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Genetic Algorithm Based Decentralized Controller for Load- Frequency Control of Interconnected Power Systems with RFB Considering TCPS in the Tie-Line

[1]I.A. Chidambaram and [2]B. Paramasivam

[1]Professor and [2]Senior Lecturer
[1,2]Department of Electrical Engg, Annamalai University,
Annamalainagar – 608002, Tamilnadu, India
E-mail: [1] driacdm@yahoo.com / iaccdm@sancharnet.in

Abstract

This paper proposes a design of Genetic Algorithm (GA) based controllers for the decentralized load-frequency control of two-area interconnected thermal reheat power systems with and without Redox Flow Batteries (RFB) considering Thyristor Controlled Phase Shifter (TCPS) in the Tie-line. The GA based integral controllers are designed using Integral Square Error (ISE) Criterion. The proposed controllers are implemented in a two-area interconnected thermal power system with and without RFB and TCPS. The output response of the system frequency, tie-line power and control input deviations for 1% step-load disturbance are presented by simulating the system. The result reveals that, the controller provides better transient response and smaller settling time, for the two-area interconnected power systems considering RFB and TCPS when compared with the output responses obtained for the two-area interconnected power system without RFB and TCPS.

Keywords: Decentralized Controllers, Genetic Algorithm, Integral Square Error Criterion, Redox Flow Batteries, Load-Frequency Control, Thyristor Controlled Phase Shifter.

Introduction

Power systems, with the increase in size and complexity, require interconnection between the systems to ensure more reliable power supply even under emergencies by sharing the spinning reserve capacities. In the Load-Frequency Control (LFC) and inter- area tie-line power flow control, a decentralized control scheme is essential. The paper proposes a control scheme that ensures reliability and quality of power supply, with minimum transient deviations and ensures zero steady state error. The importance of decentralized controllers for multi area load-frequency control system, where in, each area controller uses only the local states for feedback, is well known.

The stabilization of frequency oscillations in an interconnected power system becomes challenging when implemented in the future competitive environment. So advanced economic, high efficiency and improved control schemes [1-6] are required to ensure the power system reliability. The conventional load-frequency controller may no longer be able to attenuate the large frequency oscillation due to the slow response of the governor [7]. The recent advances in power electronics have led to the development of the Flexible Alternating Current Transmission (FACTS) devices to enhance power system stability by using reliable and high speed electronic devices. One of the capable FACTS devices is the Thyristor Controlled Phase Shifter (TCPS) [8, 9] which changes the relative phase angle between the system voltages. Therefore, the real power flow can be regulated to mitigate the frequency oscillations and enhance power system stability. The tie-line power flow will have a better control when the TCPS is installed in series with the tie-line in between the two-area interconnected power systems. This control strategy acts as new ancillary service for stabilizing the frequency oscillations and the TCPS provides improvement in dynamic and transient stabilities of power system [9].

The model development of rechargeable batteries such as redox flow batteries [10 – 12] which are not aged by frequent charging and discharging, have a quick response equivalent to SMES and outstanding function during overload. The RFB include load frequency control which gives the excellent short time overload output. The effect of generation control and absorption of fluctuation needed for power quality maintenance are expected in the present power market scenario.

Genetic algorithm is a global search technique [13] which provides the solution of optimization problems by minimizing the mechanism of natural selection and genetics.

In the view of the above, the main objectives of the present work are

(1) To develop a linearized model. case(i) Linearized model of two area interconnected thermal reheat power system. case(ii) Linearized model of two – area interconnected Thermal Reheat Power System with RFB and TCPS

(2) To optimize the gain setting of the integral controller using ISE criterion for the two case studies.

(3) To study the effect of a redox flow batteries and TCPS in the tie - line on the LFC dynamics of a interconnected power system for 1% step load disturbance in area 1by adopting Runge Kutta Gill method and compare the performances of two area interconnected power systems with and without RFB and TCPS.

Modelling For A Two – Area Interconnected Power Systems

Tie – Line Power Flow Model Considering TCPS

In this study, the figure 1 shows the schematic diagram of the two-area interconnected reheat thermal power system with TCPS in series with tie line the TCPS is placed area 1. The resistance of tie line is neglected. A TCPS is a device that changes the relative phase angle between the system voltages [8, 9]. Therefore the real power flow can be regulated to mitigate the frequency oscillations and enhance power system stability.

