Frequency-Bias Tie-Line Control of Hydroelectric Generating Stations for Long Distances

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Abstract

In this work I have tried to apply effective dedicated on-line control systems to two equal power systems connected by a long distance tie-line. When large interconnected systems are linked electrically to others by means of tie-lines, the power transfers between them are usually decided by mutual agreement and the power is controlled by regulators. Other side it is a desired feature to achieve a better frequency constancy, which has been obtained by a controller, which is being activated by frequency -bias constant. A power frequency characteristic also has been maintained approximately straight line by governor speed regulation parameter in case any perturbation in frequency is caused by load change in any one of the area.To maintain the real power flow and single frequency in tie-line power system, the governor has been manipulated by Automatic Generation Control (AGC) action. For this works various, integral (I) proportional plus integral (PI) and proportional plus integral plus derivative (PID) controllers have been tried.

Keywords

Tie-line power systems, frequency-bias constant, power frequency characteristic, Automatic Generation Control (AGC), control schemes I, PI and PID, two equal power systems, secondary controller.

1 Introduction

1.1 Previous Works

Lot of works have been reported in the field of automatic generation control for the voltage control, frequency control in parallel running generators for the same power station. The control strategy for analog and digital computers has been solved by Kutta - Merson techniques and other analysis. Simultaneously a big progress has been shown in the automatic generation control of interconnected power system centered on the tie-line frequency-bias control strategies. Concordia and Kirchmayer [1] have made analog computer simulation for AGC studies. Their studies show that for minimum interaction, frequency-bias constant (B) must be set equal to area frequency response characteristic (β). Cohn [2] has also studied in detail the effect of B and shown that the interaction between interconnected system is minimized when B = β. Elgcrd [3] and Fosha [4] have used classical control theory to optimize the integral (1) controller gain settling and the frequency-bias parameter. Proper selection of frequency - bias setting is important for AGC of tie - line or interconnected systems. Elgerd and Fosha [4], obtained an optimum value of B = 0.5 β for best dynamic performance in unconstrained mode of AGC of a two equal thermal system. But it has been observed that when B $< \beta$, the interconnected operation of the system is not satisfactory under abnormal conditions.

1.2 Motivation

The main objectives of the work in this research are to study with control scheme I, in Automatic Generation Control of a two equal area interconnected hydroelectric power systems. Since in the existing conditions, Ethiopia has only hydroelectric power systems, where high moment of inertia of generator in hydroelectric power system is a challenging factor. Which is to be moved for proper angular displacement with change in load in anyone of the area. Even in future the tie-line power systems for mutual exchanging the power during peak hours/months between neighboring countries are expected. Which has motivated the author to feel the challenge of time, place and situation.

1.3 Notations

T_{gi} = speed governor time constant.

K_{pii} = 1/Disload frequency constant.

H_1 = inertia constant (T_{pii} = $2H_1/fD_1$)

R_i = governor speed regulation parameter.

βi = area frequency response characteristic (AFRC).

Δ F_i = incremental change in tie-line power.

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$\Delta P_{tie} = 2\Pi T_{12}$

$\Pi T_{12} = \cos(\delta_1 - \delta_2) T_{12}$

T_{12} = synchronizing torque coefficient.

P_{Π} = area rated capacity ($a_{12} = -P_{rt} / P_{r2}$)

ΔX_{EI} = incremental change in governor valve change.

ΔP_{RI} = incremental change in L.P. stage.

ΔP_{gi} = incremental generation change.

T_{ti} = L.P. turbine constant.

ΔP_{pi} = incremental load change.

T_{hi} = H.P. turbine constant.

K_{ri} = transfer constant.

K_I = integral gain constant.

T = transpose of the matrix.

2 Automatic Generation Control In Frequency-Bias Tie-Line Power System

2.1 Theory

An electric energy system supposes to maintain a desired level characterized by nominal frequency voltage profile and load flow configuration. It is to be kept in this nominal state by dedicated control of real and reacting power. In generation reactive power can be controlled by changing the angular displacement (frequency control). Therefore it is a desired feature to achieve a better frequency constancy by speed governing system. In interconnected power systems, it is also desired to maintain the tie-line power flow at a given level irrespective of load change in any area. To accomplice this it becomes necessary to manipulate the operation of hydrogenates in accordance with suitable control strategy (a control of real power output) for autocratic generation control of real power system. The following definition is accepted by IEEE “the regulation of the power output of electric generation within a prescribed area in response to changes in system frequency, tie-line loading or the relation to each other, so as to maintain the scheduled system frequency and /or the established interchange with other area within predetermined limits”.

