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Generator Exciter Control for Hydro Power

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Abstract: Myanmar has very rich hydropower resources with a total potential of around 100,000 MW. For obtaining efficient stability and good regulation of generator exciter control in hydropower system, automatic voltage regulators (AVR) are increasingly used.This paperpresents the modeling and control of the excitation system with the automatic voltage regulator (AVR) to improve stability on a micro hydro power plant. The objective is to consider a generator AVR system without stabilizer and PID controller and with stabilizer and PID controller. The PID controller automated tuning was used with a view for improving the response of the system and make comparison between the frequency deviation step response. The transfer function controller blocks use linear block model and control techniques in MATLAB/ Simulink environment.

Keywords: Hydropower, Synchronous Generator, Excitation. AVR, Stabilizer, PID controller.

1. INTRODUCTION

Hydro power system performance is affected by dynamic characteristics of hydraulic turbine and its governor system during any disturbance, such as presence of a fault, harmonics on the network, and rapid change of load and loss of a line. An ideal modeling of hydro power plant components, such as synchronous machine, turbine and its governing system is necessary to analysis the power system response during any disturbance on the system.

There are two main types of generators that are used for the hydropower production: (i) synchronous generators (commonly referred as alternators) and (ii) asynchronous generators (referred as induction generators).

Synchronous generators are used in the case of standalone schemes (isolated networks). In case of weak grids where the unit may have significant influence on the network synchronous generator are used. For grid connected schemes both types of generator can be used. In case grid is weak; Induction generators be used if there are two units, one of the unit can be synchronous so that in case of grid failure; supply could still be maintained. Unit size is limited to 250 kW. In case of stronger grids induction generators up to a 2000 kW or even higher can be used. In case of isolated units, small capacity Induction generators with variable capacitor bank may be used up to a capacity of about 20 kW especially if there is no or insignificant Induction motor load less than about 20%.

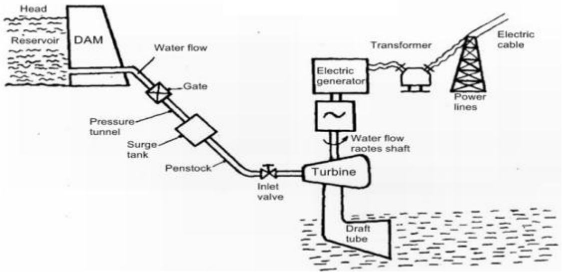

Figure 1. Layout of Hydropower plant

2. EXCITATION CONTROL SYSTEM IN GENERATORS

Types of excitation control system for speed control of the generator are:

(i) Automatic Voltage Regulator for Generator Excitation Control (AVR)
(ii) Power System Stabilizer (PSS)
(iii) PID Controller (PID)
(iv) AVR-PSS system with PID Controller

Automatic Voltage Regulator (AVR)

The automatic voltage regulator is used to regulate the voltage. It takes the fluctuate voltage and changes them into a constant voltage. The fluctuation in the voltage mainly occurs due to the variation in load on the supply system. The variation in voltage damages the equipment of the power system. The variation in the voltage can be controlled by installing the voltage control equipment at several places likes near the transformers, generator, feeders, etc. The voltage regulator is provided in more than one point in the power system for controlling the voltage variations.

Power System Stabilizer (PSS)

With addition of a power system stabilizer (PSS) as a supplementary controller to the AVR, this combined generator excitation control, could eliminate any negative effects on the damping of the post-fault oscillation. The control signal for the power system stability (PSS) is either the speed deviation, or the electric power, or the system frequency as additional feedback signals for introducing a damping torque control component. The speed signal is the most commonly used.

PID Controller

A PID controller is one of the most common controllers which calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable.
The PID controller is used to improve the dynamic response as well as to reduce or eliminate the steady-state error. The

derivative controller adds a finite zero to the open-loop plan transfer function and improves the transient response. The integral controller adds a pole at origin and increases the system type by one and reduces the steady-state error due to step function to zero.

AVR-PSS System with PID Controller

The main objective of AVR system is to reduce the error signal to zero or an acceptable value. Proportional - Integral - Derivative (PID) controller, one of the most successful controllers is used in the AVR - PSS system. Using AVR - PSS together with PID controller greatly improves the closed loop system damping ratio.

