Available online at www.ejournals.uofk.edu

UofKEJ Vol. 6 Issue 2 pp. 43-51 (August 2016)

UNIVERSITY OF KHARTOUM ENGINEERING JOURNAL (UOFKEJ)

Modeling of Automatic Generation Control and Automatic Voltage Regulator Under Generation Rate Constraint

Elfadil Z. Abdalla, Mohammed G. Abdelfadeel

Department of Electrical Engineering, College of Engineering, Sudan University of Science and Technology Khartoum, Sudan (E-mail: fzy17077@gmail.com)

Abstract: As the interconnected power system transmits power from one area to another, the frequency will inevitable deviate from scheduled frequency. In addition, the active and reactive power demands continually change with rising and falling trend. Any mismatch between system generation and demand results in change in system frequency that is highly undesired. Excitation of generator must be regulated in order to match the power demand, otherwise the bus voltage may fall beyond the permitted limit. In this paper, a simulation model is developed for each component of AGC and AVR loops considering generator rate constraints. The response with GRC is compared with the analysis done without the Generation Rate Constraint. Although the frequency deviation is less with suitable controllers when the GRC is not considered, it is not the actual frequency deviation. When GRC is considered the actual frequency deviation can be found and then accordingly the controller is tuned. 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 Results are obtained using MATLAB SIMULINK software.

Keywords: *Automatic Generation Control; Automatic Voltage Regulator; Automatic Load Frequency Control; Generation Rate Constraint.*

1. INTRODUCTION

Automatic Generation Control (AGC) is one of the most important issues in electric power system design and operation. The objective of the AGC in an interconnected power system is to maintain the frequency of each area and to keep tie-line power close to the scheduled values by adjusting the MW outputs the AGC generators so as to accommodate fluctuating load demands [1]. The generator excitation system maintains generator voltage and controls the reactive power flow. The generator excitation of older system may be provided through slip rings and brushes by mean of DC generator mounted on the same shaft as the rotor of the synchronous motor [2]. Obviously, a change in the real power demand affects essentially the frequency, whereas a change in the real power affects mainly the voltage magnitude. The interaction between voltage and frequency controls is generally weak enough to justify their analysis separately. The sources of reactive power are generators, capacitors, and reactors [3].

Load frequency control problem discussed so far does not consider the effect of the restrictions on the rate of change of power generation. In power systems having steam plants, power generation can change only at a specified maximum rate. The generation rate (from safety considerations of the equipment) for reheat units is quite low. Most of the reheat units have a generation rate around 3%/min. some have a generation rate between 5 to 10%/min. If these constraints are not considered, system is likely to chase large momentary constraints. This results in undue wear and tear of the controller. Several methods have been proposed to consider the effect of GRC. The system dynamic model becomes non-linear and linear control techniques cannot be applied for the optimization of the controller setting.

If the generation rates denoted by P_{Gi} are included in the state vector, the system order will be altered. Instead of augmenting them, while solving the state equations, it may be verified at each step if GRCs are violated. Another way of considering GRCs for both areas is to add limiters to the governors as shown in **Fig.1.** The maximum rate of valve opening or closing speed is restricted by the limiters. Here T_{sg} Gmax is the power rate limit imposed by valve or gate control. In this model $|\Delta Y_E|$ <Gmax the banded values imposed by the limiters are selected to restrict the generation rate by 10% per minute.

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.

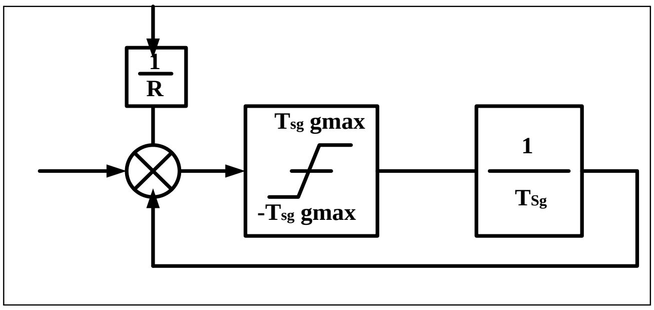

Fig.1. Governor Model with GRC

needs to be imported increased considerably as compared to the case where generation rate is not constrained. With GRC, should be selected with care so as to give the best dynamic response.

2. AUTOMATIC GENERATION CONTROL

The first step in the analysis and design of a control system is the construction of a mathematical modeling of the system. The two most common methods are the transfer function method and the state variable approach. The state variable approach can be applied to model linear as well as nonlinear systems. In order to use the transfer function and linear state equations, the system must first be linearized Proper assumptions and approximations are made to linearize the mathematical equations describing the system. A transfer function model is obtained for following components.

