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# DESIGN OF SUBOPTIMAL AGC REGULATOR FOR INTERCONNECTED POWER SYSTEM USING STEEPEST DESCENT GRADIENT ITERATIVE ALGORITHM

**Ram Naresh Mishra[1], Prabhat Kumar[2]**

[1] *Department of Electrical Engineering, GLA University, Mathura (India)*

[2]*Ex- Department of Electrical Engineering, Aligarh Muslim University, Aligarh (India)*

## ABSTRACT

*This paper presents design of suboptimal AGC regulator for an interconnected power system using steepest descent gradient iterative algorithm. Transfer function model of power system comprises hydro and thermal power generations. A proportional-plus-integral control law is considered. The easily measurable output variables are frequency deviation (*$\Delta F$*), tie-line power deviation (*$\Delta P_{tie}$*), HVDC link tie-line power deviation (*$\Delta P_{dc}$*), and integral of area control error (IACE), considered as output states. The HVDC link is assumed to be operated in constant current control (CCC) mode. Each area regulator is constrained to be a linear time-invariant combination of its output variables only, such as frequency deviation (*$\Delta F$*), area control error (ACE), and integral of area control error (IACE). System dynamic responses are obtained in the wake of 1% step load disturbance in one of the two areas. Stability of the system is investigated with the help of closed-loop system Eigen values.*

***Keywords: HVDC transmission link, Inter-connected power systems, Parallel EHVAC/HVDC transmission link, Suboptimal AGC regulator, System dynamic response.***

## I.INTRODUCTION

AGC is a significant control process that operates constantly to balance the total generation with total load demand and associated system losses. With time, the operating point of a power system changes, and hence, these systems may experience deviations in nominal system frequency and scheduled power exchanges to other areas. Two variables, frequency and tie line power exchanges are weighted together by a linear combination to a single variable called the ACE [5]. This is used as the control signal in the AGC problem. The first attempts in the area of AGC are given in several research papers [1-4].The standards definitions of the terms associated with AGC of power systems were provided by the IEEE Committee [5].Fosha and Elgerd [6] were the first to present their pioneer work on optimal AGC regulator design using this concept. Since an optimal AGC scheme needs the availability of all state variables. In actual practice, it may not be always feasible that the entire state

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variables are accessible for measurement whereas reconstruction involves additional cost and complexity in implementation. To overcome these problems, sub-optimal AGC regulator design using output states as feedback have been introduced [7-9].In this paper, an attempt has been made to design sub-optimal AGC regulators using output states as feedback for 2-area Hydro-Thermal power systems with area-1 as thermal system consisting of reheat turbines & area-2 representing a hydro system. In power system control problems, the easily available output variables which are measurable are the frequency deviation (ΔF), tie-line power deviation ($\Delta P_{tie}$), HVDC link tie-line power deviation ($\Delta P_{dc}$) and integral of area control error (IACE), considered as output states feedback to design suboptimal AGC regulator. Each area regulator is constrained to be a linear time-invariant combination of its output variables only, such as frequency deviation (ΔF), area control error (ACE) and integral of area control error (IACE). The design procedure is based on the solution of a set of necessary conditions using the steepest descent gradient iterative algorithm as reported by Hole' [10].

## II.DESIGN OF SUBOPTIMAL AGC REGULATOR

An s-area interconnected power system described by a completely controllable and observable linear time-invariant state space representation is considered for the present work. The differential equations of the system in state variable form can be written as

$$\underline{\dot{X}} = A\,\underline{X} + B\,\underline{U} + Fd\,\underline{Pd} \qquad \text{---- (1.1)}$$

$$\underline{Y} = C\,\underline{X} \qquad \text{---- (1.2)}$$

Where: $\underline{X}$, $\underline{U}$, $\underline{Pd}$ and $\underline{Y}$ are the state, control, disturbance and output vectors respectively.

A, B, C and Fd are the matrices of compatible dimensions. In the application of optimal control theory, the term Fd $\underline{Pd}$ in eqn (1.1) need not be considered, if $\underline{Pd}$ is a step disturbance as it does not alter the optimum solution.

System described by eqns (1.1) & (1.2), the problem is to obtain a control law of the form

$$[\underline{U}]_{sub} = -K^{*}\,\underline{Y} \qquad \text{---- (1.3)}$$

This minimizes the performance index, given by

$$J = \int_{0}^{\infty} \frac{1}{2}\left[\ \underline{X}^{T} Q\,\underline{X} + (\underline{U}_{sub})^{T} R\,\underline{U}_{sub}\ \right] dt \qquad \text{---- (1.4)}$$

The following set of necessary conditions is obtained for the solution of the above mentioned problem;

$$Z^{T} S + SZ + Q + C^{T}K^{T}RKC = 0 \qquad \text{---- (1.5)}$$

$$ZP + PZ^{T} + I = 0 \qquad \text{----- (1.6)}$$

$$\frac{\partial H}{\partial K} = 2(RKCPC^{T} - B^{T}SPC^{T}) \qquad \text{---- (1.7)}$$

Where; Z=A-BKC, is the closed loop system Matrix.

