International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 10, October - 2013

"Automatic Generation Control: - A Fuzzy Logic Approach"

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***Abstract*: This paper present analysis on dynamic and uncertain performance of reactive automatic voltage regulator and active load frequency control of two area interconnected system using fuzzy logic controller and conventional controller. The primary purpose of the AGC is to balance the total system generation against the system load variation and losses. Any mismatch between generation and demand causes the system frequency and terminal voltage to deviate from the scheduled value. This high deviation may lead to system collapse. So making the balance between generation and demand is the operating principle of AVR & LFC, Fuzzy logic controller is used for that purpose and use the seven triangular membership function which gives the easy way to make the rule base as compared the other MFs. Simulation result are compared using MATLAB/SIMULINK software.**

***Index*: Load Frequency Control (LFC), Automatic Gain Controller (AGC), Automatic Voltage Controller (AVR), Fuzzy logic, Fuzzy Logic Controller (FLC), Frequency Response, Voltage Response.**

INRTODUCTION

Modern power systems are characterized by extensive system interconnections and increasing dependence on control for optimum utilization of existing resources. The supply of reliable and economic electric energy is a major determinant of the industrial progress and consequent rise in the standard of living. During transmission, both the active power balance and the reactive power balance must be maintained between the generation and utilization of electric power. These two balances correspond to two equilibrium points of frequency and voltage and when the balances are broken and reset at a new level, the equilibrium points will float. A good quality of the electric power system requires both the frequency and voltage to remain at standard values during operation[3]. As the demand changes, the system voltage and frequency deviate from initial value causing an unpredictable, small amount of change in the state of the system. An automatic control system is assigned to detect the change and it initiate a set of counter-control actions in order to nullify effectively and at the earliest any deviation in the state of the system, large deviation also affect the transmission and distribution of electrical energy due to the negative effect on regulation, power balance and stability[1]. Stability of power system 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 automatic control schemes to maintain the power system at desired operating levels characterized by nominal system voltage and frequency [5].

Controllers are employed at turbine-generator units and also at selected voltage controlled buses. A well designed and operated power system should cope with changes in the load and with system disturbances, and it should provide an acceptable high level of power quality while maintaining both voltage and frequency within tolerable limits [6].

The voltage regulator adjusts the power output of the generator exciter in order to control the magnitude of generator terminal voltage V_t. When a ref. voltage V_{ref} is raised or lowered, the output voltage V_r of the regulator increases or decreases the exciter voltage applied to the generator field winding, which in turn changes the terminal voltage. The turbine-governor adjusts the steam valve position to control the mechanical power output of the turbine. When a reference power level is raised (or lowered), the governor moves the steam valve in the open (or close) direction to increase (or decrease) [7]. The governor also monitors rotor speed, which is used as a feedback signal to control the balance between power output and the electric power output of the generator.

The ability of the power system to withstand disturbances depends on dynamic performance of the LFC and AVR control loops. The conventional control strategy for the LFC and AVR problem is to take the integral of control error as the control signal. The proportional integral (PI) control approach is successful in achieving zero steady-state error in the frequency of the system, but it exhibits relatively poor dynamic performance as evidenced by large overshoot and transient oscillations. Furthermore, the controller design is normally based on a fixed parameter model of the system derived by a linearization process and for particular operating point. Hence, the fixed gain controllers designed for particular load, and regulation may no longer be suitable for all operating conditions [8]. Many investigations in the area of LFC and AVR of an isolated power system have been reported in the literature and different control strategies like conventional controller or fuzzy logic controller, have been applied to improve the performance characteristics and to reduce transient oscillations [9].

Linearized model of an AVR (Automatic Voltage Regulator) system:

An AVR is used to hold the terminal voltage magnitude of a synchronous generator at a specified level. A simple AVR system comprises four main components, namely amplifier, exciter, generator and sensor. For mathematical modelling and determining transfer functions of the four components, these components must be linearized, which takes into account the major time constant and ignores the saturation or other nonlinearities. The approximate transfer functions of these components may be represented, respectively, as follows [10].

