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Study, Design and Control of AGC and AVR for Multi Area Interconnected hydroelectric Power system

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***Abstract*: - This paper presents study, design and control of Automatic generation control (AGC) and Automatic voltage regulator (AVR) for three area interconnected hydroelectric power system using PID controller. Due to the change of load as well as power flow in tie-line, the frequency, active power, voltage and reactive power are varying dynamically. So a robust control is required for maintaining the frequency and voltage profile within permissible value. AGC controls the frequency and active power flows in the system whereas the AVR maintains the voltage profile and reactive power flow in the system. This paper presents the application of PID controller for improving the performance characteristics of the controller (steady state error, settling time and overshoot value) by using Matlab/Simulink software.**

***Keyword:* - Multi area power system, frequency, voltage, active power and Tie line power response, AGC, AVR.**

I. INTRODUCTION

Now a day's more than 17% of electrical energy produced in the World comes from hydroelectric power system. A power system normally consists of complex multi-area power system with domestic, industrial and commercial loads. For proper operation, the system operates at a constant frequency and voltage. However, the load demand is never be constant, due to which frequency and voltage do not remain constant.

Automatic generation control (AGC) is a system for adjusting the power output of multiple generators at different power plants, in response to changes in the load. Frequent adjustments of the output of generators are necessary as the grid requires that generation and load are continuously balanced.

maintain the frequency and voltage deviation. The conventional controller is given better performance and acceptably accurate results. But the major limitation of this paper is only considered a single area power system and gain values of controllers are constant for load changes.

[Karna et al, 2019] discussed load frequency control in a two area interconnected power system using PID controller. It has shown good performance during transient period with less overshooting and settling time period of the system frequency. However, this paper didn't mention about the voltage, reactive power. [Reddy et al, 2017] presented automatic generation control of multi-area thermal power system by using Active Disturbance Rejection Control for maintaining a nominal frequency within allowable. The authors concluded that their control method is more optimal than a previous conventional controller. However, the authors did not indicate the controller capacity to control terminal voltage and reactive power of the system. [Sambariya et al, 2016] worked on the Load Frequency Control by using Fuzzy Logic Based Controller for Multi-area Power System. In this work, fuzzy logic base controller is considered for load frequency control. But this paper didn't mention about the voltage, reactive power as well as the tie line power response from the simulation.

In this paper, design and control of multi area interconnected power system using AGC and AVR with the robust and multidirectional modern controller to control terminal voltage, frequency, active power, reactive power and tie line power magnitude of multi area interconnected power system at a specified level. And also, the result will be analyzed and simulated in Matlab/Simulink.

II. DESIGN AND MODELING OF CONTROLLER

A. *Automatic Voltage Regulator*

Voltage stability is the ability of a power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and after disturbance, change in load demand, or change in system conditions. The main sources of reactive power in synchronous machines are generators, capacitors, and reactors. If the field current is raised, the generated electromotive force will be increased. Then, the reactive power of the generator ~~is~~ increases to a new equilibrium so that the terminal voltage of the system increases to the desired value. AVR is the generator excitation system ~~control~~ that regulates the terminal voltage of the synchronous machine and controls the reactive power of the system [Singh et al, 2011]. The AVR system consists of four major components and the components are modelled as follows:

Amplifier model: The amplifier feds the error signal to the exciter and is represented by the following transfer function:

$$\frac{V_R(s)}{Ve(s)} = \frac{Ka}{1 + sTa}$$

Where, *Ka* is amplifier constant and *Ta* is time constant (Describe all the variables. Write the eq. with appropriate indices. Give captions to each eq.)
Exciter model: The exciter provides excitation field to the exciter so that an emf is induced to supply the excitation of the major generator.

$$\frac{V_F(s)}{V_R(s)} = \frac{Ke}{1 + sTe}$$

Where, Te time constant and Ke is exciter gain
Generator field model: The generator field produces the voltage of the generator and represented by the following transfer function.

$$\frac{Vt(s)}{V_F(s)} = \frac{Kg}{1 + sTg}$$

Where, Kg generator gain and Tg is time constant (Describe all variables)