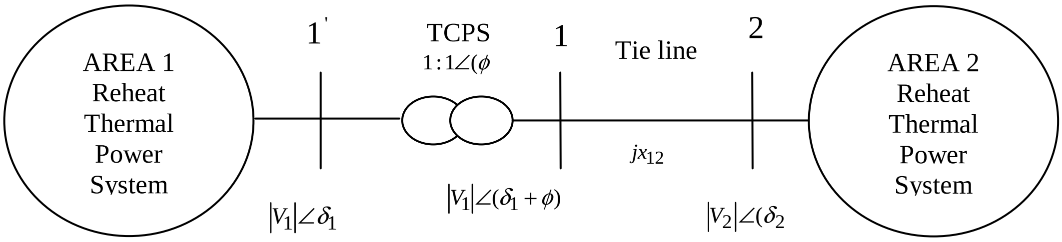

Figure 1: Schematic of a two-area interconnected thermal reheat power system with TCPS in series with tie-line.

The interconnected tie-line power flow from area 1 to area 2 without considering TCPS can be expressed as

$$\Delta P^0{}_{tie12} = \frac{2\pi T^0_{12}}{s}\left[\Delta f_1 - \Delta f_2\right] \tag{1}$$

With the TCPS is placed in series with the tie-line near area 1 as shown in fig.1,

The complex power can be written as

$$P_{tie} - jQ_{tie12} = |V_1|\angle-(\delta_1+\phi)\left(\frac{|V_1|\angle(\delta_1+\phi)-|V_2|\angle\delta_2}{jx_{12}}\right) \tag{2}$$

Separating the real part of tie-line power

$$P_{tie12} = \frac{|V_1||V_2|}{x_{12}}\sin(\delta_1-\delta_2+\phi) \tag{3}$$

In equation (3) perturbing δ_1, δ_2 and ϕ from their nominal values δ^0, δ^0 and ϕ^0 respectively. The tie line power deviation can be obtained as

$$\therefore \Delta P_{tie12} = T_{12}(\Delta\delta_1 - \Delta\delta_2) + T_{12}\Delta\phi \tag{4}$$

It is known that $\Delta\delta_1 = 2\pi\int\Delta f_1 dt \quad and \quad \Delta\delta_2 = 2\pi\int\Delta f_2 dt$ (5)

From the equation (4) and (5) $\Delta P_{tie12} = 2\pi T_{12}\left[\int \Delta f_1 dt - \int \Delta f_2 dt\right] + T_{12}\Delta\phi$ (6)

$$\Delta P_{tie12}(s) = \frac{2\pi T_{12}}{s}\left[\Delta F_1(s) - \Delta F_2(s)\right] + T_{12}\Delta\phi(s) \tag{7}$$

It is evident from the equation (7), tie line power flow can be controlled by controlling the phase shifter angle$\Delta\phi$. The phase shifter angle $\Delta\phi(s)$ can be represented as

$$\Delta\phi(s) = \frac{k\phi}{1+sT_{ps}}\Delta Error_1(s) \tag{8}$$

where $k\phi$ is the Gain of TCPS and T_{PS} is the time constant of TCPS.

Modeling of Redox Flow Batteries

The rechargeable batteries such as redox flow which are not aged by a frequent charging and discharging have a quick response and outstanding function during overload. The batteries efficiency increased when the cycle period of charging and discharging became shorter [10-12]. In addition to leveling load, the batteries are advantageous for the secondary control of the power system and maintain a power quality of distributed power resource. The RF batteries are capable of very fast response [12] and so hunting due to a delay in response will not occur. For this reason the Area Control Error (ACE) is used as the command value for the RFB in controlling the output response in the LFC problem.

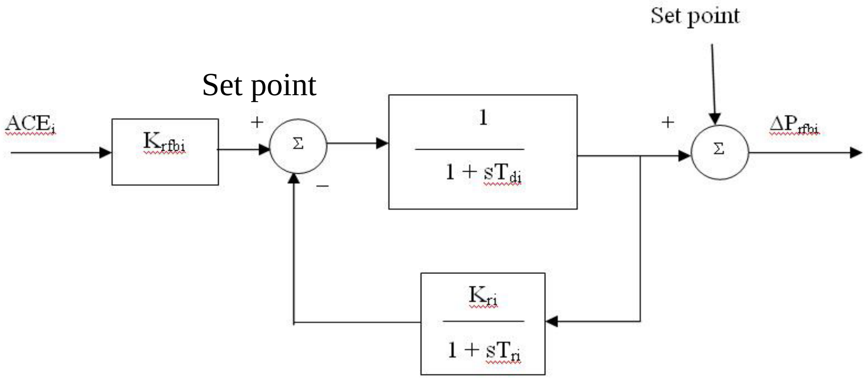

Figure 2(a): RF Battery system model.