Amplifier model: The transfer function of amplifier model is:

$$G_A(s) = \frac{\Delta V_{ex}(s)}{\Delta e(s)} = \frac{K_A}{1+sT_A} \qquad (1)$$

where, the value of K_A is in the range 10 to 400 and the value of the amplifier time constant T_A is in the range 0.02 to 0.08s. In our simulation, K_A was set to 21 and T_A was set to 0.04s.[1]

Exciter model: The transfer function of exciter model is:

$$G_{ex}(s) = \frac{\Delta V_f(s)}{\Delta V_{ex}(s)} = \frac{K_{ex}}{1+sT_{ex}} \qquad (2)$$

where, the value of K_{ex} is in the range 0.5 to 200 and the value of the amplifier time constant T_{ex} is in the range 0.5 to 1s. In our simulation, K_{ex} was set to 0.5 and T_{ex} was set to 0.6s.

Generator model: The transfer function of generator model is:

$$G_f(s) = \frac{\Delta E(s)}{\Delta V_f(s)} = \frac{K_f}{1+sT_f} \qquad (3)$$

Here the constants depend on the load; the value of K_f varies between 0.6 to 1 and generator time constant T_f in the range 1 to 2s from full load to no load. In our simulation, K_f was set to 0.65 and T_f was set to 1.1s [1].

Sensor model: The transfer function of sensor model is:

$$G_r(s) = \frac{\Delta R(s)}{\Delta E(s)} = \frac{K_r}{1+sT_r} \qquad (4)$$

where, the gain K_r is usually kept 1 and the time constant T_r is very small, ranging from 0.01 to 0.06s. In our simulation, K_r was set to 1 and T_r was set to 0.05s.

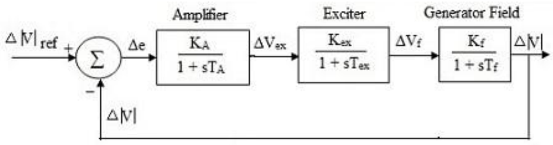

Fig. 1: A simplified block diagram of voltage (excitation) control system.

Automatic load frequency control loop modelling:

Automatic loop frequency loop divided into two loops-

- Primary ALFC loop and,
- Secondary ALFC loop.

The purpose of both these loop to achieve real power balance in the system. Same as AVR loop achieve Q- balance by maintaining the constant voltage; on other hand ALFC loop achieve power balance by maintaining the constant frequency [1].

Speed governing system model:

Speed governor model sense the machine speed and adjust the valve to change the mechanical output and to restore the frequency at nominal value.

$$G_g(s) = \frac{\Delta P_v(s)}{\Delta P_g(s)} = \frac{1}{1+sT_g} \qquad (5)$$

Turbine model: The model for the turbine relates changes in mechanical power output ΔP_g to change in the valve position (ΔP_v)

$$G_T(s) = \frac{\Delta P_T(s)}{\Delta P_v(s)} = \frac{1}{1+sT_t} \qquad (6)$$

Where T_t is time constant usually in range 0.2-0.5sec.; gain of the governor and turbine generator (K_A, and K_T) has assumed to be unity.

Power system, (Generator, Inertia and Load):

The synchronous machine as an ac generator driven by a turbine is the device, which convert mechanical energy into electrical energy. In power system if there is any change in load cause change in frequency or speed of the generator unit in the system.

$$\Delta f(s) = \frac{1}{2Hs}(\Delta P_T(s) - \Delta P_g(s))\text{...........}(7)$$

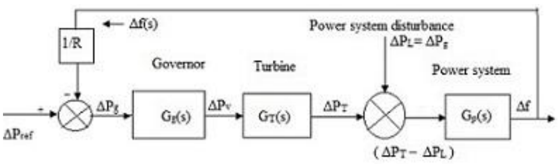

Fig.2 Simplified closing primary ALFC loop

The primary ALFC loop gives a frequency drop between zero and full load of the generator. This accuracy being unsatisfactory, a secondary control is added to the primary ALFC loop to achieve the goals.

