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Load Frequecny and Voltage Control of Two Area Interconnected Power System using PID Controller

Gurjit Singh
Postgraduate scholar,
Baba Banda Singh Bahadur Engineering College,
Fatehgarh Sahib.

Jaspreet Kaur Dhami
Assistant Professor,
Electrical Engineering Department,
Baba Banda Singh Bahadur Engineering College,
Fatehgarh Sahib

***Abstract*—In this paper, optimal tuning of Proportional-Integral-Derivative (PID) controller for both Load Frequency Control (LFC) and Automatic Voltage Regulator (AVR) of two area interconnected power system is presented. The LFC controls the frequency and thereby the active power flows in the system whereas the AVR maintains the voltage profile thereby controlling the reactive power flow in the system. A step disturbance is applied in the Area 1 and the dynamic performance of the system is analyzed by analyzing the system frequency, tie line power flow and the system voltage. The main objective is to suppress all the fluctuations of the system due to the applied step disturbance and get back the frequency and voltage at nominal values. The simulation result shows the effectiveness of the designed system by comparing the system with conventional PI controller and conventional Integral controller.**

Keywords—Automatic Generation Control (AGC), Load Frequency Control (LFC), Automatic Voltage Regulator (AVR), PID controller, Tie line control, Frequency response, Voltage response, Interconnected Power System.

I. INTRODUCTION

In recent years, power system stability has been recognized as an important problem. It is a known fact that the electrical power system demand and system load is not constant but keep on changing. For effective operation of the power system, the power generated should change in accordance with the load perturbations. In an interconnected system, every subsystem is required to regulate the power output of its installed generators in response to changes in system frequency and/or establish interchange with other areas within predetermined limits. This process is termed Load Frequency Control. It is also necessary to maintain the terminal voltage of a synchronous generator at a specified level. This is accomplished with the use of Automatic Voltage Regulator. [1][2]. The speed governor in the generating stations is to adjust the frequency and real power and hold their values at the specified limits. In other hand each generator in the generating station is equipped with an excitation control to regulate the voltage magnitude and reactive power at the nominal values.

The frequency control and voltage control is possible simultaneously and independently because there is negligible cross coupling between the LFC block and the AVR block. The reason for negligible cross coupling between the blocks is due to the fact that the time constant of the excitation system is much smaller than the time constant of the prime mover and also the transient of excitation system decay much faster and does not affect the LFC dynamic.

Research in AGC system span in various areas. For instance, some papers focus on reducing the Area Control Error (ACE) to zero, some on controlling the frequency bias factor while some papers discuss the role of decentralized generation. Apostolopoulou *et at.* have provided a detailed systematic way to determine the power allocated to each generator participating in AGC in real time [3]. Dabur *et al.* 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 [4]. Zwe-Lee Gaing has designed a novel technique to implement Particle Swarm Optimization algorithm for optimal tuning of PID controllers used in the AGC system. The author has also compared the PSO based controller design with the Genetic Algorithm [5]. Kouba *et al.* provided a optimal PID controller tuning technique based on Particle Swarm Optimization. The authors have provided a comparison of their technique with the traditional Ziegler-Nichols method, Genetic Algorithm and Bacterial Foraging optimization [6]. Parmar *et al.* have implemented LFC of a two area power system with a DC link in parallel with AC tie line [7]. 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. Soundarrajan *et al.* used PSO based tuning of PID controller for the LFC and AVR system of a single area power system. The authors have also compared the use of PSO based PID controller with conventional PID, Fuzzy and GA based controllers [8]. Jeevithavenkatachalam *et al.* used PSO technique to optimize the integral controller gains for the AGC of the interconnected two area power system. The authors have considered the integral square of the error and the integral of time multiplied absolute value of the error performances indices of the system. The authors have also provided a comparison of their work with artificial intelligent controller [9].

This paper is organized as follows, Section II describes the linearized model of an AGC system based on which the simulation model/system was developed and analyzed, Section III presents the system considered in this paper work, Section IV describes the tuning of the PID controller used for the LFC and AVR loops, and Section V demonstrates the simulation results and comparison of PID controller based results with PI controller and Integral control scheme based results. The conclusion of the work is derived in section VI followed by the future scope.

II. LINEARIZED MODEL OF THE SYSTEM

A. *Automatic Voltage Regulator (AVR)*

The AVR loop is assigned to control the magnitude of the terminal voltage of the generator, which in turn, maintains bus voltage manipulating the reactive power output. The process involves continuous sensing of the terminal voltage, its rectification, smoothening and comparison with a preset dc reference. Then this compared result “error voltage”, after amplification and shaping, is used to control the alternator field excitation.