2.1 Generator load Model

Gives the relation between the changes in frequency (Δf) as a result of the change in generation (ΔPG) when the load changes by a small amount (ΔPD). Neglecting the change in generation losses,

$$\Delta F(s) = [\Delta P_G(s) - \Delta P_D(s)]\left[\frac{K_{PS}}{1+s\,T_{PS}}\right] \quad (1)$$

TPS = (2H / Bf 0) (2)

TPS is power system time constant

KPS = 1/B (3)

KPS is power system gain

2.2 Prime mover model

The model for the turbine relates changes in mechanical power output $\Delta P_t(s)$ to changes in steam valve position, the simplest prime mover model for the non-reheat steam turbine can be approximated with a single time constant (T_t), resulting in the following transfer function:

$$\frac{\Delta P_t(s)}{\Delta y_E(S)} = \frac{K_t}{1+s\,T_t} \quad (4)$$

2.3 Speed governor model

The overall transfer function of the model is

$$\Delta y_E(s) = \left[\Delta P_C(s) - \frac{1}{R}\Delta f(s)\right] \times \left(\frac{k_{sg}}{1+T_{sg}\,s}\right) \quad (5)$$

$$R = \frac{k_1 k_C}{k_2} \quad (6)$$

R = Speed regulation of the governor

$$k_{sg} = \frac{k_1 k_3 k_C}{k_4} \quad (7)$$

k_{sg} = Gain of speed governor

$$T_{sg} = \frac{1}{k_4 k_5} \quad (8)$$

T_{sg} = Time constant of speed governor

3. AREA CONTROL ERROR OF TWO AREAS

Let us now turn our attention to ACE (area control error) in the presence of a tie line. In the case of an isolated control area, ACE is the change in area frequency which when used in integral control loop forces the steady state frequency error to zero. In order that the steady state tie line power error in a two-area control be made zero another control loop (one for each area) must be introduced to integrate the incremental tie line power signal and feed it back to speed changer. This is accomplished by a single line-integrating block by redefining ACE as linear combination of incremental frequency and tie line power, Thus for control area1.

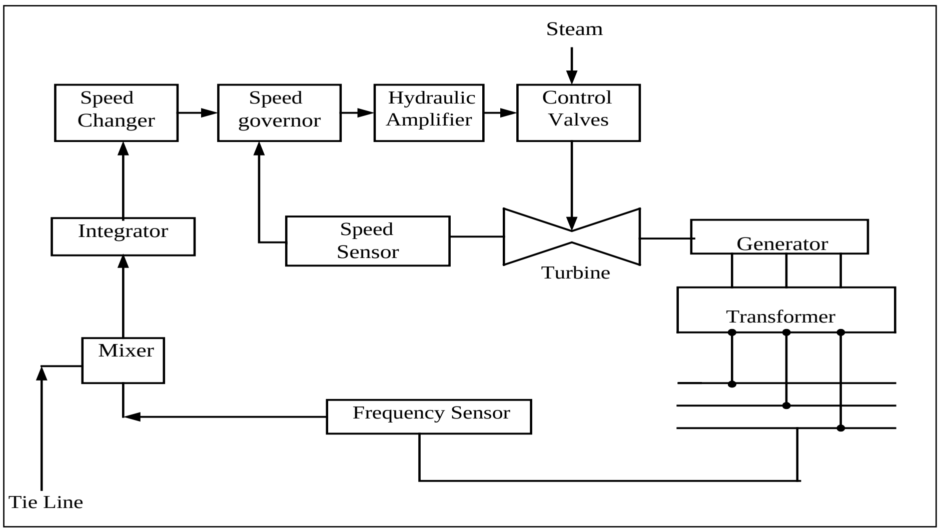

Fig.2. Block diagram of ALFC

$$ACE_1 = \Delta P_{TL_1} + B_1 \Delta f_1 \quad (9)$$

Where the constant B_1 is called area frequency bias

Eqn. (9) can be expressed in the Laplace transform as:

$$ACE_1(s) = \Delta P_{TL_1}(s) + B_1 \Delta f_1(s) \quad (10)$$

Similarly, for the control area2, ACE2 is expressed as:

$$ACE_2(s) = \Delta P_{TL_2}(s) + B_2 \Delta f_2(s) \quad (11)$$

4. AUTOMATIC VOLTAGE REGULATOR

AVR is an important part of a synchronous generator. The AVR is used for regulating the terminal voltage of the synchronous generator. Whenever, there is a sudden drop in voltage due to accidents, faults or frequent changes in loading. The AVR improves the transient stability of a system **Fig. 3 and.4** represent the block diagram of AVR system.

4.1 Amplifier Model

The comparator continuously compares the reference voltage V_{ref} and actual output voltage V_t and generates a voltage error signal, which is fed to the amplifier. The amplifier can be magnetic, rotational or electronic type. Due to the delay in the response of amplifier, its transfer function $(T.F_a)$ is given by:

$$T.F_A = \frac{K_A}{1+ST_A} = \frac{\Delta V_R(s)}{\Delta V_t(s)} \quad (12)$$

Where ΔV_R is the amplifier output and ΔV_t is the error voltage and is given by:

$$\Delta V_t = V_{ref} - V_t \quad (13)$$

4.2 Exciter

In the simplest form, the transfer function of the modern exciter may be represented by the single time constant TE and a gain KE.

$$T.F_A = \frac{K_E}{1+ST_E} = \frac{\Delta V_F(s)}{\Delta V_R(s)} \quad (14)$$

Where ΔV_F is the field voltage of synchronous generator, the time constant of the modern exciter are very small.