H = Hamiltonian.

The solution of the above equations (1.5 to 1.7) is obtained by using the steepest descent gradient iterative algorithm as reported by Hole' [10].

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## III.STEEPEST DESCENT GRADIENT ITERATIVE ALGORITHM

(i) Read the data A, B, C, R, Q, alpha and initialize K.

(ii)Set iteration count k = 1.

(iii)Compute the closed loop system matrix Z = A-BKC.

(iv)Solve Lyapunov equation for n×n matrix 'S'

$Z^T S + SZ + C^T K^T RKC + Q = 0$

(v)Compute trace of 'S' as

$$tr_i[S] = \sum_i S_{ii}$$

(vi)Solve Lyapunov equation for matrix 'P'

$ZP + PZ^T + I = 0$

(vii)Determine gradient

$DELH = 2\,(RKCPC^T - B^T SPC^T)$

(viii) Modify the feedback gain matrix

$K_1 = K - alpha*DELH$, where alpha is step size.

(ix)Compute the new value of 'S' and $tr_2$ i.e. trace of 'S'.

(x)Check the convergence. If convergence is achieved then stop and print the optimum value of K & go to step (xii). Otherwise, proceed to next step.

(xi)Increase iteration count by 1. Set $K = K_1$ and $tr_1 = tr_2$. Repeat from step (iii) onwards.

(xii)Set K = optimum K.

(xiii)Set iteration count as 1.

(xiv)Initialize x=0, t=0 and $\Delta t = 0.1$.

(xv)Apply Runga-Kutta routine to find new value of x.

(xvi)Check if $t \geq T_{max}$. If yes, plot the characteristics, else go to next step.

(xvii)Increase iteration count by 1 and t by $\Delta t$.

## IV.POWER SYSTEM MODEL

The block diagram with transfer function representation is shown in Fig.(1) for parallel EHVAC/HVDC transmission link.