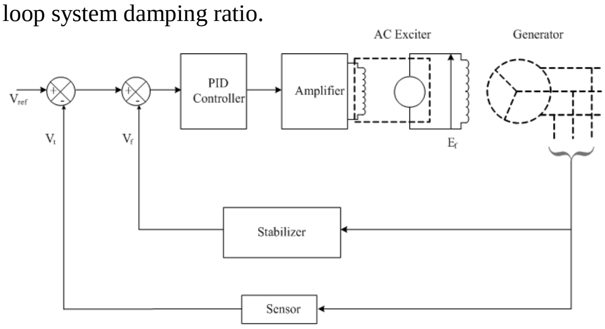

Figure 2. Schematic diagram of Generator Excitation system

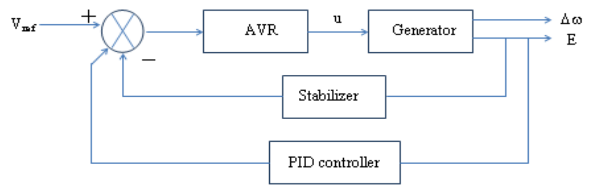

Figure 3. Block diagram of AVR-PSS system with PID

3. MATHEMATICAL MODELLING OF AVR SYSTEM

3.1 Amplifier Model

Transfer function of an amplifier is:

$$TF_A = \frac{K_a}{1 + s\tau_a}$$

where, K_a and τ_a represent the gain and time constant of the amplifier. The values of K_a are in the range of 10 to 40 and τ_a are in the range of 0.02 to 0.1 sec.

3.2 Exciter Model

Transfer function of an exciter is:

$$TF_E = \frac{K_e}{1 + s\tau_e}$$

where, K_e and τ_e represent the gain and time constant of the exciter. The values of K_e are in the range of 1 to 2 and τ_e are in the range of 0.4 to 1.0 sec.

3.3 Generator Model

Transfer function of a generator is:

$$TF_G = \frac{K_g}{1 + s\tau_g}$$

where, K_g and τ_g represent the gain and time constant of the generator. The values of K_g are in the range of 0.7 to 1.0 and τ_g are in the range of 1.0 to 2.0 sec from no load to full load.

3.4 Sensor Model

Transfer function of a sensor is:

$$TF_S = \frac{K_s}{1 + s\tau_s}$$

where, K_s and τ_s represent the gain and time constant of the sensor. The values of K_s are in the range of 0.02 to 1.0 and τ_s are in the range of 0.01 to 2.2 sec.

3.3 Stabilizer Model

Transfer function of a sensor is:

$$TF_F = \frac{K_f}{1 + s\tau_f}$$

where, K_f and τ_f represent the gain and time constant of the sensor. The values of K_f is 1.0 and τ_f are in the range of 0.01 to 0.06 sec.

3.6 PID Controller Model

There are several methods for tuning a PID loop. The most effective methods generally involve the development of some form of process model, choosing P, I, and D based on the dynamic model parameters. Manual tuning methods can be relatively inefficient, particularly if the loops have response times on the order of minutes or longer.

The choice of method will depend largely on whether or not the loop can be taken "offline" for tuning, and on the response time of the system. If the system can be taken offline, the best tuning method often involves subjecting the system to a step change in input, measuring the output as a function of time, and using this response to determine the control parameters.

Transfer function of a PID controller is:

$$TF_{\text{PID}} = K_P + \frac{K_I}{s} + K_D s$$

where, K_P, K_I and K_D represent the gain constants of PID controller.

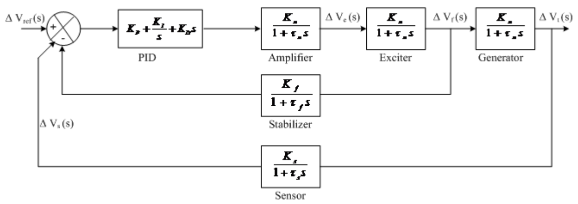

Figure 4. Transfer Function Model of Generator Exciter System with PID Controller

3.7 Calculation of AVR Parameters

For control system stability, the Routh-Hurwitz array was constructed and chooses the amplifier gain constant Ka. Assume AVR parameters as follow:

Amplifier gain constant, K_a	-
Amplifier time constant, τ_a	0.05
Exciter gain constant, K_e	1
Exciter time constant, τ_e	0.4
Generator gain constant, K_g	1
Generator time constant, τ_g	0.5
Sensor gain constant, K_s	1
Sensor time constant, τ_s	0.01