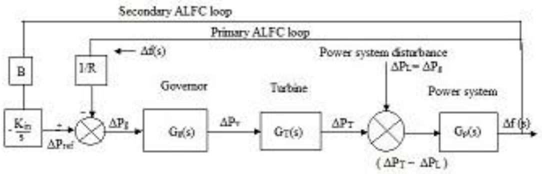

Fig.3 Simplified complete ALFC loop

Modelling of interconnected system:

The complete loop model in fig.3 is valid for single generator only and the frequency response is slow. In an interconnected or multi area system load change in one area will affect the generation in all other interconnected areas. When the frequencies in two areas are different, a power exchange occurs through the tie-line the two areas. Suppose now that we have an interconnected power system broken into two areas each having one generator. The areas are connected by a single transmission line. The power flow over the transmission line will appear as a positive load to one area and an equal but negative load to the other, or vice versa, depending on the direction of flow [1].

Fuzzy Logic controller design:

In last three decades, fuzzy control has gained much popularity owing to its knowledge base algorithm, better non-linearity handling features and independence of plant modelling. The Fuzzy Logic Controller (FLC) owes its popularity to linguistic control. Here, an exact mathematical model for the system to be controlled is not required. Hence, fuzzy logic basically tries to replicate the human thought process in its control algorithm. The FLC has thereby proven to be very beneficial in the industries as it has the proficiency to provide complex non-linear, control to even the uncertain nonlinear systems. In addition to the aforementioned attributes, a fuzzy logic controller also makes good performance in terms of stability, precision reliability and rapidity achievable.

It takes two inputs, viz. Error and rate of change of Error to model a Fuzzy Logic Controller with the help of simple IF-THEN rules. No complicated hardware is required for the same. The modelling of a FLC in MATLAB/SIMULINK has been shown below.

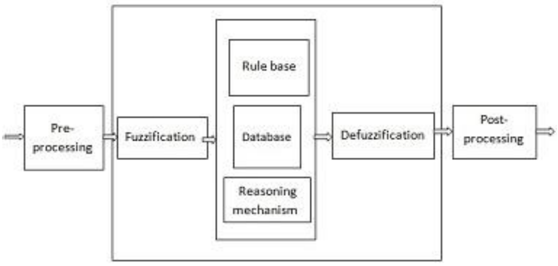

Fig.4 Fuzzy Logic Controller Structure

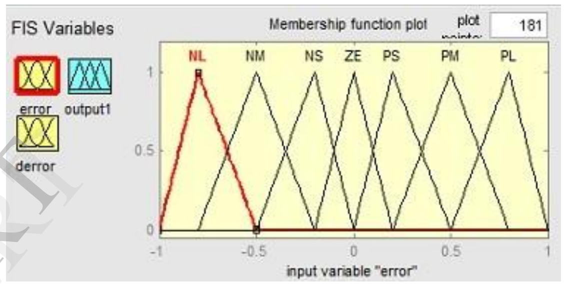

Fig.5 Membership function for input error (e)

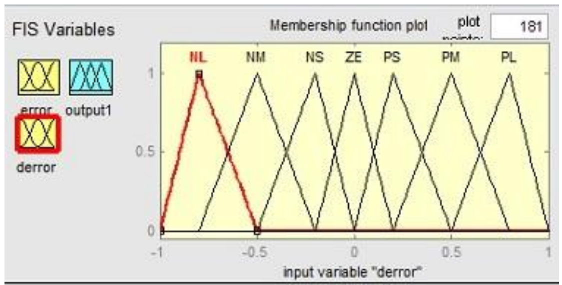

Fig.6 Membership function for input derror (Δe)

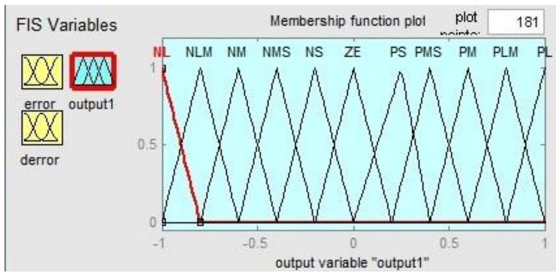

Fig.7 Membership function for the output

Change of control

e \ de	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NLM	NM	NMS	NS	ZE
NM	NL	NLM	NM	NMS	NS	ZE	PS
NS	NLM	NM	NMS	NS	ZE	PS	PMS

