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Design of Integral Controller for SSSC and TCPS based AGC of hydrothermal System under Deregulated Environment

K.Subbaramaiah[1], V.C Jagan Mohan[2], V.C Veera Reddy[3]

*(EEE Department, Yogananda Institute of technology and Science, Tirupathi, India)
** (Research Scholar, S.V University, Tirupathi, India
** (Department of Electrical Engineering, S.V.University, Tirupathi

ABSTRACT

This paper presents the design of integral controller for Automatic Generation Control (AGC) of hydrothermal system under deregulated environment employing simulated annealing (SA). Static Synchronous Series Compensator (SSSC) has also been proposed to further increase the dynamic performance of the system in terms of peak time, overshoot and settling time. The concept of soft computing techniques greatly helps in overcoming the disadvantages posed by the conventional controllers. Open transmission access and the evolving of more socialized companies for generation, transmission and distribution affects the formulation of AGC problem. So the traditional AGC system is modified to take into account the effect of bilateral contracts on the dynamics. Simulation results show that the simulated annealing based system employing Static Synchronous Series Compensator has better dynamic performance over the system without SSSC.

***Keywords* - Automatic Generation Control, Static Synchronous Series Compensator, Simulated annealing, Hydrothermal system**

I. INTRODUCTION

Successful operation of a power system is the process of properly maintaining several sets of balances. Two of these balances are between load-generation and scheduled and actual tie line flows. These two balances are predominant factors to keep frequency constant. Constant frequency is identified as the primary index of healthy operation of system and the quality of supplied power to consumer as well. Both of these balances are maintained by adjusting generation keeping load demand in view. If frequency is low, generation is increased and if the actual outflow is greater than the scheduled outflow, generation is decreased. Since system conditions are always changing as load constantly varies during different hours of a day, precise manual control of these balances would be impossible. Automatic Generation Control (AGC) was developed to both maintain a (nearly) constant frequency and to regulate tie line flows [1-3].

Under open market system (deregulation) the power system structure changed in such a way that would allow the evolving of more specialized industries for generation (Genco), transmission (Transco) and distribution (Disco). A detailed study on the control of generation in deregulated power systems is given in [4]. The concept of independent system operator (ISO) as an unbiased coordinator to balance reliability with economics has also emerged [5-6]. The assessment of Automatic Generation control in a deregulated environment is given in detail in [7] and also provides a detailed review over this issue and explains how an AGC system could be simulated after deregulation.

In recent years intelligent methods such as simulated annealing (SA) have been applied to various problems of electrical engineering. The salient feature of these soft computing techniques are that they provide a model-free description of control systems and do not require any model identification. SA is a search and optimization method developed by mimicking the principle of annealing of molten metals. For comparison, the considered power system is controlled by using both simulated annealing based integral controller and SSSC. The results obtained show that the system with SSSC and SA based integral controller gives good dynamic response with respect to conventional controller.

The remainder of the paper is organized as follows: Section (II) focuses on Automatic Generation Control under restructured scenario. Section (III) emphasizes on modelling and implementation of SSSC. The concept of SA applied to AGC is discussed in Section (IV) and results and discussions are carried out in Section (V).

II. DYNAMIC MATHEMATICAL MODEL

The Automatic Generation Control (AGC) system investigated is composed of an interconnection of two areas under deregulated scenario. Area 1 comprises of a reheat system and area 2 comprises of hydro system. Three generators in each area have been considered for this study. Fig. 1 is the block diagram of two-area hydrothermal system under open market scenario where ACE of each area is fed to the corresponding controller. The accurate control signal is generated for every incoming ACE at that particular load change. In order to compare the performance of both the systems a performance index has been considered and the performance index which has been considered is given by

$$J = \int_0^t \left(\alpha \cdot \Delta f_1^2 + \beta \cdot \Delta f_2^2 + \Delta P_{tie12}^2 \right)$$

