AGC & AVR of Interconnected Thermal Power System While Considering the Effect of GRCs

Sandeep Kumar, Gourav Sharma, Gurdeepinder Singh

Abstract— **As the interconnected power system transmits the power from one area to another system frequency will inevitable deviate from scheduled frequency, resulting in a frequency error. A control system is essential to correct the deviation in the presence of external disturbances and structural uncertainties to ensure a safe and smooth operation of power system. Thus design of Automatic Generation Control (AGC) and Automatic Voltage Regulator (AVR) system play a vital role in the automation of power system. This paper deals with automation of three area interconnected reheat thermal power with consideration of Generation Rate Constraint (GRCs). The primary object of the AGC is to balance the total system generation against system load and losses, while considering the effect of Generation Rate Constraint (GRCs). So that the desired frequency and power interchange with neighboring systems are maintained in order to minimize the transient deviations and to provide zero steady state error in appropriate short time. Further the role of automatic voltage control is to maintain the terminal voltage of synchronous generator in order to maintain the bus bar voltage. Otherwise bus bar voltage goes beyond permitted limit.**
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Index Terms— **Area Control Error (ACE), Automatic Generation Control (AGC), Automatic Voltage Control (AVC), Automatic Voltage Regulator (AVR), Generation Rate Constraints (GRCs).**

I. INTRODUCTION

Everyone expect/desire the uninterrupted power supply. But it is always not possible for a system to remains in normal steady state, since both the active and reactive power demands are continually changes with rising and falling trend. In modern interconnected network where a number of utilities are interconnected and power is exchanged between them over tie-line, The AGC problem is the major requirement. Any mismatch between system generation and demand results in change in system frequency that is highly undesired [1]. Excitation of generator must be regulated in order to match the reactive power demand; otherwise bus voltage falls beyond the permitted limit. In modern vast interconnected power system manual control is not feasible, hence automatic equipments are installed on each generator.

The objective of control strategy is to generate and deliver power in an interconnected system as economically and reliably as possible while maintaining the voltage and frequency within permissible limits [2]. The AGC and AVR loop are considered independently. Since excitation control of generator have small time constant contributed by field winding, where AGC loop is slow acting loop having major time constant contributed by turbine and generator moment of inertia, therefore a tendency for the AVR dynamics to settle down before they can make themselves felt in the slower AGC loop [3]. Thus, the cross-coupling between the AGC and AVR loop is negligible and active power and reactive power control are analyzed independently & then combined these two loops. In this model load changes in all areas are considered at a time.

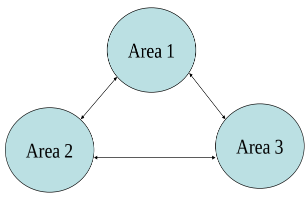

fig. 1: General form of three areas interconnected system

II. SYSTEM INVESTIGATION

The interconnected power systems under investigation consist of three control areas interconnected by tie-line. In each control area, all generators are assumed to form a coherent group. Area 1, Area 2 and Area 3 are of different sizes reheat thermal system interconnected in ring main fashion. A simplified representation of such interconnected areas in general form is shown in fig. 1. Change in load is considered in all the area at a time.

Manuscript received July 09, 2011.
Sandeep Kumar, Electrical Engg., BMIET, Sonipat, India, 08059520007, (e-mail: sandeeprathee84@gmail.com).
Gourav Sharma, Electrical Engg. M.M.U, Mullana, Ambala, India, 8059931094, (e-mail: : sharmafarms@yahoo.com).
Gurdeepinder Singh, Electrical Engg., H.I.T, Sonipat, India, 09466664611, (e-mail: gi_singh143@yahoo.co.in).