ZE	NM	NMS	NS	ZE	PS	PMS	PM
PS	NMS	NS	ZE	PS	PMS	PM	PLM
PM	NS	ZE	PS	PMS	PM	PLM	PL
PL	ZE	PS	PMS	PM	PLM	PL	PL

Fig.8 Fuzzy Rule Table for Output

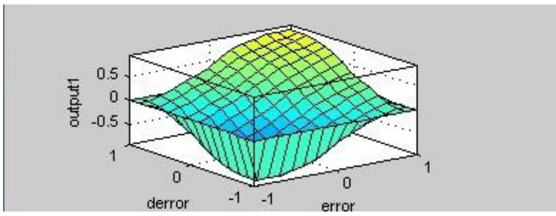

Fig.9 Three dimensional plot of the control surface.

SIMULATION AND RESULTS:

MATLB/SIMULINK design of Automatic Voltage Regulator:

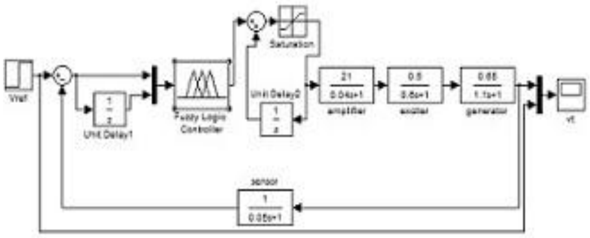

Fig.10 Automatic Voltage Control using Fuzzy Logic Controller.

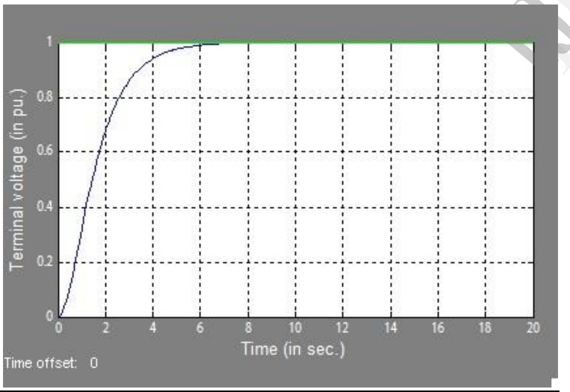

Fig.11 Simulation result of AVR using Fuzzy Logic controller with saturation value= ±1.465

Figure 11; display the graphs of the closed loop with fuzzy logic controller for the AVR system. It shows that fuzzy logic controllers produce the good settling time with no overshoot and steady state error.

MATLAB/SIMULINK design of Automatic Two area Load Frequency Controller loop:

The detailed designed model of two area hydro-thermal power system for load frequency control investigated is shown in Fig.12. An extended power system can be divided into a number of load frequency control areas interconnected by means of tie lines. Without loss of generality one can consider a two area case connected by tie lines.

The control objectives are as follows:
(i) Each control area as for as possible should supply its own load demand and power transfer through tie line should be on mutual agreement.

(ii) All control areas should controllable to the frequency control for different change in load.

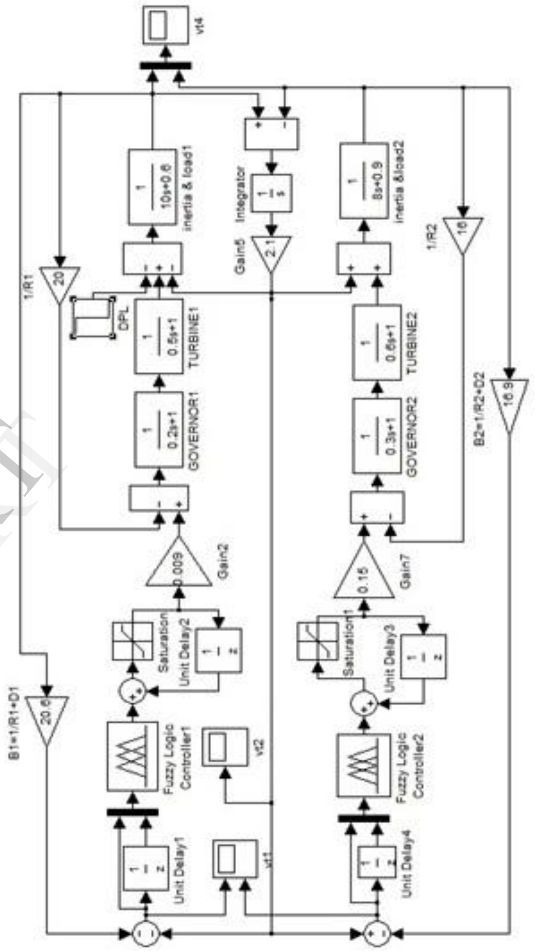

Fig.12 MATLAB/SIMULINK diagram of two area load frequency control using fuzzy logic controller.

