Global Journal of Researches in Engineering: F
Electrical and Electronics Engineering
Volume 22 Issue 2 Version 1.0 Year 2022
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Automatic Generation Control and Automatic Voltage Regulator Design for Load Frequency Control of Interconnected Thermal Power System

By Omer Elmukhtar & Jianhua Zhang
North China Electric Power University

Abstract- This paper presents a new model for each component of Automatic generation control (AGC) and automatic voltage regulator (AVR) loops considering generator rate constraints (GRC) of one and two areas interconnected thermal power system. Any mismatch between system generation and demand results in a change in system frequency that is highly undesired. Excitation of the 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.

Keywords: automatic generation control (AGC); automatic voltage regulator (AVR); automatic load frequency control (ALFC); generation rate constraint (GRC).

GJRE-F Classification: DDC Code: 621.31 LCC Code: TK153

AUTOMATICGENERATIONCONTROLANDAUTOMATICVOLTAGEREGULATORDESIGNFORLOADFREQUENCYCONTROLOFINTERCONNECTEDTHERMALPOWERSYSTEM

Strictly as per the compliance and regulations of:

Automatic Generation Control and Automatic Voltage Regulator Design for Load Frequency Control of Interconnected Thermal Power System

Omer Elmukhtar [α] & Jianhua Zhang [σ]

Abstract- This paper presents a new model for each component of Automatic generation control (AGC) and automatic voltage regulator (AVR) loops considering generator rate constraints (GRC) of one and two areas interconnected thermal power system. Any mismatch between system generation and demand results in a change in system frequency that is highly undesired. Excitation of the 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. Although the frequency variation was found to be less with suitable controllers when the GRC is not considered, it is not the frequency variation. The frequency variation can be found when GRC is considered and then accordingly the controller is tuned. So that the required frequency and power interchange with adjacent structures are maintained in order to minimize the transient deviations and to provide zero steady-state error in a proper short time, the response without GRC is compared with the analysis done with the GRC, the behaviour of the planned is checked by MATLAB SIMULINK software.

Keywords: automatic generation control (AGC); automatic voltage regulator (AVR); automatic load frequency control (ALFC); generation rate constraint (GRC).

I. Introduction

The 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 for reheat units is quite low. 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.

Load frequency control (LFC) performs a very important role in power stability between load and generation sides. In the latest years, many robust design strategies have been delivered for LFC[1-3] the dynamic behaviour of the many industrial plants are heavily influenced by means of disturbances and, in particular, by adjustments in the operating point. This is often sometimes typically the case for power systems [4]. Automatic Generation Control (AGC) is the most necessary problems in electric strength machine sketch and operation. The goal of the AGC in an interconnected strength machine is to hold tie-line electricity strength and to keep the frequency of every area shut to the scheduled values through adjusting the MW outputs of the AGC generators which will accommodate fluctuating load demands [5]. The generator excitation device keeps the generator voltage and controls the reactive electricity flow. A generator excitation of the older system may additionally be furnished via slip rings and brushes via implying of DC generator hooked up on the equal shaft as the rotor of the synchronous motor [6].

Obviously, trade in the real electricity demand impacts if truth be told the frequency, whereas a change in the actual strength influences by the voltage magnitude. The communication between frequency control and voltage is typically weak enough to justify their analysis separately. The sources of reactive strength are generators, capacitors, and reactors [7].

Generators with identical response characteristics for load variations assembled together to meet a particular load demand is referred to as the area. These areas are interconnected with tie lines these tie lines are used to alternate energy between areas, which will increase fault level and inter-area support just in case of abnormal situations [8-10]. The area may also have mixed of various sources combination of different sources in this paper every area consists of thermal with reheat type turbine system, fuel electricity technology hydro, gas power generation [11]. The conventional control approach for the frequency regulation problem is based totally on applying corrective signal governor summing point using PI, PID controllers. These controllers achieve zero steady-state error however dynamic performance exhibited by these controllers may be very poor. Greater over PI, PID controllers fail to

Author α: Department of Computer Science and Control Engineering North China Electric Power University, Beijing, China.
e-mail: omer90mizo@ncepu.edu.cn
Author σ: State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources, North China Electric Power University, Beijing, China.

provide satisfactory performance over a variety of operating conditions.

A literature review on LFC shows varied control strategies have been utilized for the load frequency control problem. Optimal state feedback control approaches, sub-optimal state feedback controllers are projected in [12-13] Adaptive and self-tuning methods are proposed in [14-15] Evolutionary algorithms like GA, PSO, optimization, bacterial foraging, etc. applied by several authors [16-19]. In an extensive literature survey, LFC shows that LFC with ANN & Fuzzy logic control application providing better performance for load frequency control problems [19-22].

II. Automatic Generation Control

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

a) Generator Load Model

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

$$\Delta F(s) = \Delta P_G(s) - \Delta P_D(s)\frac{KP_S}{1+sTP_S} \quad (1)$$

TPS is a power system time constant

KPS is a power system gain

b) Prime Mover Model

he model for the turbine relates modifications in mechanical power output ΔPt(s) to modifications in steam valve position, the simplest prime mover model for the non-reheat steam turbine can be approximated with a single time constant (Tt), resulting in the following transfer function:

$$\frac{\Delta P_t(s)}{\Delta y_E(s)} = \frac{K_t}{1+ST_t} \quad (2)$$

c) Speed Governor Model

Most modem governors use electronic means to sense speed changes.

$$\Delta Y_E(s) = \Delta P_c(s) - \frac{1}{R}\Delta f(s) \times \frac{K_{sg}}{1+T_{sg}(s)} \quad (3)$$

R = Speed regulation of the governor

KSg = Gain of speed governor

Tg (s) = Time constant of speed governor

III. Area Control Error of Two Areas

The normal switch characteristic of the mannequin is Let us now flip our attention to ACE (area control error) in the presence of a tie line. In the case of an isolated manage area, ACE is the exchange in place frequency which when used in crucial manage loop forces the steady country frequency error to zero. In order that the regular country tie line strength error in a two-area manipulate be made zero every other control loop (one for every area) has to be brought to combine the incremental tie line strength signal and feed it lower back to velocity changer. This is performed by using a single line-integrating block through redefining ACE as a linear combination of incremental frequency and tie-line power.

IV. 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 an unexpected drop in voltage due to accidents, faults or common changes in loading. The AVR improves the transient stability of a system.

a) Amplifier Model

The comparator continuously compares the reference voltage Vref and actual output voltage Vt and generates 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 the amplifier, its transfer function (T. FA) is given by:

$$T.F_A = \frac{K_A}{1+ST_A} = \frac{\Delta V_R(S)}{\Delta V_T(S)} \quad (4)$$

Where ΔVR (S) is the amplifier output and ΔVT (S) is the error voltage and is given by:

$$\Delta V_T(S) = V_{ref} - V_T \quad (5)$$

b) Exciter

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

$$T.F_A = \frac{K_E}{1+ST_E} = \frac{\Delta V_F(S)}{\Delta V_R(S)} \quad (6)$$

Where ΔVF (S) is the field voltage of the synchronous generator, the time constant of the modern exciter is very small.

c) Generator Field Model

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

$$T.F_G = \frac{K_R}{1+ST_R} = \frac{\Delta V_T(S)}{\Delta V_F(S)} \quad (7)$$

d) Sensor Model

The sensor sensed voltage through a potential transformer.

$$T.F_S = \frac{K_R}{1+ST_R} = \frac{\Delta V_S(S)}{\Delta V_T(S)} \quad (8)$$

a) Two Areas Load Frequency Control

Figure 1 represented the simulation of the block diagram of two areas.