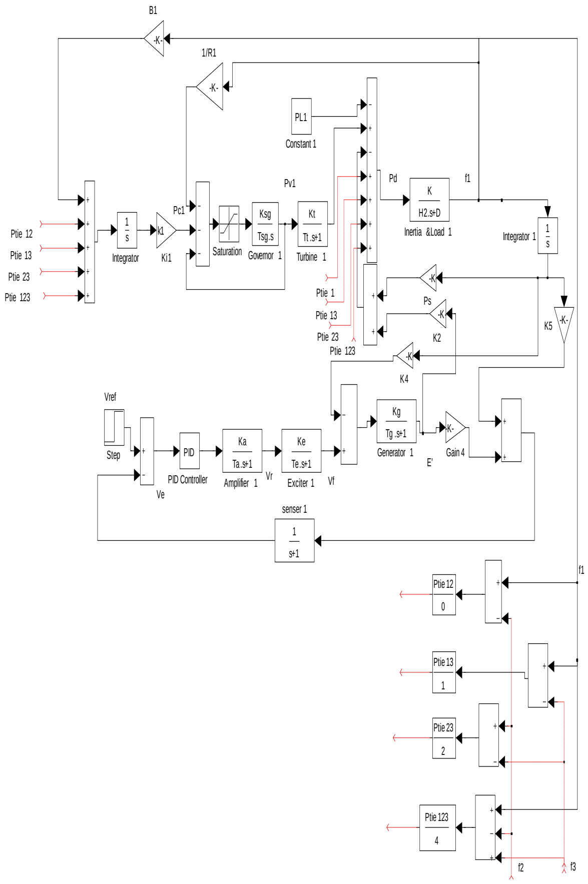

fig. 2: Simplified model of three areas interconnected system

A. Automatic Generation Control

AGC model of interconnected three control areas is shown in fig. 2. All the generators in each control area constitute a coherent group. It means that all generators speed up/down together while maintaining their relative power angle. Zero steady state error is maintained by providing a signal from change in frequency Δf through an integrator to speed changer of each generator, known as proportional plus integral controller. The prime objective of AGC model is to regulate the frequency of each area and to regulate the tie-line power as per contract.

The interaction of Area 1 with Area 2 & Area 3:

$$\Delta P_{tie,1}(s) = \frac{2\pi T_{12}}{s}\left[\Delta F_1(s) - \Delta F_2(s)\right] \quad (1)$$

$$\Delta P_{tie,13}(s) = \frac{2\pi\, a_{13} T_{13}}{s}\left[\Delta F_3(s) - \Delta F_1(s)\right] \quad (2)$$

In order to maintain the steady state tie line power , another integrate control loop is provided that integrate the incremental tie line power signal and feed back to speed changer. The area control error in the presence of tie line

$$ACE_1(s) = \Delta P_{tie,12}(s) + b_1 \Delta F_1(s) \quad (3)$$

The interconnection of Area 2 with Area 1 & Area 3:

$$\Delta P_{tie,2}(s) = \frac{2\pi\, a_{21} T_{21}}{s}\left[\Delta F_2(s) - \Delta F_1(s)\right] \quad (4)$$

$$\Delta P_{tie,23}(s) = \frac{2\pi\, a_{23} T_{23}}{s}\left[\Delta F_3(s) - \Delta F_2(s)\right] \quad (5)$$

The Area Control Error in the presence of tie line

$$ACE_2(s) = \Delta P_{tie,2}(s) + b_2 \Delta F_2(s) \quad (6)$$

The interconnection of Area 3 with Area 1 & Area 2:

$$\Delta P_{tie,3}(s) = \frac{2\pi T_{31}}{s}\left[\Delta F_3(s) - \Delta F_1(s)\right] \quad (7)$$

$$\Delta P_{tie,32}(s) = \frac{2\pi\, a_{32} T_{32}}{s}\left[\Delta F_3(s) - \Delta F_2(s)\right] \quad (8)$$