Parameter: $T_{g1} = 0.2$, $T_{t1} = 0.5$, $T_{L1} = 16.67$; $T_{g2} = 0.3$, $T_{t2} = 0.6$, $T_{L2} = 8.89$; R1 = 0.05, R2 = 0.0625, D1= 0.6, D2= 0.9.

Simulation result of two area load frequency control using fuzzy logic controller for different change in load.

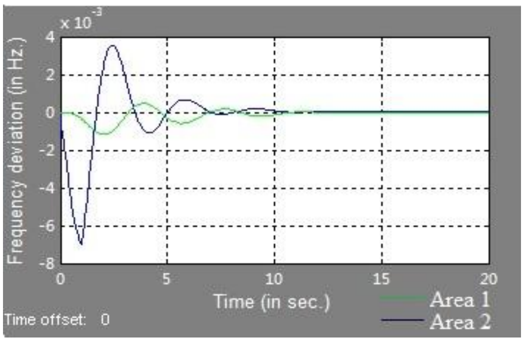

Fig.13 Change in Load ΔP_L = 0.1pu

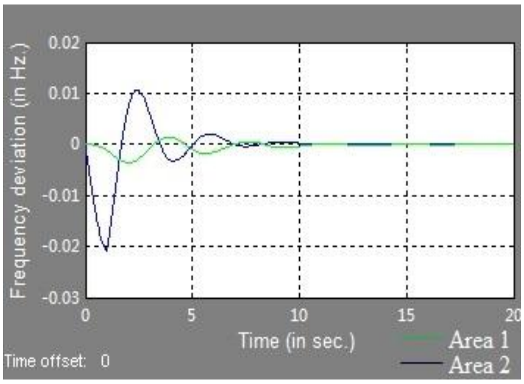

Fig.14 Change in Load ΔP_L = 0.3pu.

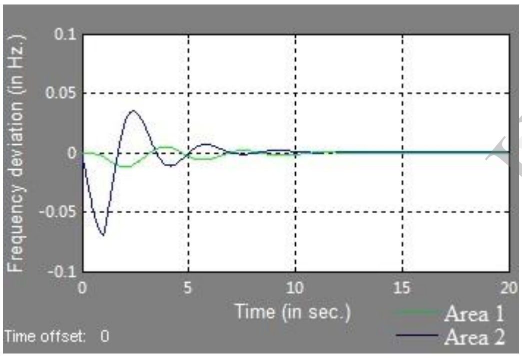

Fig.15 Change in Load ΔP_L = 1.0pu

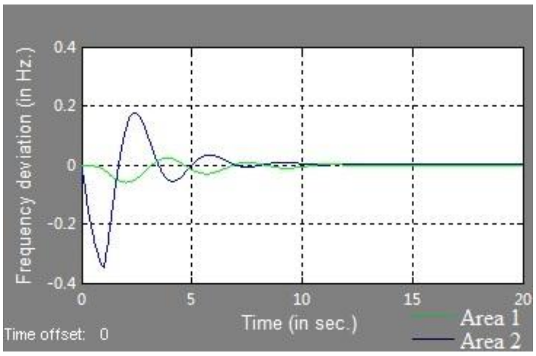

Fig.16 Change in Load ΔP_L = 5.0pu

CONCLUSION

In this paper, analysis is done on the simulation study, the fuzzy logic controller is very effective in suppressing the frequency oscillations caused by rapid load disturbances and it will improve the system performance (voltage regulation) by effectively reduce the overshoot. The results are shown that by using the time delay the dynamic response of the system will increase and the degradation in the system performance can be compensated effectively using fuzzy logic controller.

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