Automatic Generation & Voltage Control of Interconnected Thermal Power System Including Load Scheduling Strategy

Gurdeepinder Singh, Rajni Bala

Abstract— ***This paper deals with the automatic generation control (AGC) of three area interconnected thermal power systems with combination of the automatic voltage control using automatic voltage regulator (AVR). The interconnected thermal unit is considered with three area concept. The primary object of the AGC is to balance the total system generation against system load and losses, 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 regulator 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. The interaction between active and reactive power demand is also analyzed in this paper. In this paper Load scheduling strategy is also considered in combination with AGC and AVR, in which utility takes steps to control the peak demand of plant by shifting peak load of different consumers towards valley with the aim of system stability, minimize the generation cost, postpone/ delay construction of new plant. Literature survey also shows, almost no attempt is made to combine the AGC with load scheduling strategy.***

Keywords: - Automatic Generation Control (AGC), Automatic Voltage Control (AVR), Area Control Error (ACE), Load Scheduling Strategy (LSS).

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. Literature survey shows that very little attempt is done in which load change in all the interconnected areas are considered at a time.

Ever increasing demand for electrical energy has become a notable feature of modern civilization for quite some time, now we find them in situation, where the gap between the demand and supply of electrical energy is continuously widening. The gap between demand & supply of electric energy is widening at the rate of 3% day by day. Bridging this gap by setup of new power plant is very difficult & expensive proposition. This situation is not likely to improve in immediate future. Electricity is an important input in all the sectors of any country’s economy, hence need to find alternate methods to reduce peak demand [6]. One simple solution is applying load scheduling strategy by which modify the consumer’s energy uses time by clip off the peak demand and shift this load towards valley [6]-[8]. As a result maximum demand is reduce. Thus avoid or postpone the construction of new generating plant [13].

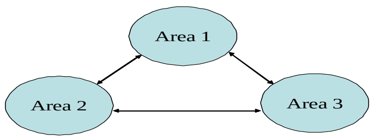

fig. 1: General form of three areas interconnected system

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.

Manuscript received October 01, 2011.
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Change in load is considered in all the area at a time.

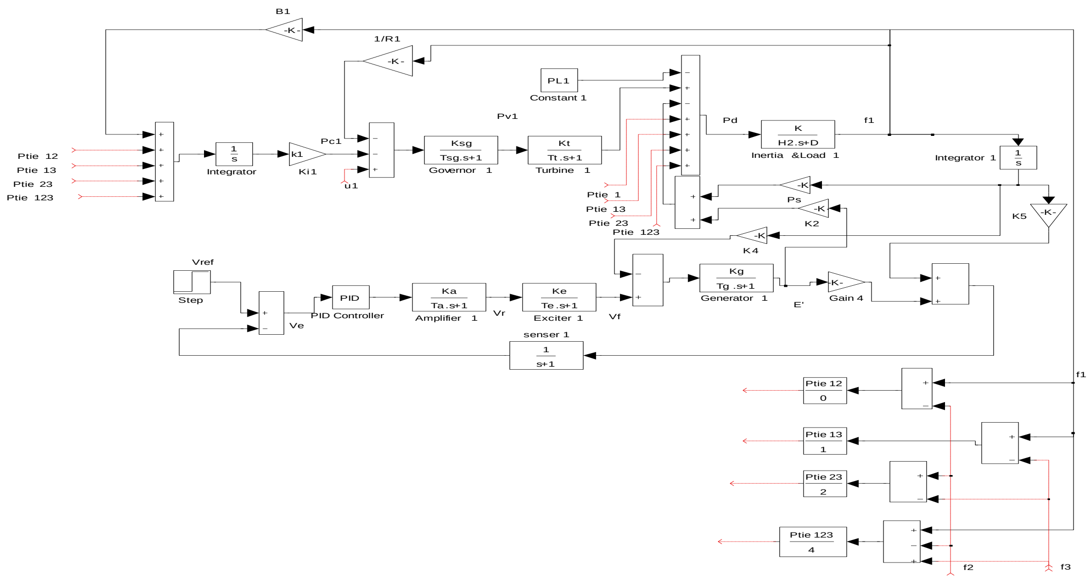

fig. 2: Simplified model of three areas interconnected system

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:

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

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

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

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

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

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

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

The Area Control Error in the presence of tie line

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

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

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

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

The Area Control Error in the presence of tie line

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

B. 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

$$\frac{V_S(S)}{V_t(s)} = \frac{K_R}{1 + sT_R} \qquad (10)$$

Where,
K_R is gain of sensor and T_R is time constant.

