Grenze International Journal of Engineering and Technology, July 2015

Design and Simulation of Generation Control Loops for Multi Area Interconnected System

[1]Abhilash M G and [2]Frenish C Francis
[1,2]Department of EEE, Thejus Engineering College, Thrissur, Kerala, India
[1]abispash@gmail.com, [2]frenishcf@gmail.com

***Abstract*—This work deals with the automatic generation control (AGC) of interconnected thermal systems with combination of the automatic voltage control (AVR). In this particular work three thermal areas connected with tie-line are considered. The primary purpose of the AGC is to balance the total system generation against system load plus losses so that the desired frequency and power interchange with neighboring areas are maintained. Any mismatch between generation and demand causes the system frequency to deviate from scheduled value. Thus high frequency deviation may lead to system collapse. Further the role of automatic voltage regulator is to hold terminal voltage magnitude of synchronous generator at a specified level. The interaction between frequency deviation and voltage deviation is analyzed in this paper. System performance has been evaluated at various loading disturbances.**

***Index Terms*— Automatic Generation Control, Automatic Voltage Control, Frequency deviation, Tie-line flow, Fuzzy Logic Controller.**

I. INTRODUCTION

With the growth of power system networks and the increase in their complexity, many factors have become influential in electric power generation, demand or load management. The increasing demand for electric power coupled with resource, and environmental constraints pose several challenges to system planners. Stability of power systems has been and continues to be of major concern in system operation and control. The maximum preoccupation and concern of power system engineers are the control of megawatt, the real power and reactive power, because it is the governing element of revenue. Because of increased size and demand, it has forced them to design and control more effective and efficient control schemes to maintain the power system at desired operating levels characterized by nominal system frequency and voltage. The main function of a power system is to supply the real and reactive power demand with good quality in terms of constancy in voltage and frequency. Furthermore, for interconnected power system the tie-line power flow between utilities must be maintained within prescribed limits.

It is in fact impossible to maintain both active and reactive power without control which would result in variation of voltage and frequency levels. To cancel the effect of load variation and to keep frequency and voltage level constant a control system is required. Though the active and reactive powers have a combined effect on the frequency and voltage, the control problem of the frequency and voltage can be separated. Frequency is mostly dependent on the active power and voltage is mostly dependent on the reactive power. Thus the issue of controlling power systems can be separated into two independent problems. The active

Grenze ID: 01.GIJET.1.2.556

power and frequency control is called as load frequency control (or Automatic Generation Control). The most important task of AGC is to maintain the frequency constant against the varying active power loads, which is also referred as un- known external disturbance.

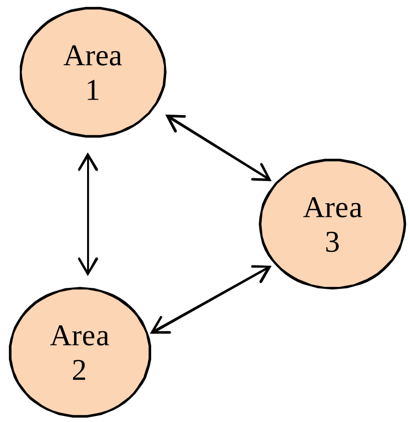

Figure 1.Simplified representation of 3 area interconnected system

Power exchange error is an important task of AGC. Generally a power system is composed of several generating units. To improve the fault tolerance of the whole power system, these generating units are connected through tie-lines. This use of tie-line power creates a new error in the control problem, which is the tie-line power exchange error. When sudden change in active power load occurs to an area, the area will get its energy through tie-lines from other areas. Eventually the area that is subject to the change in load should balance it without external support. Or else there will be economic conflicts between the areas. This is why each area requires separate load frequency controller to regulate the tie line power exchange error so that all the areas in an interconnected system can set their set points differently. In short, the AGC has two major duties, which are to maintain the desired value of frequency and also to keep the tie line power exchange under schedule in the presence of any load changes. Also, the AGC has to be unaffected by unknown external disturbances and system model and parameter variation. Where as in the AVR loop, the excitation for the generators must be regulated in order to match the reactive power demand otherwise the voltages at various system may goes to beyond the prescribed limit. The maximum permissible of change in frequency is about ± 5% Hz and voltage is about is ± 5% if not there will be a highly undesirable conditions in the power system like frequency and voltage fluctuations. So it is necessary to keep the frequency and voltage at constant level.

