Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 38 (2012) 753 – 762

Procedia Engineering

www.elsevier.com/locate/procedia

Modelling Optimization and Computing

# A Fuzzy Approach of Autonomous Power Generating Systems

V.Shanmugasundaram[a*], T.Jayabarathi[b]

[a]Asst.Prof,Department of Electrical Engineering,Sona College of Technology,Salem-5,Tamilnadu,India
[B]professor,·School of Electrical Engineering,VIT University,Vellore-203,Tamilnadu,India

---

**Abstract**

In this paper ,an fuzzy approach for determining the optimal values for the proportional-integral(PI) controller parameters of load frequency control(LFC) Automatic voltage regulator(AVR) system for single area power system using the Fuzzy Gain Scheduled proportional-integral controller (FGSPIC) techniques is presented. The LFC loop controls real power and frequency and AVR loop controls reactive power and voltage. Due to rising and falling power demand, the real and reactive power balance is harmed, hence frequency and voltage get deviated from nominal value. This necessitates designing of an accurate and fast controller to maintain the system parameters at nominal value.atahe main purpose of system generation control is to balance the system generation against the load and losses so that the desired frequency and power interchange between neighbouring systems are maintained.This work demonstrates the application of fuzzy method to search efficiently optimal PI controller parameters of LFC and AVR system. The proposed method had superior features like, stable convergence characteristics, easy implementation and good computational efficiency. The simulation results demonstrate the effectiveness of the designed system in terms of reducing settling time, overshoot and oscillllations.This results are compared with conventional Integral .PI,PID and fuzzy based controller.

*Keywords:* Load frequency control; Automatic voltage regulator; Fuzzy controller; Area control error; Power systems

---

## 1. Introduction

In recent years electricity has been used to power more sophisticated and technically complex manufacturing processes, and a variety of high-technology consumer goods. These products and processes are sensitive not only to the continuity of power supply but also on the quality of power supply such as voltage and frequency. In power system, both active and reactive power demands are never steady they continuously change with the rising or falling trend. The changes in real power affect the system frequency, while reactive power is less sensitive to changes in frequency and is mainly dependent on Changes in voltage magnitude. The quality of power supply must meet certain minimum standards with regard to constancy of voltage and frequency. The function of excitation control is to regulate generator voltage and reactive power output. The desired real power outputs of the

*Corresponding author. Tel:+919894640610

Email address : shasu1982@gmail.com

1877-7058 © 2012 Published by Elsevier Ltd.
doi:10.1016/j.proeng.2012.06.095

individual generating units are determined by the system generation control. The voltage and frequency controller has gained importance with the growth of interconnected system.

**Nomenclature**

| | | | |
|---|---|---|---|
| ACE | area control error | $\Delta\omega$ | Incremental change in electrical angular frequency |
| AVR | automatic voltage regulator | H | Inertia co-efficient. |
| FLC | fuzzy logic controller | D | Damping co-efficient. |
| FGSPIC | fuzzy gain scheduled proportional -integral controller | $T_g$ | Governor time constant |
| | | $T_t$ | Turbine time constant |
| ISE | integral square error | $K_a$ | Amplifier gain |
| IAE | integral absolute error | $T_a$ | Time constant of amplifier |
| ITAE | integral time absolute error | $K_e$ | Exciter gain |
| PI | proportional-integral | $T_e$ | Time constant of exciter |
| PID | proportional-integral-derivative | $K_P$ | Proportional Gain Constant |
| P-f | real frequency control | K | Integral Gain Constant |
| Q-V | reactive voltage control | MVAR | Megawatt Volt Amp Reactive Control |

And has made the operation of power system more reliable. The main purpose of system generation control is to balance the system generation against the load and losses so that the desired frequency and power interchange between neighbouring systems are maintained. The main goal of LFC and AVR in the power systems is to protect the balance between production and consumption and to maintain zero steady state errors in an interconnected power system. Many investigations in the area of LFC and AVR of an isolated power system have been reported and a number of control schemes like integral (I), Proportional and Integral (PI), Proportional, Integral and Derivative (PID) control have been proposed to achieve improved performance. The conventional method exhibits relatively poor dynamic performance as evidenced by large overshoot and transient frequency oscillations. These conventional fixed gain controllers based on classical control theories in literature are insufficient because of change in operating points during a daily cycle. Fuzzy controllers are increasingly being accepted by engineers and scientist alike as a viable alternative for classic controllers. Fuzzy controllers closely imitate human control process. Human responses to stimuli are not governed by transfer function and neither are those from fuzzy controllers. Due to rising and falling power demand, the real and reactive power balance is harmful effects and hence frequency and voltage deviated from its rated value. In order to maintain the system parameters of the given system at nominal value, FGSPIC is proposed The FGSPIC was developed to regulate and improve the frequency and also control the voltage and reactive power flow, thereby enhancement of system stability. Fuzzy gain scheduling of PI controllers have been proposed to solve power system problems, and developed different fuzzy rules for the proportional and integral gains separately. Two performance criteria were utilized for the comparison. First, settling times and overshoots. Later, the study state error was calculated to compare all the controllers. The comparison of the proposed FGPI, the conventional I, PI and PID controllers suggests that the overshoots and settling time with the proposed FGSPI controller are better than the rest.