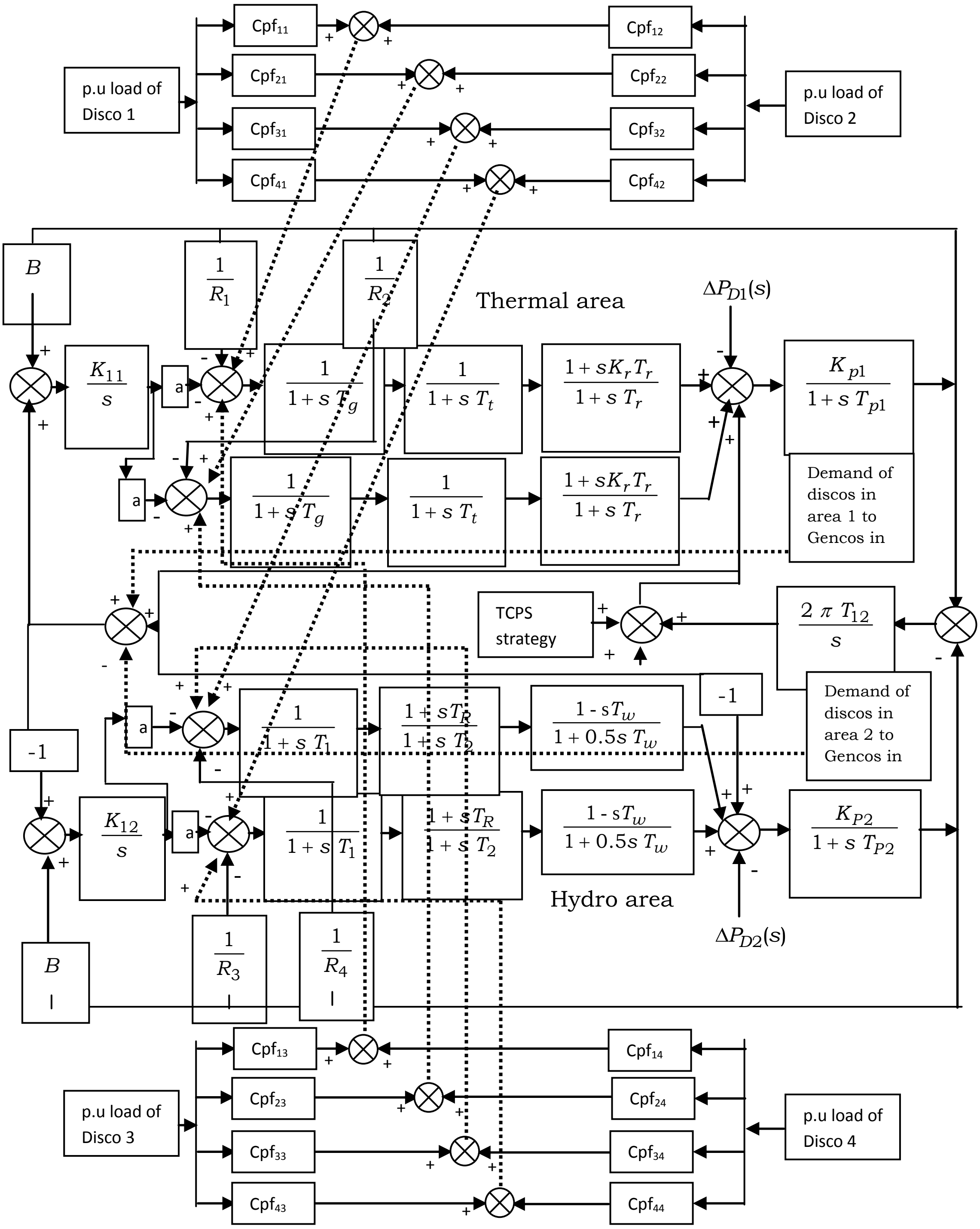

Figure. 1. Two area hydrothermal AGC block diagram under deregulated scenario

III. MODELING OF SSSC

A SSSC employs self-commutated voltage-source switching converters to synthesize a three-phase voltage in quadrature with the line current, emulates an inductive or a capacitive reactance so as to influence the power flow in the transmission lines. The compensation level can be controlled dynamically by changing the magnitude and polarity of injected voltage, V_S and the device can be operated both in capacitive and inductive mode. The schematic of an SSSC, located in series with the tie-line between the interconnected areas, can be applied to stabilize the area frequency oscillations by high speed control of the tie-line power through interconnection as shown in Figure. 2. The equivalent circuit of the system shown in Figure 2 can also be represented by a series connected voltage source V_S along with a transformer leakage reactance X_S. The SSSC controllable parameter is V_S, which in fact represents the magnitude of injected voltage. Figure 3 represents the phasor diagram of the system taking into account the operating conditions of SSSC.