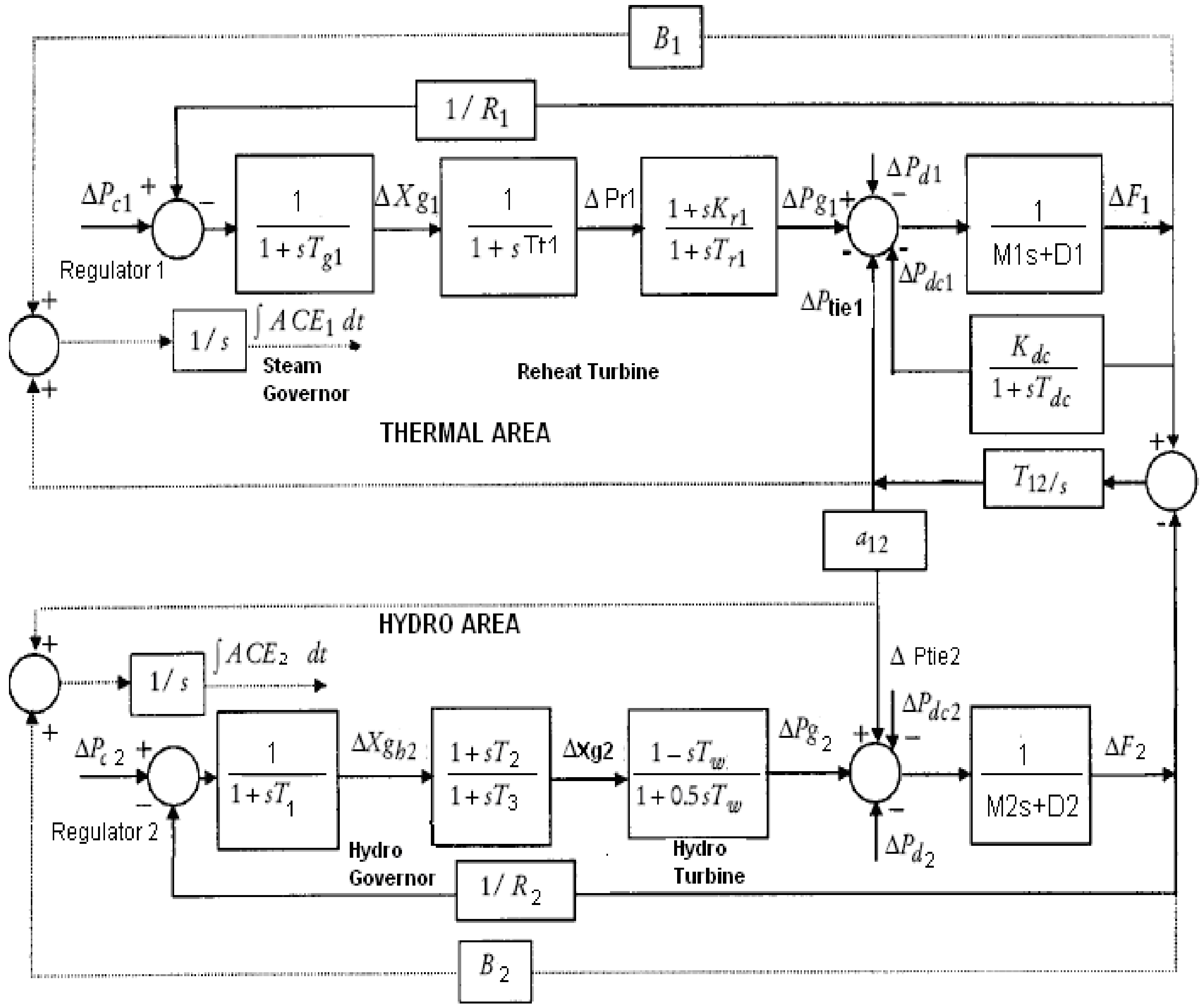


**Fig (1)**

## V.CASE STUDIES

Power Systems interconnections are:

($s_1$) EHVAC transmission link only.

($s_2$) Parallel EHVAC / HVDC transmission link.

**State Variables**

$[Xs_1] = [\Delta f_1, \Delta Pg_1, \Delta Pr_1, \Delta f_2, \Delta Pg_2, \Delta Xg_2, \Delta Xgh_2, \Delta Ptie, \int ACE_1, \int ACE_2]^T$

$[Xs_2] = [\Delta f_1, \Delta Pg_1, \Delta Pr_1, \Delta f_2, \Delta Pg_2, \Delta Xg_2, \Delta Xgh_2, \Delta Ptie, \Delta P_{dc}, \int ACE_1, \int ACE_2]^T$

**Control Vectors**

$[Us_1] = [Us_2] = [\Delta P_{c1}, \Delta P_{c2}]^T$;

**Disturbance Vectors:**

$[Pd\text{-}s_1] = [Pd\text{-}s_2] = [\Delta Pd_1, \Delta Pd_2]^T$;

**Output Feedback Vectors**

$[Y\text{-}s_1] = [\Delta f_1, \Delta f_2, \Delta Ptie, \int ACE_1, \int ACE_2]^T$

$[Y\text{-}s_2] = [\Delta f_1, \Delta f_2, \Delta Ptie, \Delta Pdc, \int ACE_1, \int ACE_2]^T$

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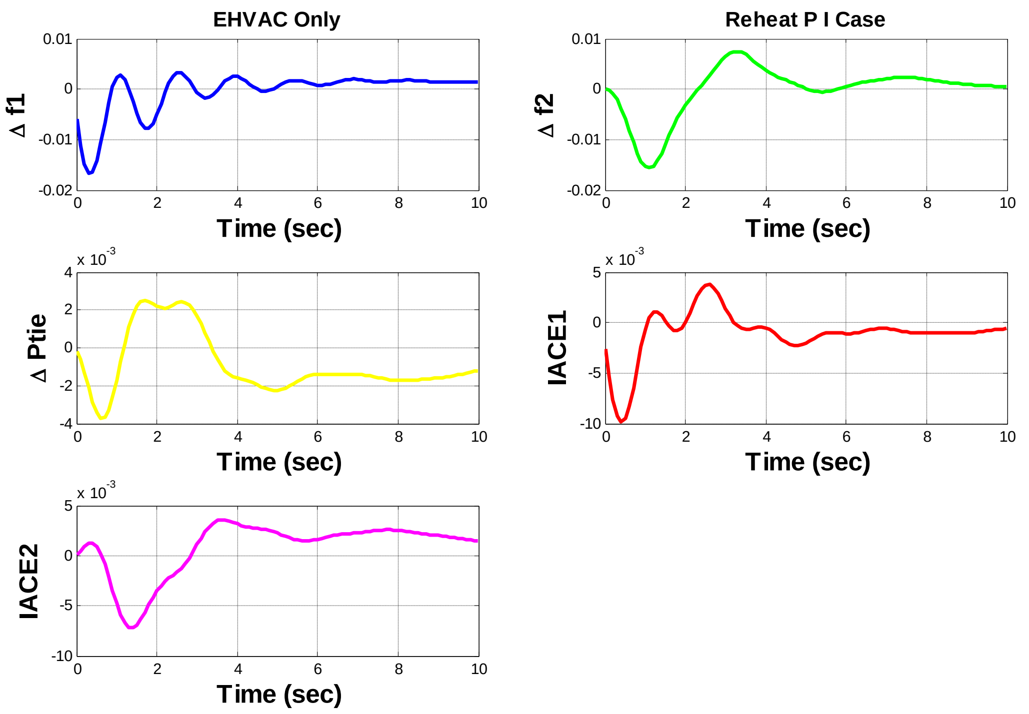
## VI. RESULTS & DISCUSSION