The Area Control Error in the presence of tie line

$$ACE_3(s) = \Delta P_{tie,3}(s) + b_3 \Delta F_3(s) \quad (9)$$

B. Generation Rate Constraints

In the thermal power plants, power generation can change only at a specified maximum rate. The generation rate for a unit is quite low. Most of reheat units have a generation rate around 3% per minute, some may have generation rate between 5-10% per minute. If these constraints are not considered, system is subjected to large momentary disturbances. This leads to undue wear and tear of controller. Several methods have been proposed to consider the effect of GRCs in the design of AGC. As described in adding limiters to the governors can restrict the generation rate for the steam plants. A typical value of the Generation Rate Constraint (GRC) for thermal units is considered as 3%/min.

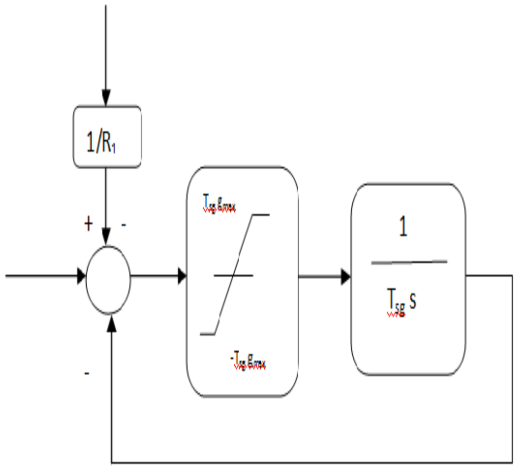

fig.3: Governor Model with GRC

Here $T_{sg}\, g_{max}$ is power rate limit imposed by valve or gate control. In this model

$$|\Delta Ye| < gmax \quad (10)$$

The generation rate constraints for all the areas are taken into account by adding limiters to the turbines as shown in fig. 3. The GRC result in larger deviations in ACEs as the rate at which generation can change in the area is constrained by limits imposed. Therefore, the duration for which the power needs to be imported increased considerably as compared to the case where generation rate is not constrained.

C. Automatic Voltage Control

The primary objective of reactive power control is the generator excitation control that can be obtained by using automatic voltage regulator (AVR). It maintains the generator voltage and reactive power demand. The main components of AVR are:

a. Voltage Sensor

The voltage is sensed by a potential transformer (PT). Then ac signal is converted in dc using bridge rectifier. The transfer function of sensor is represented by

$$\frac{V_S(S)}{V_t(s)} = \frac{K_R}{1+sT_R} \tag{11}$$

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b. Excitation System Amplifier

It may be a magnetic amplifier, rotation or electronic amplifier. It amplifies the error signal and fed to exciter. The transfer function is represented by

$$\frac{V_R(S)}{V_e(s)} = \frac{K_A}{1+sT_A} \tag{12}$$

c. Main Exciter

Main exciter is the main component of AVR that excite the alternator field to control the output voltage. The exciter field is automatically controlled through error signal. The output of exciter is nonlinear function of field voltage because of magnetic saturation effect. A reasonable linear model is considered here. The transfer function of a modern exciter may be represented by

$$\frac{V_F(S)}{V_R(s)} = \frac{K_E}{1+sT_E} \tag{13}$$

d. Generator

The transfer function relating the generator terminal voltage to its field voltage can be represented by the transfer function

$$\frac{V_t(S)}{V_F(s)} = \frac{K_G}{1+sT_G} \tag{14}$$

e. PID Controller

The PID controller is used to improve the dynamic response and to reduce the steady state error. The transfer function of PID controller is represented by

$$\mathrm{Gc(s)} = K_P + \frac{K_I}{s} + K_D s \tag{15}$$

D. Combined AGC and AVR loops

The AGC and AVR loop are considered independently, since excitation control of generator have small time constant contributed by field winding, where AGC loop is slow acting loop having major time constant contributed by turbine and generator moment of inertia. Thus transient in excitation control loop are vanish much fast and does not affect the AGC loop. Practically these two are not non- interacting, the interaction exists but in opposite direction. Since AVR loop affect the magnitude of generated e.m.f, this e.m.f determines the magnitude of real power and hence AVR loop felt in AGC loop.