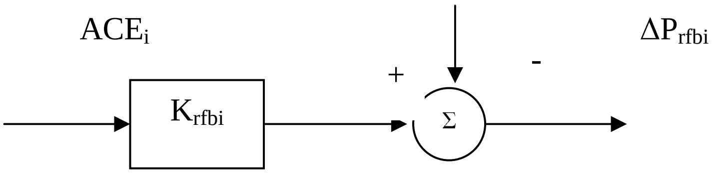

Figure 2(b): RF Battery system reduced model.

$$\Delta P_{rfbi} = \frac{K_{rfbi}}{1+sT_{di}}\Delta P_{ci} \text{ or} \tag{9}$$

$$\Delta P_{rfbi} = K_{rfbi}\Delta P_{ci} \tag{10}$$

State Space Representation

The power system model can be represented by the standard state model as shown in figure (3)

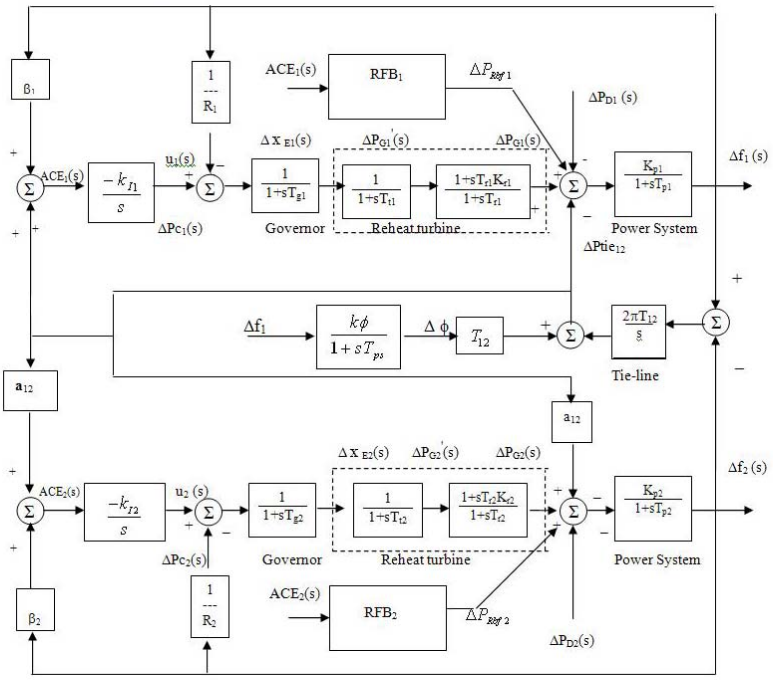

Figure 3: Block diagram of two area interconnected thermal reheat power system with RFB considering TCPS in the tie line.

The state space equations

$$\dot{x} = Ax + Bu + \Gamma d \tag{11}$$

$$y = Cx$$

where A is system matrix, B is the input distribution matrix, Γ is the disturbance distribution matrix, C is the control output distribution matrix, x is the state vector, u is the control vector and d is the disturbance vector consisting of load changes.

Mathematical Model

Case: i For a two-area interconnected thermal power system with reheat turbines

The proposed decentralized controller design is applied to interconnected two-area thermal reheat power systems. Data for the system is taken from [5] and is given in the appendix.

The state and other variables of the two-area interconnected thermal reheat power system are

$$x = \left[\Delta f_1, \Delta P_{G1}, \Delta P_{G1}{}', \Delta x_{E1}{}', \Delta P_{tie12}, \Delta f_2, \Delta P_{G2}, \Delta P_{G2}{}', \Delta x_{E2}{}'\right]^T;$$

$$u_1 = \Delta P_{c1}; u_2 = \Delta P_{c2}; d_1 = \Delta P_{D1}; d_2 = \Delta P_{D2}; v_1 = ACE_1; v_2 = ACE_2;$$