Sensor model: The sensor compares the output voltage with a dc set point signal to generate the error signal through a bridge rectifier.

$$\frac{Vs(s)}{Vt(s)} = \frac{Kr}{1 + sTr}$$

Where, *Kr* is rectifier gain constant and *Tr* rectifier time constant. (Describe all variables and edit indices appropriately.)
Controller (PID): To improve the dynamic response and to achieving zero steady-state error. The transfer function of a PID controller can be written as:

$$G_{PID}(s) = K_p + \frac{K_i}{s} + K_d s$$

The block diagram of synchronous generator with AVR is shown in Fig.1:

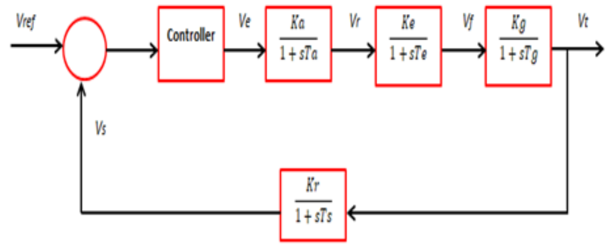

Fig. 1: Block diagram of AVR

B. *Automatic Generation Control*

The main objective of power system operation and control is to maintain continuous supply of power with an acceptable quality, to all the consumers in the system. The system will not be in equilibrium, when there is unbalance between the power demand and the power generated. A large frequency deviation can damage equipment, degrade load performance, cause the transmission lines to be overloaded and can interfere with system protection schemes and ultimately lead to an unstable condition for the power system [Nath et al 2016]. The main objectives of the AGC are to eliminate the deviation of frequency, active power, tie-line power in a short period of time and to allocate generation ~~in~~ economically [Reddy et al, 2017]. A simple block diagram of AGC for a single area power system is sown in Fig. 2:

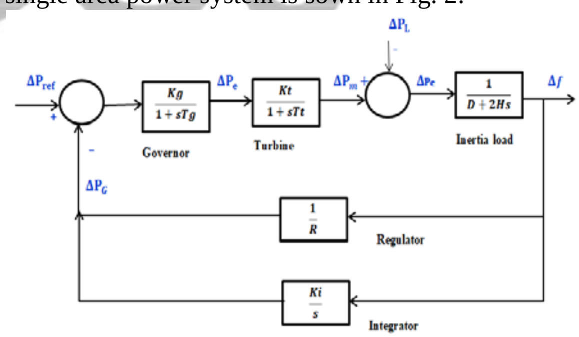

Fig. 2: Block diagram of AGC

C. *Multi Area Interconnected System*

Power systems have variable and complicated characteristics and comprise different control parts and also many of the parts are nonlinear. These parts are connected to each other by tie lines and need controllability of frequency and power flow [Pujan et al 2013]. [Dabur *et al, 2011]* presents AGC of a four area interconnected thermal power system with demand side management to reduce the total load demand of power systems during periods of peak demands in order to maintain the security of the system. [Parmar *et al., 2011]* have implemented LFC of a two area power system with a DC link in parallel with AC tie line. The proposed LFC and AVR loops in this paper contribute to the satisfactory operation of the power system by maintain the frequency and terminal voltage of the synchronous generator at prescribed limits. A multi area interconnected system is represented in a ring fashion and in a longitudinal manner [Nath et al, 2015]. A simplified representation for three area interconnected system is sown in Fig. 3:

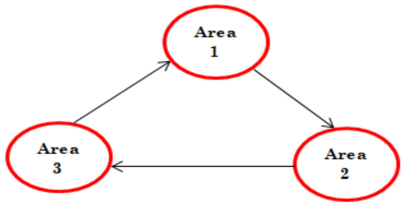

Fig. 3: Representation of Three areas interconnected system

Tie line power flow from area 1 to area 2 can be written as:

$$P_{tie,12} = \frac{E_1 E_2}{X} sin(\delta_1 - \delta_2)$$

Tie line power flow from area 1 to area 3 can be written as:

$$P_{tie,13} = \frac{E_1 E_3}{X} sin(\delta_1 - \delta_3)$$

Tie line power flow from area 3 to area 2 can be written as:

$$P_{tie,32} = \frac{E_3 E_2}{X} sin(\delta_3 - \delta_2)$$

Where δ is load angle, X is transmission impedance and E_i is voltage magnitude of each power.