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

$$\frac{V_R(S)}{V_e(s)} = \frac{K_A}{1 + sT_A} \qquad (11)$$

Where,
K_A is gain of Amplifier & T_A is time constant

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.

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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

$$\frac{V_F(S)}{V_R(s)} = \frac{K_E}{1 + sT_E} \quad (12)$$

Where,

K_E is gain and T_E is time constant.

d. *Generator*

The transfer function relating the generator terminal voltage to its field voltage can be represented by a gain K_G and a time constant T_G and the transfer function is

$$\frac{V_t(S)}{V_F(s)} = \frac{K_G}{1 + sT_G} \quad (13)$$

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

$$Gc(s) = K_P + \frac{K_I}{s} + K_D s \quad (14)$$

C. *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:

$$\Delta P_e = P_S\,\Delta\delta + K_2 E' \quad (15)$$

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

$$\Delta V_t = K_5\,\Delta\delta + K_6 E' \quad (16)$$

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

$$E' = \frac{K_g}{1 + T_g}\left(V_f - K_4\,\Delta\delta\right) \quad (17)$$

D. *Load Scheduling Strategy*

Consider a power plant having load curve as shown in fig. 3. Such power plant having maximum demand of 2000 kW and average load of 1200 kW. Load factor which is the ratio of average demand to the maximum demand is 0.6. Load factor of a plant is less than unity. Lower the load factor higher the rate per generation as power plants are design to meet the maximum demand. Higher the peak demand, Resulting in the higher generating cost per unit and demand additional generating units which is not possible due to high fuel cost and long time to construct and operate the plant satisfactory.

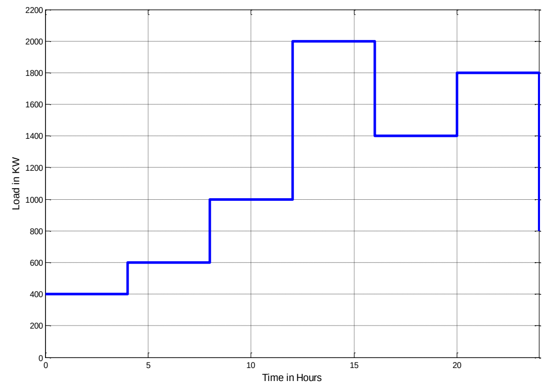

fig. 3: Load curve of Power Plant

In order to reduce the peak demand, here we apply the load scheduling strategy, in which 400 KW load is considered as base load, this load is allowed to supply for 24 hours and remaining 19200 KW load is scheduled into three groups. Each group is allowed to operate for 8 hours. The simulation model of load scheduling in combines with AGC and AVR is shown in fig. 4.

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 deviation in frequency response of area12, area 13, and area 23 is shown in fig. 5, 6, and 7 respectively. Where fig. 8 shows the deviation in frequency of three areas interconnected via single tie line. The deviation in power (pu) Vs time response of area12, area 13, and area 23 is shown in fig. 9, 10 and 11 respectively.

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. Base load of 400 KW is allowed to operate for 24 hours and load curve is shown in fig. 16. Load curves after load scheduling of individual groups group 1, group 2 and group 3 that are allowed to operate for 8 hours are shown in fig. 17, 18, and 19 respectively. Load curve of all the load groups as combined is shown in fig. 20. Total load curve of plant after scheduling is shown in fig. 21.