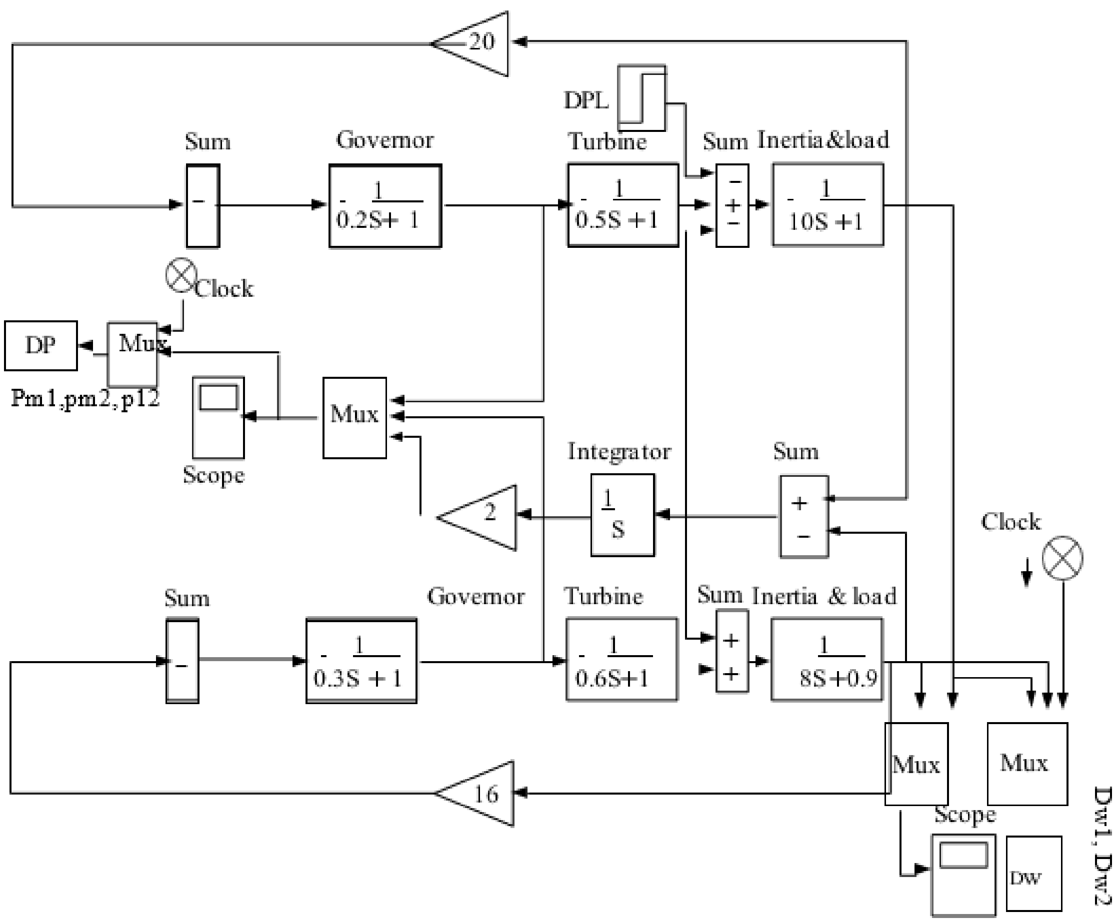

Figure 1: Model of two areas load frequency control

V. Simulation and Results

The design and simulation of the system are analysing using MATLAB SIMULINK environment. And it's using it to testing the individual blocks of automatic voltage control and automatic voltage regulator system of single and two areas with generation rate constraint and used area control error to improve the dynamic response and to reduce the steady-state error to zero.

In this study there are many assumptions, the model of thermal generation plant, also the system with two control areas that had one tie line between them and the basic block diagram for a single and two areas AGC, the system is in a normal operating mode and the loss of a generating unit will not be considered.