4.3 Generator Field Model

The synchronous machine generated EMF is a function of magnetization curve, and its terminal voltage is dependent on generator load.

$$T.F_G = \frac{K_G}{1+ST_G} = \frac{\Delta V_t(s)}{\Delta V_F(s)} \quad (15)$$

4.4 Sensor Model

Sensor sensed voltage through a potential transformer.

$$T.F_S = \frac{K_R}{1+ST_R} = \frac{\Delta V_S(s)}{\Delta V_t(s)} \quad (16)$$

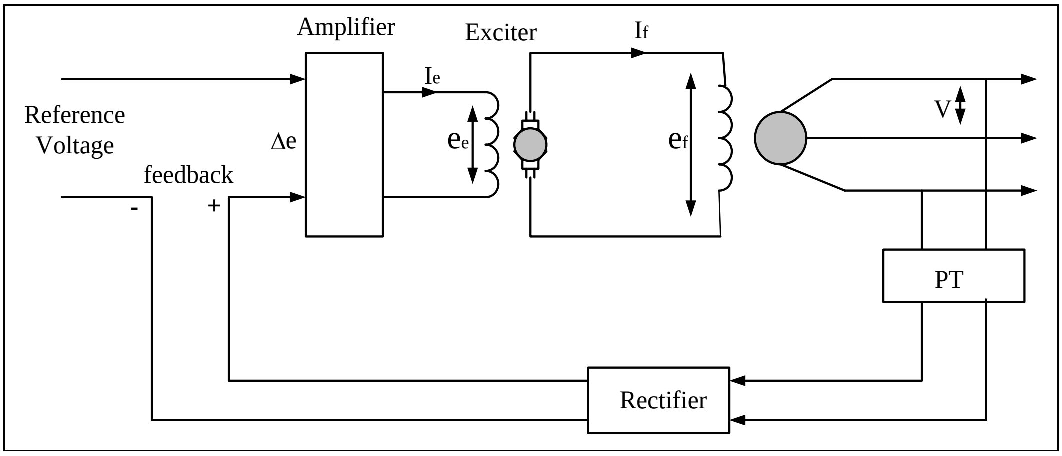

Fig. 3. AVR System

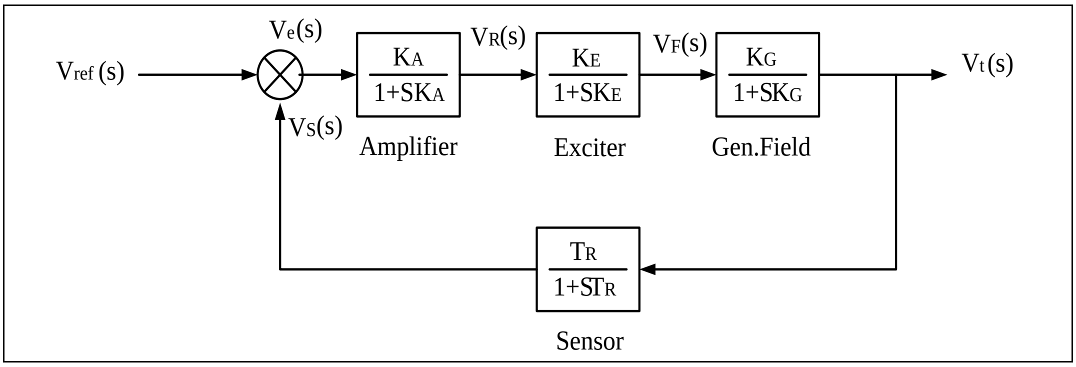

Fig. 4. Automatic voltage regulator models

5. SIMULATION AND RESULTS

5.1Model of two areas with GRC

The two-area interconnected power system is taken as a test system in this study, which consists of reheat turbine type thermal unit in each area. The conventional AGC scheme has two control loops: The primary control loop, which controls the frequency by self-regulating feature of the governor, however, frequency error is not fully eliminated and the supplementary control loop, which has a controller that can eliminate the frequency error with the help of conventional integral control action. The main objective of the supplementary control is to restore balance between each control area load and generation after a load perturbation so that the system frequency and the tie-line power flows are maintained at their scheduled values. So the control task is to minimize the system frequency deviation Δf_1 in area 1, Δf_2 in area 2 and the deviation in the tie-line power flow ΔPtie between the two areas under the load disturbances ΔPd_1 and ΔPd_2 in the two areas. This is achieved conventionally with the help of integral control action. The supplementary controller of the ith area with integral gain Ki is therefore, made to act on ACEi, which is an input signal to the controller.

$$\Delta f_1(s) = \left[\Delta P_{C_1}(s) - \Delta P_{D_1}(s) - \Delta P_{TL_1}(s)\right]\left[\frac{K_{Ps}}{1+ST_{Ps}}\right] \quad (17)$$

$$\Delta P_{TL_1}(s) = \frac{2\pi T_{12}}{S}\left(\Delta f_1(s) - \Delta f_2(s)\right) \quad (18)$$

$$\Delta P_{TL_2}(s) = -\frac{2\pi a_{12} T_{12}}{S}\left(\Delta f_1(s) - \Delta f_2(s)\right) \quad (19)$$

$$\Delta f = \frac{\Delta P_{D_2} + a_{12}\Delta P_{D_1}}{\left[\left(\frac{1}{R_2}+B_2\right)+a_{12}\left(\frac{1}{R_1}+B_1\right)\right]} \quad (20)$$

$$\text{Tie line frequency } \Delta f = \frac{\Delta P_{D_1} + a_{12}\Delta P_{D_2}}{[\beta_2 + a_{12}\beta_1]} \quad (21)$$

$$\Delta P_{TL_1} = \frac{\beta_1 \Delta P_{D_2} - \beta_2 \Delta P_{D_1}}{\beta_2 + a_{12}\beta_1} \quad (22)$$

$$\beta_1 = \left(\frac{1}{R_1} + B_1\right) \quad (23)$$

$$\beta_2 = \left(\frac{1}{R_2} + B_2\right) \quad (24)$$

Equation (21) and (22) give the value of the static change in frequency and tie line power.

