Matlab Design and Simulation of AGC and AVR for Multi Area Power System and Demand Side Management

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Abstract—This paper deals with the automatic generation control (AGC) of interconnected thermal systems with combination of the automatic voltage control (AVR) and Demand Side Management (DSM). In this particular work thermal unit is considered with four 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 demand side. In this paper DSM scheme is also considered. Demand side 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. It has been used for this purpose in the past 10 years so that utilities can defer the need of reinforcing their networks as well as the need of increasing the capacity of the generators. Research has been carried out in order to identify additional functions and benefits that demand side management can bring to end users and utilities. In this paper scheduled loading availability strategy is used to maintain the load.

Index Terms—Automatic Generation Control (AGC), Automatic Voltage Regulator (AVR), Area Control Error (ACE), Economic Dispatch, Frequency Response, Voltage Response, Governor Action, Power System Operation, Tieline Control, Scheduled Loading Availability (SLA).

I. INTRODUCTION

The AGC problem, which is the major requirement in parallel operation of several interconnected systems, is one of very important subjects in power system studies [1].

In this paper, the power system with four areas connected through tie-lines is considered in Matlab/Simulink environment. The perturbation of frequencies at the areas and resulting tie-line power flows arise due to unpredictable load variations that cause mismatch between the generated and demanded powers. The objective of AGC is to

minimize the transient deviations and to provide zero steady state errors of these variables in a very short time [2] – [5].

The generator excitation system maintains generator voltage and controls the reactive power flow. The generator excitation of older system may be provided through slip rings and brushes by means of DC generators mounted on the same shaft as the rotor of the synchronous machine. A change in the real power demand affects essentially the frequency, whereas a change in the reactive power affects mainly the voltage magnitude. The interaction between voltage and frequency controls is generally weak enough to justify their analysis separately. The sources of reactive power are generators, capacitors, and reactors. The generator reactive powers are controlled by field excitation. Other supplementary method of improving the voltage profile in the electric transmission systems are transformer load tap changers, switched capacitors, step voltage regulators and static var control equipment. The primary means of generator reactive power control is the generator excitation control using automatic voltage regulator (AVR). The role of an AVR is to hold the terminal voltage magnitude of synchronous generator at a specified level [7].

An increase in the reactive power load of the generator is accompanied by a drop in the terminal voltage magnitude. The voltage magnitude is sensed through a potential transformer on one phase. This voltage is rectified and compared to 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 result in an increase in the generated emf. The reactive power generation is increased to a new equilibrium, raising the terminal voltage to the desired value.

Demand-side management (DSM) has traditionally seen as a means of reducing peak electricity demand so that utilities can delay building further capacity. In fact, by reducing the overall load on an electricity network, DSM has various beneficial effects, including mitigating electrical system emergencies, reducing the number of blackouts and increasing system reliability. Possible benefits can also include reducing dependency on expensive imports of fuel, reducing energy prices and reducing harmful emissions to the environment. Finally, DSM has a major role to play in deferring high investments in generation, transmission and distribution networks [9] – [11]. Thus DSM applied to electricity systems provides significant economic, reliability and environmental benefits.

When DSM is applied to the consumption of energy in general – not just electricity but fuels of all types – it can also bring significant cost benefits to energy users (and corresponding reductions in emissions). Opportunities for

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reducing energy demand are numerous in all sectors and many are low-cost, or even no-cost [13], items that most enterprises or individuals could adopt in the short term, if good energy management is practiced.

II. SYSTEM INVESTIGATED

The AGC system investigated consists of four generating areas. Area 1, Area 2, Area 3 & Area 4 of different sizes is reheat thermal systems [1]. An automatic voltage regulator for an excited AC generator comprising at least one controlled rectifier for conducting the field current of the generator, a trigger signal supplying means for supplying a trigger signal to the controlled rectifier when the controlled rectifier is forward biased, a voltage detection circuit for detecting the output voltage of the generator, an inhibiting circuit for inhibiting turn-on of the controlled rectifier when the instantaneous value of the voltage detection circuit exceeds a predetermined voltage, characterized in that the voltage detection circuit comprises a phase shifting circuit receiving and shifting the phase of the output voltage of the generator. A multiarea interconnected system is represented in a ring fashion and in a longitudinal manner. In practice it is a combination of the two. A simplified representation for an interconnected system in a general form is shown in Fig. 1.