$$A_{11} = A_{22} = \begin{bmatrix} -\frac{1}{T_{p1}} & \frac{k_{p1}}{T_{p1}} & 0 & 0 & \frac{-k_{p1}}{T_{p1}} & 0 & 0 & 0 & 0 \\ 0 & \frac{-1}{T_{t1}} & \left(\frac{1}{T_{r1}} - \frac{k_{r1}}{T_{t1}}\right) & \frac{k_{r1}}{T_{t1}} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{-1}{T_{t1}} & \frac{1}{T_{t1}} & 0 & 0 & 0 & 0 & 0 \\ \frac{-1}{T_{g1} R_1} & 0 & 0 & \frac{-1}{T_{g1}} & 0 & 0 & 0 & 0 & 0 \\ 2\pi T_{12} & 0 & 0 & 0 & 0 & -2\pi T_{12} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{-a_{12} k_{p2}}{T_{p2}} & -\frac{1}{T_{p2}} & \frac{k_{p2}}{T_{p2}} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{r2}} & \left(\frac{1}{T_{r2}} - \frac{k_{r2}}{T_{t2}}\right) & \frac{k_{r2}}{T_{t2}} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{t2}} & \frac{1}{T_{t2}} \\ 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{g2} R_2} & 0 & 0 & \frac{-1}{T_{g2}} \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & 0 & 0 & \frac{-1}{T_{g1}} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{g2}} \end{bmatrix}^T \qquad \Gamma = \begin{bmatrix} \frac{-k_{p1}}{T_{p1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{-k_{p2}}{T_{p2}} & 0 & 0 & 0 \end{bmatrix}^T$$

Case ii: For a two area interconnected thermal reheat power system with RFB considering TCPS in the tie line

The proposed decentralized controller design is applied to interconnected two-area thermal reheat power systems with RFB considering TCPS in the tie-line shown in figure 3. Data for the system is taken from [5, 9, 11] and is given in the appendix.

The state and other variables of the two-area interconnected thermal power systems with RFB & TCPS are

$$x_1 = \left[\Delta f_1, \Delta P_{G1}, \Delta P_{G1}{}', \Delta x_{E1}{}', \Delta\Phi, \Delta Ptie, \Delta f_2, \Delta P_{G2}, \Delta P_{G2}{}', \Delta x_{E2}{}'\right]^T;$$

$$u_1 = \Delta P_{c1}; u_2 = \Delta P_{c2}; d_1 = \Delta P_{D1}; d_2 = \Delta P_{D2}; v_1 = ACE_1; v_2 = ACE_2;$$

$$A_{11}=A_{22}=\begin{bmatrix}
\frac{-1}{T_{P1}} & \frac{k_{p_1}}{T_{P1}} & 0 & 0 & 0 & \frac{-k_{p_1}}{T_{P1}} & 0 & 0 & 0 & 0\\
0 & \frac{-1}{T_{r1}} & \left(\frac{1}{T_{r1}}-\frac{k_{r_1}}{T_{t1}}\right) & \frac{k_{r_1}}{T_{t1}} & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & \frac{-1}{T_{t1}} & \frac{1}{T_{t1}} & 0 & 0 & 0 & 0 & 0 & 0\\
\frac{-1}{T_{g_1}R_1} & 0 & 0 & \frac{-1}{T_{g1}} & 0 & 0 & 0 & 0 & 0 & 0\\
\frac{k\phi}{T_{ps}} & 0 & 0 & 0 & \frac{-1}{T_{ps}} & 0 & 0 & 0 & 0 & 0\\
2\pi T_{12}+\frac{T_{12}K\phi}{T_{ps}} & 0 & 0 & 0 & \frac{T_{12}}{T_{ps}} & 0 & -2\pi T_{12} & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & \frac{-k_{p2}}{T_{p2}} & \frac{-1}{T_{P2}} & \frac{k_{p2}}{T_{p2}} & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{r2}} & \left(\frac{1}{T_{r2}}-\frac{k_{r2}}{T_{t2}}\right) & \frac{k_{r_2}}{T_{t2}}\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{t2}} & \frac{1}{T_{t2}}\\
0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{g_2}R_2} & 0 & 0 & \frac{-1}{T_{g2}}
\end{bmatrix}$$

$$B=\begin{bmatrix}
\frac{K_{p1}}{T_{p1}}Krfb_1 & 0 & 0 & \frac{-1}{T_{g1}} & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & \frac{k_{p2}}{T_{p2}}krfb_2 & 0 & 0 & \frac{-1}{T_{g2}}
\end{bmatrix}^T$$

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

Optimization of Integral Gain Setting Using Genetic Algorithm

The proposed design of GA based integral controller with objective of achieving minimum cost function and to ensure better transient response and gain setting. The following quadratic performance index[14] is considered to obtain the optimum decentralized controller output feedback integral gains for the interconnected two-area (identical areas) thermal reheat power system $\left(k_{1_i}=\cdots=k_{2_i}\right)$.

$$J_i = \int_0^t \left(\mathrm{x}_{ei}^T W_i \, \mathrm{x}_{ei} \right) dt \qquad i = 1, 2 \quad (12)$$

where $W_i = diag\{w_{i1}, w_{i2}\}$ and $\mathrm{x}_{ei}{}^T = [\Delta f_i, \Delta p_{ei}]$

w_{i1} and w_{i2} are weighting factors for the frequency deviation and tie–line power deviation respectively of area i.