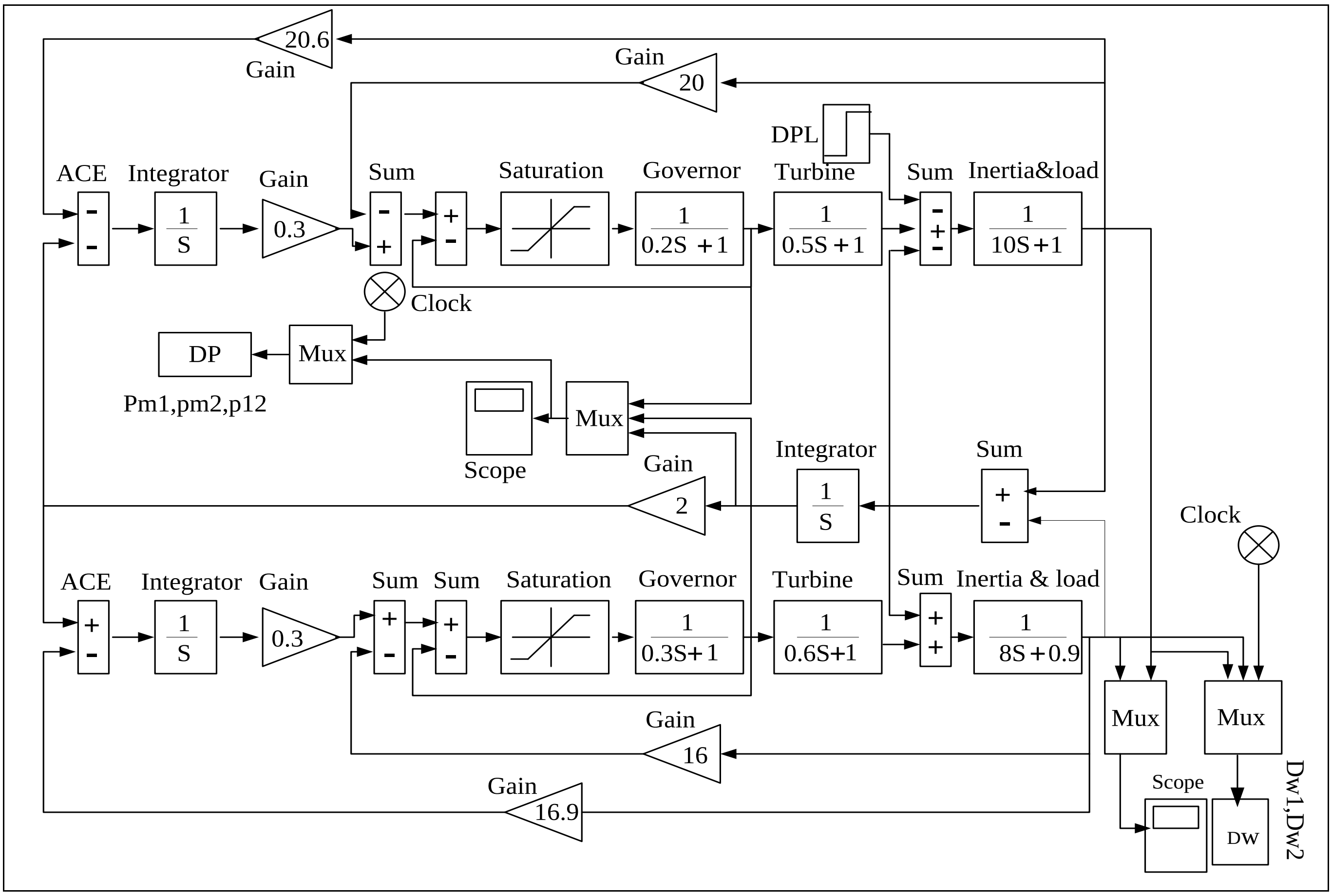

Fig. 5. Model of two areas with area control error and Considering GRC

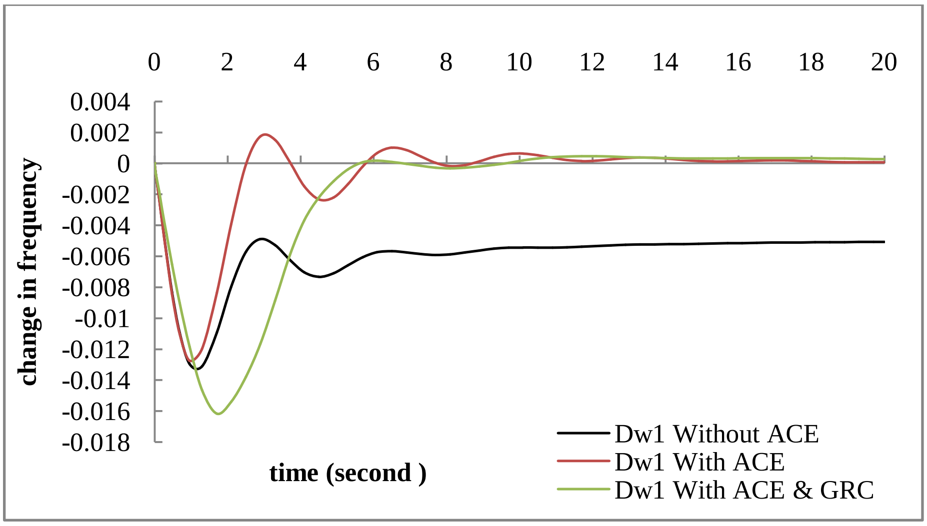

Fig. 6. Comparisons between Dw1 with and without ACE &GRC

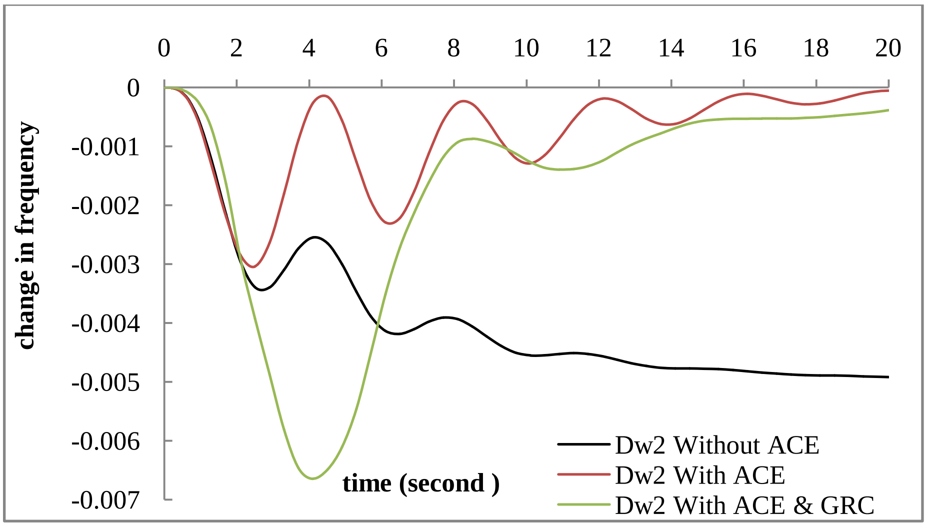

Fig. 7. Comparisons between Dw2 with and without ACE and GRC

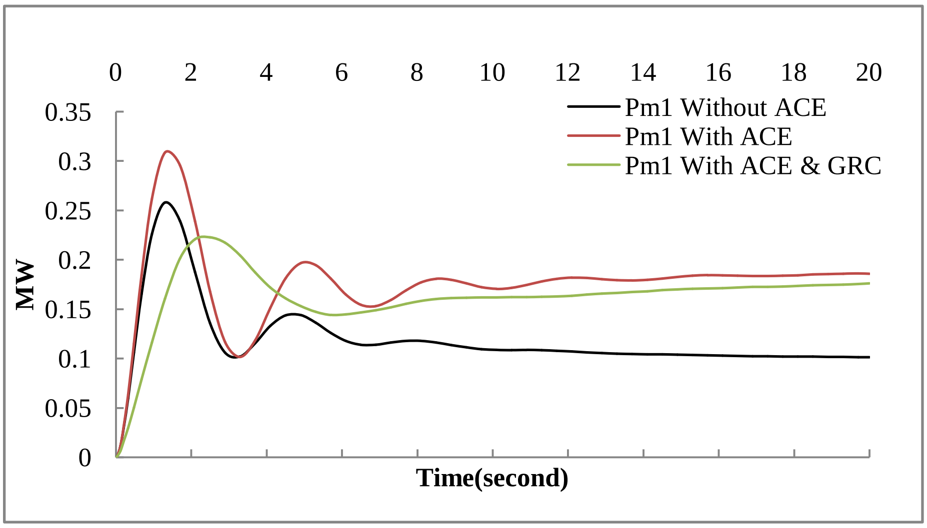

Fig. 8. Comparisons between Pm1 with and without ACE and GRC

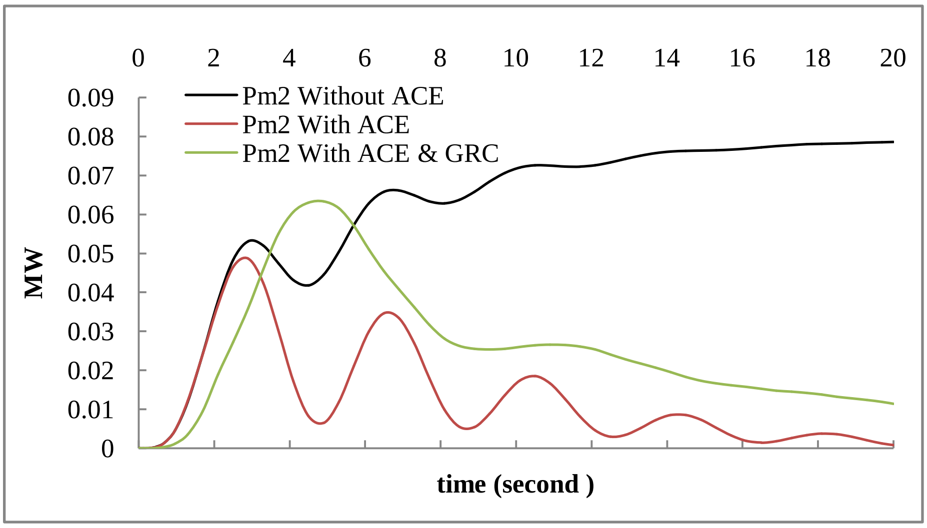

Fig.9. Comparisons between Pm1 with and without ACE and GRC

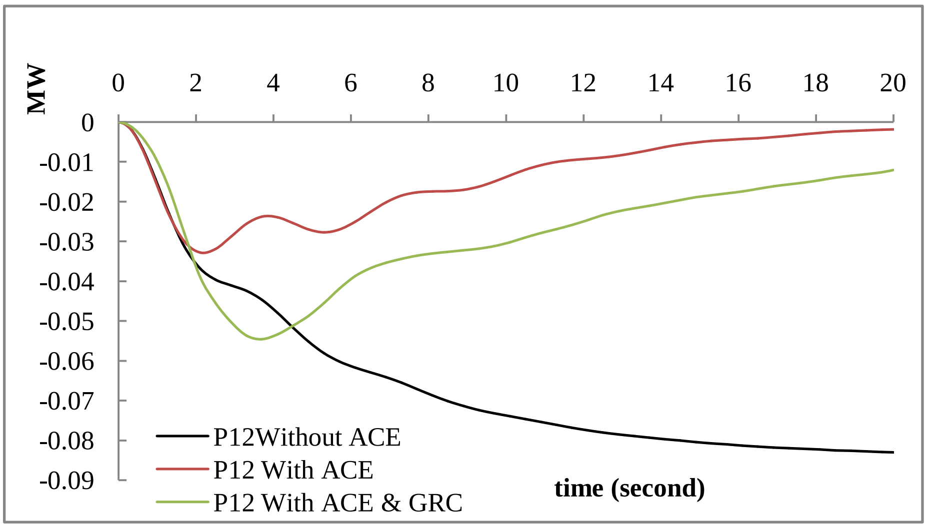

Fig. 10. Comparisons between P12 with and without ACE and GRC

Figs 6-10 represent the comparisons between results of the models when we used and without the ACE and ACE with GRC.
The best response when we use the ACE and GRC its clear that the steady state and settling time is less but the over shoot is peak because the GRC represents the actual curve.
.

5.2 Coupling between automatic generation control and automatic voltage regulator while considering generation rate constraint of two areas

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 vanish much fast or 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 emf, this emf determines the magnitude of real power and hence AVR loop felt in AGC loop.

In this section develop AGC scheme is employed with AVR and considering generation rate constraint. Here coupling between AGC and AVR scheme is employed. The interaction between frequency and voltage exists and cross coupling does exist and can some time troublesome. AVR loop affect the magnitude of generated emf. The internal emf determines the magnitude of real power. It is concluded that changes in AVR loop is felt in AGC loop.

Generation rate constraint is not effect on the terminal voltage because the GRC is applied only from the speed governor system.