Fig. 1: Simplified diagram of interconnected system

Fig. 2 shows the AGC & AVR model of a four area thermal system.

Fig. 2: Area-1(AGC+AVR) of Four area power system

A. Automatic generation control

The combining equations (tie-line) are:

The interconnection of Area 1 with Area (2, 3, 4) is:

$$\Delta P_{tie,1}(s) = \frac{2\pi T_{12}}{s} [\Delta F_1(s) - \Delta F_2(s)] \quad (1)$$

$$\Delta P_{tie,13}(s) = \frac{2\pi a_{13} T_{13}}{s} [\Delta F_3(s) - \Delta F_1(s)] \quad (2)$$

$$\Delta P_{tie,14}(s) = \frac{2\pi a_{14} T_{14}}{s} [\Delta F_4(s) - \Delta F_1(s)] \quad (3)$$

$$ACE_1 = \Delta P_{tie,12} + b_1 \Delta f_1 \quad (4)$$

$$ACE_1(s) = \Delta P_{tie,12}(s) + b_1 \Delta F_1(s) \quad (5)$$

The interconnection of Area 2 with Area (1, 3, 4) are:

$$\Delta P_{tie,2}(s) = \frac{2\pi a_{21} T_{21}}{s} [\Delta F_2(s) - \Delta F_1(s)] \quad (6)$$

$$\Delta P_{tie,23}(s) = \frac{2\pi a_{23} T_{23}}{s} [\Delta F_3(s) - \Delta F_2(s)] \quad (7)$$

$$\Delta P_{tie,24}(s) = \frac{2\pi T_{24}}{s} [\Delta F_4(s) - \Delta F_2(s)] \quad (8)$$

$$ACE_2 = \Delta P_{tie,2} + b_2 \Delta f_2 \quad (9)$$

$$ACE_2(s) = \Delta P_{tie,2}(s) + b_2 \Delta F_2(s) \quad (10)$$

The interconnection of Area 3 with Area (1, 2, 4) are:

$$\Delta P_{tie,3}(s) = \frac{2\pi T_{31}}{s} [\Delta F_3(s) - \Delta F_1(s)] \quad (11)$$

$$\Delta P_{tie,32}(s) = \frac{2\pi a_{32} T_{32}}{s} [\Delta F_3(s) - \Delta F_2(s)] \quad (12)$$

$$\Delta P_{tie,34}(s) = \frac{2\pi a_{34} T_{34}}{s} [\Delta F_4(s) - \Delta F_3(s)] \quad (13)$$

$$ACE_3 = \Delta P_{tie,3} + b_3 \Delta f_3 \quad (14)$$

$$ACE_3(s) = \Delta P_{tie,3}(s) + b_3 \Delta F_3(s) \quad (15)$$

The interconnection of Area 4 with Area (1, 2, 3) are:

$$\Delta P_{tie,4}(s) = \frac{2\pi a_{41} T_{41}}{s} [\Delta F_4(s) - \Delta F_1(s)] \quad (16)$$

$$\Delta P_{tie,42}(s) = \frac{2\pi a_{42} T_{42}}{s} [\Delta F_4(s) - \Delta F_2(s)] \quad (17)$$

$$\Delta P_{tie,43}(s) = \frac{2\pi T_{43}}{s} [\Delta F_4(s) - \Delta F_3(s)] \quad (18)$$

$$ACE_4 = \Delta P_{tie,4} + b_4 \Delta f_4 \quad (19)$$

$$ACE_4(s) = \Delta P_{tie,4}(s) + b_4 \Delta F_4(s) \quad (20)$$

B. Automatic voltage regulator

• Amplifier model

The excitation system amplifier may be magnetic amplifier, rotating amplifier, or modern electronic amplifier. The amplifier is represented by a gain K_A and a time constant T_A and the transfer function is