A. General Structure of GA

The sequential steps for searching optimal solution integral gain using GA as shown in fig 4(a)

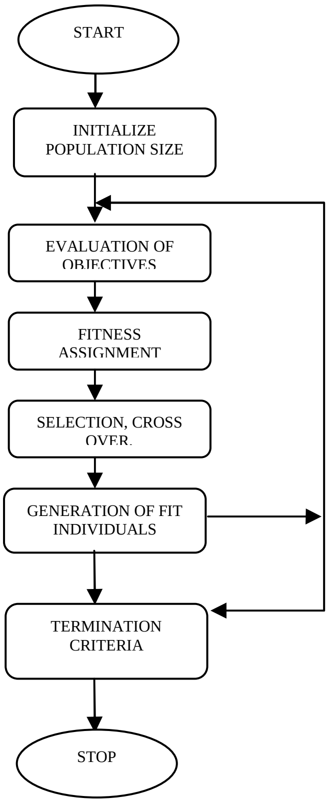

Figure 4(a): Computational Flow Chart.

B. Design Methodology

The following algorithm describes the use of GA for determining the feedback gains optimally.

(i) Randomly generate a set of possible feedback gains

(ii) Evaluate the Performance Index to ensure the zero frequency deviation and zero tie-line power deviation for a step load change in area 1.

(iii) Use selection, crossover and mutation genetic operators to develop new generation of feedback gains.

(iv) Evaluate the Performance Index in step (ii) for the new generation of feedback gains. Terminate if there is no more improvement in the value of the Performance Index or if certain predetermined number of generations has been used, otherwise go to step (iii)

The optimum integral feedback controller gain of case(i) and case(ii) at nominal condition as shown in Table 1

Simulation Results and Observations

The decentralized integral controllers using output feedback designed on the basis of GA criterion are implemented in the interconnected two-area power system with and without RFB and TCPS. The performance of these controllers is as shown in figures 5 to 7. The proposed controller is implemented in a two-area interconnected thermal reheat power system with and without RFB and TCPS for a step load disturbance of 0.01 p.u.MW in area 1 and the responses of the frequency deviations ΔF, tie-line power deviation ΔPe and the control input deviations ΔPc are obtained. For easy comparison, the responses of ΔF, ΔPe, ΔPc of the system with the optimum integral controller designed on the basis of GA for the two-area interconnected thermal reheat power system with RFB and TCPS in the tie-line is compared with the responses obtained for the two-area interconnected thermal reheat power systems.

The gain values and the cost function values of the various decentralized integral controllers for the two-area thermal reheat power system with and without RFB and TCPS are given in table 1. The settling time for the frequency deviations in area 1, area 2 and tie-line power deviation for the two case studies are tabulated.

From the tabulation, it can be found that the controller designed for two-area thermal reheat power system with RFB and TCPS have not only have less cost function but also have better stability, faster settling time and require less control effort when compared with the controller designed for the two-area thermal reheat power system without RFB and TCPS.

Moreover, the proposed controllers for the two-area thermal reheat power system with RFB and TCPS very well satisfy the classical requirements of the decentralized load-frequency control.

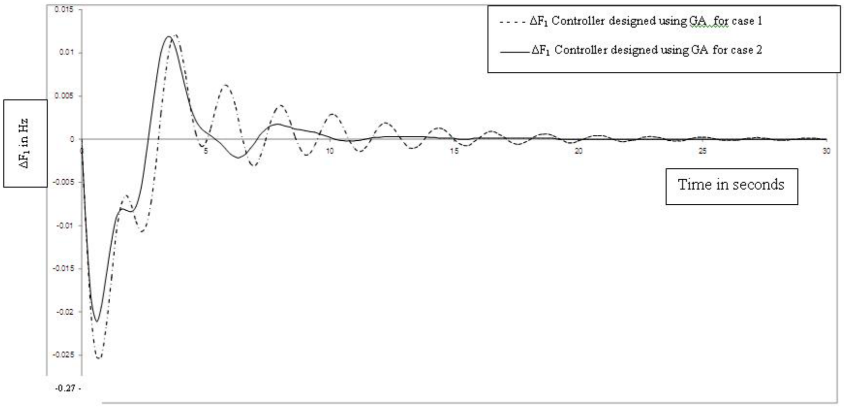

Figure 5(a): Frequency deviation in area 1 of a two area interconnected thermal reheat power systems without and with RFB and TCPS for 0.01 p.u.MW step load change in area 1