Open-loop transfer function of AVR is

$$G(s)H(s) = \frac{K_a(1)(0.1)}{(1+0.05s)(1+0.4s)(1+0.5s)(1+0.01s)}$$

$$= \frac{10000K_a}{s^4 + 124.5s^3 + 2545s^2 + 9600s + 10000}$$

The characteristic equation is

$$1 + G(s)H(s) = 1 + \frac{10000K_a}{s^4 + 124.5s^3 + 2545s^2 + 9600s + 10000} = 0$$

$$\therefore s^4 + 1245s^3 + 2545s^2 + 9600s + 10000 + 10000K_a = 0$$

The Routh-Hurwitz array for this polynomial is

$$\begin{array}{l|ccc} s^4 & 1 & 2545 & 10000+10000K_a \\ s^3 & 124.5 & 9600 & 0 \\ s^2 & 2467.89 & 10000+10000K_a & 0 \\ s^1 & 504.48K_a-9095.52 & 0 & \\ s^0 & 10000+10000K_a & & \end{array}$$

From the s^1 row, to find K_a for control system stability,

$504.48K_a – 9095.52 < 0$

$K_a < 18.03$

For K_a = 18.03, the auxiliary equation from the s^2 row,

$2467.89s^2 + 10000 + 10000 (18.03) = 0$

$s = \pm j8.78$

Since, for K_a = 18.03, a pair of conjugate poles on the jω axis, and the control system is marginally stable.

Closed-loop transfer function of AVR is

$$\frac{G(s)}{1+G(s)H(s)} = \frac{V_t(s)}{V_{ref}(s)}$$

$$= \frac{0.01K_a(s+100)}{s^4 + 124.5s^3 + 2545s^2 + 9600s + 10000 + 10000K_a}$$

For the system to be stability, the amplifier gain of K_a should be chosen less than 18.03.

Choosing K_a= 11, the steady-state response is

□□,□□ = □□□□→0 □□□(□) =
□

$$V_{t,ss} = \frac{11}{1+11} = 0.9167$$

The steady-state error is

$V_{e,ss}$ = 1.0- 0.9167 = 0.0833

In order to reduce the steady-state error, the amplifier gain must be increased, which results in an unstable control system. Therefore, choose K_a = 11.

For the AVR parameters to get the lowest steady-state error, the calculation result shows in Table 1.

Table 1. Calculation result of AVR parameters

Quality	Transfer function	
Amplifier	$TF_A = \frac{K_a}{1+s\tau_a}$	$TF_A = \frac{11}{1+0.05s}$
Exciter	$TF_E = \frac{K_e}{1+s\tau_e}$	$TF_E = \frac{1}{1+0.4s}$
Generator	$TF_G = \frac{K_g}{1+s\tau_g}$	$TF_G = \frac{1}{1+0.5s}$
Sensor	$TF_S = \frac{K_s}{1+s\tau_s}$	$TF_S = \frac{1}{1+0.01s}$
Stabilizer	$TF_F = \frac{K_f}{1+s\tau_f}$	$TF_F = \frac{0.4s}{1+0.04s}$
PID	$G_C(s) = K_P + \frac{K_I}{s} + K_D s$	$G_C(s) = 1 + \frac{0.25}{s} + 0.28s$

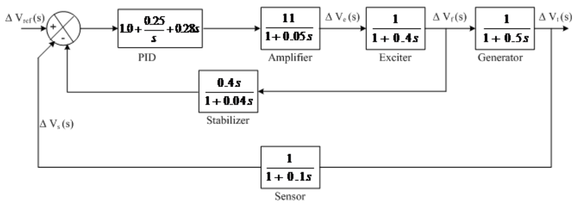

Figure 5. Block diagram of AVR-PSS with PID controller

4. RESULTS AND DISCUSSIONS

4.1 Simulink Model and Result of Simple AVR

Figure 6 shows an AVR system model in MATLAB simulink, where a combined simulation block model was constructed for the amplifier, exciter, and generator cases in order to obtain their respective step response.