## 2. Basic Generation Control Loops

In an interconnected power system, LFC and AVR Equipment is installed for each generator. The schematic diagram of the voltage and frequency control loop is represented in Fig.1. The controllers are set for a particular operating condition and take care of small changes in load demand to maintain the frequency and voltage magnitude within the specified limits. Small changes in real power are mainly dependent on changes in rotor angle δ and, thus, the frequency f. The reactive power is mainly dependent on the voltage magnitude (i.e. on the generator excitation). Change in angle δ is caused by momentary change in generator speed. Therefore, load frequency and excitation voltage controls are non-interactive for small changes and can be modelled and analyzed independently. Furthermore, excitation control is fast acting while the power frequency control is slow acting since, the major time constant contributed by the turbine and generator moment of inertia-time constant is much larger than that of the generator field. Thus, the cross-coupling between the LFC loop and the AVR is negligible, and the load frequency and excitation voltage control are analyzed independently.

### *2.1 Load Frequency Control (LFC)*

The aim of LFC is to maintain real power balance in the system through control of system frequency. Whenever the real power demand changes, a frequency change occurs. The change in frequency and tie – line power are sensed, which is a measure of the change in rotor angle δ, i.e., the error Δ δ to be corrected. The error signal, i.e. Δf and $\Delta p_{ie}$~~, are~~ amplified, mixed, and transformed into a real power command signal $\Delta p_{v,}$ which is sent to turbine governor. The governor operates to restore the balance between the input and output by changing the turbine output, which will change the values of Δf and $\Delta p_{tie}$ within the specified tolerance This method is also referred as Megawatt frequency or Power-frequency (P-f) control [7].

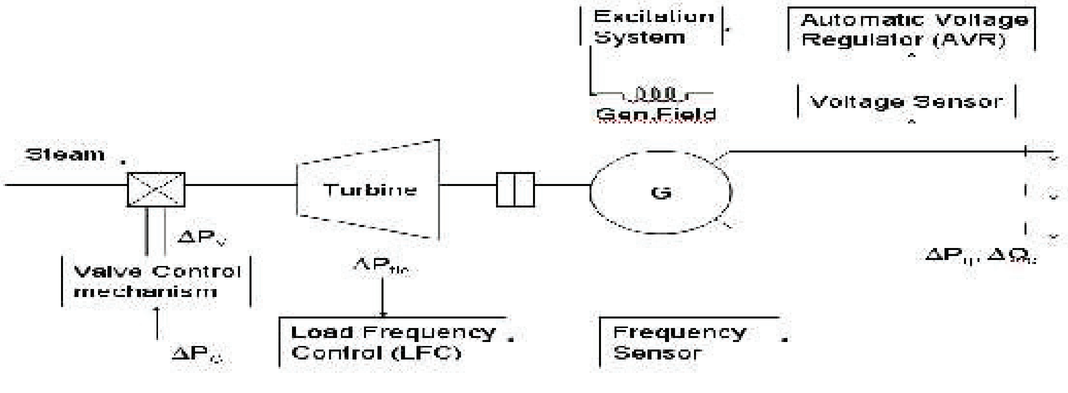


Fig. 1 Schematic diagram of LFC and AVR of a synchronous generator

### *2.2 Automatic Voltage Regulator (AVR)*

The aim of this control is to maintain the system voltage between limits by adjusting the excitation of the machines. The input signals for voltage control are error of terminal voltage and its derivative. Whenever the reactive power load changes a drop in the terminal voltage magnitude resulted. The voltage magnitude is sensed through a potential transformer in one phase. This voltage is rectified and compared to a dc set point signal. The amplified error signal controls the exciter field and increases the exciter terminal voltage .Thus, the generator field current is increased, which results in an increase in the generated emf.The reactive power generation is increased in a new equilibrium, raising the terminal voltage to the desired value. The change of excitation maintains the VAR balance in the network. This method is also referred as Megawatt Volt Amp Reactive (MVAR) control or Reactive-Voltage (QV) control. The models of LFC and AVR with PID controller are shown in Fig.2 and Fig.3, respectively.