B. *Load Frequency Control (LFC)*

The LFC loop regulates the real power output and the corresponding frequency of the generator power output. The primary LFC loop senses the turbine speed and controls the operation of the control valves of turbine power input via the speed governor. This loop is relatively faster than the secondary LFC loop which senses the electrical frequency of the generator output and maintains proper power interchange with the interconnections. This loop is slower in response and is insensitive to rapid load and frequency changes. Usually, the primary LFC loop operates in order of seconds while secondary LFC loop operates in order of minutes.

The operational block diagram of a LFC and AVR loop of AGC system is shown in Fig. 1.

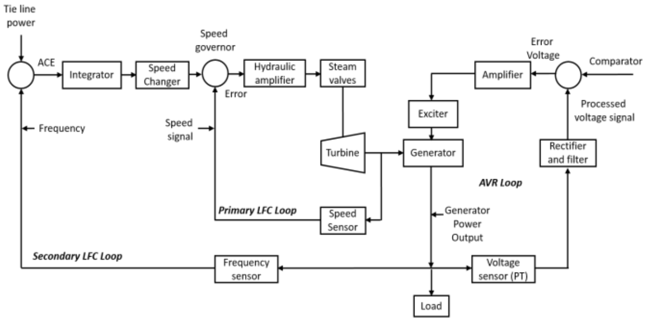

Fig. 1. Combined LFC and AVR loops of a Generator

The LFC and AVR loops are designed to operate around normal state with small variable excursions. The loops may therefore be modeled with linear, constant coefficient differential equations and represented with linear transfer functions [10].

III. SYSTEM INVESTIGATED

The AGC is applied to a two area interconnected power system, each area consisting of a thermal generating unit of non-reheat type. The two areas are interconnected with the help of a tie-line. The same arrangement can be applied for a multi-area interconnected power system. The simulation models of LFC and AVR is constructed based on the block diagram approach as proposed by Hadi Sadaat [2]. The Simulink model of the combined LFC and AVR system is shown in Fig. 2.

IV. CONTROL STRATEGY AND CONTROLLER

The conventional control strategy for the problem of AGC is to take the integral of area control error as the control signal. In this paper work, the uncontrolled system is subjected to a steady state error for a step load change, and to reduce this steady state error, a negative feedback signal from the frequency deviation is introduced. A PID controller is used to improve both the transient and steady state performances. The PID controller is applied separately to the LFC block and the AVR block of the AGC system. This controller with its three term functionality covering treatment to both transient and steady state responses, offers the simplest yet most efficient solution to many real world control problems [11]. The transfer function of a standard PID controller is given by

$$G(s) = K_P + K_I \frac{1}{s} + K_D s \tag{1}$$

The “three term” functionalities of the PID controller are highlighted by the following:

- The proportional term - providing an overall control action proportional to the error signal through the all-pass gain factor.
- The integral term – reducing steady state errors through low frequency compensation by an integrator.
- The derivative term – improving transient response through high frequency compensation by a differentiator.

The tuning of the controller can be achieved with the following three steps [12]:

Step 1: Set K_D and K_I to zero. By trial and error select K_P that results in a stable oscillatory performance. In case of multi input system, select K_P that results near to critical damping.

Step 2: Vary K_D with K_P fixed so as to reduce the oscillations and result in reasonable overshoot and settling time.

Step 3: Till here the transients are taken care of. For the steady state performance vary K_I with K_P and K_D fixed such that there is zero steady state error in minimum time.

This completes the tuning of the PID controller.

V. RESULTS AND DISCUSSIONS

The system was observed under a 0.18 p.u. step load perturbation in the first area. The simulation time was set to 50 seconds. The areas considered here have similar parameters [13]. Typical simulation parameters for running the system are mentioned in Table 1. The performance of the system under investigation is analyzed in terms of dynamic response of the system characterized by settling time, minimum and maximum overshoot, etc. All the simulation work was carried out in MATLAB 2015a Simulink package and on a computer with configuration 4GB RAM, Intel Core i5 64bit processor.