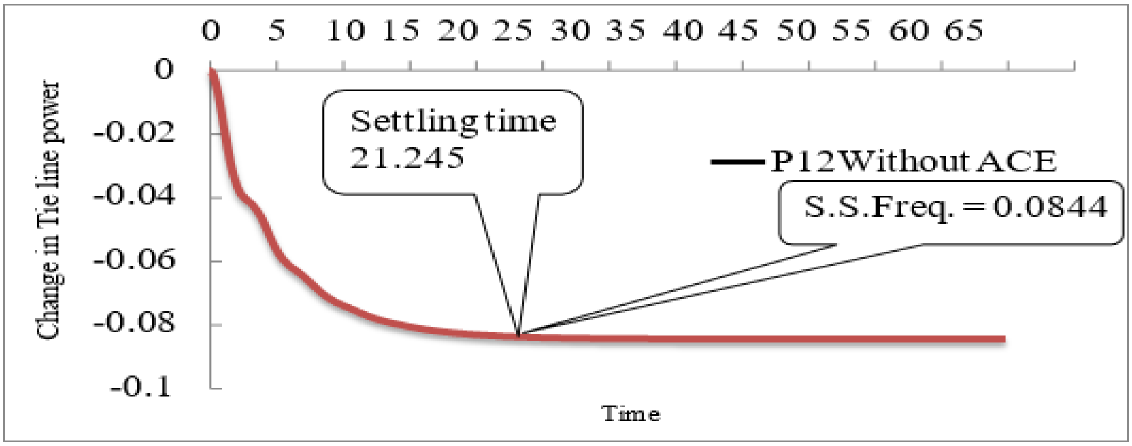

Figure 2: Change in tie-line power

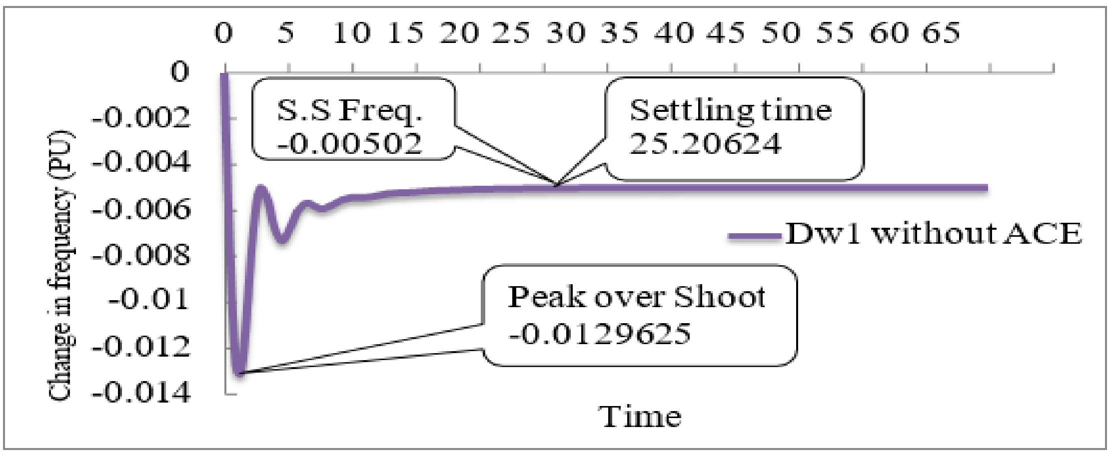

Figure 3: Change in frequency of area one without ACE

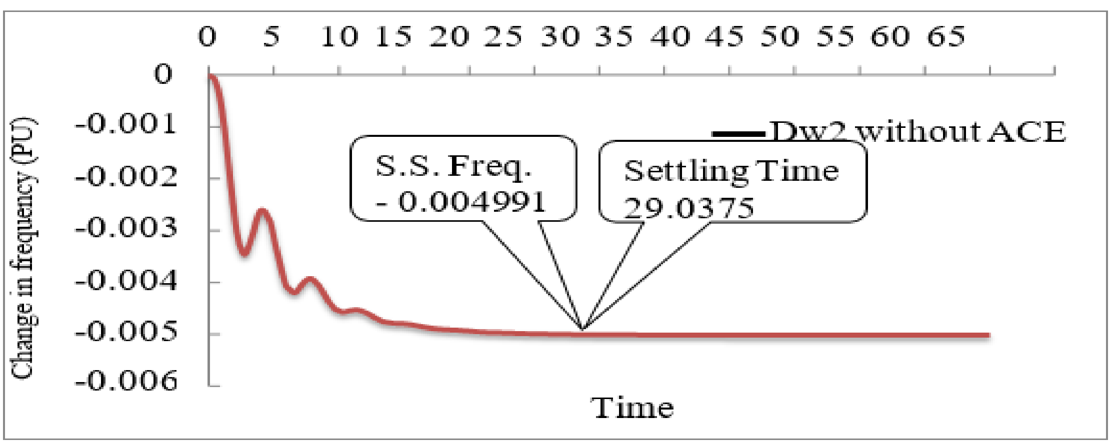

Figure 4: Change in frequency of area two without ACE

Figure 4 shows the schematic of the LFC of the 2-area system without the secondary loop while figures 2, 3, 4 shows the simulation results. As the two systems are interconnected, the frequency drifts of the two will settle down to equal value after some oscillations. The mechanical inputs of the two vary to reduce the mismatched power between the electrical load in area 1 and the mechanical inputs. It can also be observed that area 2 will generate excess power to share the load change in area1. It can observe the tie-line power flow following a load disturbance in area 1. Compared to the same result with the system, I appreciated the stability improvement with interconnection.

b) Two Areas Load Frequency Control with Area Control Error

The tie line deviation reflects the contribution of the regulation characteristic of one area to another. The basic objective of supplementary control is to restore the balance between each area load generation. This objective is met when the control action maintains frequency at the scheduled value. The supplementary control should ideally correct only for changes in that area. In other words, if there is a load change in Area1, there should be supplementary control only in Area1 and not in Area2. For this purpose, the area control error (ACE) is used.