A. Automatic Generation Control

The AGC is to control the frequency deviation by maintaining the real power balance in the system. The main functions of the AGC are to maintain the steady frequency, control the tie-line flows and distribute the load among the participating generating units. The control signals are the tie line deviation ΔP_{tie}(measured from the tie line flows), and the frequency deviation Δf(obtained by measuring the angle deviation $\Delta\delta$). These errors signals Δf and ΔP_{tie} are amplified, mixed and transformed to a real power signal, which then controls the valve position. Depending on the valve position, the turbine changes its output power to establish the real power balance.

The combining equations for tie-line power are:

$$\Delta Ptie_1 = \Delta Ptie_{12} + \Delta Ptie_{13} \quad (1)$$

$$\Delta Ptie_2 = \Delta Ptie_{21} + \Delta Ptie_{23} \quad (2)$$

$$\Delta Ptie_3 = \Delta Ptie_{31} + \Delta Ptie_{32} \quad (3)$$

$$\Delta Ptie_{12}(s) = \frac{2\pi T_{12}}{s}[\Delta f_1(s) - \Delta f_2(s)] \quad (4)$$

$$\Delta Ptie_{13}(s) = \frac{2\pi T_{13}}{s}[\Delta f_3(s) - \Delta f_1(s)] \quad (5)$$

$$\Delta Ptie_{21}(s) = \frac{2\pi T_{21}}{s}[\Delta f_2(s) - \Delta f_1(s)] \quad (6)$$

$$\Delta Ptie_{23}(s) = \frac{2\pi T_{23}}{s}[\Delta f_2(s) - \Delta f_3(s)] \quad (7)$$

$$\Delta Ptie_{31}(s) = \frac{2\pi T_{31}}{s}[\Delta f_3(s) - \Delta f_1(s)] \quad (8)$$

$$\Delta Ptie_{32}(s) = \frac{2\pi T_{32}}{s}[\Delta f_3(s) - \Delta f_2(s)] \quad (9)$$

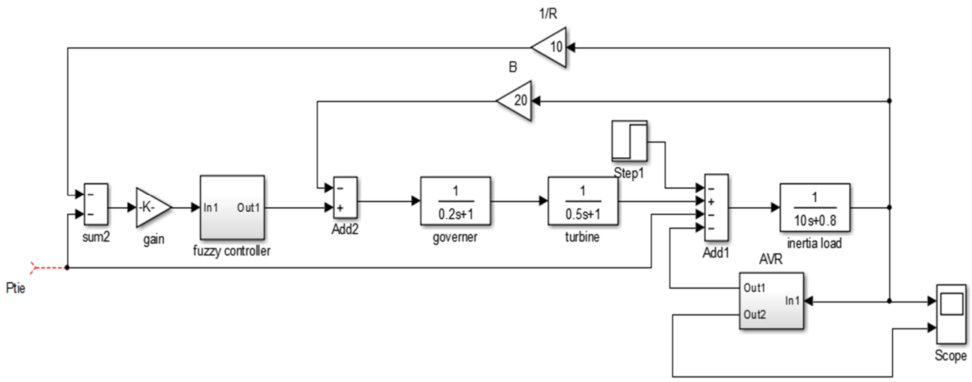

Figure 2. Block diagram representation of AGC including AVR and Fuzzy control (Area 1)