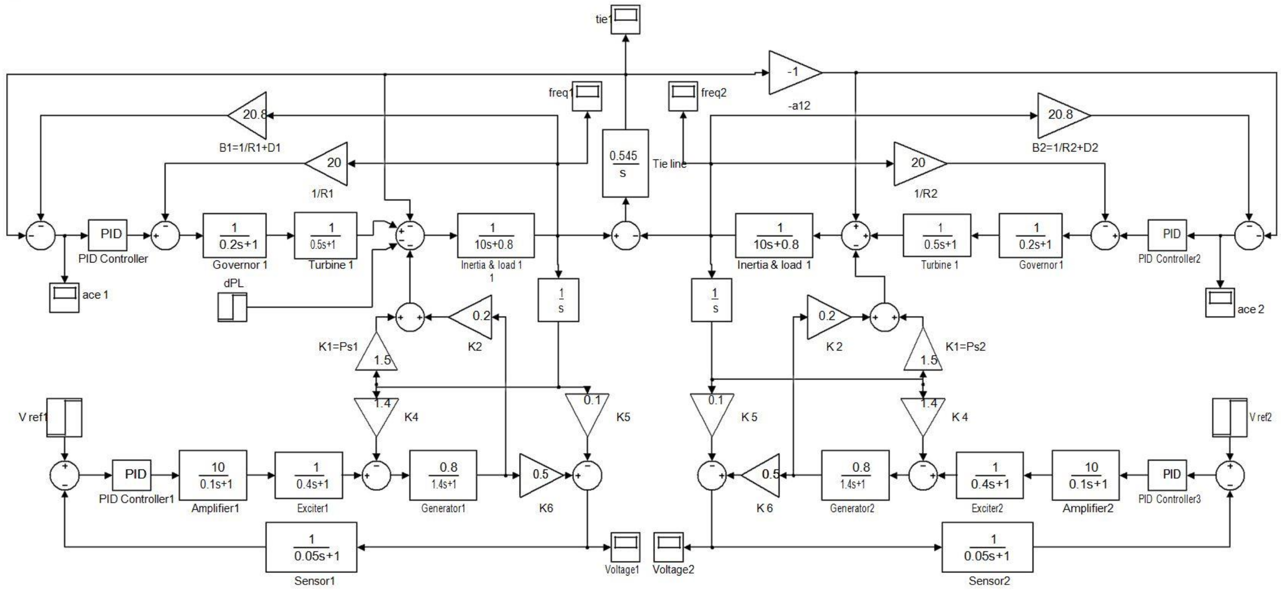

Fig. 2. Simulink model of Combined LFC and AVR of a Two Area Interconnected Power System

The dynamic performance of the system was measured in terms of the following system parameters:

Δf_1 : Frequency deviation in Area 1
Δf_2 : Frequency deviation in Area 2
ΔACE_1 : Area control error in Area 1
ΔACE_2 : Area control error in Area 2
ΔP_{TIE} : Change in tie line power flow
ΔV_1 : Voltage deviation in Area 1
ΔV_2 : Voltage deviation in Area

SIMULATON PARAMETERS FOR LFC SYSTEM

Quantity	Area 1	Area 2
Load Change	ΔP_{L1} = 0.1875 p.u.	-
Load change in MW	ΔP_{L1} = 187.5 MW	-
Base Power	1000MW	1000MW
Governor time constant	τ_{g1} = 0.2 sec	τ_{g2} = 0.2 sec
Turbine time constant	τ_{t1} = 0.5 sec	τ_{t2} = 0.5 sec
Load damping constant	D_1 = 0.8	D_2 = 0.8
Generator inertia constant	H_1 = 5 MW/MVA	H_2 = 5 MW/MVA
Governor speed regulation	R_1 = 0.05 Hz/p.u.	R_2 = 0.05 Hz/p.u.
Frequency bias factor	B_1 = 20.8 p.u. MW/Hz	B_2 = 20.8 p.u. MW/Hz
Tie line constant	a_{12} = 1	-
Tie line synchronizing coefficient	T_{12} = 0.0867 p.u	-

TABLE I.
SIMULATON PARAMETERS FOR AVR SYSTEM

Quantity	Area - 1	Area - 2
Amplifier gain	K_{A1} = 10	K_{A2} = 10
Amplifier time constant	τ_{A1} = 0.1 sec	τ_{A2} = 0.1 sec
Exciter gain	K_{E1} = 1	K_{E2} = 1
Exciter time constant	τ_{E1} = 0.4 sec	τ_{E2} = 0.4 sec
Generator gain	K_{G1} = 0.8	K_{G2} = 0.8
Generator time constant	τ_{G1} = 1.4 sec	τ_{G2} = 1.4 sec
Sensor gain	K_{R1} = 1	K_{R2} = 1
Sensor time constant	τ_{R1} = 0.05 sec	τ_{R2} = 0.05 sec

The terminal voltage response for Area 1 and Area 2 is shown in Fig. 3 and Fig. 4 respectively. The change in Area control error for Area 1 and Area 2 is shown in Fig. 5 and Fig. 6 respectively. The change in frequency for Area 1 and Area 2 is shown in Fig. 7 and Fig. 8 respectively. The change in Tie line power flow is shown in Fig. 9. Further comparison of use of Integral Control scheme, PI controller, PID controller and system operation without any controller is shown in the respective figures.

