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Design and Simulation of AGC and AVR for a Multi Area Interconnected System

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Abstract

This work deals with the automatic generation control (AGC) of interconnected thermal systems with combination of the automatic voltage control (AVR) and load Management. In this particular work thermal unit is considered with three area concept. The primary purpose of the AGC is to balance the total system generation against system load and losses so that the desired frequency and power interchange with neighboring systems 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. On the other hand, in those days more emphasis on generation side rather than load side. In this paper load management scheme is also considered. Load management is normally used to reduce the total load demand of power systems during periods of peak demands in order to maintain the security of the system. Research has been carried out in order to identify additional functions and benefits that load management can bring to end users and utilities.

Keywords: *Automatic Generation Control, automatic Voltage Generator, Area Control Error, fuzzy Logic Control.*

1. 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 [1]. 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 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 [2].

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 [3]. 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 [4]. 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.

2. System investigated

The interconnected power systems under investigation consist of three control areas interconnected by tie-line. In each control area, all generators are assumed to form a coherent group. Area 1, Area 2 and Area 3 are of equal sizes reheat thermal system interconnected in ring main fashion. A simplified representation of such interconnected areas in general form is shown in figure 1. (a) [1].

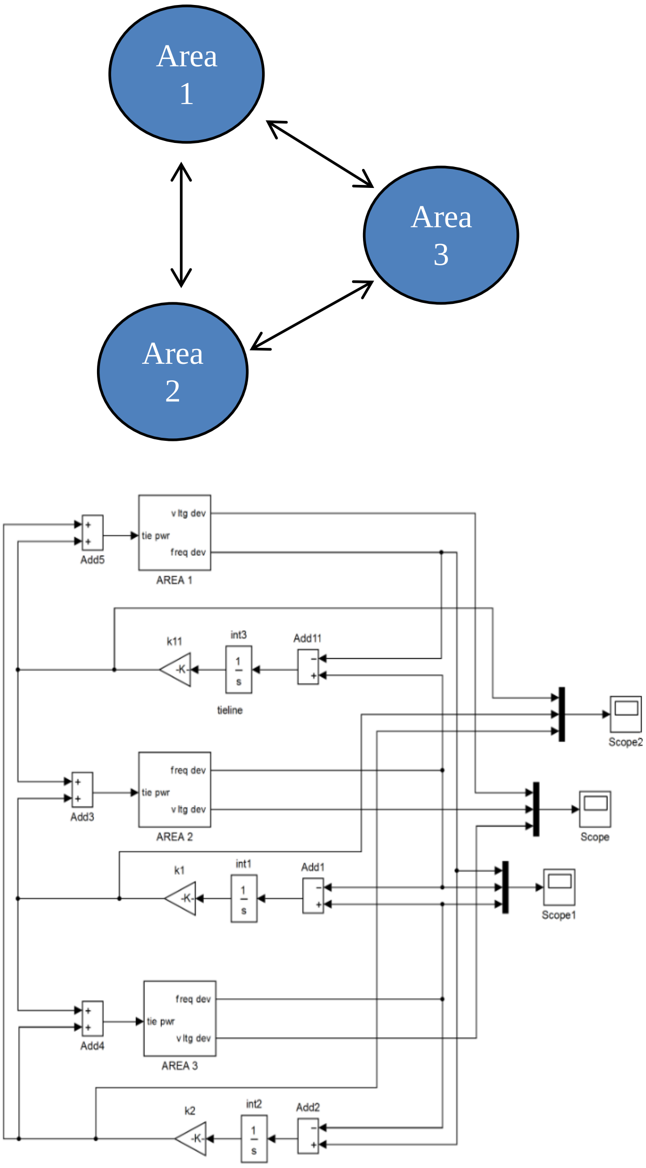


Figure 1: (a). Simplified representation of interconnected system. (b). Simulation diagram of interconnected system.

2.1.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 i) to maintain the steady frequency; ii) control the tieline flows; and iii) distribute the load among the participating generating units. The control (input) 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 (prime mover) changes its output power to establish the real power balance [5],[10],[11],[16].

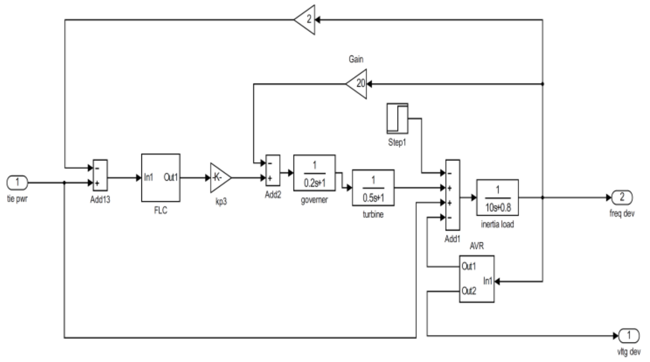


Figure 2: block diagram representation of AGC including AVR and Fuzzy control

2.2.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). For the alternators, the excitation is provided by a device (another machine or a static device) called exciter. For a large alternator the exciter may be required to supply a field current of as large as 6500A at 500V and hence the exciter is a fairly large machine.