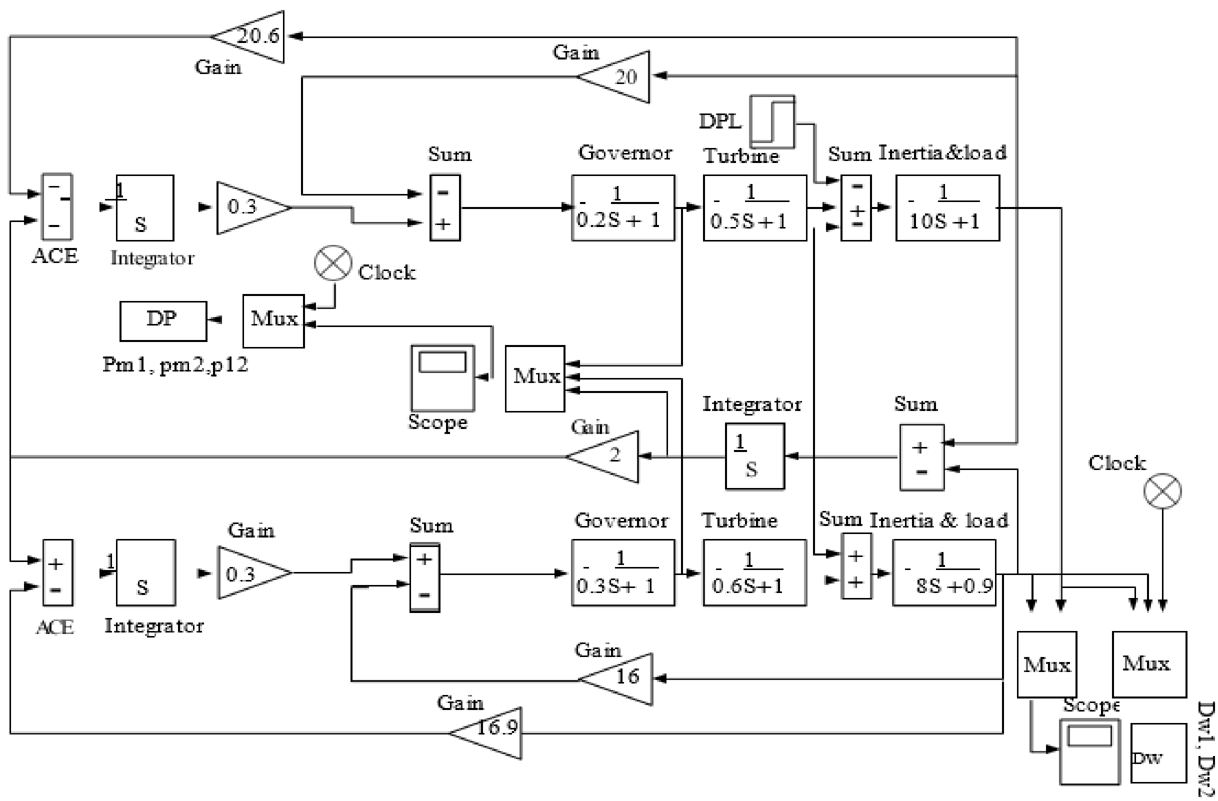

Figure 5: Model of two areas loads frequency control with area control error

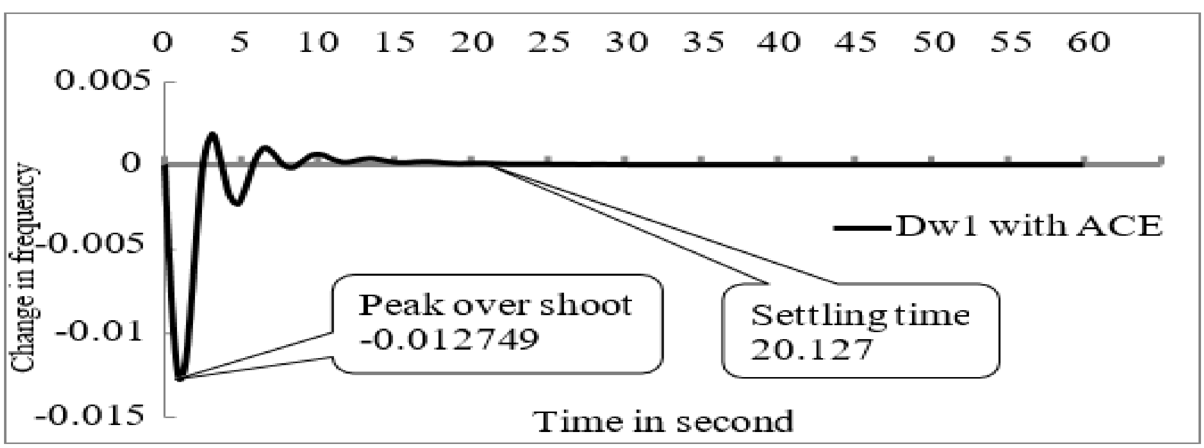

Figure 6: Change in frequency of area one with ACE

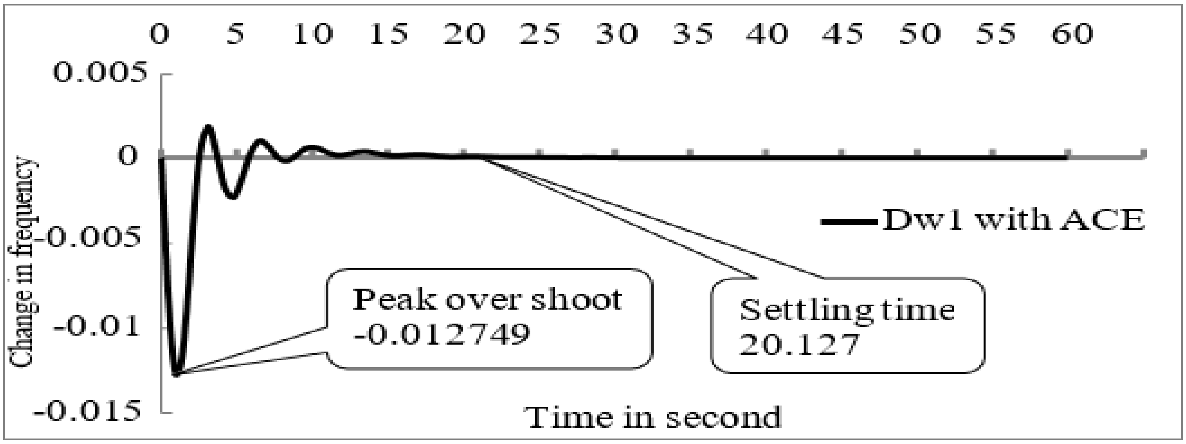

Figure 7: Change in frequency of area one with ACE

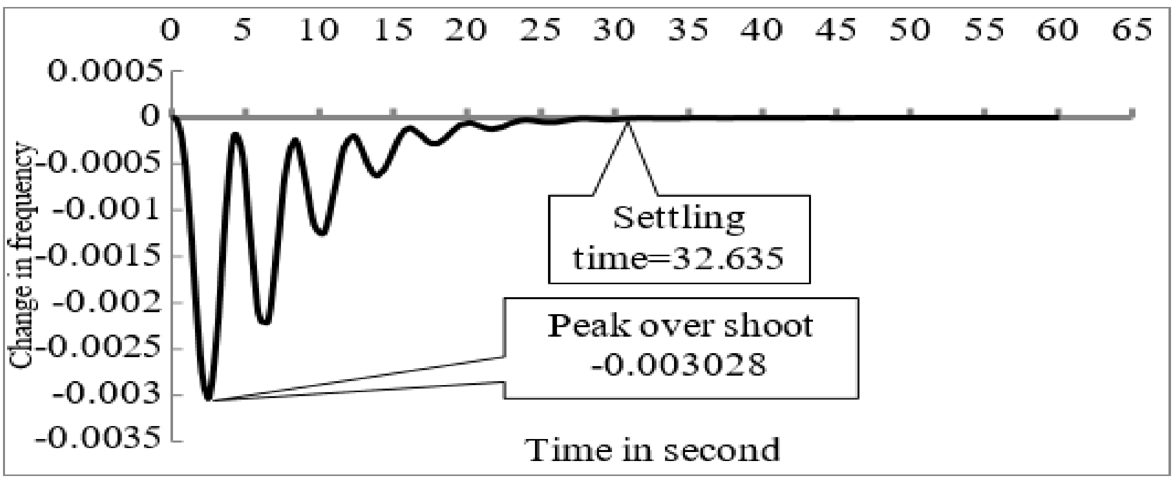

Figure 8: Change in frequency of area two with ACE

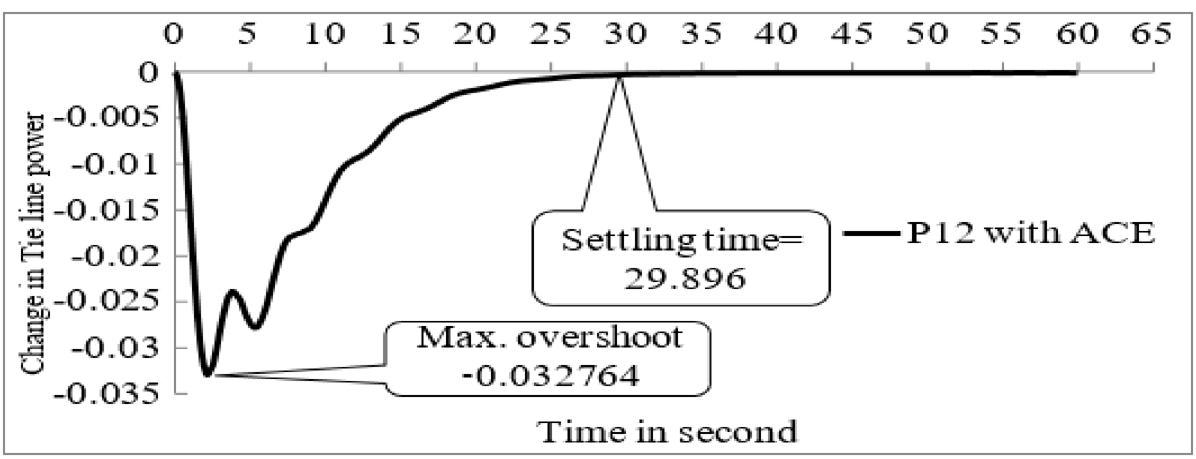

Figure 9: Tie line of two areas with ACE

As seen from the figures the secondary loop causes the return of frequency drifts to zero.