$$\frac{V_R(s)}{V_e(s)} = \frac{K_A}{1 + sT_A} \quad (21)$$

• Exciter model

The transfer function of a modern exciter may be represented by the single time constant T_E and a gain K_E

$$\frac{V_F(s)}{V_R(s)} = \frac{K_E}{1 + sT_E} \quad (22)$$

- *Generator field model*

The transfer function relating the generator terminal voltage to its field voltage can be represented by a gain K_G and a time constant T_G and the transfer function is

$$\frac{V_t(s)}{V_F(s)} = \frac{K_G}{1 + sT_G} \quad (23)$$

- *Sensor model*

The voltage is sensed through a potential transformer and, in one form, it is rectified through a bridge rectifier. The sensor is modeled by a simple first order transfer function, is given by

$$\frac{V_s(s)}{V_t(s)} = \frac{K_R}{1 + sT_R} \quad (24)$$

Where K_R is sensor gain constant and T_R be Sensor time constant.

C. Combined AVR and AVR loops

The AVR and AGC Loops are not in the truest sense no interacting; *cross coupling does exist* and can some time troublesome. There is little if any coupling from AGC to AVR loop, but interaction exist in the opposite direction [12]. We understand this readily by realizing that control action in the AVR loop affect the magnitude of generated emf E' . As the internal emf determines the magnitude of real power. It is clear that changes in AVR loop must felt in AGC loop. However, the AVR loop is much faster than the AGC loop and there is tendency for AVR dynamics to settle down before they can make themselves in slower AGC channel.

If we include small effect of voltage on real power, we obtained following liberalized equation:

$$\Delta P_g = P_s \Delta \delta + K_2 E' \quad (25)$$

Where K_2 is change in electrical power for small change in stator emf and P_s is synchronizing power coefficient. Also including the small effect of rotor angle upon generator terminal voltage, We may write

$$\Delta V_t = K_5 \Delta \delta + K_6 E' \quad (26)$$

Where K_5 is change in terminal voltage for small change in rotor angle at constant stator emf and K_6 is change in terminal voltage for small change in stator emf at constant rotor angle. Finally, modifying the generator field transfer function to include effect of rotor angle we may express the stator emf as

$$E' = \frac{K_g}{1 + T_g} (V_f - K_4 \Delta \delta) \quad (27)$$

D. Demand side 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 some time 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. Demand side can be managed by controlling tariff in demand side. This is called Demand Side Management and this can deal with two points as

- AGC, AVR and Frequency Availability Based Tariff.
- AGC, AVR and Availability of Scheduled Loading.

Fig. 3 shows a simplified model of Scheduled loading Availability.

Fig 3: Simplified model of Scheduled loading availability.

III. DESIGN AND SIMULATION

The testing was completed using the MATLAB Simulink tool. Testing was done on each of the individual blocks of the AGC system. Tests were also conducted on the uncontrolled AGC system, and the integrator controlled system. Each test included inserting the block diagram into Simulink and plugging in the values for each of the parameters, also involved was the addition of the scopes that would be used to measure the outputs of the system. The inputs for each of the tests were varied to allow for more data. The simulink block diagram representation is shown in Fig. 2. The frequency Vs time responses for interconnected system of Area 1 with area 2,3,4 is shown in Fig. 4, Fig. 5, Fig. 6 respectively. Similarly interconnection of Area 2 with Area 3, 4 is shown in Fig. 7, Fig. 8, and interconnection of Area 3 with Area 4 is shown in Fig. 9. Now all the four area systems can be connected to single tie-line and frequency v/s time response can be obtained as

shown in Fig. 10. The Voltage Vs time responses for interconnected system of Area 1,2,3 & 4 is shown in Fig. 11. The tie line response (MW v/s Time) for interconnected system of Area 1, 2, 3 & 4 is shown in Fig. 12. This four area interconnection scheme may be implemented for reducing the interconnection between two areas. The assumptions used for AGC simulation are shown in Table I and assumptions used simulation is shown in Table II.

Fig. 4: AGC and AVR response for Area1 & 2 Systems

Fig. 5: AGC and AVR response for Area1 & 3 Systems.

Fig. 6: AGC and AVR Response Area 1 & 4 System.