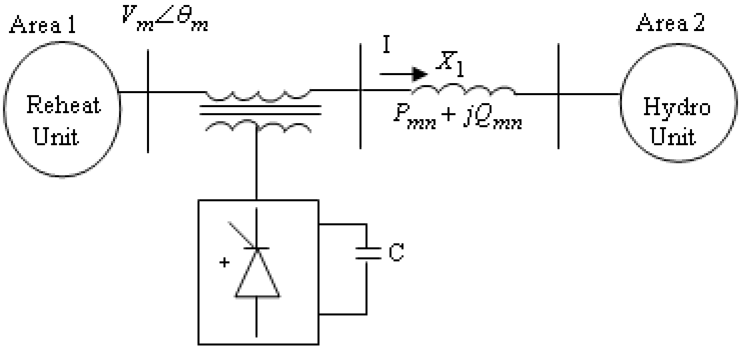

Figure 2: Schematic of SSSC applied to AGC

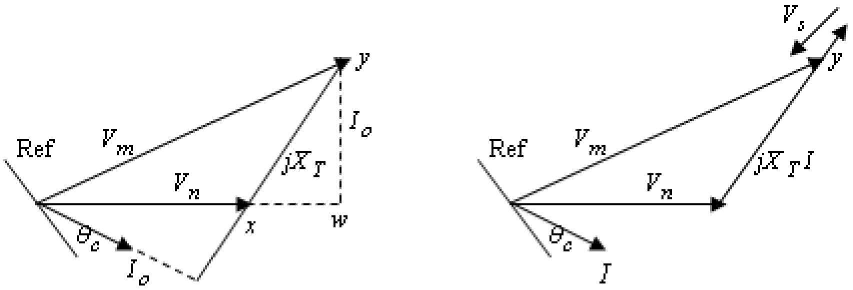

Figure 3: Phasor diagram at V_s=0 and V_s lagging I by 90°

Based on the above figure when $V_s = 0$, the current I_o of the system can be written as

$$I_o = \frac{V_m - V_n}{jX_T} \qquad (1)$$

Where $X_T = X_L + X_S$. The phase angle of the current can be expressed as

$$\theta_c = \tan^{-1}\left[\frac{V_n\cos\theta_n - V_m\cos\theta_m}{V_m\sin\theta_m - V_n\sin\theta_n}\right] \qquad (2)$$

But Eqn (1) can be expressed in a generalized form as

$$I = \frac{V_m - V_s - V_n}{jX_T} = \left[\frac{V_m - V_n}{jX_T}\right] + \left[\frac{-V_s}{jX_T}\right] = I_o + \Delta I \qquad (3)$$

The term ΔI is an additional current term due to SSSC voltage V_s. The power flow from bus m to bus n can be written as $S_{mn} = V_m I^* = S_{mno} + \Delta S_{mn}$ which implies

$$P_{mn} + jQ_{mn} = (P_{mno} + \Delta P_{mn}) + j(Q_{mno} + \Delta Q_{mn}) \quad (4)$$