From the above simulation plots, it can be observed that the system experiences frequency drift following a load disturbance and it is mainly due to the mismatch between the electrical load and the mechanical input to the turbine. The system oscillation is serious in single area system compared to two area system because all the load change in load is to be met by only one area. Also, using the second loop in both the single area as well as the two area system the change in frequency is brought to zero.

c) Two Areas Load Frequency Control with Generation Rate Constraint

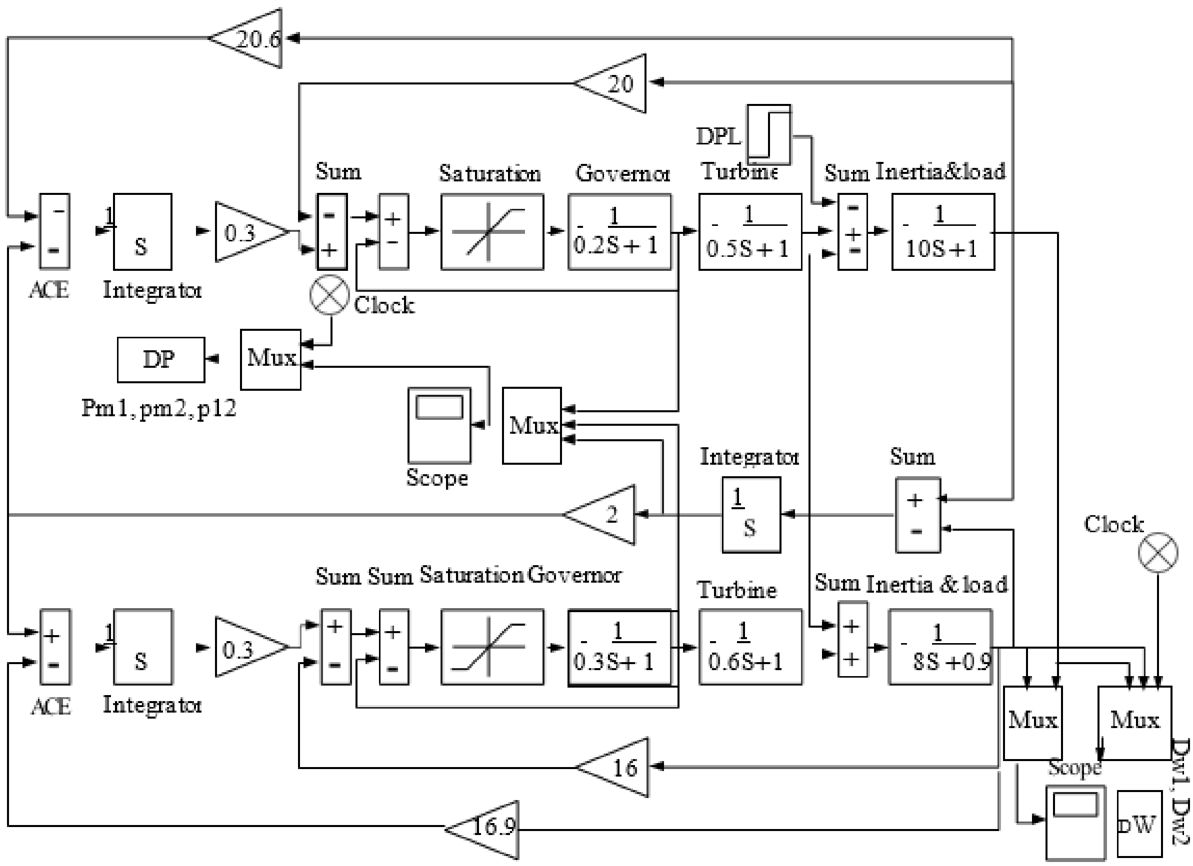

Figure 10: Models of two areas with generation rate constraint

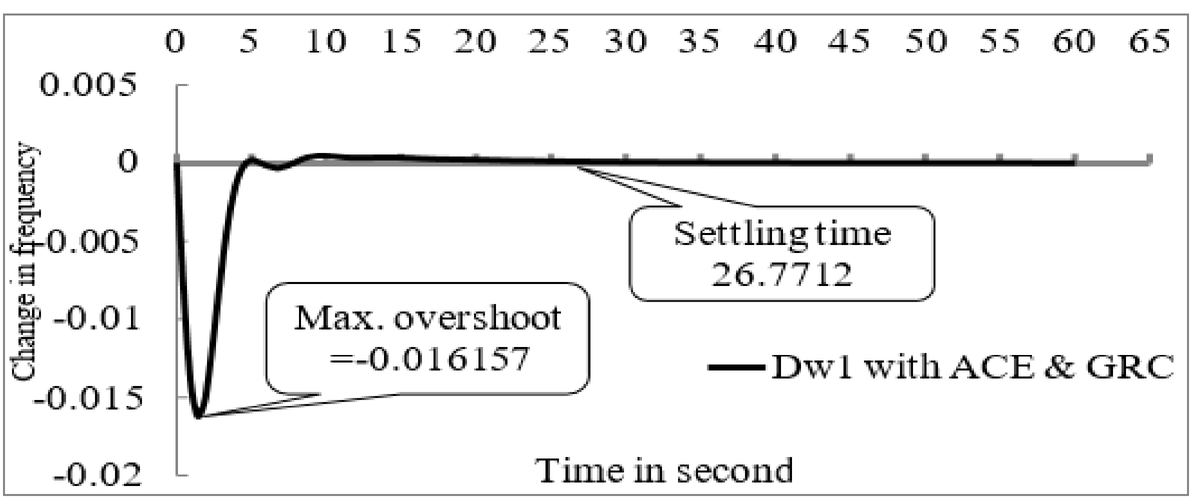

Figure 11: Change in frequency of area one with ACE and GRC

Global Journal of Researches in Engineering (F) Volume XXII Issue II Version I Year 2022