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 $K_F/(1+sT_F)$ [6],[7].

2.3.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

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

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 [2],[4].

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:

$$\Delta P_e = P_s\Delta\delta + K_2E' \qquad (2)$$

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

$$\Delta V_t = K_5\Delta\delta + K_6E' \qquad (3)$$

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

$$E' = \frac{K_g}{1+T_g}(V_f - K_4\Delta\delta) \qquad (4)$$

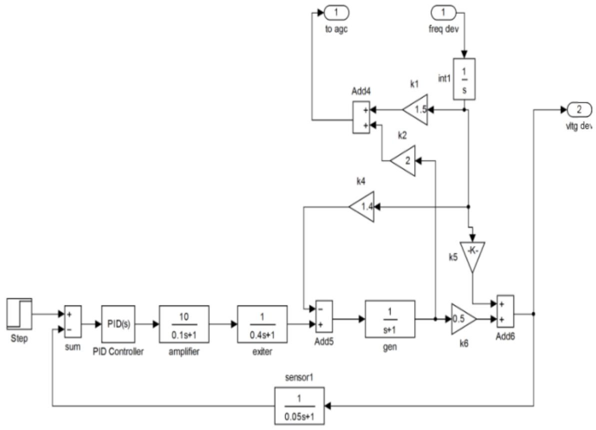


Figure 3: Block diagram representation for single machine connected to infinite bus.

2.4.Load management

The total amount of real power in network emanates from generator stations, the location and size of which are fixed. The generation must be equal to demand at each moment and since this power must be divided between generators in unique ratio, in order to achieve the economic operation. We conclude that individual generator output must be closely maintained at predetermined set point. But it does not happen. Sometimes demand is very large than generation and sometime surplus power in a duration of 24 hrs. It is important to remember that demand undergo slow but wide changes throughout the 24 hr. of the day. So it is necessary Basic idea for its solution to manage generation as well as demand. Here problem for management is in demand side[12]-[15]. **Fig. 3** shows a simplified model of Scheduled loading Availability.

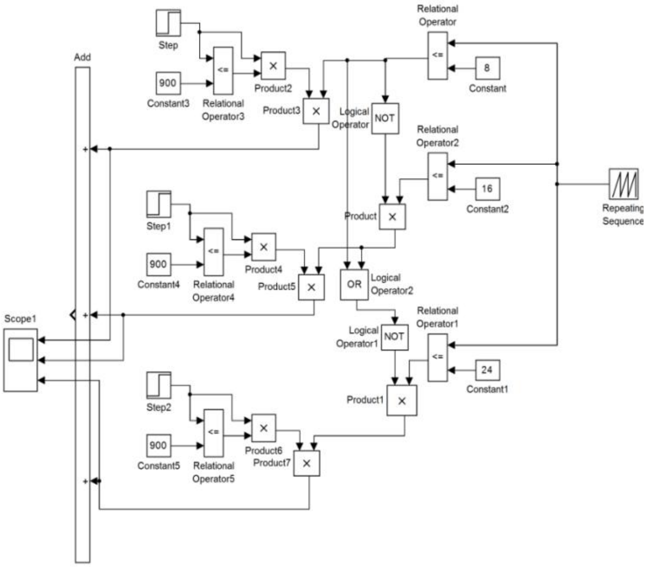


Figure 4: Representation of scheduled loading availability scheme

3. Controllers

3.1.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.

$$G_C(s) = K_P + \frac{K_I}{s} + sK_D \qquad (5)$$

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.

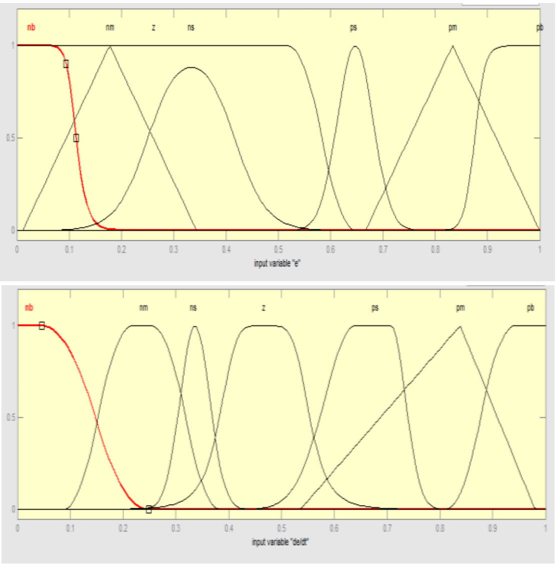
3.2.Fuzzy Controller

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 (e.g., IF-THEN 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 [8].

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 [9].