Fig. 7: AGC and AVR Response Area 2 & 3 System

Fig. 8: AGC and AVR response Area 2 & 4 System

Fig. 9: AGC and AVR Response Area 3 & 4 System

Fig. 10: AGC and AVR Response Area 1,2,3 & 4 for Four Area System

Fig. 11: AGC and AVR Voltage Response for Four Area System

Fig. 12: Combined Loop of AGC and AVR for Four Areas System

TABLE I: ASSUMPTIONS USED IN THE SIMULATION RUNS FOR AGC

Quantity	Area-I	Area-II	Area-III	Area-IV
Governor speed regulation	$R_1 = 0.051$	$R_2 = 0.065$	$R_3 = 0.089$	$R_4 = 0.066$
Frequency bias factors	$D_1 = 0.62$	$D_2 = 0.91$	$D_3 = 0.95$	$D_4 = 0.92$
Inertia constant	$H_1 = 5$	$H_2 = 4$	$H_3 = 4.5$	$H_4 = 4$
Base power	1000MVA	1000MVA	1000MVA	1000MVA
Governor time constant	$T_{sg1} = 0.2$ sec	$T_{sg2} = 0.3$ sec	$T_{sg3} = 0.4$ s	$T_{sg4} = 0.3$ sec
Turbine time constant	$T_{t1} = 0.5$ sec	$T_{t2} = 0.6$ sec	$T_{t3} = 0.7$ s	$T_{t4} = 0.6$ sec
Constant	$k = 1/2\pi = 0.159$	$k = 1/2\pi = 0.159$	$k = 1/2\pi = 0.159$	$k = 1/2\pi = 0.159$
Nominal frequency	$f_1 = 50$ Hz	$f_2 = 50$ Hz	$f_3 = 50$ Hz	$f_4 = 50$ Hz
Load change	$\Delta P_{L1} = 180.2$ MW	$\Delta P_{L2} = 180.2$ MW	$\Delta P_{L3} = 180.2$ MW	$\Delta P_{L4} = 180.2$ MW
Load disturbance in per unit	$(\Delta P_{L1})_{p.u} = 0.1802$	$(\Delta P_{L2})_{p.u} = 0.1802$	$(\Delta P_{L3})_{p.u} = 0.1802$	$(\Delta P_{L4})_{p.u} = 0.1802$

TABLE II: ASSUMPTIONS USED IN THE SIMULATION RUNS FOR AVR

Quantity	Gain	Time Const
Amplifier	9	0.1
Exciter	1	0.4
Generator	1	1.0
Sensor	1	0.05

Quantity	Gain
PID Controller	KP = 1.0 KI = 0.25 KD = 0.28

Now let us discuss the simulation results of DSM

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 6 hrs shown in fig. 13
- Demand L2 for next 6 hrs shown in fig. 14.
- Demand L3 for next 6 hrs shown in fig. 15.
- Demand L4 for next 6 hrs shown in fig. 16.

Fig. 13: Scheduled for Demand L1

Fig. 14: Scheduled for Demand L2.

Fig. 15: Scheduled for Demand L3.

Fig. 16: Scheduled for Demand L4.

IV. CONCLUSION

In this paper attempt is made to develop AGC scheme with AVR and DSM. 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 generated emf E' as the internal emf determines the magnitude of real power. It is concluded that changes in AVR loop is felt in AGC loop.

It is concluded that 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 some time 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.

ACRONYMS

- B : Frequency Bias factor
D : Percent change in load divided by the percent change in frequency
Ki : Supplementary control constant
H : Inertia Constant
 ΔP : Change in power
 ΔP_{Mech} : Change in mechanical power input
 ΔP_D : Change in power demanded by the load
In an area
 $\Delta P_{Tie-flow}$: Change in power transmitted over tie line
 ΔP_{valve} : Change in valve position from nominal
R : Speed Droop Characteristic
 T_{ps} : Power system time constant
 T_{SG} : Speed governor time constant
 T_t : Turbine time constant
f : Frequency of system
 f_{ref} : Reference frequency for system
 Δf : Change in system frequency
 X_{tie} : reactance of tie line

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