When we include the small effect of voltage on real power, we get following equation:

$$\Delta P_e = P_S\ \Delta\delta + K_2 E' \tag{16}$$

Where

K_2 is change in electrical power for small change in stator e.m.f and Ps is synchronizing power coefficient.

By including the small effect of rotor angle upon generator terminal voltage, we may write

$$\Delta V_t = K_5\ \Delta\delta + K_6 E' \tag{17}$$

Where

K_5 is change in terminal voltage for small change in rotor angle at constant stator e.m.f and K_6 is change in terminal voltage for small change in stator e.m.f at constant rotor angle.

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

$$E' = \frac{K_g}{1+T_g}\left(V_f - K_4\,\Delta\delta\right) \tag{18}$$

III. DESIGN AND SIMULATION RESULTS

The design and simulation of problem is done in MATLAB Simulink environment. Testing was done on each of the individual blocks of the AGC system and AVR system. The change in power in area12, area 13, area 23 and area 123 are shown in fig. 4, 5, and 7 respectively. The change in frequency of area12, area 13, and area 23 is shown in fig. 8, 9 and 10 respectively. Where fig. 11 shows the deviation in frequency of three areas interconnected via single tie line.

The change in voltage vs time response of area12, area 13, area 23, and area 123 is shown in fig. 12, 13, 14 and 15 respectively.