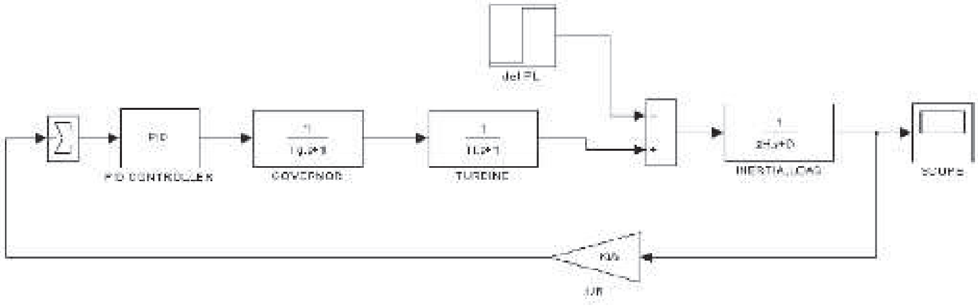


Fig.2 Simulink model of LFC with PID Controller

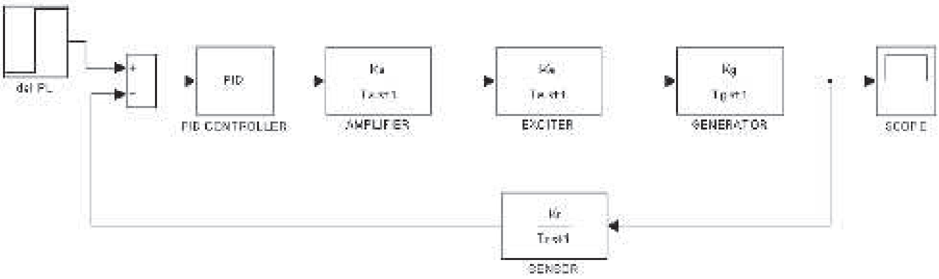


Fig.3 Simulink model of AVR with PID Controller

## 3.Conventional PI Controller

The proportional plus integral controller (PIcontroller) produces an output signal consisting of two terms-one proportional to error signal and the other proportional to the integral of error signal. The transfer function of PI controller is

$$K_P\left[1+\frac{1}{T_i s}\right] \quad \text{or} \quad K_P\left[\frac{T_i s+1}{T_i s}\right] \qquad (1)$$

Where $K_P$ is equal to proportional gain and $T_i$ is equal to integral time. A typical conventional PI control system is shown in Fig.4.

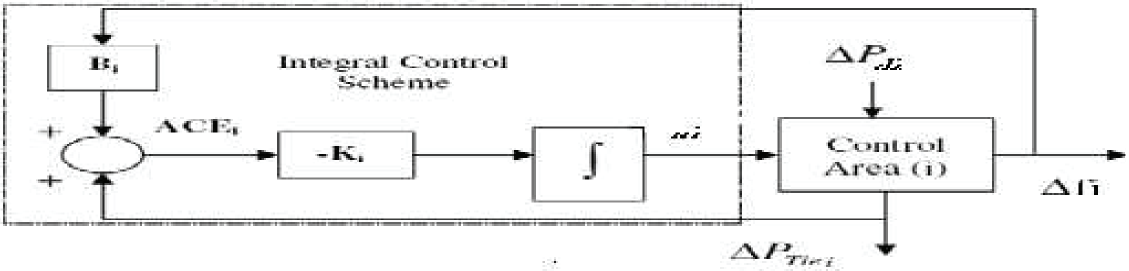


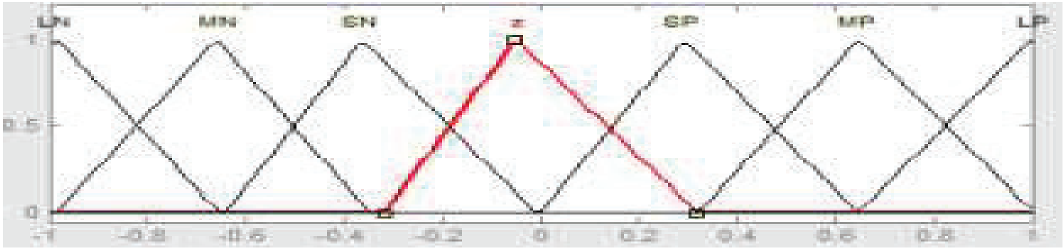
**Fig.4 Conventional PI Controller**

Conventional proportional plus integral controller (PI) provides zero steady state frequency deviation, but it exhibits poor dynamic performance (such as more number of oscillation and more settling time).