Linearizing about an initial operating point we have:

$$\Delta P_{tie,ij} = T_{ij}\,\Delta\delta_{ij} = T_{ij}\,(\delta_i - \delta_j)$$

Where synchronizing coefficient

$$T_{ij} = \frac{|E_i||E_j|}{P_{ri}\,X}\cos\big((\delta_i - \delta_j\big)$$

$$\Delta P_{tie,ij} = 2\pi T_{ij}\,(\Delta f_i - \Delta f_j)$$

A simplified representation of AGC and AVR for three area interconnected system is sown in Fig. 4:

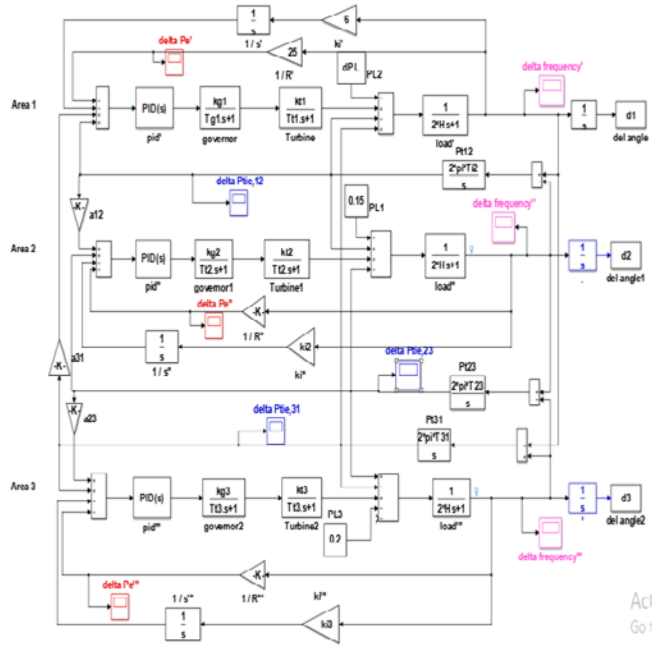

Fig. 4: Block diagram of three area interconnected system

D. AGC And AVR Relation

The relationship between of AVR and AGC controller are considered independently. The main objective of an AVR is to hold the terminal voltage magnitude of a synchronous generator at a desired value [6]. This e.m.f determines the magnitude of real power. When we include the small effect of voltage on real power, we get the following equation:

$$\Delta P_e = P_s \Delta\delta + K_2 E'$$

Where P_e is real power and Ps is synchronizing power coefficient. By including the small effect of rotor angle upon generator terminal voltage, we may write

$$\Delta V_t = K_5 \Delta\delta + K_6 E'$$

Finally, modifying the generator field transfer function to include the effect of rotor angle, we may express the stator e.m.f as

$$E' = \frac{K_g}{1 + T_g}(V_f - K_4 \Delta\delta)$$

The constants K_1, K_2, K_3, K_4, and K_6 are usually positive; however, K_5 may take either positive or negative value depending on the impedance. The overall block diagram of AGC and AVR