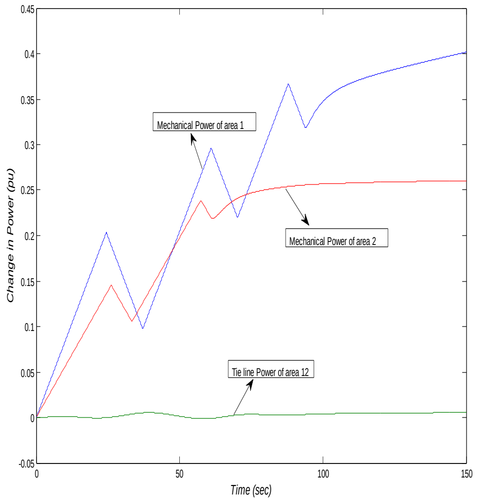

Fig. 4: Change in power of area 12

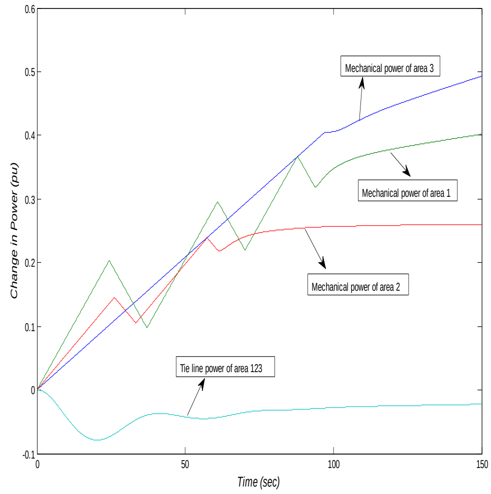

Fig. 7: Change in power of area 123

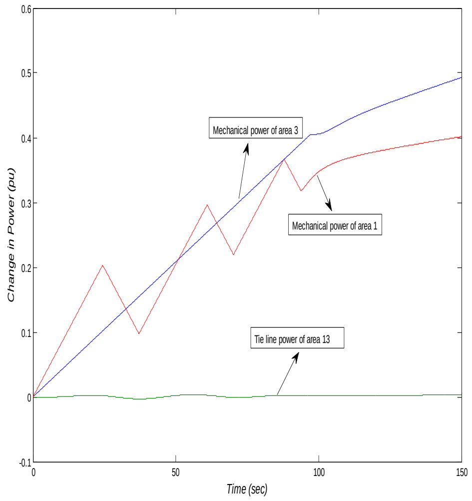

Fig. 5: Change in power of area 13

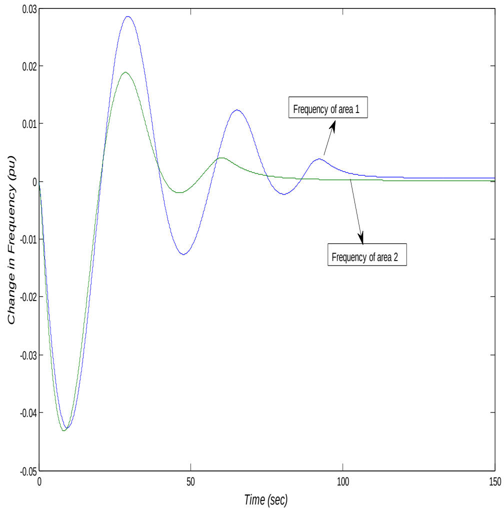

Fig. 8: Frequency response of area 12

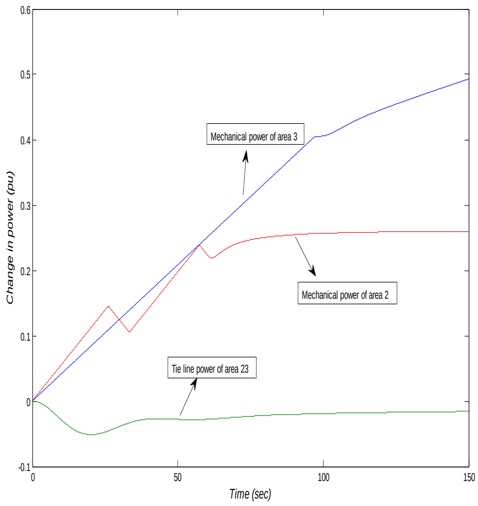

Fig. 6: Change in power of area 23

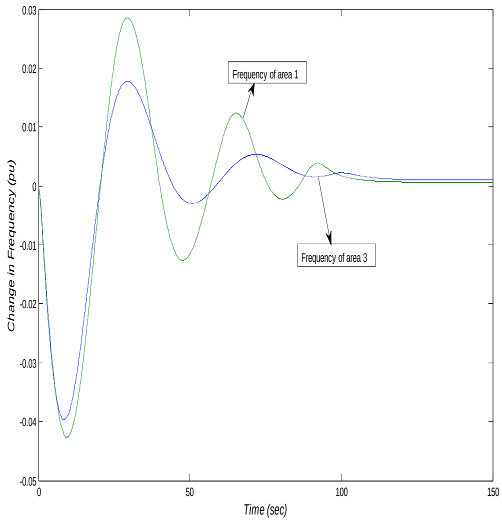

Fig. 9: Frequency response of area 13

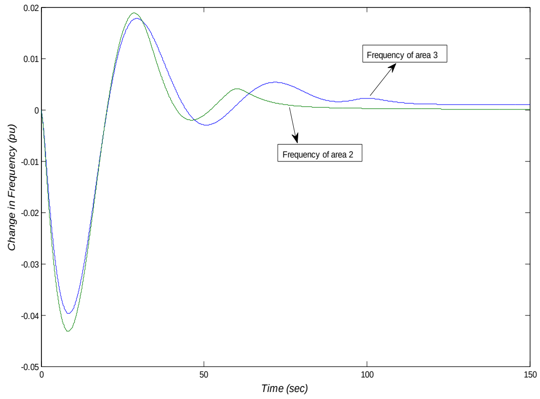

Fig. 10: Frequency response of area 23