This load frequency-bias tie-line control problem has been studied by considering coherent group of generators forming a control area. A large wide spread electric power system can be divided into two equal control systems interconnected by means of tie-line as shown in Figure 1.

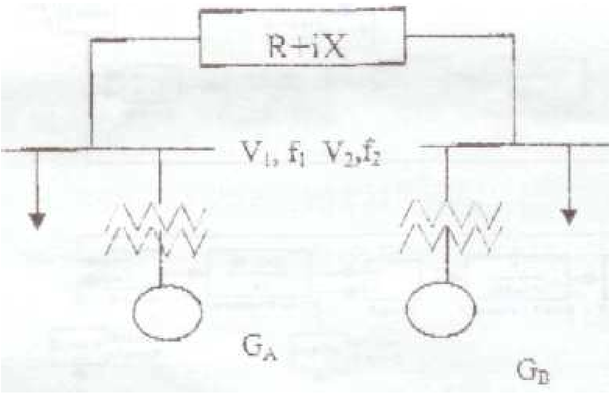

Figure 1: Two generating station linked by an inter connector impedance ($f_1 > f_2$)

2.2 Analysis

The problem of automatic generation control can be subdivided into fast (primary) and slow (secondary) modes. The overall AGC performance depends on proper design of both primary and secondary control loops. Secondary controller (frequency-bias tie- line control in this paper) has been designed to regulate the area control errors (ACEi) to zero.

$$ACEiP = N_{ji} - P_{si} + B_i(f - f_g) \qquad (1)$$

Where, P_{Jii} = the actual net interchange, positive power output of area J in MW

P_{gi} = the scheduled net interchange of area I in MW.

Bi = frequency-bias constant is MW/Hz (p.u.MW).

f = actual frequency scheduled in Hz.

f_s = the system frequency in area II is Hz.

Area control error may be expressed in p.u.MW and define:

$$ACEi = P_{tie} + B_i \Delta f \qquad (2)$$

Where P_{tie} = the deviation in tie-line power in P.u.MW, Δ f = the deviation in frequency in Hz (+ve for high frequency). This frequency-bias tie-line control system (secondary controller) controls by considering both load transfer and frequency such that the following equation holds:

$$\sum \Delta P_{tie} + B_i \Delta f = 0 \qquad (3)$$

2.3 Mathematical Models

2.3.1 Transfer Function/Block - Diagram Method

Figure 2 shows transfer function/block - diagram model of tow hydroelectric power systems inter connected by tie-line. Figure 3 shows transfer function model with typical value of constants in hydroelectric power systems inter connected by tie-line.

2.3.2 Dynamic Model In State-Space Method

The dynamic model in state-space form is obtained from the small perturbation from the reduced transfer function model as:

$$X = AX + BU + \Gamma P \tag{4}$$

Where X, U and P are the state, control and disturbance vectors respectively, A, B and Γ are compatible matrices and depend upon system parameters and operating points. For the investigated system the state vector X, control vector U (Γ) and the disturbance vector P(X) and system matrices A(nxn) (see Table 1), B(nxΓ) and Γ(nxΓ) are:

$$\begin{aligned} X^{\Gamma} &= [\Delta f_1, \Delta P_{g1}, \Delta P_{R1}, \Delta X_{E1}, \Delta P_{tie}, \\ &\quad \Delta f_2, \Delta P_{g2}, \Delta P_{R2}, \Delta X_{F2}] \\ U^{\Gamma} &= [\Delta P_{c1}, \Delta P_{c2}] \\ P^{\Gamma} &= [\Delta P_{D1}, \Delta P_{D2}] \end{aligned}$$

$$B^{\Gamma} = \begin{bmatrix} 0 & 0 & 0 & \frac{1}{T_{k1}} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{k2}} \end{bmatrix}$$

$$\Gamma^{\Gamma} = \begin{bmatrix} \frac{-K_{r1}}{T_{p1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{-k_{p2}}{T_{P2}} & 0 & 0 & 0 \end{bmatrix}$$

3 Results

This paper work has bean simulated with the help of MATLAB, SIMULINK. Each unit in power system has been denoted by is linear, time invariant model and whose transfer function is created by some typical values keeping in view the high inertia constant of generator which is to be given angular displacement within a short time by manipulating the governor, a two stage hydro-turbines with their transfer function model has been utilized. To manipulate the governor assembly both for primary and secondary control (frequency-bias tie-line) has been used to apply control actions for detected frequency change, which is a cause of load change in any area.Based on this various waveforms at various output points (on SIMULINK output device, scope are shown in Figure 3 above) under normal and abnormal conditions have been observed. Some of the output results with I controller have been shown in Figures 4-7.