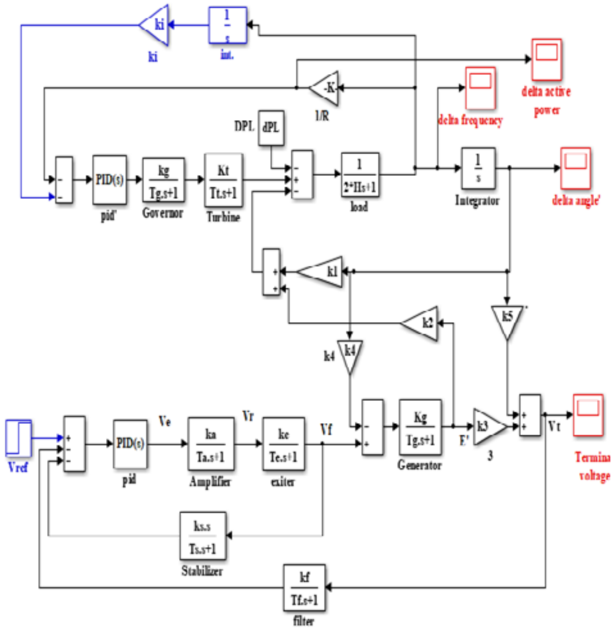

Fig. 5: Block diagram of AGC and AVR loop

III. SIMULATION RESULT AND DISCUSSION

The following operating conditions for a synchronous machine connected to an infinite bus through transmission line of sample hydroelectric power system to compare the performance of the angle, speed, frequency, active power and voltage of the generator chose with a reference.

Table 1: Assumptions used in the Simulation for AGC

Quantity	Area 1	Area 2	Area 3
Governor time constant	T_{g1} = 0.5 s	T_{g2} = 0.5 s	T_{g3} = 0.5 s
Turbine time constant	T_{t1} =0.05s	T_{t1} =0.04s	T_{t1}=0.05s
Inertia constant	H_1 = 2.6	H_1 = 3.14	H_1 =2.5
Speed regulation	R_1 =0.04	R_1 =0.05	R_1 =0.04
Load disturbance (pu)	ΔP_{L1}= 0.1	ΔP_{L1}=0.15	ΔP_{L1}= 0.2
Tie line coefficient (pu)	$\Delta T12$=0.011	$\Delta T23$=0.006	$\Delta T31$= 0.018
Normal frequency	f_1 =50Hz	f_1 =50Hz	f_1 =50Hz

Table 2: Assumptions used in the simulation for AVR

Quantity	Gain	Time constant
Amplifier	K_a = 60	T_a = 0.02 s
Exciter	K_e = 1	T_e = 0.4
Generator	K_g = 0.7	T_g = 1
Filter/sensor	K_f = 1	T_f = 0.05