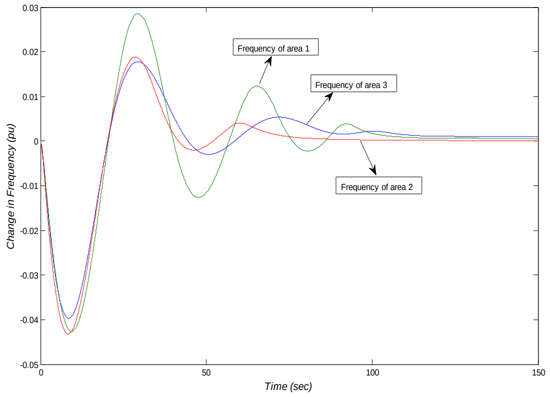

Fig. 11: Frequency response of area 123

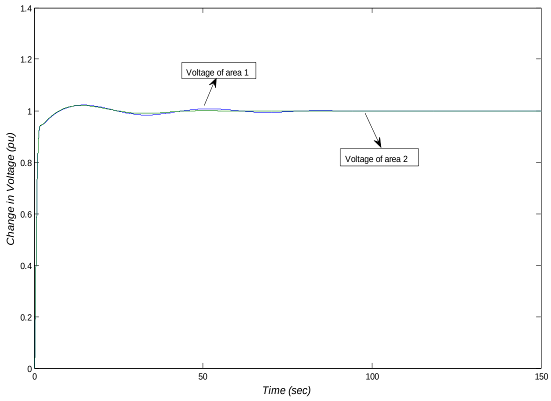

Fig. 12: Voltage response of area 12

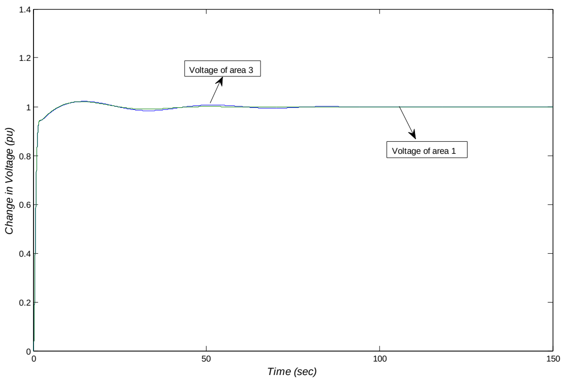

Fig. 13: Voltage response of area 13

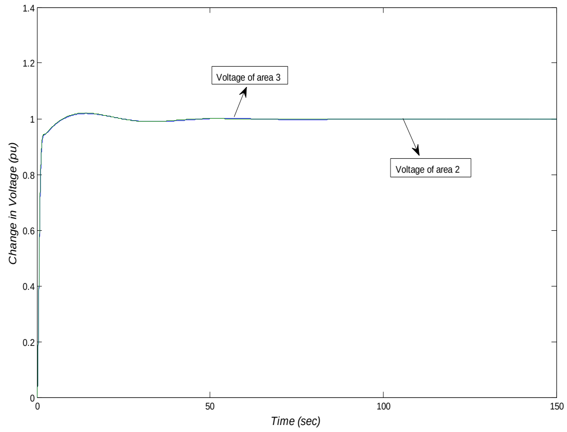

Fig. 14: Voltage response of area 23

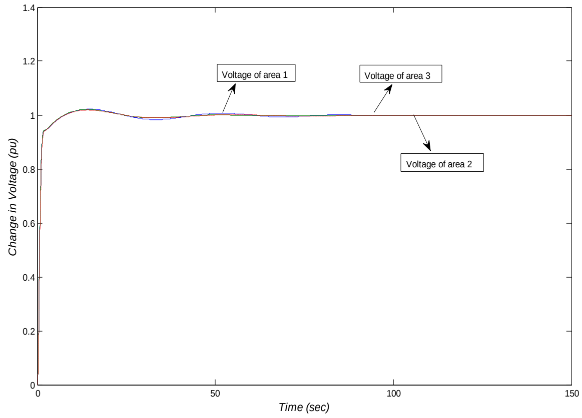

Fig. 15: Voltage response of area 123

The assumptions used for AGC simulation are shown in Table I and assumptions used for AVR simulation is shown in Table II.