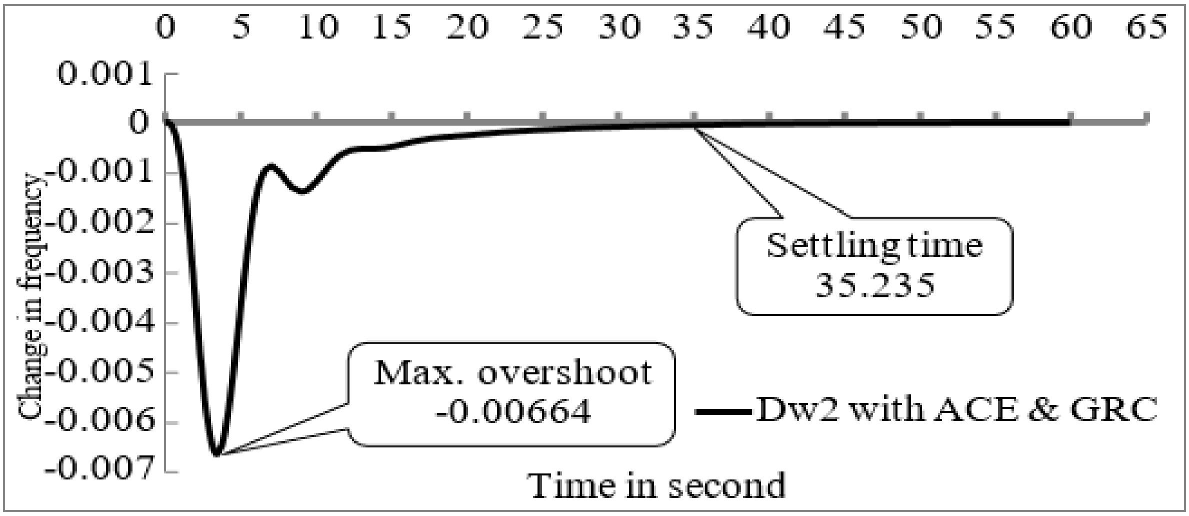

Figure 12: Change in frequency of two areas with ACE and GRC

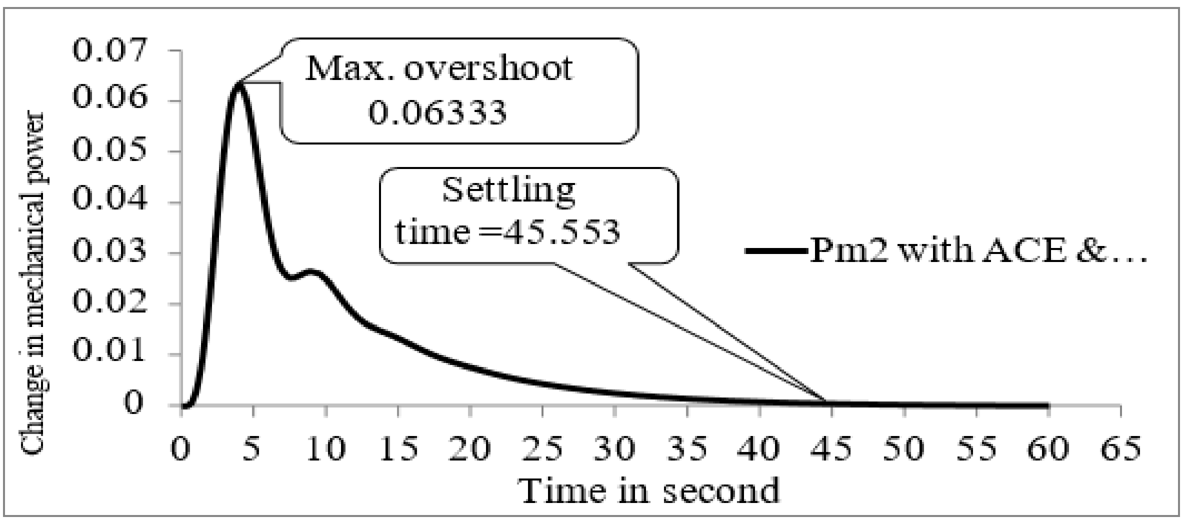

Figure 13: Change in mechanical power of area two with ACE and GRC

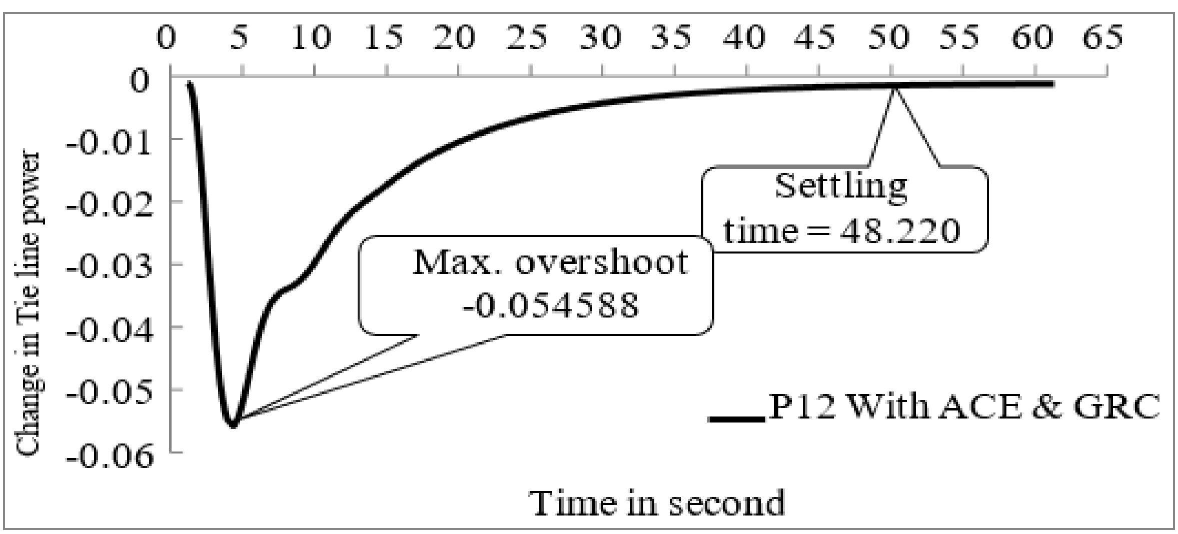

Figure 14: Change in tie-line power of two areas with ACE and GRC

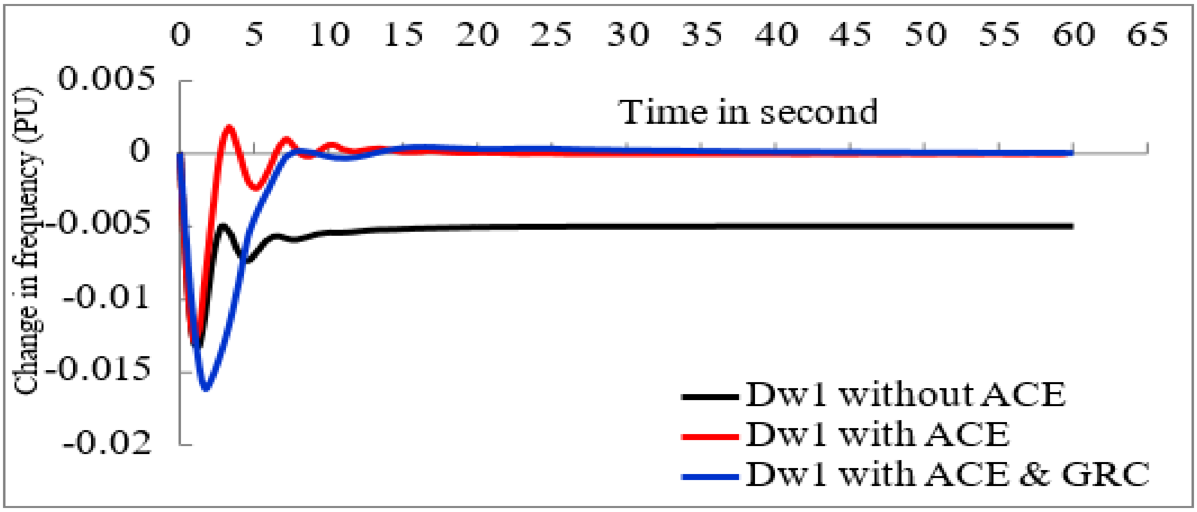

Figure 15: Comparisons between Dw1 with and without ACE & GRC

Table 1: Represent summary of figure 15

	Peak over shoot	S.S.Freq.	Settling time
First order	-0.01296	-0.00502	25.20624
Without ACE	-0.012749	0.0	20.1273
With ACE	-0.016157	0.0	26.7712