Table 3: Assumptions used in the simulation for PID

Quantity	Gain
PID controller	K_P = 0.1
	K_D = 0.07
	K_I = 0.06

- ***The simulation result of combination of AGC and AVR***

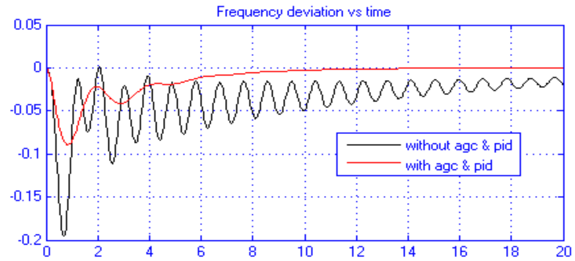

Fig. 6: Frequency deviation response of AGC with AVR

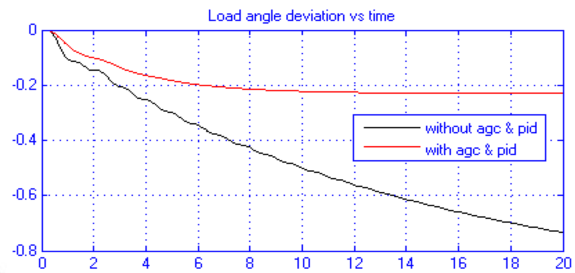

Fig.7: Load angle deviation response of AGC with AVR

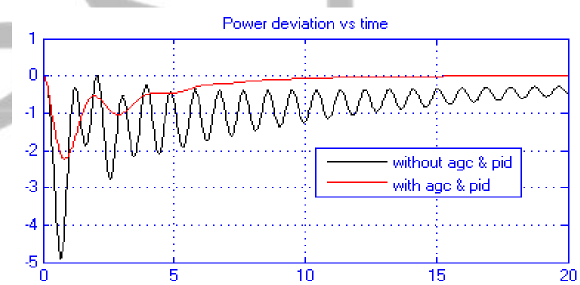

Fig. 8: Active power deviation response of AGC with AVR

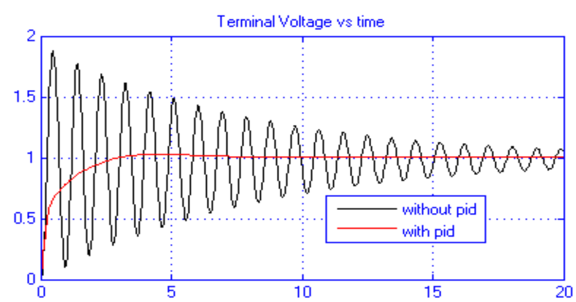

Fig.9: Terminal voltage response of AGC with AVR

Table 4: Comparisons of the simulation result for the output response of AGC with AVR.

Mode	Controller	Settle time	Rise time	Over shoot	SS error
Δf	without agc & pid	30s	1s	-0.2	-0.003

	with agc & pid	4s	1s	-0.09	0
$\Delta\delta$	without agc & pid	40s	40s	0	-0.9
	with agc & pid	4s	-0.23	0	-0.23
ΔPe	without agc & pid	30s	0.9s	-0.5	-0.2
	with agc & pid	4s	0.9s	-0.21	0
Vt	without agc & pid	35s	0.5	1.8	-0.01
	with agc & pid	2.5s	0	0	0