B. Automatic Voltage Regulator

The voltage of the generator is proportional to the speed and excitation (flux) of the generator. The speed being constant, the excitation is used to control the voltage. Therefore, the voltage control system is also called as excitation control system or automatic voltage regulator (AVR). The generator terminal voltage Vt is compared with a voltage reference Vref to obtain a voltage error signal ΔV. This signal is applied to the voltage regulator shown as a block with transfer function $K_A/(1+T_A)$. The output of the regulator is then applied to exciter shown with a block of transfer function Ke/(1+Te). The output of the exciter E_{fd} is then applied to the field winding which adjusts the generator terminal voltage. The generator field can be represented by a block with a transfer function $K_F/(1+sT_F)$.

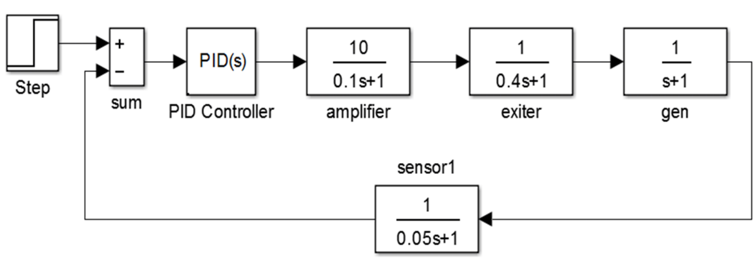

Figure 3.Block diagram representation of AVR

C. Single Machine connected to Infinite Bus

The rotational inertia equations describe the effect of unbalance between electromagnetic torque and mechanical torque of individual machines in a LFC system. By having small perturbation and small deviation in speed, the complete swing equation becomes

$$\Delta f = \frac{K_p}{1+sT_p}[\Delta P_m - (\Delta P_L + \Delta P_e)] \quad (10)$$

Where, *Pe* is the deviation of internal electrical power that is sensitive to load characteristics. A combined model includes load frequency control and AVR system. This model can be used to show the mutual effect between LFC and AVR loops and depict the slight change in response of turbine output power in the steady state.

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:

$$\Delta P_e = P_s\Delta\delta + K_2E' \quad (11)$$

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

$$\Delta V_t = K_5\Delta\delta + K_6E' \quad (12)$$

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

$$E' = \frac{K_g}{1+T_g}(V_f - K_4\Delta\delta) \quad (13)$$

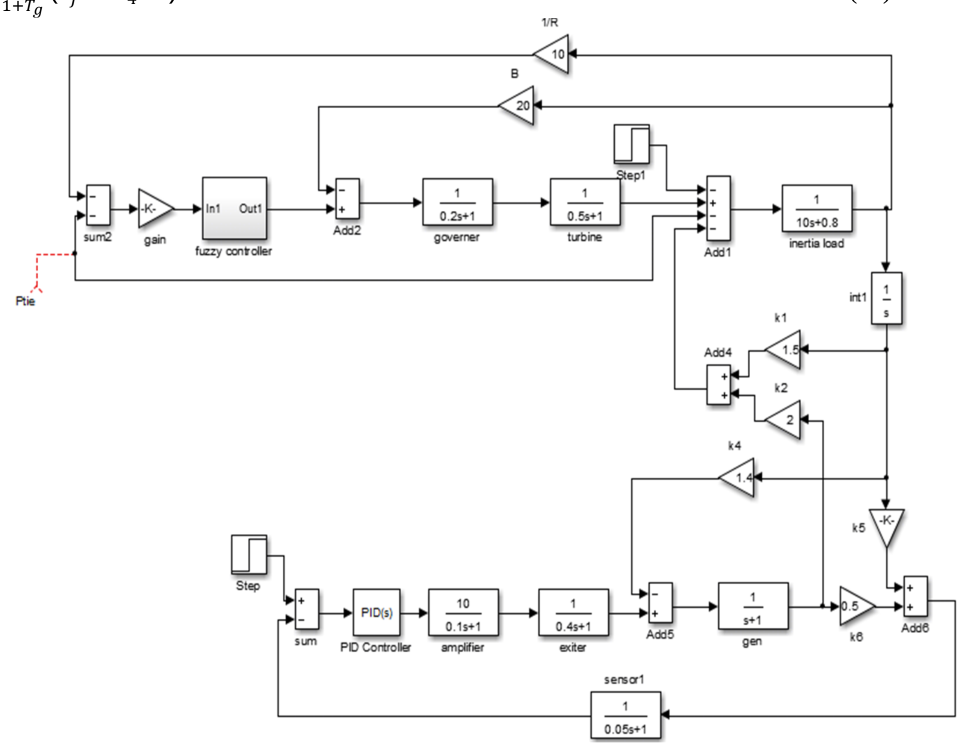

Figure 4. Block diagram representation for single machine connected to infinite bus

II. CONTROLLERS

A. PID Controller

PID controller has all the necessary dynamics: fast reaction on change of the controller input (D mode), increase in control signal to lead error towards zero (I mode) and suitable action inside control error area to eliminate oscillations (P mode). Derivative mode improves stability of the system and enables increase in gain K and decrease in integral time constant Ti, which increases speed of the controller response. The transfer function of PID controller is

$$G_C(s) = K_P + \frac{K_I}{s} + sK_D \qquad (14)$$

PID controller is used when dealing with higher order capacitive processes (processes with more than one energy storage) when their dynamic is not similar to the dynamics of an integrator (like in many thermal processes). PID controller is often used in industry, but also in the control of mobile objects (course and trajectory following included) when stability and precise reference following are required. Conventional autopilot is for the most part PID type controllers.

B. Fuzzy Controller

In contrast to conventional control techniques, fuzzy logic control (FLC) is best utilized in complex ill-defined processes that can be controlled by a skilled human operator without much knowledge of their underlying dynamics. The basic idea behind FLC is to incorporate the "expert experience" of a human operator in the design of the controller in controlling a process whose input – output relationship is described by collection of fuzzy control rules involving linguistic variables rather than a complicated dynamic model. The utilization of linguistic variables, fuzzy control rules, and approximate reasoning provides a means to incorporate human expert experience in designing the controller.

FLC is strongly based on the concepts of fuzzy sets, linguistic variables and approximate reasoning introduced in the previous chapters. This chapter will introduce the basic architecture and functions of fuzzy logic controller, and some practical application examples. A typical architecture of FLC is shown below, which comprises of four principal comprises: a fuzzifier, a fuzzy rule base, inference engine, and a defuzzifier.