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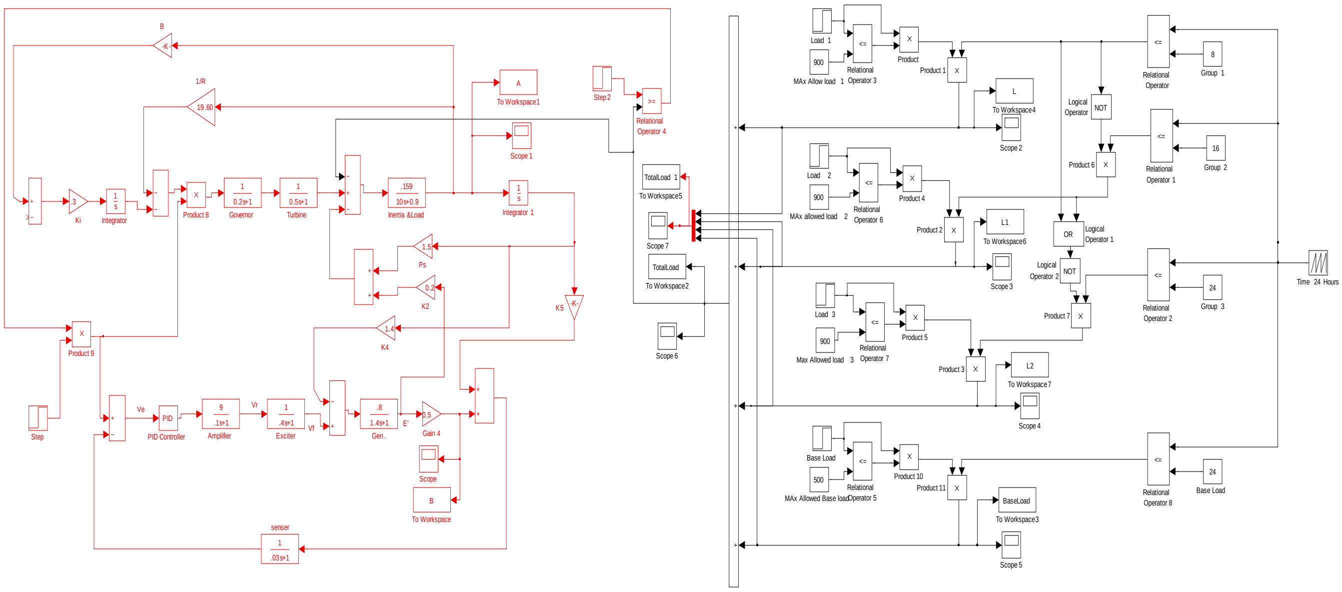