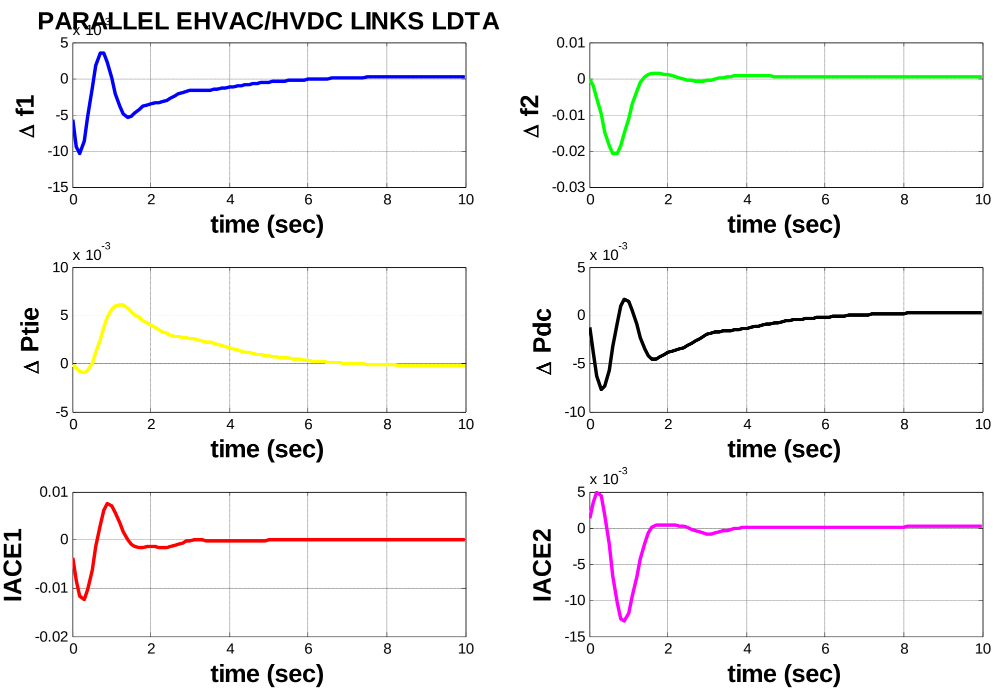




**Fig. (2) & (3)**

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The system dynamic responses (Fig 2 & 3) are obtained with suboptimal AGC regulators using output vector feedback control strategy; it is observed that there is an appreciable reduction in the magnitude of first peak. But oscillatory modes have been increased in the steady state time responses. This led to deterioration in the dynamic response of the system resulting reduces the degree of stability of the system. It is notice that the system settling time remains nearly same for both output vector feedback control strategy and full state vector feedback control strategy [21].The Eigen values of the system are presented in Table 1&2.

**TABLE 1: With EHVAC link**

| Suboptimal Control | Optimal Control |
|---|---|
| -13.9584 | -17.6314 |
| -0.5253 ± 4.2141i | -3.3075 ± 0.1659i |
| -2.8795 | -0.6120 ± 2.5813i |
| -0.2199 ± 1.7214i | -1.5058 ± 0.4913i |
| -1.0304 | -0.4163 |
| -0.3252 | -0.1128 ± 0.0828i |
| -0.1922 | -0.1988 |
| -0.0633 ± 0.1880i | |

**TABLE 2: With parallel EHVAC/HVDC link**

| Suboptimal Control | Optimal Control |
|---|---|
| -13.7931 | -17.6111 |
| -1.6630 ± 5.7620i | -2.0654 ± 5.6360i |
| -1.0265 ± 2.4897i | -4.2668 |
| -2.2730 ± 0.6208i | -3.5872 |
| -0.7081 | -1.3449 ± 0.8514i |
| -0.0616 ± 0.1880i | -0.9890 |
| -0.2655 | -0.2955 |
| -0.1881 | -0.1984 |
| | -0.1124 ± 0.0821i |

At first glance, it is inferred that with sub-optimal AGC regulators designed, the closed loop system stability is ensured in all cases. But stability margin is reduced, in case of suboptimal output vector feedback control strategy as compared to optimal full state vector feedback control strategy. A reduction in the magnitude of negative real parts and an increment in the magnitude of imaginary parts of the closed loop system Eigen values is observed in case of suboptimal output vector feedback control strategy as compared to optimal full state vector feedback control strategy. This led to deterioration in the dynamic responses of the system and thereby reduces the degree of stability of the system.

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