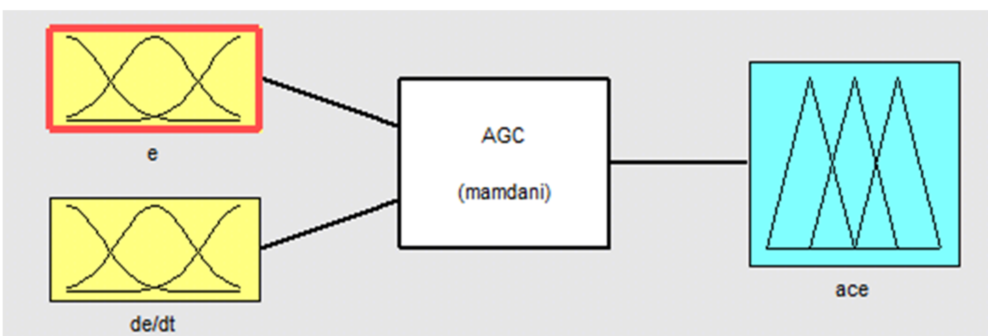

Figure 5. Fuzzy editor : one input and output of the FLC

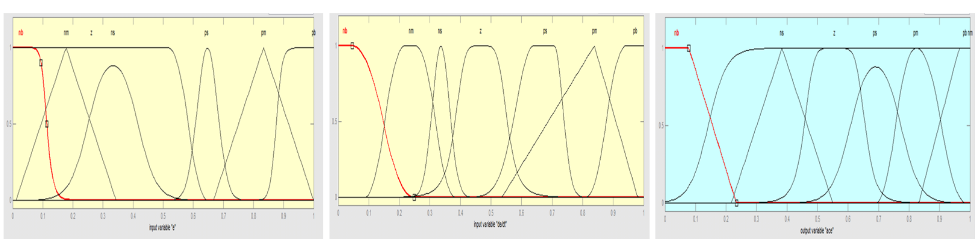

Figure 6. (a) Membership functions for input error, (b) Membership functions for input change in error, (c) Membership functions for fuzzy output

TABLE I. RULES FOR FUZZY LOGIC CONTROLLER

e/de	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NM	Z
NM	NB	NB	NB	NM	NS	Z	PM
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

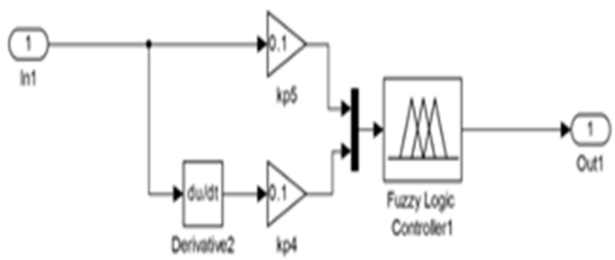

Figure 7. Fuzzy controller subsystem

III. EXPERIMENTAL RESULTS

In the simulation study, the combined proposed model is applied for three area power system. To illustrate the performance of this model, simulations are performed for the possible operating conditions of a power system. In this simulation the performance of the proposed combined model is analyzed with a load change in each area.

In order to demonstrate the effectiveness of the fuzzy controller, the Simulink model for three area power system is simulated and the frequency response is plotted for a time period of 50 seconds. The change in frequency for different loads is obtained, and transient responses are found to be stable. It is clear from the simulation results that, FLC can bring down the frequency to its rated value immediately after the disturbance and without any oscillations. Figure 8 shows the response of frequency obtained for a sudden increase in load of 1p.u.

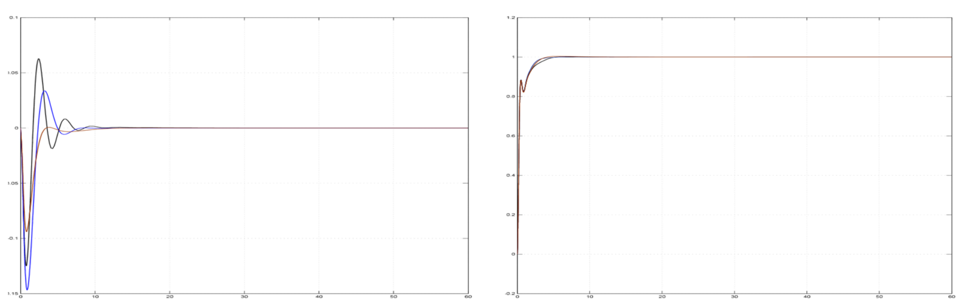

Figure 8. (a). AGC response for Area 1, 2 &3, (b). AVR response for area 1, 2 &3

TABLE II. ASSUMPTIONS USED FOR SIMULATION OF AGC

AGC	Area 1	Area 2	Area 3
Governor time constant	0.2	0.3	0.2
Turbine time constant	0.5	0.4	0.4
Inertia	5	5	6
D	8	1	5
1/R	20	10	5
Bias	2	2	2

TABLE III. ASSUMPTIONS USED FOR SIMULATION OF AVR

AVR	Time constant	Gain
Amplifier	0.1	10
Exciter	0.4	1
generator	1	1
Sensor	0.05	1