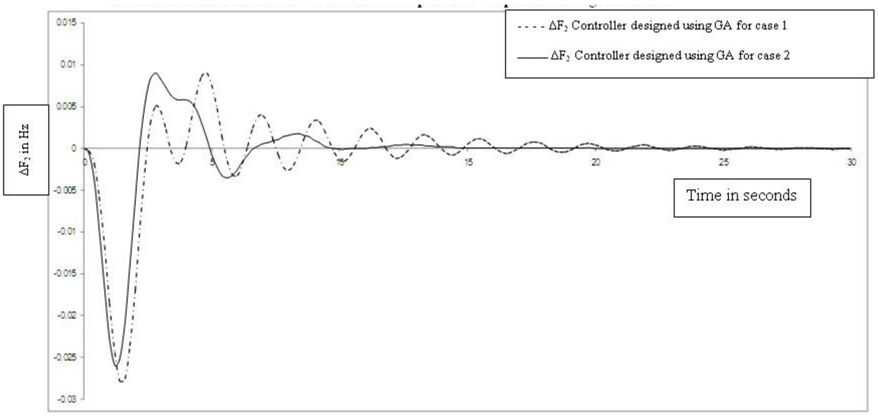

Figure 5(b): Frequency deviation in area 2 of a two area interconnected thermal reheat power systems without and with RFB and TCPS for 0.01 p.u. MW step load change in area 1.

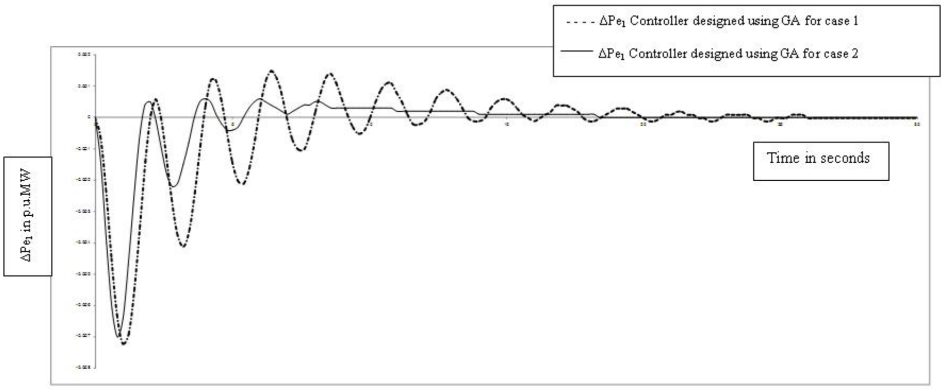

Figure 6: Tie - line power deviation of two area inter connected thermal reheat power systems without and with RFB and TCPS for 0.01 p.u.MW step load change in area 1

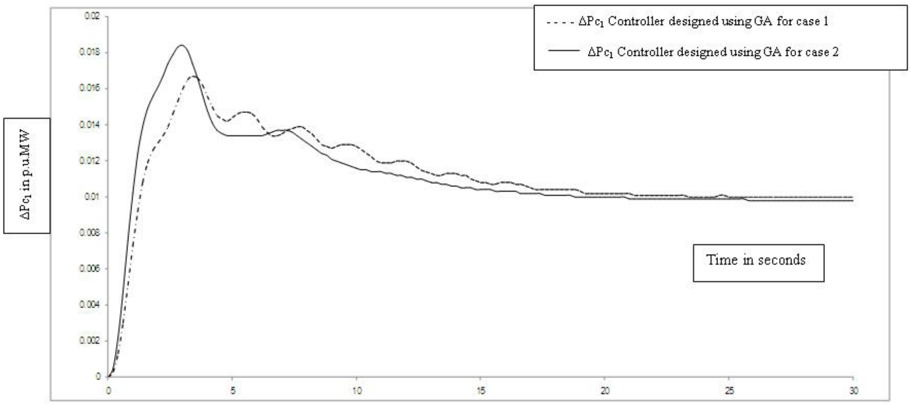

Figure 7(a): Control input deviation in area 1 of a two area interconnected thermal reheat power systems without and with RFB and TCPS for 0.01 p.u.MW step load change in area1