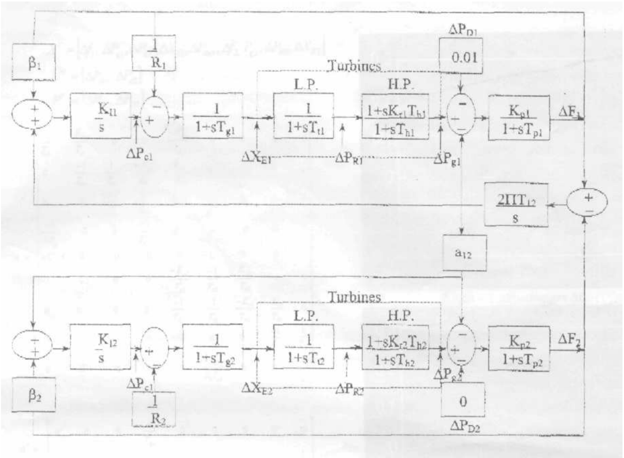

Figure 2: Transfer function modal of two equal hydroelectric systems connected by tie-line

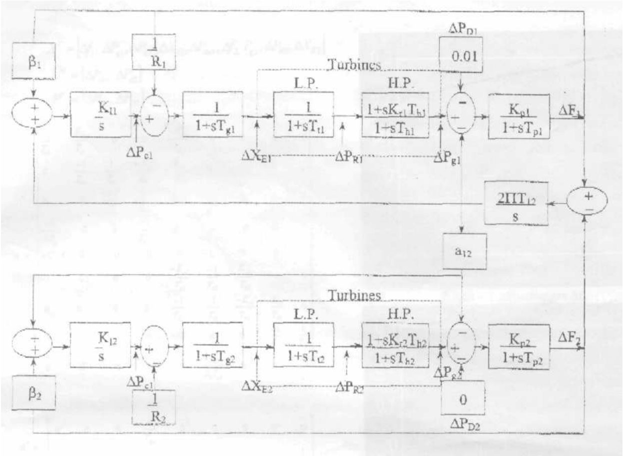

Figure 3: Transfer function model with typical values of constants in hydroelectric power systems interconnected by tie-line in SIMULINK, MATLAB

4 Conclusion

I have tried [I] control action to minimize the time of dynamic response, keeping in view that any change in frequency leads to failure of power generation system in few minutes. I found that integral control ensures zero steady-state error following a step load change. As long as error exists, the integrator output makes the speed changer to move to attain a constant value only when the area control error has been reduced to zero. A portion controller may be added to adjust the amplifier gain. Further it is concluded that under normal conditions each area is maintaining its own load demand. Under abnormal conditions for steady-state per-

$$A = \begin{bmatrix} \frac{-1}{T_m} & \frac{K_m}{T_m} & 0 & 0 & \frac{-K_m}{T_m} & 0 & 0 & 0 & 0 \\ 0 & \frac{-1}{T_m} & \frac{1}{T_m} & \frac{-K_m}{T_m} & \frac{K_m}{T_m} & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{-1}{T_m} & \frac{1}{T_m} & 0 & 0 & 0 & 0 & 0 \\ \frac{-1}{R_1 T_{g1}} & 0 & 0 & \frac{-1}{T_{g1}} & 0 & 0 & 0 & 0 & 0 \\ C & 0 & 0 & 0 & 0 & -C & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{-K_{pz}}{T_{pz}} & \frac{-1}{T_{pz}} & \frac{K_{pz}}{T_{pz}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{-1}{T_{h2}} & \frac{1}{T_{h2}} & \frac{-K_{r2}}{T_{h2}} & \frac{K_{r2}}{T_{h2}} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{r2}} & \frac{1}{T_{r2}} \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{R_2 T_{k2}} & 0 & 0 & \frac{-1}{T_{r2}} \end{bmatrix}$$

Table 1: A(nxn)