Table 1: 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



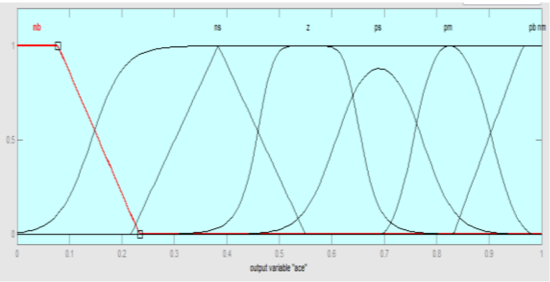


Figure 5: (a) Membership functions for input error (b) Membership functions for input change in error (c)Membership functions for fuzzy output

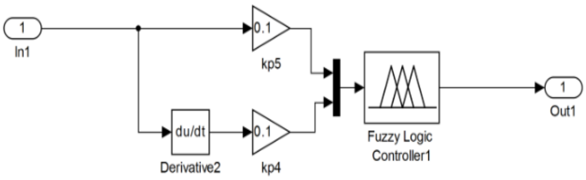


Figure 6: fuzzy controller subsystem

4. 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 7** shows the response of frequency obtained for a sudden increase in load of 1p.u.

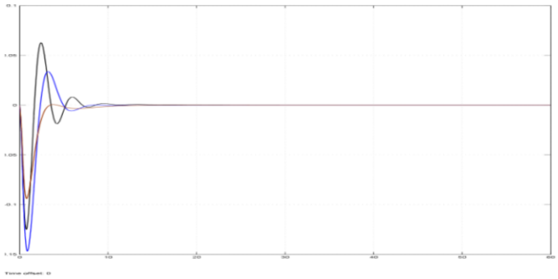


Figure 7: AGC response for Area 1,2&3

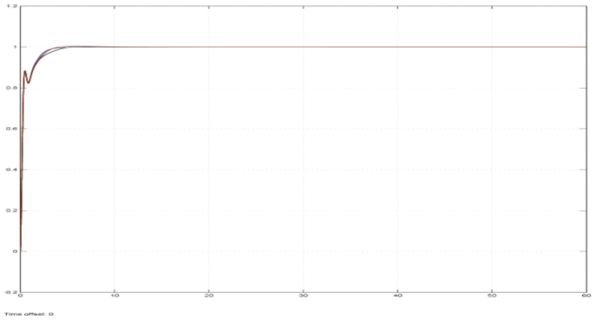


Figure 8: AVR response for area 1, 2 &3

Table 2: 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 3: 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

If schedule is available for load change in duration of day, better frequency characteristics can be obtained as shown in **Fig. 3**. Consider the scheduled loading for 24 hrs in a day as under:-

- Demand L1 for first 8 hrs. shown in figure 9(a).
- Demand L2 for next 8 hrs. shown in figure 9(b).
- Demand L3 for next 8 hrs. shown infigure 9(c).

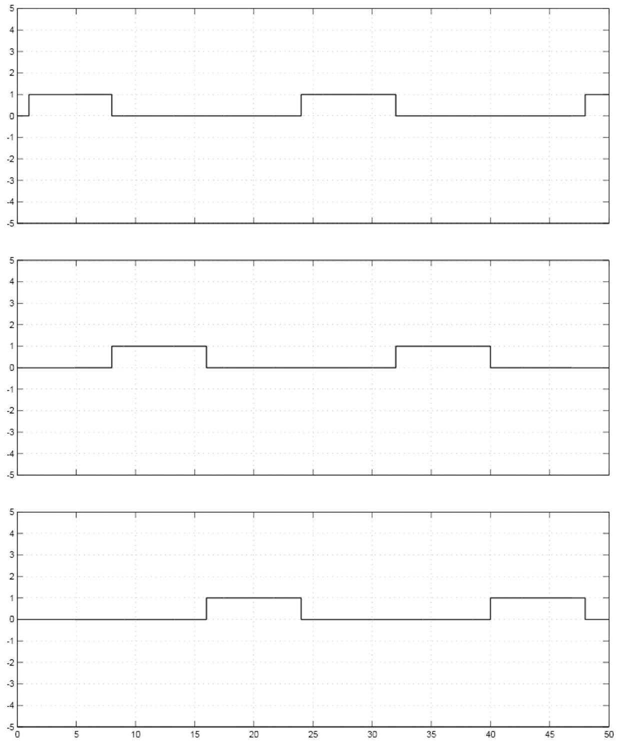


Figure 9: (a) scheduled for demand L1, (b) scheduled for demand L2, (c) scheduled for demand L3.

5. Conclusion

In this paper attempt is made to develop AGC model with AVR and demand side management. 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.

Here the objective is to maintain the system in stable. Hence the generation must be equal to demand at each moment, since this power must be divided between generators in unique ratio, in order to achieve the economic operation. It is seen that sometime demand is very large than generation and sometime surplus power in a duration of 24 hrs so it is important to remember that demand undergo slow but wide changes throughout the 24 hr of the day. So this is a need to manage generation as well as demand.

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