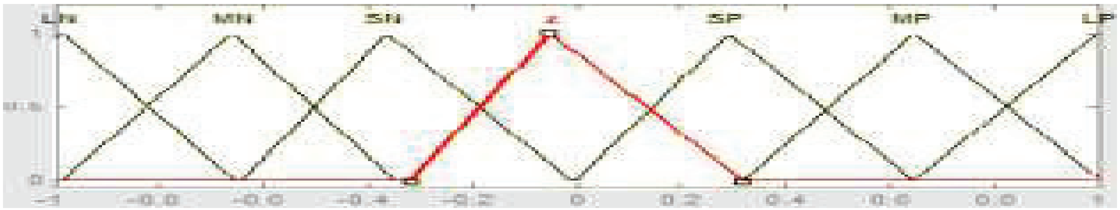
## 4. Fuzzy gain scheduled PI Controller

Gain scheduling is a technique commonly used in designing controllers for systems whose dynamics change nonlinearly with operating conditions. It is normally used when the relationship between the system dynamics and operating conditions are known, and for which a single linear time-invariant model is insufficient.In the present study, the gain scheduling is done based on the frequency deviation step response of the system for different values of $K_I$. A higher value of $K_I$ results in reduction of maximum deviation of the system frequency but the system oscillates for longer times, whereas decreasing the value of $K_I$ yields relatively higher maximum frequency deviation at the beginning but provides effective damping in the later cycles. This necessitates a variable $K_{I;}$ therefore, higher values of $K_I$ are scheduled at the initial stage and then changed gradually depending on the system frequency changes. In this paper, we use this technique to schedule the parameters of the PI controller according to change of the new area control error ACE ,and ΔACE ,as shown in Fig.5.

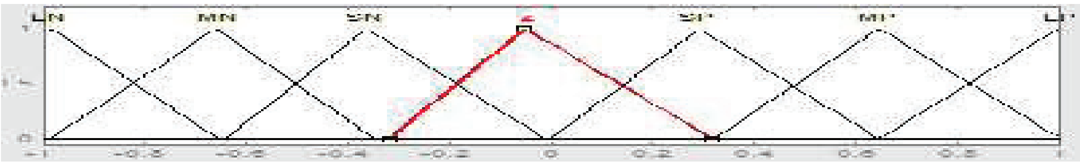
Fig.5The scheme of fuzzy gain scheduling



(a)



(b)



( c)

Fig.6 Membership functions for FGSPI controller of (a) ACE, (b) ΔACE, (c) $K_p$, $K_i$.

Table 1

Fuzzy logic rules for FGSPI controller

| ΔACE/ACE | LN | MN | SN | Z | SP | MP | LP |
|---|---|---|---|---|---|---|---|
| LN | LN | LN | LN | LN | MN | SN | Z |
| MN | LN | LN | LN | MN | SN | Z | sp |
| SN | LN | LN | MN | SN | Z | SP | MP |
| Z | LN | MN | SN | Z | SP | MP | LP |
| SP | MN | SN | Z | SP | MP | LP | LP |
| MP | SN | Z | SP | MP | LP | LP | LP |
| LP | Z | SP | MP | LP | LP | LP | LP |

LP-large positive MN-medium negative SN-small negative Z-zero SP-small positive MP-medium positive LN-large negative

For the proposed controller, the Mamdani fuzzy inference engine was selected and realized by triangular membership functions for each of the three linguistic variables (ACE, d/dt(ACEi), Ki) with suitable choice of intervals of the membership functions as shown in Fig.6 , where ACE and d/dt(ACE) act as the inputs of the controller and $K_i$ is the output of the controller.Defuzzification has been performed using bisector of area method. The appropriate fuzzy rules, as used in our study, for the FGSPIC controller are given in Table.1

## 5.Simulation results

The LFC and AVR are simulated using I, PI, PID ,and the proposed FGSPI controllers. The terminal voltage graphs for a change in load of 0.2 p.u is shown in Fig.7.