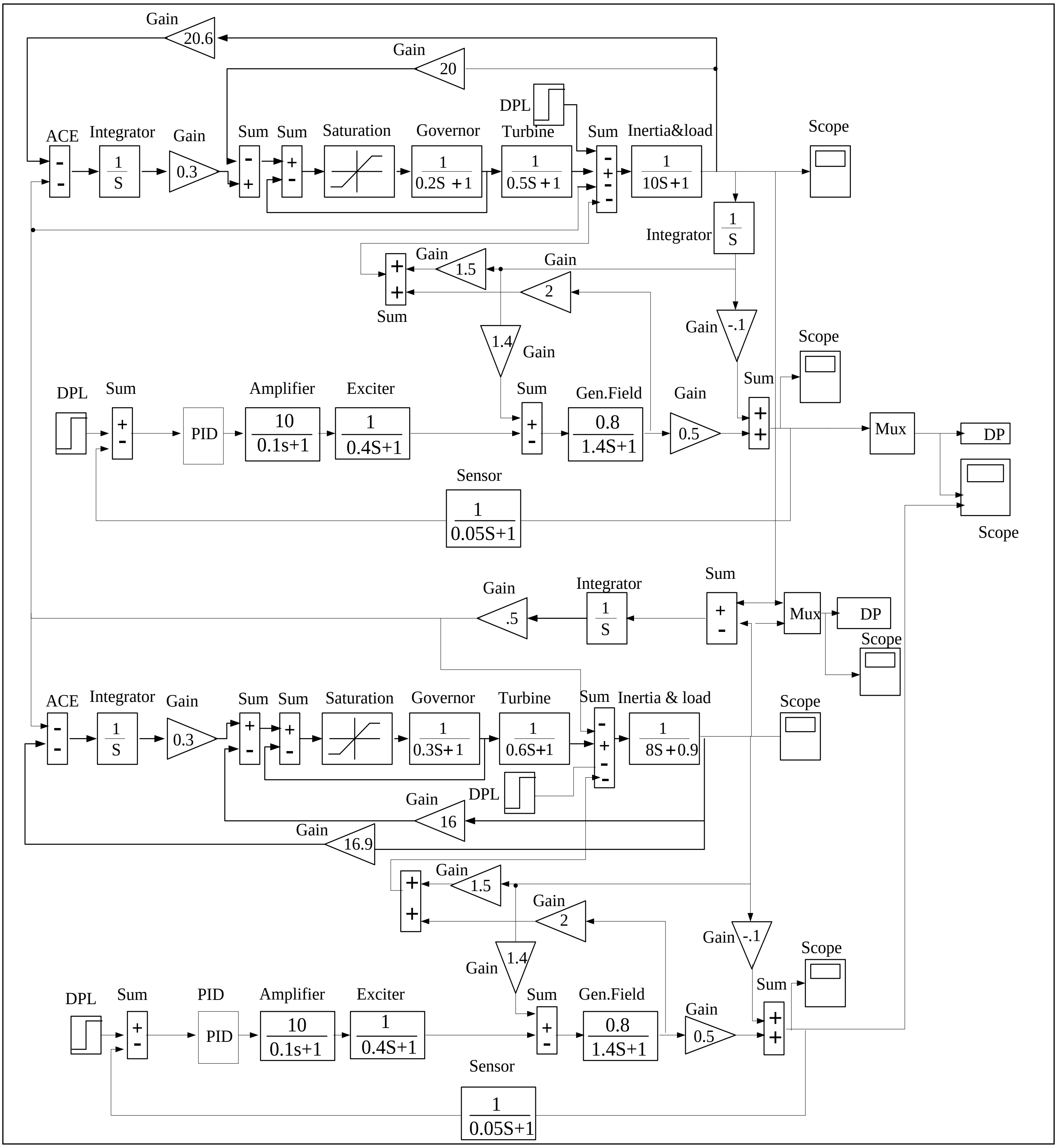

Fig. 11. *SIMULINK* model of two areas of AGC and AVR considering GRC

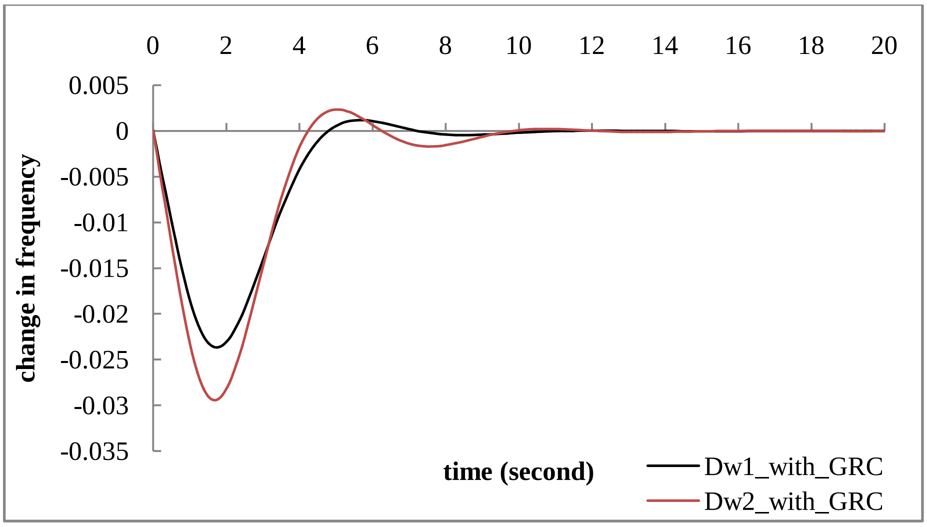

Fig.12. Change frequency of two areas AGC, AVR and GRC

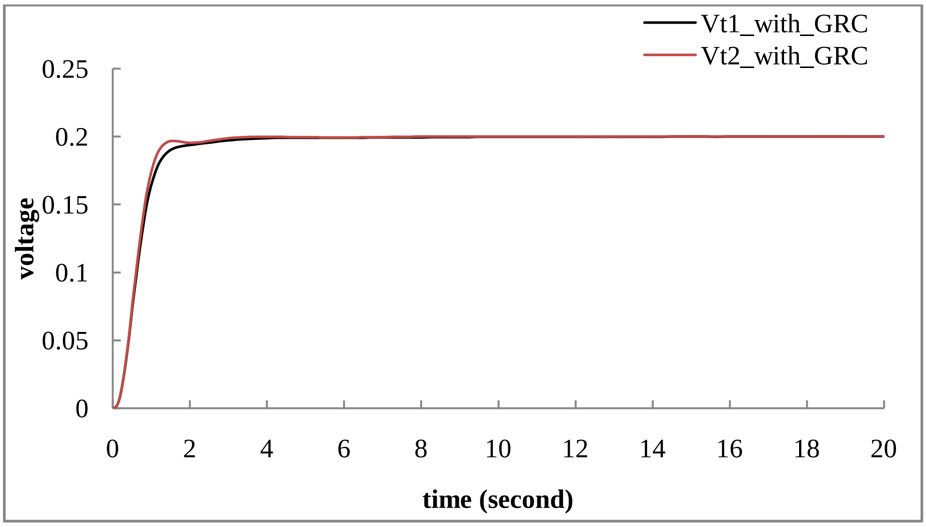

Fig.13. Terminal voltage of two areas AGC, AVR and GRC

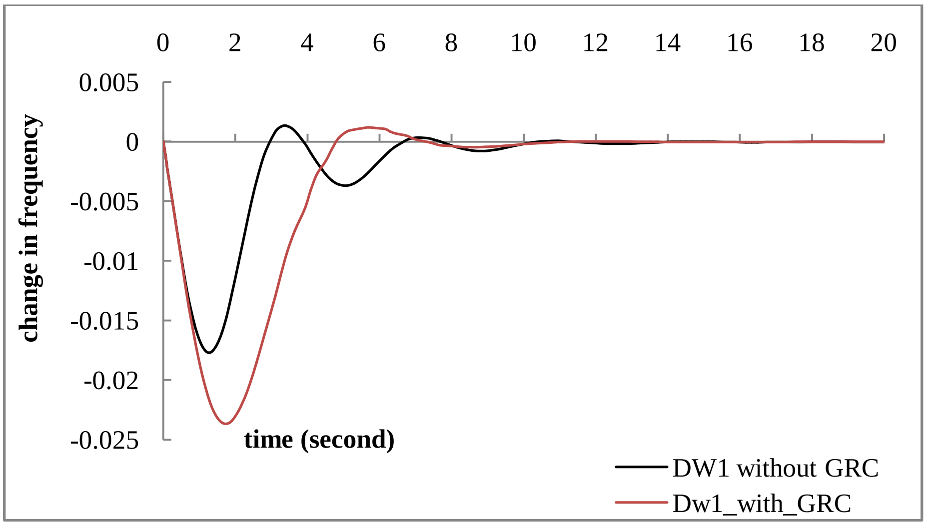

Fig.14. Comparison of change in frequency of area one

In **Fig. 11** develop AGC scheme with AVR and considering generation rate constraint of two areas. Here coupling between AGC and AVR scheme is employed. The interaction between frequency and voltage exists and cross coupling does exist and can some time troublesome. AVR loop affect the magnitude of generated emf. The internal emf determines the magnitude of real power. It is concluded that changes in AVR loop is felt in AGC loop.

Fig. 12 represent the change in frequency of area 1 and area 2 the time settling and steady state error is less when coupling, **Fig. 13** represent the comparison between frequency of area 1 its clear that the steady state and settling time is less but the over shoot is increase because that the GRC give the real state. **Fig. 14** represent the generation rate constraint is not effect on the terminal voltage because the GRC is applied only from the speed governor system.

6. CONCLUSIONS