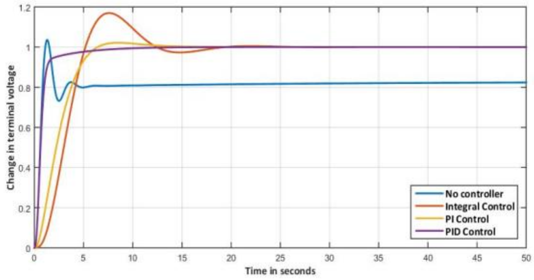

Fig. 3. Terminal voltage response of Area 1

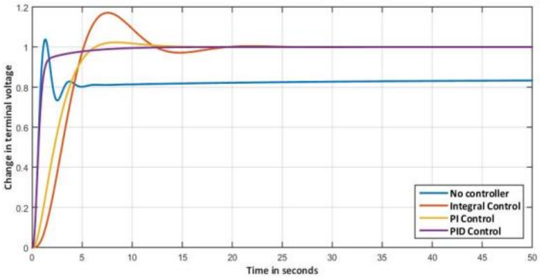

Fig. 4. Terminal voltage response of Area 2

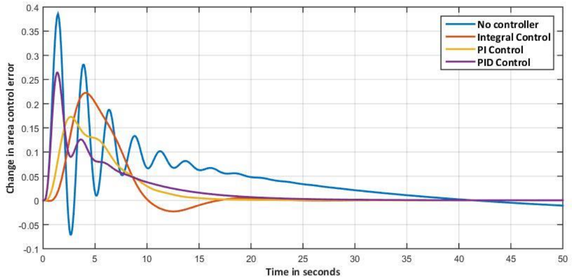

Fig. 5. Change in Area control error for Area 1

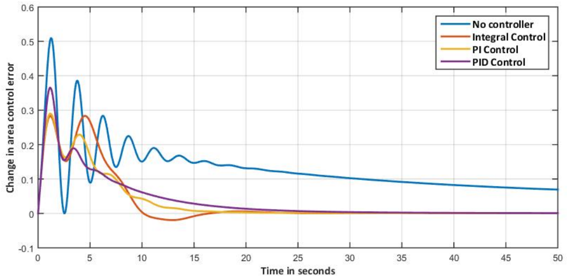

Fig. 6. Change in Area control error for Area 1

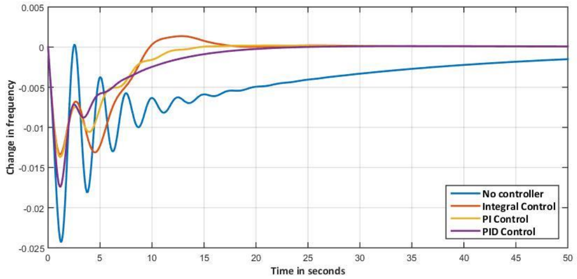

Fig. 7. Frequency deviation response of Area 1

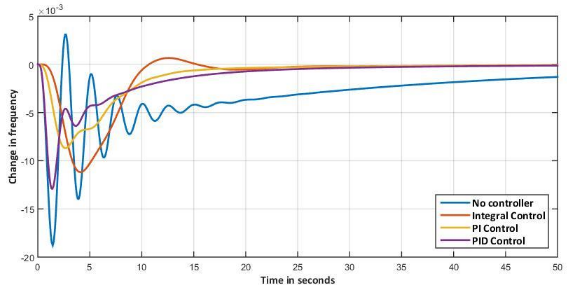

Fig. 8. Frequency deviation response of Area 2

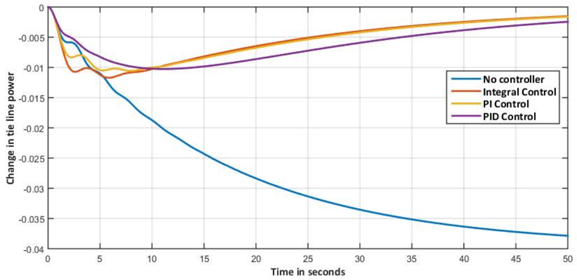

Fig. 9. Tie line power deviation response

The PID controller parameters for LFC and AVR system are provided in Table III.

TABLE II.
SIMULATON PARAMETERS FOR LFC AND AVR SYSTEM

PID Parameters	**Area - 1**	**Area – 2**
PID Parameters for LFC	$K_P = 1$	$K_P = 1$
	$K_I = 0.25$	$K_I = 0.25$
	$K_D = 0.3$	$K_D = 0.3$
PID Parameters for AVR	$K_P = 1$	$K_P = 1$
	$K_I = 0.25$	$K_I = 0.25$
	$K_D = 0.3$	$K_D = 0.3$

VI. CONCLUSION AND FUTURE SCOPE

Dynamic response of the system is observed for a 0.18 p.u. step load change. The use of PID controller results in relatively smaller peak overshoot and lesser settling time with zero steady state error as compared to the use of conventional Integral controller and PI controller. Further work can be done on the system with controllers tuned with the help of modern optimization techniques such as Particle Swarm Optimization (PSO).

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