Fig. 4 Simulation Model of load scheduling in Combined with AGC and AVR

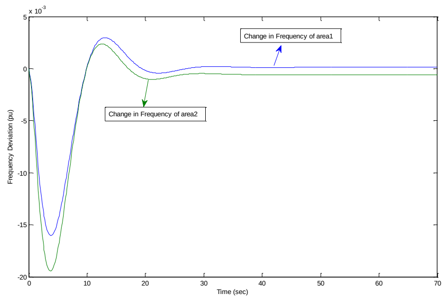

fig. 5: Deviation in Frequency of area 1 and 2

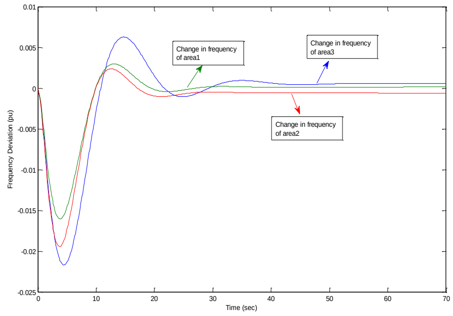

fig. 8: Deviation in Frequency of area 123

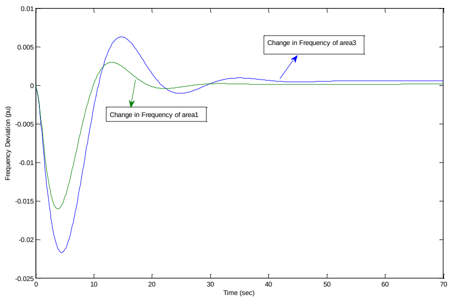

fig. 6: Deviation in Frequency of area 1 and 3

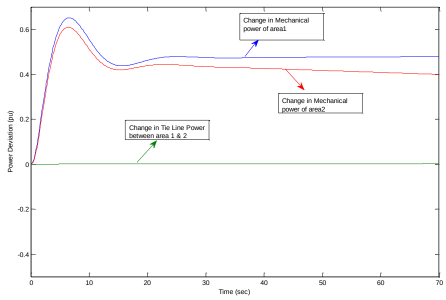

fig. 9: Deviation in Power of area 1 and 2

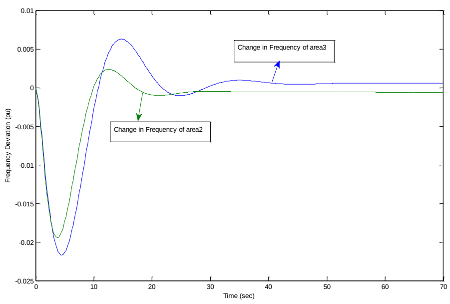

fig. 7: Deviation in Frequency of area 2 and 3

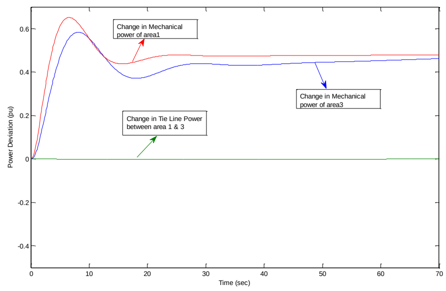

fig. 10: Deviation in Power of area 1 and 3

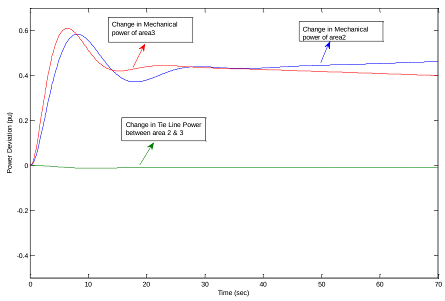

fig. 11: Deviation in Power of area 2 and 3

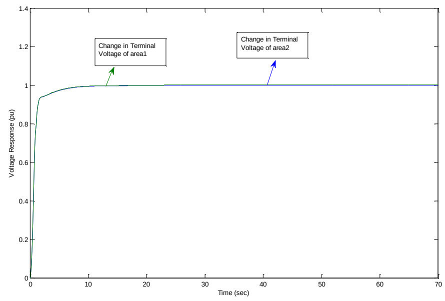

fig. 12: Change in Voltage of area 1 and 2

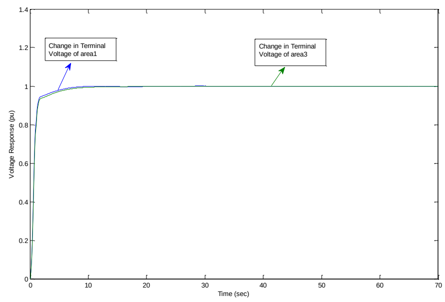

fig. 13: Change in Voltage of area 1 and 3

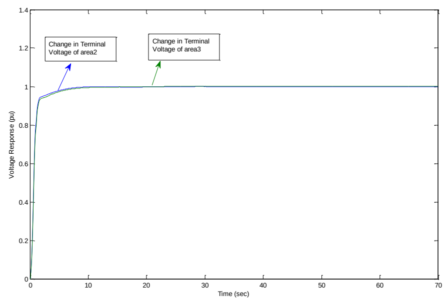

fig. 14: Change in Voltage of area 2 and 3

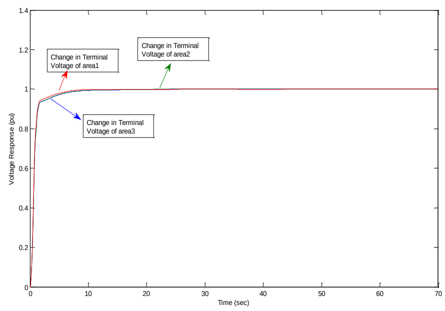

fig. 15: Change in Voltage of area 123

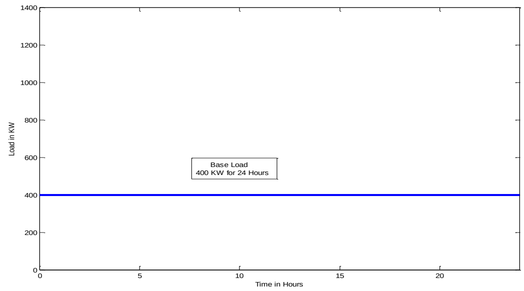

fig. 16: Load curve of Base Load (0-24hours)