Where P_{mno} and Q_{mno} are the real and reactive power flow respectively when $V_s = 0$. The change in real power flow caused by SSSC voltage is given by

$$\Delta P_{mn} = \frac{V_m V_s}{X_T}\sin(\theta_m - \alpha) \qquad (5)$$

When V_s lags the current by 90^o, ΔP_{mn} can be written as

$$\Delta P_{mn} = \frac{V_m V_s}{X_T}\cos(\theta_m - \theta_c) \qquad (6)$$

From Eqn (2) the term $\cos(\theta_m - \theta_c)$ can be written as

$$\cos(\theta_m - \theta_c) = \frac{V_n}{V_m}\cos(\theta_n - \theta_c) \qquad (7)$$

Referring to Fig 3 it can be written as

$$\cos(\theta_n - \theta_c) = \frac{yw}{xy} \qquad (8)$$

And it can be seen as $yw = V_m\sin\theta_{mn}$ (9)

Also $xy = \sqrt{V_m^2 + V_n^2 - 2V_m V_n\cos\theta_{mn}}$ and

$\theta_{mn} = \theta_m - \theta_n$ (10)

Using these relationships Eqn (6) can be modified as follows

$$\Delta P_{mn} = \frac{V_m V_n}{X_T}\sin\theta_{mn} \times \frac{V_s}{\sqrt{V_m^2 + V_n^2 - 2V_m V_n\cos\theta_{mn}}} \qquad (11)$$

From Eqn (4) it can be written as $P_{mn} = P_{mno} + \Delta P_{mn}$ which implies

$$P_{mn} = \frac{V_m V_n}{X_T}\sin\theta_{mn} + (\frac{V_m V_n}{X_T}\sin\theta_{mn} \times \frac{V_s}{\sqrt{V_m^2 + V_n^2 - 2V_m V_n \cos\theta_{mn}}}) \qquad (12)$$

Linearizing Eqn (12) about an operating point it can be written as

$$\Delta P_{mn} = \frac{V_m V_n}{X_T}\cos(\theta_m - \theta_n)(\Delta\theta_m - \Delta\theta_n) + (\frac{V_m V_n}{X_T}\sin\theta_{mn} \times \frac{\Delta V_s}{\sqrt{V_m^2 + V_n^2 - 2V_m V_n \cos\theta_{mn}}}) \qquad (13)$$

$\Delta P_{mn} = \Delta P_{tie} + \Delta P_{SSSC}$ which implies

$$\Delta P_{SSSC} = (\frac{V_m V_n}{X_T}\sin\theta_{mn} \times \frac{\Delta V_s}{\sqrt{V_m^2 + V_n^2 - 2V_m V_n \cos\theta_{mn}}}) \qquad (14)$$

Based on Eqn (14) it can be observed that by varying the SSSC voltage ΔV_s, the power output of SSSC can be controlled which will in turn control the frequency and tie line deviations. The structure of SSSC to be incorporated in the two area system in order to reduce the frequency deviations is provided in Figure 4 shown below. The frequency deviation of area 1 can be seen as input to the SSSC device.

Modelling of TCPS

Figure 5 shows the schematic of the two-area interconnected hydrothermal system considering a TCPS in series with the tie-line. TCPS is placed near area 1. Area 1 is the thermal area comprising of three reheat units and area 2 is the hydro area consisting of three hydro units. With TCPS, the incremental tie-line power flow from area 1 to area 2 under open market system can be expressed as (16)

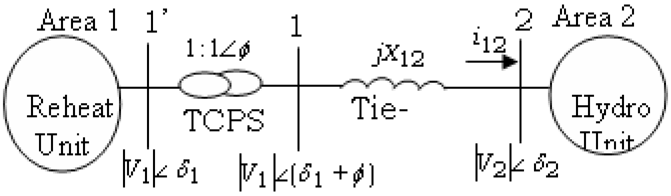

Figure.4. Schematic of TCPS in series with Tie line

The phase shifter angle $\Delta\phi$ (s) can be written as

$$\Delta\phi(s) = \frac{K_\phi}{1 + sT_{ps}}\Delta Error_1(s) \qquad (15)$$

Where K_ϕ and T_{ps} are the gain and time constants of the TCPS and $\Delta Error_1(s)$ is the control signal which controls the phase angle of the phase shifter. Thus, it can be written as

$$\Delta P_{tie12}(s) = \frac{2\pi T_{12}^{'}}{s}\left[\Delta F_1(s) - \Delta F_2(s)\right] + T_{12}^{'}\frac{K_\phi}{1 + sT_{ps}}\Delta Error_1(s) \qquad (16)$$