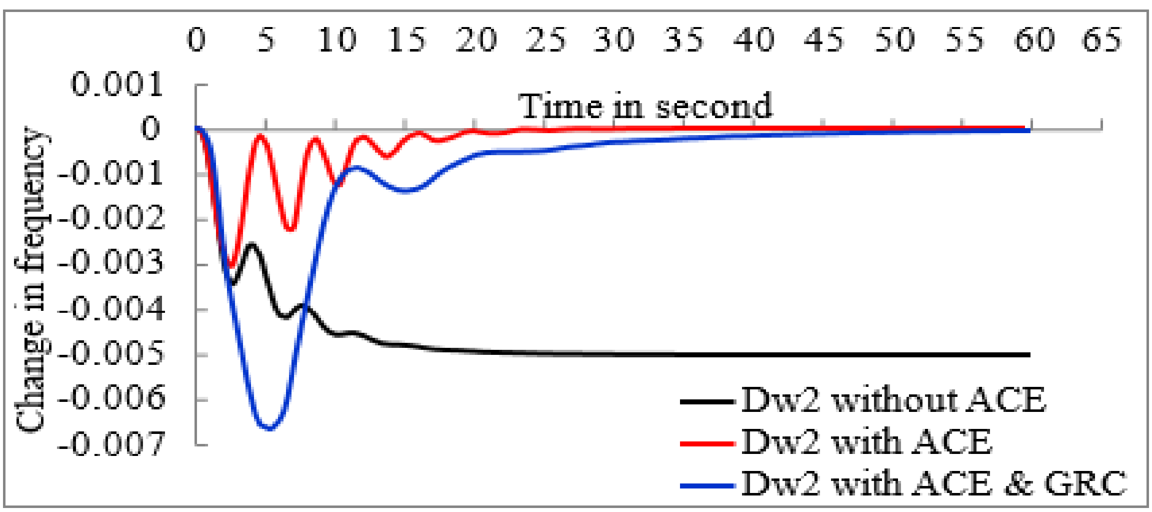

Figure 16: Comparisons between Dw2 with and without ACE & GRC

Table 2: Represent summary of figure 16

	Peak over shoot	S.S.Freq.	Settling time
Without ACE	-0.004991	-0.004991	29.037
With ACE	-0.003028	0.0	32.635
With GRC	-0.00664	0.0	35.235

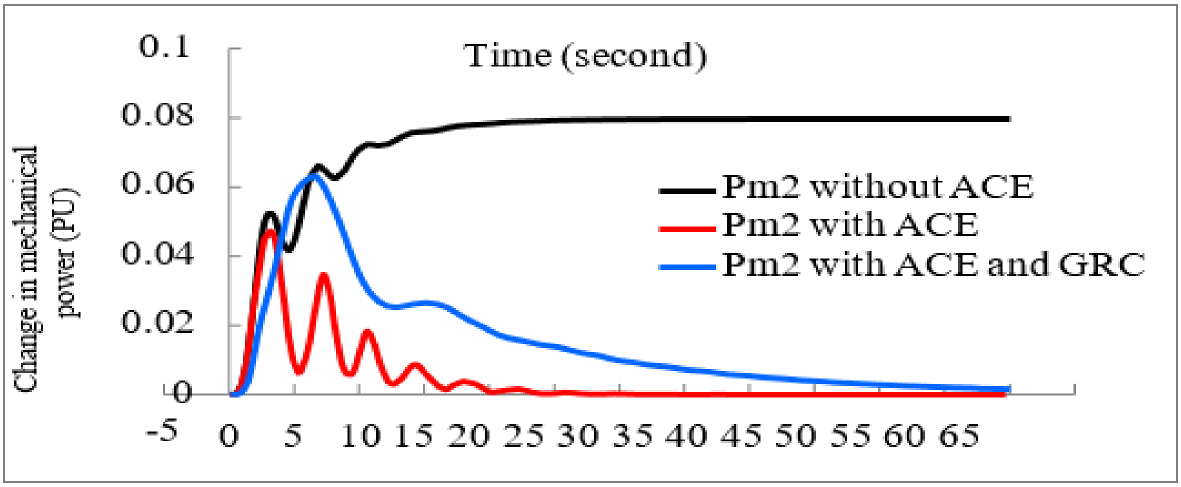

Figure 17: Comparisons between Pm2 with and without ACE & GRC

Table 3: Represent summary of figure 17

	Peak over shoot	S.S.Freq.	Settling time
Without ACE	0.07996	0.07996	25.206
With ACE	0.04721	0.0	32.452
With GRC	0.06333	0.0	45.553

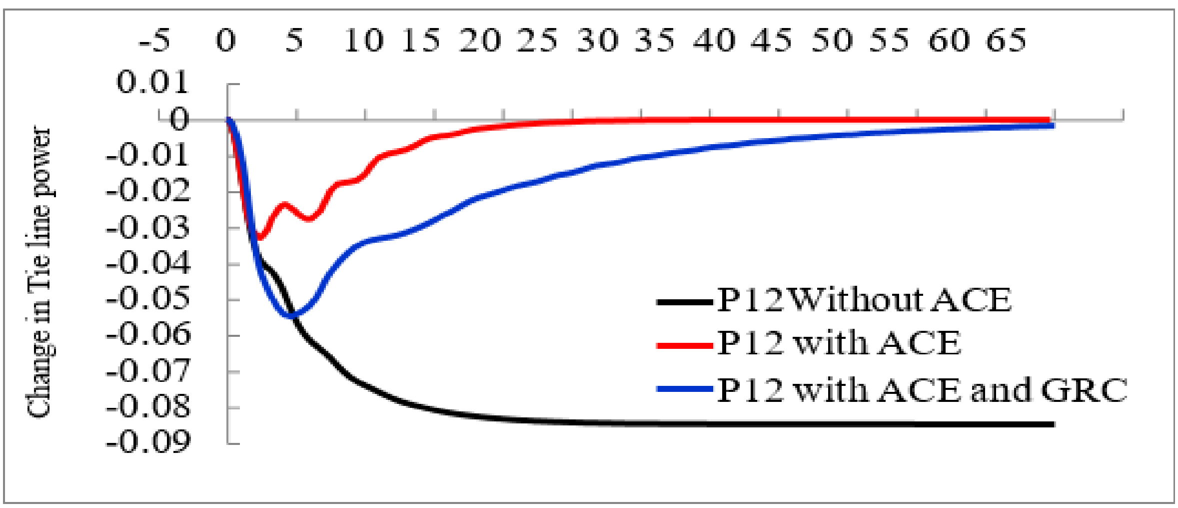

Figure 18: Comparisons between P12 with and without ACE

Table 4: Represent summary of figure 18

	Peak over shoot	S.S.Freq.	Settling time
Without ACE	-0.0844	-0.0844	21.245
With ACE	-0.0327	0.0	29.896
With GRC	-0.0546	0.0	48.220

Automatic Generation Control was implemented in the system under study in a deregulated environment. The effect of GRC is clearly distinct with large oscillations the system overshoots increase and more settling time.