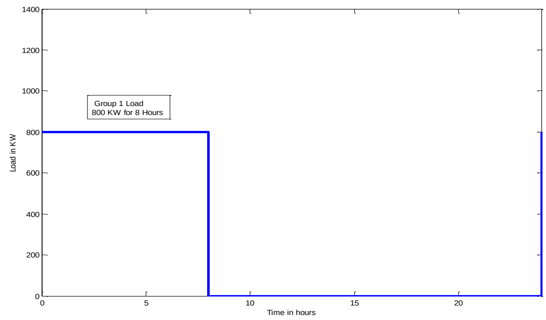

fig. 17: Load curve of Group 1 (0-8hours)

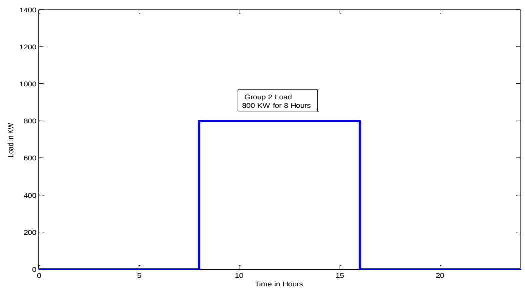

fig. 18: Load curve of Group 2 (8-16hours)

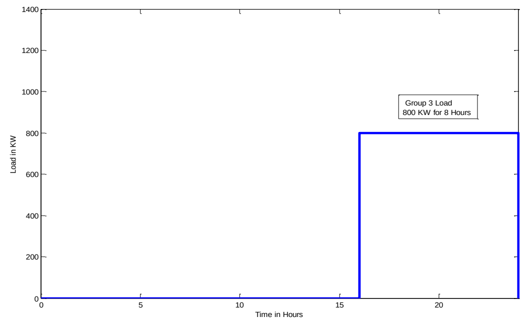

fig. 19: Load curve of Group 3 (16-24hours)

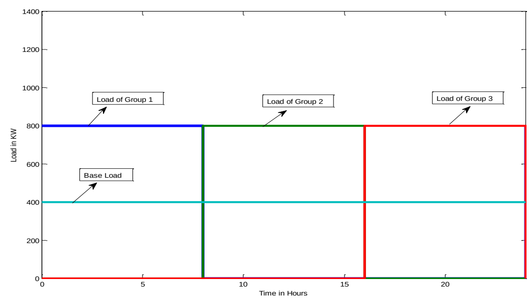

fig. 20: Load curve of All the Groups (0-24hours)

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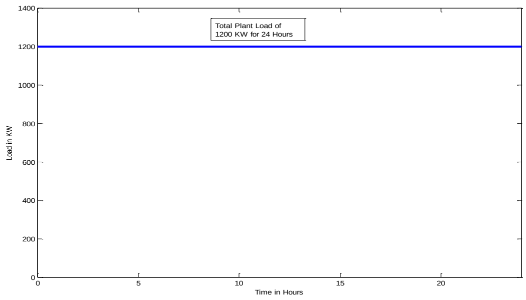

fig. 21: Total Load curve of plant (0-24hours)

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} = 180.2 MW	Δ P_{L2} = 180.2MW	Δ P_{L3} = 180.2 MW

Table II

Quantity	Gain	Time Constant
Amplifier	9	0.1
Exciter	1	0.4
Generator	1	1.0
Sensor	1	0.05
PID Controller	KP = 1.0 KI = 0.25 KD = 0.28	

IV. 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.

Load curve shown after Load scheduling is fatter, hence lesser peak load that demand less plant capacity, lesser cost of transmission & distribution, less cost per unit results in reduce the customer's bills, reduces green house gas emissions, reduce the cost of construction for transmission and distribution, increases the system reliability and increase the national security . In addition to that such strategy also helps to maintain the constant system frequency which is also highly desirable.

APPENDIX

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
B : Frequency Bias factor
D : Frequency Bias Factor (ΔPD/Δf)
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
Kt : Turbine gain
Tt : Turbine time constant
X_{tie} : Reactance of tie line
K : Costant

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