$\Delta Error_1$ can be any signal such as the thermal area frequency deviation Δf_1 or hydro area frequency deviation Δf_2

IV. SA APPLIED TO AGC

SA is a point by point method. The algorithm begins with an initial point, $x_t = (x_1, x_2)$ where x_1, x_2 correspond to the gains of integral controllers of both areas in Fig 1 and a high temperature, T. A second point is created in the vicinity of the initial point with the help of increment vector, Δ and the difference in the function values Δf at these two points is calculated. f the second point has a smaller function value, the point is accepted otherwise the point is accepted with a probability given by $\exp\left(\frac{-\Delta f}{T}\right)$. In order to do this a random point, r is created and checked whether $r \le \exp\left(\frac{-\Delta f}{T}\right)$. If the condition is satisfied and the termination criteria is not met, the temperature, T is lowered and the procedure continues till the termination criteria is met. The algorithm is terminated when sufficiently small temperature and small enough change in function values are obtained. In order to simulate the thermal equilibrium at every temperature, a number of iterations 'n' are tested at a particular temperature before reducing the temperature by using temperature reduction parameter.

V. RESULTS AND DISCUSSIONS

The proposed system is modeled in MATLAB/SIMULINK environment and the results have been presented. A load change of 0.04 p.u M.W in each area has been considered to study the comparison between SSSC based system with SA controller and system with conventional integral controller and without SSSC. Due to application of SA to the system, optimal values of $k_{i1} = 1.35$ and $k_{i2} = 0.267$ have been obtained. The

Discos contract with the Gencos as per the following Disco participation matrix. The Disco participation matrix (DPM) in this work is taken as follows:

$$DPM=\begin{bmatrix} 0.1 & 0.0 & 0.3 & 0.4 \\ 0.0 & 0.1 & 0.0 & 0.2 \\ 0.3 & 0.4 & 0.1 & 0.0 \\ 0.2 & 0.0 & 0.2 & 0.1 \\ 0.2 & 0.3 & 0.0 & 0.1 \\ 0.2 & 0.2 & 0.4 & 0.2 \end{bmatrix}$$

Figure 5 shows the various frequency deviations and tie line power deviations in both the areas during a load change of 0.04p.u MW. Figure 6-7 show the generations of various Gencos in both the areas. It can be observed that the system with SSSC is far superior to the system without SSSC in terms of peak time, overshoot and settling time in both the areas. Three generators in each area have been considered for the study. Each Genco participates in AGC as defined by following area participation factors (apfs):
apf_1 =0.5, apf_2 =0.25, apf_3 =0.25, apf_4 =0.5, apf_5 =0.25, apf_6 =0.25. Coefficients that distribute ACE to several Gencos are termed as “ACE participation factors” (apfs). It should be noted that $\sum_{j=1}^{m} apf_j$ =1,where m is the number of Gencos.Figure 8 shows the comparison of performance index of both the systems.