The two major loops that are AVR loop and ALFC loop has been studied for two areas power system. The frequency of the system is dependent on real power output and is taken care of by ALFC. Terminal voltage of the system is dependent on the reactive power of the system and is taken care of by AVR loop. The cross coupling effects between the two loops are studied that are associated with low-frequency oscillations. It has been observed that even with GRCs the system remains stable and that the response with and without Generation Rate Constraints are not much different.

REFERENCES

[1] D. Lathwal, P. Malik, S. Kumar, "Analysis of Automatic Generation Control Two Area Network using ANN and Genetic Algorithm" *International Journal of Science and Research (IJSR),* India Online ISSN, pp. 2319-7064.

[2] G. V. Hicks, B. Jeyasurya, P. Eng; "An investigation of automatic generation control for an isolated transmission system", 1997, pp. 31- 34.

[3] P. Kundur, "Power System Stability and Control", Mc Graw- Hill, New Delhi, 2002.

[4] I. J. Nagrath, D. P. Kothari, "Modern Power System Analysis", BSP, Hyderabad, 2002.

[5] H. Saadat "Power System Analysis" WCB Mc Graw-Hill, 1999.

[6] S. Sivanagaraju, Gsreenivasan, "Power System Operation and Control", Oearson, 2010.

[7] V. Donde, M. A. Pai, and I. A. Hiskens; "Simulation and Optimization in an AGC System after Deregulation", Vol.16, No 3, August 2001.

[8] B. H. Bakken, K. Uhlen; "Market based AGC with online bidding of regulating reserves", 2001, pp. 848-853.

[9] J. Kumar, K. HoiNg, and G. Shevle, "AGC simulator for price based operation Part- 2", Vol.12, No. 2, May 1997, pp. 533- 538.

[10] K. Kumar, M. D. Singh, and A. K. Singh; "Modelling and simulation of AGC for SCADA based interconnected power system operation", pp.1-10.