The main reason to consider GRC is that the rapid power increase would draw out excessive steam from the boiler system to cause steam condensation due to adiabatic expansion. Since the temperature and pressure in the HP turbine are normally very high with some margin, it is expected that the steam condensation would not occur with about 20% steam flow change unless the boiler steam pressure itself does not drop below a certain level. Thus it is possible to increase generation power up to about 1.2 pu of normal power during the first tens of seconds. After the generation power has reached this marginal upper bound, the power increase of the turbine should be restricted by the GRC. GRC affecting large turbo generator is generally bounded by 0.1/min. As the constraint of the generator and that of control effort calculated in LFC are in direct proportions, GRC will be transformed into system control constraints.

VI. Conclusion

A simulation study of two area systems with automatic generation control is carried out with models developed in SIMULINK. The simulation of these systems has been carried out and results analyzed. The operation of two area systems with and without automatic voltage regulator are very well depicted through simulation models. The advantage of interconnection is best understood by comparing the results of two area systems. It can be seen that the oscillations due to the change in load in any area are damped down quickly because of tie-line power flow. It can also be observed that the dynamic response is mainly governed by the secondary loop and hence design criteria of which is extremely vital for efficient implementation.

The frequency of the system is dependent on real power output and is taken care of by ALFC. The terminal voltage of the system is dependent on the reactive power of the system and is taken care of by the AVR loop. The cross-coupling effects between the two loops are studied which is associated with low-frequency oscillations. It is clear from the results that the AVR loop is able to maintain the voltage and frequency deviations in the specified limits and the power system thus becomes more robust. The dynamic responses are further improved in terms of peak deviations and settling time.

References Références Referencias

1. H. Bevrani, Robust Power System Frequency Control. Cham, Switzerland: Springer International Publishing, 2014.
2. S. Saxena and Y. V. Hote, Load frequency control in power system via internal model control scheme and model-order reduction, IEEE Trans. Power Syst., vol. 28, no. 3, Aug. 2013, pp. 2749– 2757.
3. L. Jiang, W. Yao, Q. H. Wu, J. W. Wen, and S. J. Cheng, Delay-dependent stability for load frequency control with constant and time-varying delays, IEEE Trans. Power Syst., vol. 27, no. 2, May 2012, pp. 932–941.
4. G. Eason, B. Noble, and I. N. Sneddon, on certain integrals of Lipschitz-Hankel type involving products of Bessel functions, Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences, 247(935), 1955, pp.529-551.
5. 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, 2013, pp. 2319-7064.
6. G. V. Hicks, B. Jeyasurya, P. Eng; An investigation of automatic generation control for an isolated transmission system, IEEE, 1997, pp.31-34.
7. P. Kundur, Power System Stability and Control, Mc Graw- Hill, New Delhi, 2002.
8. Dar, S. Z. N., 2017, May. Improved load frequency response in two area power system with battery energy storage. International Conference on Computing, Communication, and Automation (ICCCA), IEEE, 2017, pp. 977-981.
9. A. G. Ter-Gazarian, Energy Storage for Power Systems UK: IET Power and Energy Series, 2011.
10. F. D. Gonzalez, A. Sumper, O. G-Bellumunt, and R. V Robles, A review of energy storage technologies for wind power applications, Renewable, and Sustainable Energy Reviews, 2012 vol.16, no.4, pp2154-2171.
11. Jyothi, T. D., Lavanya, N., Shankar, C. B. and Sudhakar, T. An Intelligent Load Frequency Control for Two Area System. In 7th International Advance Computing Conference (IACC) IEEE, 2017, January, pp. 355-360.
12. Liu, F., Li, Y., Cao, Y., She, J. and Wu, M. A two-layer active disturbance rejection controller design for load frequency control of interconnected power system. IEEE Transactions on Power Systems, 2016, pp.3320-3321.
13. Ramjug-Ballgobin, R., Hassen, S. S. and Veerapen, S, Load frequency control of a nonlinear two-area power system. In 2015 International Conference on Computing, Communication and Security (ICCCS), IEEE, 2015, December, pp. 1-6.
14. AnilKumar, A. and Srikanth, N. V., October. Load frequency control for diverse sources of interconnected two area power system: An adaptive fuzzy approach. In 2016 International Conference on Control, Computing, Communication, and Materials (ICCCCM) IEEE, 2016, pp1-4.
15. Parmar, K. S., Majhi, S. and Kothari, D. P. Load frequency control of a realistic power system with multi-source power generation. International Journal

of Electrical Power & Energy Systems, 2012, pp.426-433.
16. Daneshfar, F. and Bevrani, H, Multiobjective design of load frequency control using genetic algorithms. International Journal of Electrical Power & Energy Systems, 2012, pp.257-263.
17. Nagarjuna, N. and Shankar, G.. Load frequency control of two area power system with AC-DC tie line using PSO optimized controller. In 2015 International Conference on Power and Advanced Control Engineering (ICPACE) IEEE, 2015, August, pp.227-231.
18. Kumari, N. and Jha, A. N. Frequency control of multi-area power system network using PSO based LQR. In 2014 6th IEEE Power India International Conference (PIICON) IEEE, 2014, December. pp. 1-6.
19. Chokpanyasuwan, C. Robot Fuzzy logic-PID Controller for Wind-Diesel Power System using Particle Swarm Optimization. In GMSARN International Conference on Sustainable Development: Issues and Prospects for the GMS, 2008.
20. Mallesham, G., Mishra, S. and Jha, A. N. Automatic generation control of microgrid using artificial intelligence techniques. In 2012 IEEE Power and Energy Society General Meeting, 2012, July, pp. 1-8.
21. Elmas, C., Deperlioglu, O., and Sayan, H. H. Adaptive fuzzy logic controller for DC-DC converters. Expert Systems with Applications, 2009, pp.1540-1548.
22. Parmar, K. S., Majhi, S. and Kothari, D. P. Load frequency control of a realistic power system with multi-source power generation. International Journal of Electrical Power & Energy Systems, 2012, pp.426-433.

Appendix

Table 5: 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	$tg1$=0.2 sec	$tg2$=0.3 sec
Turbine time constant	$tT1$=0.5 sec	$tT2$=0.6 sec
Constant	K=1/2π	K=1/2π
Inertia constant	H1=5	H2=4
Nominal frequency	F1=50Hz	F2=50Hz
Load change	$\Delta PL1$=180MW	$\Delta PL2$=0MW