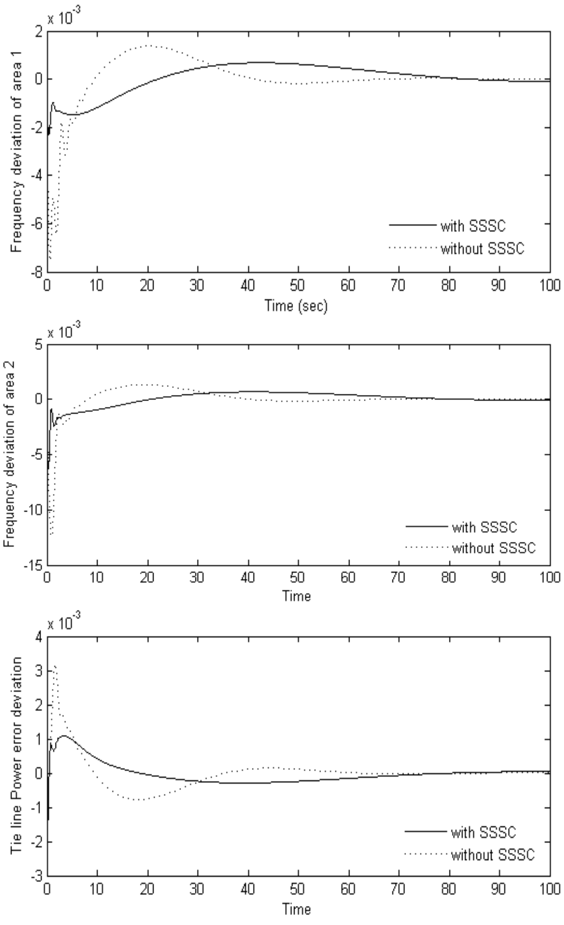

Figure 5: Frequency and tie line power deviations for both areas

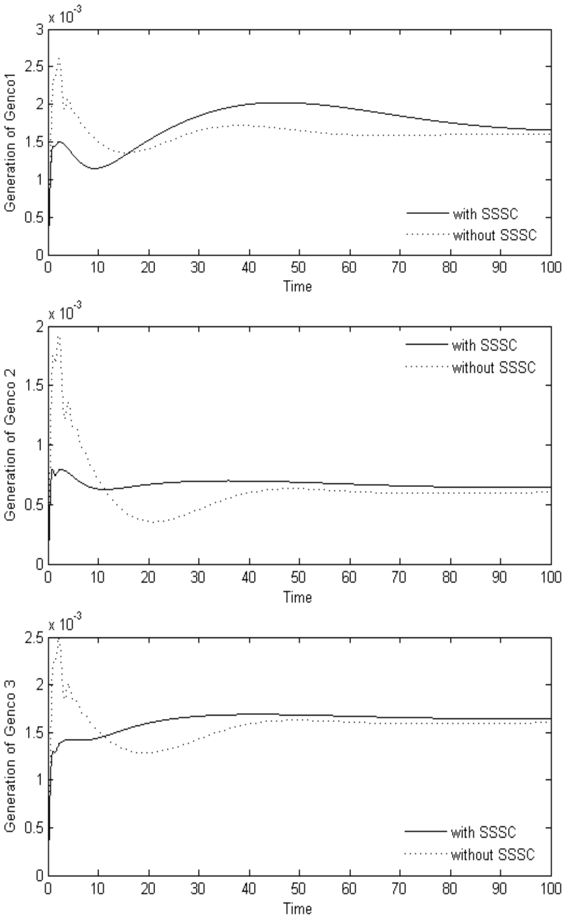

Figure 6: Generation of Gencos in area 1

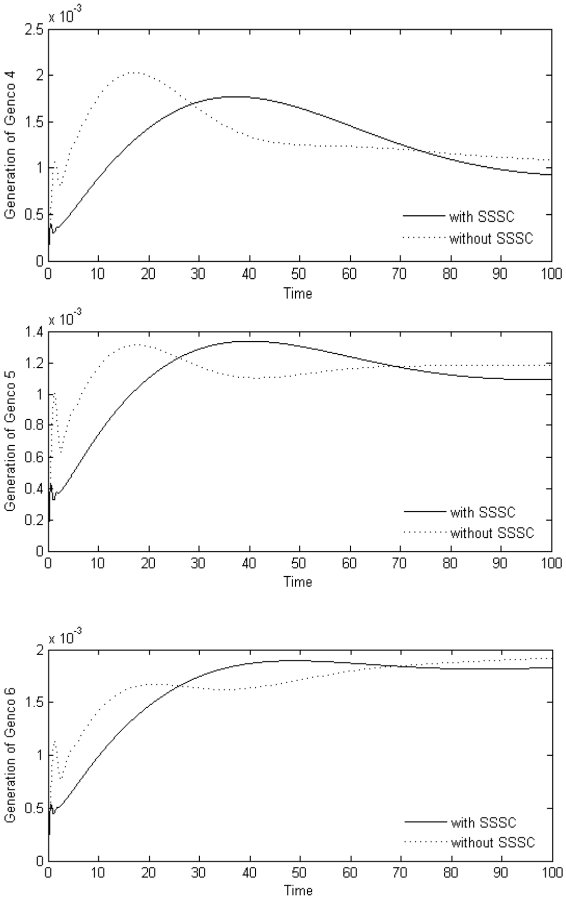

Figure 7: Generation of Gencos in area 2

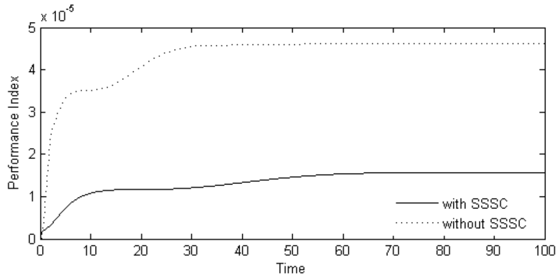

Figure 8: Comparison of performance Index

VI. CONCLUSIONS

A systematic method has been suggested for the design of a static synchronous series compensator and TCPS for a two-area hydrothermal system under deregulated scenario. This paper has also investigated the design of integral controller through Simulated Annealing technique. Effort has been made to study the performance of the system with SSSC-TCPS and integral controller tuned with the help of SA with respect to reduction of frequency deviations and tie line power deviations during a load change on a two area hydrothermal system under deregulated scenario. The simulation results indeed show that the proposed method indeed successfully mitigates the frequency and tie line power deviations during a load change and also it can be seen that the performance index of the system with SSSC-TCPS-SA based integral controller is less than the system without SSSC-TCPS-Integral controller which indicates the superiority of the proposed method.

REFERENCES

[1] C. Concordia and L.K.Kirchmayer, *Tie-Line Power and Frequency Control of Electric Power System* - Part II, *AIEE Transaction*, vol. 73, Part- 111-A, pp. 133-146, April 1954.