[11] A. Sreenath, Y. R. Atre ,D. R. Patil, "Two Area Load Frequency Control with Fuzzy Gain Scheduling of PI Controller", *First International Conference on Emerging Trends in Engineering and Technology*, 2008 IEEE.

[12] J. katachalam, Rajalaxmi, "Automatic generation control of two area interconnected power system using particle swarm". Volume 6, Issue 1 (May. - Jun. 2013), pp. 28-36.

[13] S. D. Fellow, S. Mishra, and L. Chandra "optimization technique in multi area automatic generation control", Vol. 26, No. 2, May 2008.

[14] G. Panda, S. Panda and, H. A. shavenger "Automatic Generation Control of Interconnected Power System with Generation Rate Constraints by Hybrid Neuro Fuzzy Approach". *International Journal of Electrical and Electronics Engineering* 2009.

[15] A. Usman, B. Divakar, "Simulation Study of Load Frequency Control of Single and Two Area Systems", IEEE 2012, pp. 214-219.

APPENDIX

Table.1: Parameter of AGC model

Quantity	Area–I	Area–II
Governor Speed regulation	R1=0.051	R2=0.062
Frequency bias factors	D1= 0.62	D2= 0.91
Base power	1000MVA	1000MVA
Governor time constant	t_{g1}=0.2 sec	t_{g2}=0.3 sec
Turbine time constant	t_{T1}=0.5 sec	t_{T2}=0.6 sec
Constant	K=1/2π	K=1/2π
Inertia constant	H_1=5	H_2=4
Nominal frequency	F_1=50Hz	F_2=50Hz
Load change	ΔPL_1=180MW	ΔPL_2=0MW

Table.2: Parameter of AVR model

Quantity	Area–I	Area–II
Amplifier	10	0.1
Exciter	1	0.4
Generator	1	1
Sensor	1	0.05

Table.3: Parameter of PID Controller model

Quantity	Gain
PID Controller	KP=1
	K1=0.25
	KD=0.28