TABLE IV. PARAMETERS OF PID CONTROLLER

Parameters	**Value**
K_p	1.0
K_i	0.35
K_d	0.15

IV. CONCLUSION

In this paper attempt is made to develop AGC model with AVR. In this scheme coupling between AGC and AVR is employed and interaction between frequency and voltage exists and cross coupling does exist. AVR loop affect the magnitude of emf as the internal emf determines the magnitude of real power. It is concluded that changes in AVR loop is felt in AGC loop. In this study, fuzzy control approach is employed for an Automatic Generation Control (AGC) of interconnected power system with Automatic Voltage Regulator. The effectiveness of the proposed controller in increasing the damping of local and inter area modes of oscillation is demonstrated in a three area interconnected power system.

REFERENCES

[1] Lalit Chandra Saikia, Sanjoy Debbarma, N. Sinha, Puja Dash, ”AGC of a Multi-area Hydrothermal System Using Thyristor Controlled Series Capacitor”, Annual IEEE India Conference (INDICON), 2013.

[2] P. Kundur, Power system stability and control, McGraw Hill, 2012.

[3] H. Saadat, *Power system analysis,* USA: McGraw-Hill; 1999.

[4] O.I. Elgard, Electrical Energy System theory an Introduction, McGraw-Hill, New Delhi, 2005.
[5] Z.M. Ai-Homouz and Y.L. Abdel-Magid , Variable Structure Load Frequency Controllers for Multiarea Power Systems, Int.J. Electr. Power Energy System. 15(5),1993.
[6] El-Zonkoly, A.M., Optimal tuning of power systems stabilizers and AVR gains using particle swarm optimization. Expert Systems with Applications, pp 551-557, 2006.
[7] K. Hirayama, Y.T., K. Takagi, H. Murakami, M. Shibata, H. Nagamura, Y. Takagi, , "Digital AVR application to power plants". IEEE Transactions on Energy Conversion, 1993. 8(4): p. 602-609.
[8] Hou Guolian, Zheng Xiaobin, Jiang Pengcheng , Zhang Jianhua, "Study of Modeling and Intelligent Control on AGC System with Wind Power" , IEEE, 2014
[9] Muthana T. Alrifai and Mohamed Zribi "Decentralized Controllers for Power System Load Frequency Control" *ASCE Journal*, Vol 5, Issue II, June,2005.
[10] Sivaramakrishnan, A. Y., Hariharan, M. V. and Srisailam, M. C. "Design of Variable Structure Load Frequency Controller Using Pole Assignment technique", *Int. Journal of Control*, Vol. 40, No. 3, pp. 487-498,1984.
[11] Li Pingkang Beijing and Ma Yongzhen; "Some New Concepts in Modem Automatic Generation Control Realization", IEEE 1998,pp1232-1236,
[12] Lim Yun Seng, Philip Taylor; "Innovative Application of Demand Side Management to Power Systems" First International Conference on Industrial and Information Systems, ICIIS 2006, pp 8 – 11 August 2006, Sri Lanka.
[13] C.C.A Rajan, "Demand side management using expert system",IEEE Conference on Convergent Technologies for Asia-Pacific Region, 2003.
[14] Hongming Yang, Yeping Zhang, Xiaojiao Tong; "System Dynamics Model for Demand Side Management" Electrical and Electronics Engineering, 2006 3rd International Conference on 6-8 Sept. 2006.
[15] Vincent Thornley, Ruth Kemsley, Christine Barbier, Guy Nicholson; "User Perceptron Of Demand Side Management" CIRED Seminar 208, Smart Grids for Distribution, Frankfurt, 23 – 24 June 2008. Paper 70.
[16] G. V. Hicks and Jeyasurya, B, "An investigation of automatic generation control for an isolated transmission system", *IEEE Canadian Conference on Electrical and Computer Engineering,* Vol. 2, 1997, pages: 31- 34.