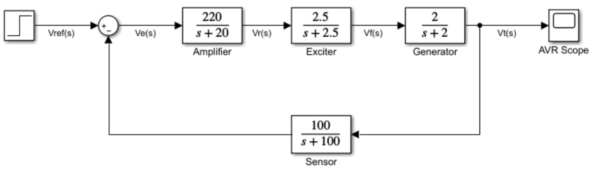

Figure 6 (a) Simulink model of simple AVR system

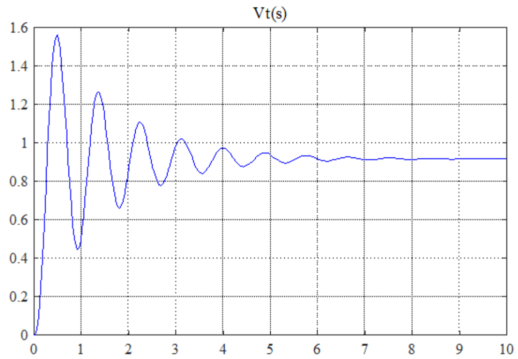

Figure 6(b) Output Waveform of Simple AVR

From Figure (b), the result shows that for an amplifier gain K_a = 11, the response is highly oscillatory, with a large overshot and a long settling time. Since the steady-state error is 8.33%, there is high steady-state error and unsatisfactory transient response.

4.2 Simulink Model and Result of AVR with Stabilizer

Figure 7 shows an AVR with stabilizer in MATLAB simulink, where a combined simulation block model was constructed for AVR and stabilizer cases in order to obtain their respective step response.

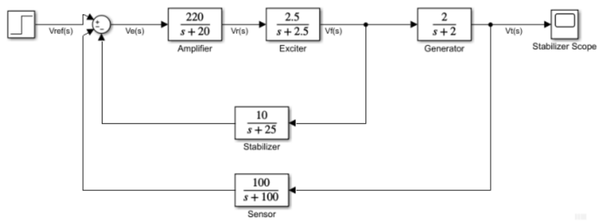

Figure 7(a) Simulink Model of an AVR with Stabilizer

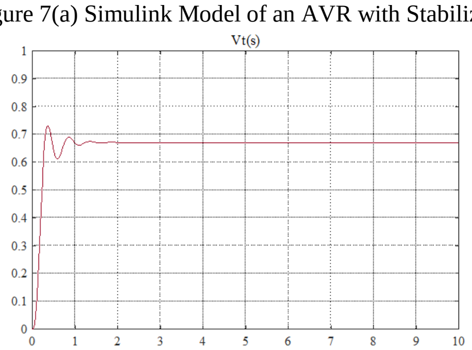

Figure 7(b) Output Waveform of AVR with Stabilizer

From Figure 7(b), the result shows that a very satisfactory transient response with steady state error of 5.4% and a settling time of approximately 2.5 seconds.

4.3 Simulink Model and Result of AVR with PID Controller

Figure 8 shows an AVR system model with PID controller without stabilizerin MATLAB simulink, where a combined simulation block model was constructed for AVR and PID controller cases in order to obtain their respective step response.

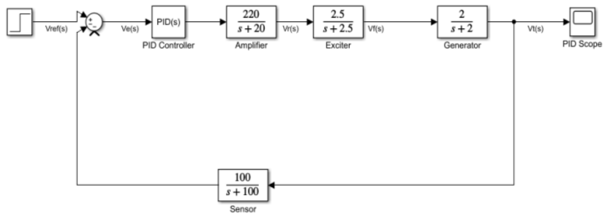

Figure 8(a) Simulink Model of an AVR with PID Controller

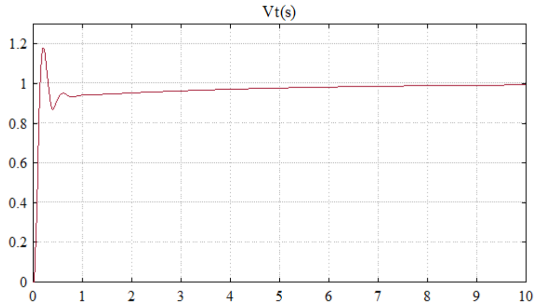

Figure 8 (b) Output Waveform of AVR with PID Controller

From Figure 8(b), the result shows that a very satisfactory transient response with an overshoot and a settling time of approximately 1.7 seconds.

4.4 Simulink Model and Result of AVR-PSS with PID Controller

Figure 9 shows an AVR system model with PID controller and stabilizer in MATLAB simulink, where a combined simulation block model was constructed for AVR, stabilizer and PID controller cases in order to obtain their respective step response.