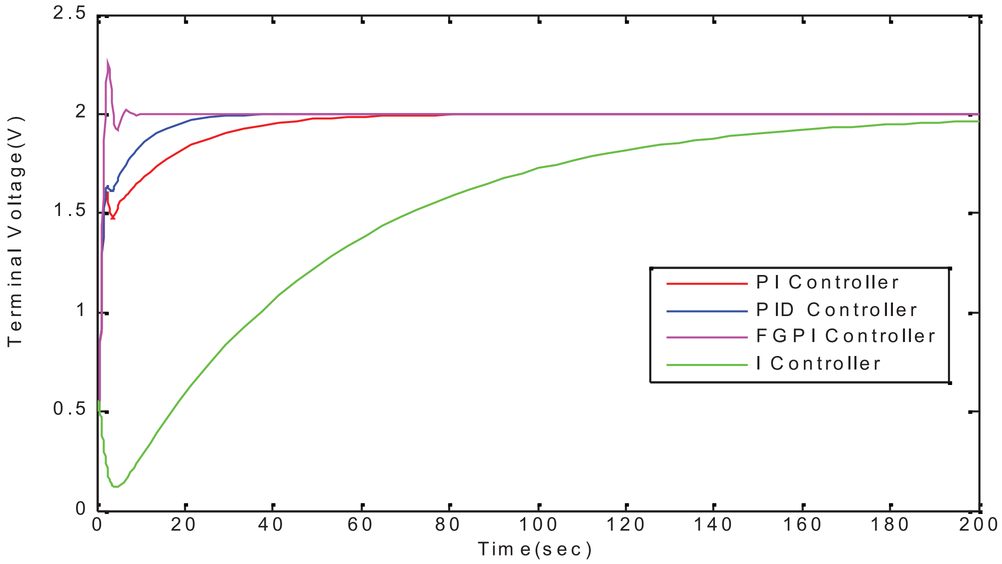


Fig.7 AVR with I, PI, PID and Proposed FGPI Controller

Here, settling times , overshoots and steady state errors of the terminal voltage of the controllers were compared against each other. The comparison results with change in load of 0.1 p.u and 0.2 p.u are provided in Table.2

Table 2
Performance analysis of FGSPIC based AVR

| Methods | Settling time(sec) | | Overshoot(Hz) | | Steady state error | |
|---|---|---|---|---|---|---|
| | ΔPL=0.1 | ΔPL=0.2 | ΔPL=0.1 | ΔPL=0.2 | ΔPL=0.1 | ΔPL=0.2 |
| I Controller | 120 | 160 | 2.2 | 2.25 | 0.00033 | 0.00032 |
| PI Controller | 77 | 80 | 1.6 | 1.65 | 0.000002 | 0.000002 |
| PID Controller | 25 | 33 | 1.55 | 1.61 | 0.000002 | 0.000002 |
| FGPI Controller | 6 | 7 | 0.11 | 0.12 | 0 | 0 |

Similarly the LFC model was simulated with different loads and regulations. The frequency deviation for a change in load of 0.2 p.u is shown in Fig.8

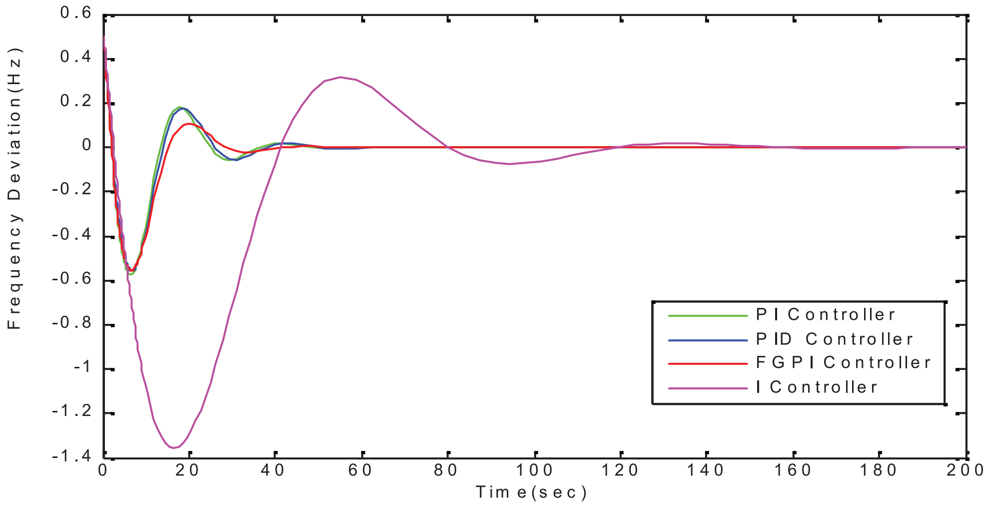


Fig.8 LFC with I, PI, PID and Proposed FGPI Controller

The comparison results with change in load of 0.1 p.u and 0.2 p.u are provided in Table.3