Table I

Area–I	**Area-II**	**Area-III**
R_1 = 0.051	R_2 = 0.065	R_3 = 0.089
D_1= 0.62	D_2= 0.91	D_3= 0.95
H_1= 5	H_2= 4	H_3= 4.5
T_{sg1}= 0.2 sec	T_{sg2} = 0.3 sec	T_{sg3} = 0.4 sec
T_{t1} = 0.5 sec	T_{t2} = 0.6 sec	T_{t3} = 0.7 sec
k = 1/ 2π	k = 1/ 2π	k = 1/ 2π
f_1 = 50 Hz	f_2 = 50 Hz	f_3 = 50 Hz
Δ P_{L1} = .180 pu	Δ P_{L2} = .180 pu	Δ P_{L3} = .180 pu

Table II

K_A = 9	T_A = 0.1
K_E = 1	T_E = 0.4
K_G = 1	T_G = 1.0
K_S = 1	T_S = 0.05
K_P = 1.0 K_I = 0.25 K_D = 0.28	

V. CONCLUSION

In this paper attempt is made to develop AGC combined with AVR and load scheduling strategy. In this scheme coupling between AGC and AVR is employed. AVR loop affect the magnitude of generated e.m.f E′ as the internal e.m.f determines the magnitude of real power. It is concluded that changes in AVR loop is felt in AGC loop. Thus interaction between frequency and voltage exists. But exist in opposite direction. If GRCs are not considered, system is subjected to large momentary disturbances. This leads to undue wear and tear of controller. The GRC result in larger deviations in ACEs as the rate at which generation can change in the area is constrained by limits imposed and the duration for which the power needs to be imported increased considerably as compared to the case where generation rate is not constrained. However, when GRCs is considered the system become non-linear.

ACRONYMS

Subcript 1, 2, 3: Control area 1, area 2, area 3
$\Delta P_{Tie\text{-}flow}$: Change in power transmitted over tie line
f : Nominal Frequency of system
Δf : Change in system frequency
ΔP_{Mech} : Change in mechanical power input
ΔP : Change in power
ΔP_L : Change in Load
X_{tie} : Reactance of tie line
K : Costant
B : Frequency Bias factor
D : Frequency Bias Factor ($\Delta PD/\Delta f$)
H : Inertia Constant
R : Governor Speed Regulator
Ki : Supplementary control constant
T_{PS} : Power system time constant
Ksg : Speed governor gain
Tsg : Speed governor time constant
K_T : Turbine gain
T_T : Turbine time constant
K_E : Exciter gain
T_E : Exciter time constant
K_G : Generator gain
T_G : Generator time constant
K_P : Proportional constant
K_I : Integrator constant
K_D : Differential constant

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BIOGRAPHIES

Sandeep kumar received his B.E. degree in Electrical Engineering from M.D.U. Rohtak, India in 2006 and pursuing M. Tech. degree in Electrical engineering (Power Eletronics & Drives) from M. M. University Mullana, Ambala (Haryana),India. His area of interest includes power system deregulation and optimal control of interconnected power systems & power drives.

Er. Gourav Sharma received his B.Tech degree in Electrical Engg. From KUK University Kurukshetra, india in 2004 and M.Tech degree in EE (power system) from RVDU, Rajasthan in 2007. His area of interest includes electrical machines and drives.

Gurdeepinder Singh, received his B.E. degree in Electrical Enggineering from Hindu College of Engg, Sonepat, Haryana (India) in 2007 and received his M.Tech (Power Engg) from Baba Banda Singh Bahadur Engg. College, Fatehgarh Sahib, Punjab (India). His area of interest includes power system deregulation, energy efficiency and optimal control of thermal power system.