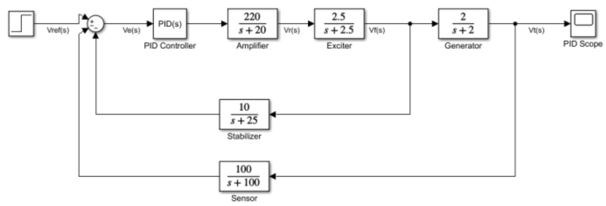

Figure 9(a) Simulink Model of AVR-PSS with PID controller

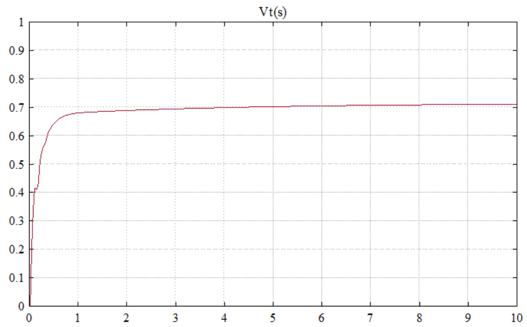

Figure 9(b) Output Waveform of AVR-PSS with PID controller

From Figure 9(b), a proportional gain K_P = 1.0, an integral gain of K_I = 0.25 and a derivative gain of K_D = 0.28 is tuned and it is found to be satisfactory. The response settles in about 2 seconds with no overshoot. The PID controller reduces the steady-state error to zero.

4.4 Simulink Model and Result of Overall AVR System

Figure 10 shows an overall AVR system model with AVR, stabilizer, and PID controller in MATLAB simulink.

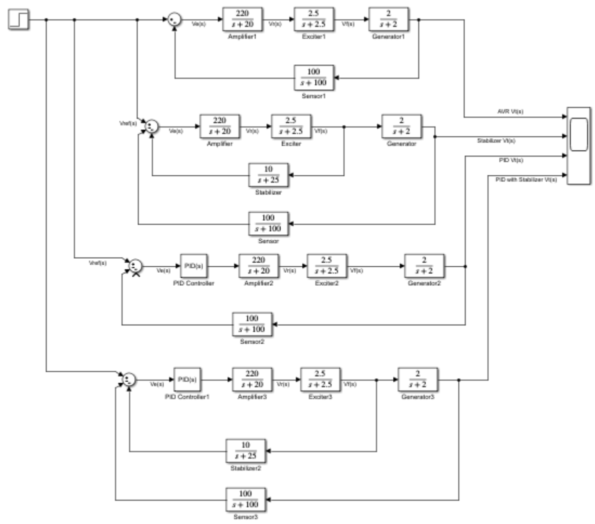

Figure 10(a) Simulink Model of an Overall AVR System

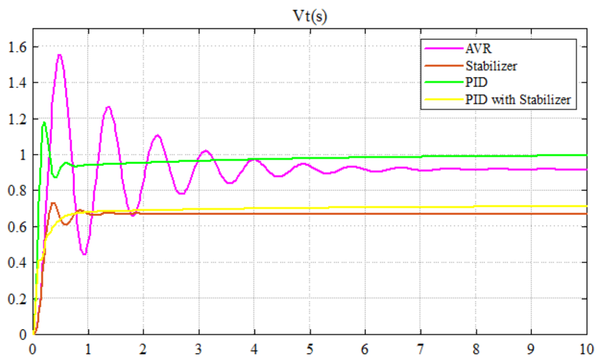

Figure 10(b) Output Waveform for Overall AVR System

The AVR was simulated with stabilizer and PID controller. It was observed that the AVR shows 1 pu output voltge with PID controller.It also shows that low frequency and less oscillation. The reliability of generating system is determined by its ability for maintaining voltage and frequency within permissible limit. It can be concluded that the generating system for AVR with PIDcontroller shows satisfactory performance.

5. CONCLUSION

In this paper, application of PID controller and stabilizer in exciter control system with variation in its time constant and gain was examined. By using PID controller and stabilizer, not only the system will have an appropriate steady-state error but also provides good dynamic response with a less over shoot for the voltage terminal. Finally, the AVR system was simulated and effects of some parameters were investigated.

The hydraulic transient analysis of the hydropower plant at different values of AVR with PID controller has been carried out. From the obtained results at different value of gain parameters, it is observed that the effect on hydraulic transient is more significant when the AVR with PID controller as compare to simple AVR. Therefore, automatic voltage regulator with PID controller is is recommended for stable operation of the hydropower plant.

The aim is to demonstrate the potential advantages of these relatively new techniques for adaptive approach to controller design and simulation, while highlighting some of the limitations and areas of potential difficulty for practical application.

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