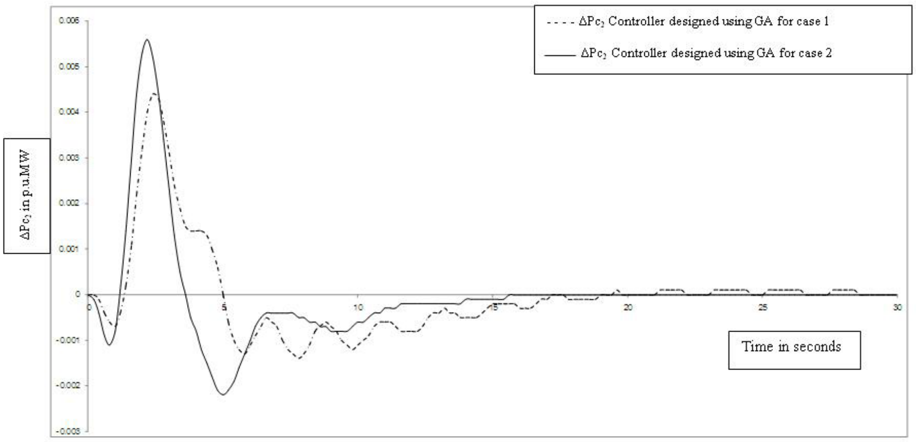

Figure 7(b): Control input deviation in area 2 of a two area interconnected thermal reheat power systems without and with RFB and TCPS for 0.01 p.u.MW step load change in area 1.

Table 1: Comparison of the system performance for the two case studies.

System under 0.01 p.u.MW step load disturbance in area 1	**Feedback gain(K_i)**	**Cost function value [J]**	**Setting time (τ_s) in seconds**		
			ΔF_1	**ΔF_2**	**ΔP_{tie}**
Case:1 Two-area interconnected thermal reheat power system	0.6400	0.1300	33.60	32.80	26.80
Case:2 Two-area interconnected thermal reheat power system with RFB & TCPS in tie-line	0.9400	0.1048	19.40	20.00	20.8

Conclusion

This paper presents a design of decentralized controllers for load-frequency control of interconnected power systems with and without RFB and TCPS in the tie-line. The main aim in introducing RFB in the interconnected power system is to enhance reduced ACE in the interconnected areas and TCPS regulates the tie line power flow. This design has been successfully applied to an interconnected two-area thermal power system with and without RFB and TCPS. The proposed controller design is found to be simple. Simulation results of the two-area thermal power system with RFB and TCPS reveal that, the output response with the proposed controller provides a high quality transient and steady state response when compared to that of the output response of the system without RFB and TCPS.

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Nomenclature

f	Area frequency in Hz
J_i	Cost function of area i
k_r	Reheat coefficient of the steam turbine
k_I	Optimum Integral feedback gain obtained using Integral Squared Error (ISE) Criterion
K_{rfbi}	Gain constant aim to ACE of the area i
ΔP_{rfbi}	Power output from RFB in area i to meet ACE
N	Number of interconnected areas
P_{ei}	The total power exchange of area i in p.u.MW / Hz
P_{Di}	Area real power load in p.u.MW
P_G	Mechanical (turbine) power output in p.u.MW
R	Steady state regulation of the governor in Hz / p.u.MW
s	Laplace frequency variable
T_p	Area time constant in seconds
T_g	Time constant of the governing mechanism in seconds
T_r	Reheat time constant of the steam turbine in seconds
T_t	Time constant of the steam turbine in seconds
X_E	Governor valve position in p.u.MW
β_i	Frequency bias constant in p.u.MW / Hz
Δ	Incremental change of a variable
$\Delta\phi$	Phase Shifter angle

Superscript

^{T} Transpose of a matrix

Subscripts i, j Area indices $(i, j = 1,2,...N)$

References

[1] Shayeghi.H, Shayanfar.H.A, Jalili.A, "Load frequency Control Strategies: A state-of-the-art survey for the researcher", Energy Conservation and Management. 2009. 50(2); 344-353

[2] Ibraheem I, Kumar P and Kothari DP, "Recent philosophies of automatic generation control strategies in power systems" IEEE Transaction on power system 2005: 20(1): 346-357.

[3] Malik OP, Ashok Kumar, Hope GS, "A load-frequency control algorithm based on a generalized approach" IEEE Transactions on Power Systems 1988:3(2):375-382.