[2] M.L.Kothari, B.L.Kaul and J.Nanda, *Automatic Generation Control of Hydro-Thermal system*", *journal of Institute of Engineers(India)*, vo1.61, pt EL2, pp85-91, Oct 1980.

[3] J.Nanda, M.L.Kothari, P.S.Satsangi, *Automatic Generation Control of an Interconnected hydrothermal system in Continuous and Discrete modes considering Generation Rate Constraints*, *IEE Proc*., vol. 130, pt D, No.*1*, pp 455- 460, Jan. 1983

[4] Robert P. Schulte, "Automatic generation Control modification for present demands on interconnected power systems", *IEEE Trans. On Power Systems,* August 1996,pp. 1286- 1291.

[5] Jayant Kumar, Kah-Koeng and Gerald Sheble, "AGC simulator for price based operation Part1", IEEE *Transactions on Power Systems, vol.12,no.2,* May 1997,pp. 527-532.

[6] Jayant Kumar, Kah-Hoeng and Gerald Sheble, "AGC simulator for price based operation part- 2", *IEEE Transactions on Power Systems, Vol.12, no. 2,* May1997, pp 533-538.

[7] Bjorn H.Bakken and OvesGrande, "Automatic generation control in a deregulated environment", *IEEE Transactions on Power Systems, vol.13, no.4,* Nov1998,pp. 1401-1406.

[8] David Goldberg. *Genetic algorithms in search, optimization and machine learning*. Addison-Wesley, 1989.

[9] J. H. Holland. *Adaptation in nature and artificial systems.* Michigan, 1975.

[10] Dynamic Models for steam and Hydro Turbines in Power system studies, *IEEE committee report. Transactions in Power Apparatus & Systems,* Vol.92, No.6,pp.1904-915,Nov./Dec.1973.