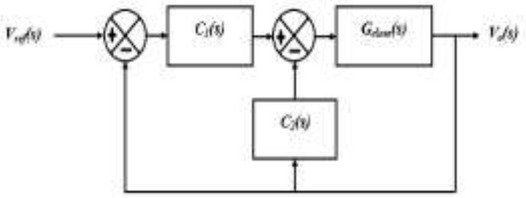

Fig. 5 Proposed two loop configurature for AVR system

IV. SIMULATION RESULTS AND DISCUSSION

1) ***Simulation Results for $G_1(s)$*:** Simulations are conducted considering the lowest of the limit values of the AVR system given in Eq. (6).

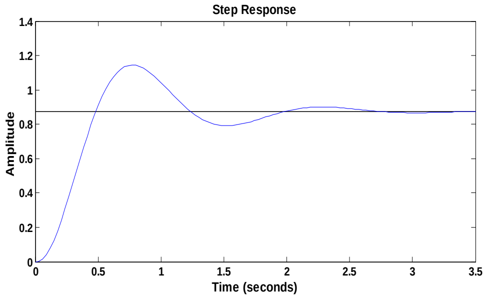

Fig. 6 Uncompensated step response of $G_1(s)$

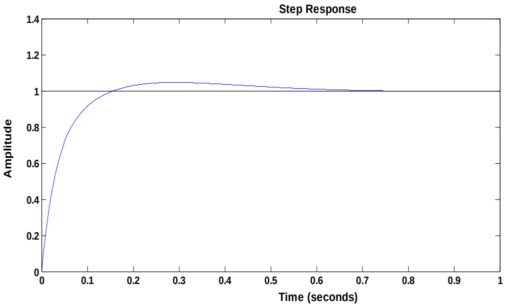

Fig. 7 Compensated step response of $G_2(s)$

2) ***Simulation Results for $G_2(s)$*:** Simulations are conducted considering the highest of the limit values of the AVR system given in Eq. (7).

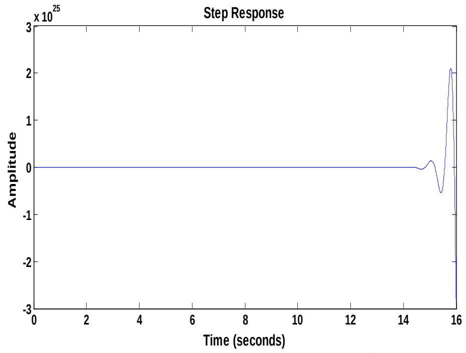

Fig. 8 Uncompensated step response of $G_2(s)$

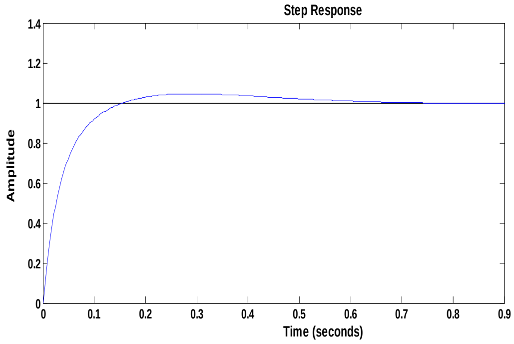

Fig. 9 Compensated step response of $G_2(s)$

The step response performance of simulation plots are presented in Table 4.

Table 4 Step response performance of the simulation result

Characteristics	Fig. 6	Fig. 7	Fig. 8	Fig. 9
Rise time (s)	0.314	0.0893	N/A	0.088
Settling time (s)	2.48	0.507	-	0.502
Overshoot (%)	30.9	4.64	N/A	4.55

3) ***Discussion:*** The results of the simulations carried out in MATLAB for the proposed two loop compensator structure for effective AVR system performance have been presented. During the operation of the system considering the uncompensated state of $G_1(s)$, the system is highly unstable (Fig. 6) with overshoot of 30.9%. In Fig. 8 also, the step response of $G_2(s)$ showed that the system is unstable. Hence, the need for a compensator. With the designed compensators added based on two loop configuration, the step response performance of the AVR system significantly improved as shown in Fig. 7 and Fig. 9. The performance analysis presented in Table 4 indicated that the proposed system is can effective regulate the voltage level of a generator within the performance range obtained from the simulation results in terms rise time, settling time, and percentage overshoot. This is because the simulation has considered the extreme values of the AVR system parameters. Hence, irrespective of the changing load, the proposed system can provide rise time within (0.0893s, 0.088s), settling time within (0.507s, 0.502s), and overshoot within (4.64%, 4.55%).

V. CONCLUSION

The paper has presented performance improvement of Automatic Voltage Regulation system using two loop configurations. The objective is to improve the tracking performance of an AVR system so as to reduce the error voltage and eliminated generator output voltage instability.

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