[4] Doola.S, Bhatti.TS, "Automatic Generation Control of an isolated small hydro power plant", Electric Power System Research, 2006:76(9-10); 889-896

[5] Chidambaram IA, Velusami S, "Design of decentralized biased controllers for load-frequency control of interconnected power systems, International Journal of Electric Power Components and Systems", 2005:33(12):1313-1331.

[6] Velusami S, Chidambaram IA, "Decentralized biased dual mode controller for LFC of interconnected power systems considering GDB and GRC nonlinearities", Energy Conversion & Management. 2007:48:1691-1702.

[7] Jaleeli N, Vanslyen LS, Ewart DN, Fink LH, Hoffmann AG, "Understanding automatic generation control" IEEE Transactions on Power Systems, 1999:7:1106-1122.

[8] [8] Baker R, Guth G, Egli W, Eglin P, "Control algorithm for a static phase shifting transformer to enhance transient and dynamic stability of large power systems", IEEE Transactions on Power Apparatus and Systems 1982: 9 PAS-101(9): 3532-3542.

[9] Abraham RJ, Das D, Patra A, "AGC of a hydrothermal system with thyristor controlled phase shifter in the tie-line", IEEE Transaction on Power Systems 2006: 0-7803-9525.

[10] Sasaki T, Enomoto K, "Dynamic analysis of generation control performance standards", IEEE Transactions on Power systems 2002:17:806-811.

[11] Tokuda N, "Development of redox flow battery system", Engineering conf., CO 1998: IECEC-98-1074.

[12] Enomoto K, Sasaki T, Shigematsu T, Deguchi H, "Evaluation study about redox flow battery response and its modeling". IEEE Transaction Power Eng., 2002: 122-B(4):554-560.

[13] Abdel-Magid YL, Dawoud MM, "Optimal AGC tuning with genetic algorithms". Electric Power System Research 1996:38(3): 231-238.

[14] Ogata Katsuhiko. Modern control engineering, New Delhi, India: Prentice Hall of India Private Limited; 1986.

Biographies

I.A.Chidambaram (1966) received Bachelor of Engineering in Electrical and Electronics Engineering (1987), Master of Engineering in Power System Engineering (1992) and Ph.D in Electrical Engineering (2007) from Annamalai University, Annamalainagar. During 1988 - 1993 he was working as Lecturer in the Department of Electrical Engineering, Annamalai University and from 2007 he is working as Professor in the Department of Electrical Engineering, Annamalai University, Annamalainagar. He is a member of ISTE and ISC. His research interests are in Power Systems, Electrical Measurements and Controls. (Electrical Measurements Laboratory, Department of Electrical Engineering, Annamalai University, Annamalainagar – 608002, Tamilnadu, India, Tel: - 91-04144-238501, Fax: -91-04144-238275) **driacdm@yahoo.com**, **iaccdm@sancharnet.in**

B.Paramasivam (1976) received Bachelor of Engineering in Electrical and Electronics Engineering (2002), Master of Engineering in Power System Engineering (2006) and he is working as Senior Lecturer in the Department of Electrical Engineering, Annamalai University He is currently pursuing Ph.D in Electrical Engineering at Annamalai University, Annamalainagar. His research interests are in Control Systems, Electrical Measurements. (Electrical Measurements Laboratory, Department of Electrical Engineering, Annamalai University, Annamalainagar-608002, Tamilnadu, India,

Appendix

(A) System Data [5]

Rating of each area = 2000 MW, Base power = 2000 MVA, f^o = 60 Hz, $R_1 = R_2 = 2.4$ Hz / p.u.MW, $T_{g1} = T_{g2} = 0.08$ sec, $T_{r1} = T_{r2} = 10$ sec, $T_{t1} = T_{t2} = 0.3$ sec, $K_{p1} = K_{p2} =$ 120Hz/p.u.MW, $T_{p1} = T_{p2} = 20$ sec, $\beta_1 = \beta_2 = 0.425$ p.u.MW / Hz, $K_{r1} = K_{r2} = 0.5$, $2\pi T_{12} = 0.545$ p.u.MW / Hz, $a_{12} = -1$, $\Delta P_{D1} = 0.01$ p.u.MW

(B) TCPS and RFB data[9,11]

$T_{PS} = 0.1$sec $k\phi = 1.5 rad / Hz$, $\Phi_{max} = 10^0$, $\Phi_{min} = 10^0$, $K_{rfbi} = 1.8$, $T_{di} = 0$, $T_r = 0$, $K_r = 0$