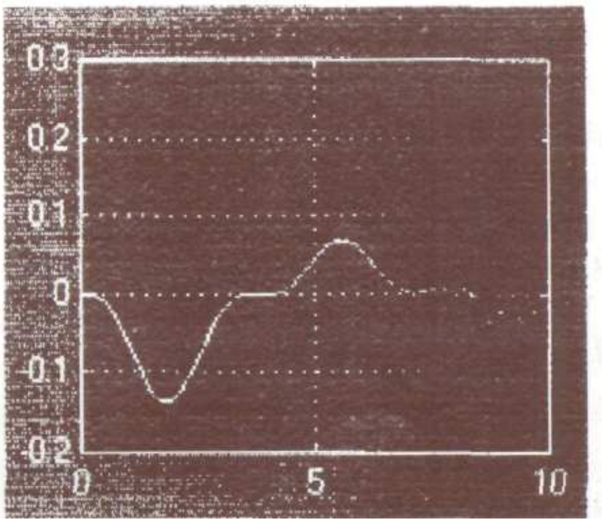

Figure 4: Scope 1Δp_{Di} changes Δf_1

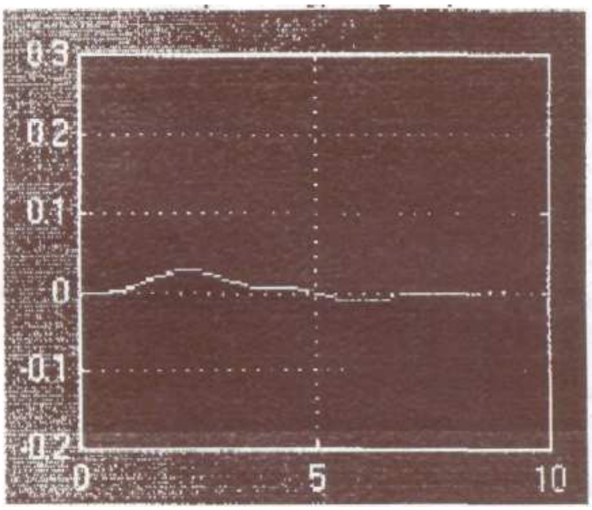

Figure 5: Scope 2HP turbine output changes in-I

formance when B = β permits natural governing response to persist and for B $> \beta$ reduces to the natural governor response.

References

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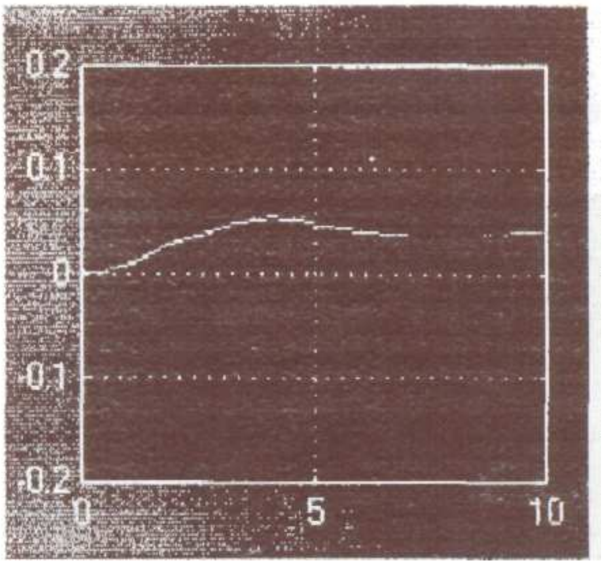

Figure 6: Scope 3 HP turbine output changes in-II

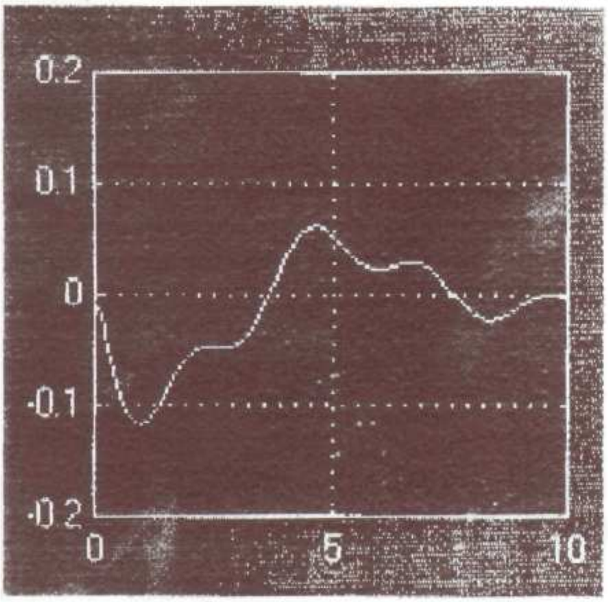

Figure 7: Scope - Output at Δf_2: Outputs at different points as shown in Figure 3