- ***The simulation result of three area interconnected system***

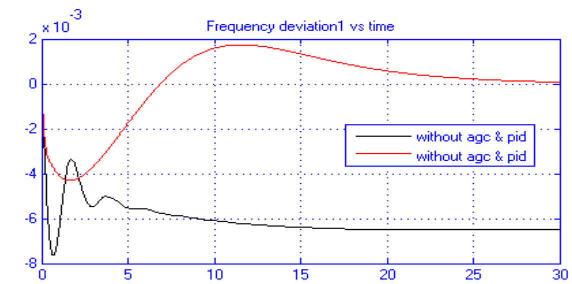

Fig. 10: Frequency deviation response for Area 1

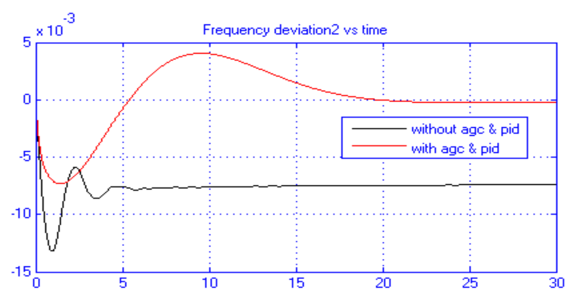

Fig.11: Frequency deviation response for Area 1

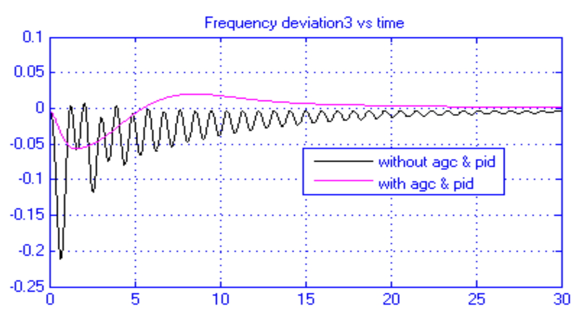

Fig.12: Frequency deviation response for Area 2

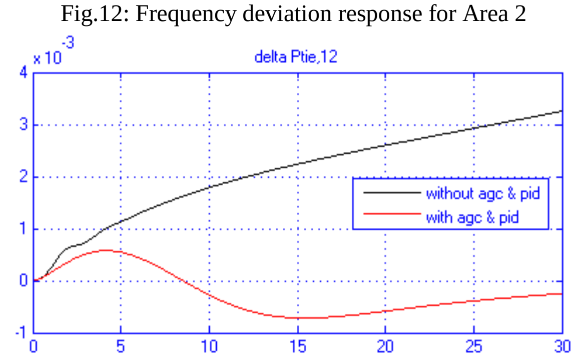

Fig.13: Tie line Power deviation response for Area 12

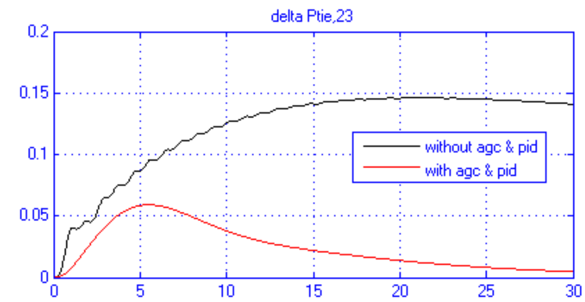

Fig. 14: Tie line Power deviation response for Area 23

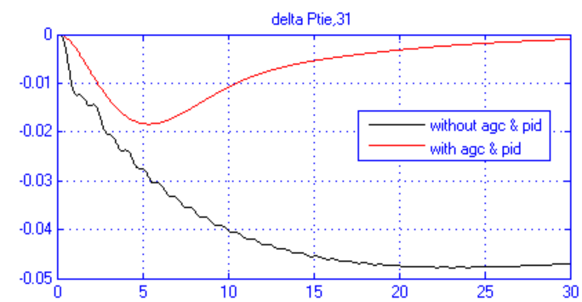

Fig.15: Tie line Power deviation response for Area 31

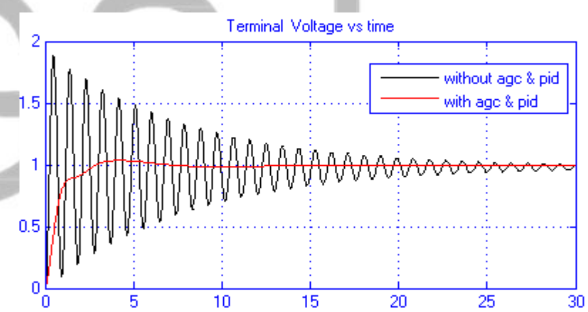

Fig.16: Terminal voltage response of interconnected system

Table 5: Comparisons of simulation result for the output response of three area interconnected system

Mode	Controller	Settle time	Rise time	Over shoot	SS error
$\Delta f1$	without agc & pid	7s	1s	-0.008	-0.006
	with agc & pid	25s	2s	-0.004	0
$\Delta f2$	without agc & pid	5s	1s	-0.012	-0.01
	with agc & pid	20s	2s	-0.007	0
$\Delta f3$	without agc & pid	30ss	1s	-0.2	-0.01
	with agc & pid	12s	2s	-0.05	0
$\Delta Pt,12$	without agc & pid	30s	30s	0.003	0.003
	with agc & pid	25s	15	0	0
$\Delta Pt,23$	without agc & pid	20s	20s	0.15	0.15
	with agc & pid	25s	5s	0.05	0

$\Delta Pt,31$	without agc & pid	15s	15s	-0.045	-0.045
	with agc & pid	20s	5s	-0.02	0
Vt	without agc & pid	30s	1s	1.8	-0.01
	with agc & pid	2s	1s	0	0

IV. CONCLUSION

The aim of this paper was to study, design and evaluate the performance of AGC, and AVR control for multi area interconnected hydroelectric power system using PID controller. The conventional controller (LFC with PID) method exhibits relatively poor dynamic performance as evidenced by large overshoot and steady state error. So, the proposed modern controller used in this work provides stabile the terminal voltage, tie line power, active and reactive power overshoot, zero steady state error, rise time and settling time.

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BIOGRAPHIES

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He was learned from primary to preparatory school in Bahirdar. He graduated from Adama Science and Technology University in B.Sc. by Electrical Engineering specialized Control System Engineering in 2013G.C and finished a Master degree in June, 2016G.C with Electrical Engineering specialized Power system Engineering. And now studied PhD. from Bahirdar Institute of Technology, Ethiopia by Power System Engineering. My employment experience included the lecturer on the Bahirdar Institute of Technology. My special fields of interest include teaching modern control systems, machine, and other related courses.