Table.3
Performance analysis of FGSPIC based LFC

| Methods | Settling time(sec) | | Overshoot(Hz) | | Steady state error | |
|---|---|---|---|---|---|---|
| | ΔPL=0.1 | ΔPL=0.2 | ΔPL=0.1 | ΔPL=0.2 | ΔPL=0.1 | ΔPL=0.2 |
| I Controller | 115 | 120 | -0.58 | -0.59 | 0.0066 | 0.0070 |
| PI Controller | 33 | 34.5 | -0.55 | -0.56 | 0.0062 | 0.0066 |
| PID Controller | 32 | 33.5 | -0.54 | -0.55 | 0.0052 | 0.0060 |
| FGPI Controller | 25 | 26 | -1.35 | -1.4 | 0.0025 | 0.0030 |

Table.4
Performance indices

| Methods | ISE | IAE | ITAE |
|---|---|---|---|
| I Controller | 0.1495 | 0.0065 | 0.3496 |
| PI Controller | 0.1429 | 0.0039 | 0.3488 |
| PID Controller | 0.1000 | 0.0018 | 0.3409 |
| FGPI Controller | 0.0951 | 0.0016 | 0.3159 |

## 6.Conclusion

The quality of the power supply is determined by the constancy of frequency and voltage. Minimum frequency deviation and good terminal voltage response are the characteristics of a reliable power supply. The conventional controllers used for this problem have large settling time, overshoot and oscillations. Hence, an intelligent technique has been proposed for combined voltage and frequency control in an isolated power system. When fuzzy logic controllers are applied to control system problems, their typical characteristics show a faster and smoother response. The proposed FGSPIC controller provides a satisfactory stability between frequency overshoot and transient oscillations with zero steady state error. The simulation results demonstrate the effectiveness of the proposed controller under changing loads and regulations.

### Appendix A

| Simulation Parameters | |
|---|---|
| LFC | Tg = 0.095, Tt = 0.5, H = 10, D = 0.8, R = 100,125 ΔPL = 0.10, 0.20p.u |
| AVR | Ka =1.1165, Ta =0.2, Te = 0.4,<br>Kf = 0.75, Tf =1.4, KR= 1, TR = 0.05 |

## References:

[1].A.Soundarrajan, Member, IAENG, Dr.S.Sumathi, C.Sundar, Particle Swarm Optimization Based LFC and AVR of Autonomous Power Generating System,IAENG International Journal of Computer Science, 2010.

[2] H.D. Mathur and S.Ghosh, “A comprehensive analysis of Intelligent control for load frequency control”, *IEEE* Power India conference,2006.

[3].M.S.Anower et al., Fuzzy Frequency Controller For an AGC for the improvement of power system dynamics, Proc. Of 4th International Conference on Electrical & Computer Engineering, 2006.

[4]H.D.Mathur and H.V.Manjunath, Frequecny stabilization using fuzzy logic based controller for multi-area power system, The South Pacific Journal of Natural Science, 4(2007), 22-30.

[5]Zwe-Lee Gaing , A particle Swarm Optimization approach for optimum design of PID controller in AVR system, IEEE Transactions on Energy Conversion, Vol.19, No.2, 2004, pp384-391.

[6].Ertugrul Cam and Ilhan Kocaarslm, A Fuzzy Gain Scheduling PI Controller Application for an Interconnected Electrical Power System,Electrical Power Systems Research, 2004

[7] Hadi saadat, eds 1999. Power System Analysis., Mcgraw-Hill International edition, 2009

[8] Ilhan Kocaarslan, Ertug˘rul C¸ am Fuzzy logic controller in interconnected electrical power systems for load-frequency control . Electrical Power and Energy Systems 27 (2005) 542–549

[9] Talaq J, Al-Basri F. Adaptive fuzzy gain scheduling for load frequency control. IEEE Trans Power Systems 1999;14(1):145–50.

[10] Elgerd OI. Electric energy systems theory: An introduction. McGraw-Hill; 1971