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Comparison of Performance of SSSC and TCPS in Automatic Generation Control of Hydrothermal System under Deregulated Scenario

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Abstract

This paper presents the modelling and simulation of Static Synchronous Series Compensator (SSSC) in a two area system for Automatic Generation Control (AGC) under deregulated environment. The modelling of Thyristor Controlled phase Shifter (TCPS) is also carried out and comparison is made between SSSC and TCPS. A two area hydrothermal system under deregulated environment has been considered for this purpose. The devices are modeled and attempt has been made to incorporate these devices in the two area system thus improving the dynamic response of the system. The effect of these parameters on the system is demonstrated with the help of computer simulations. A systematic method has also been demonstrated for the modeling of this component in the system. Computer simulations reveal that due to the presence of SSSC along with TCPS, the dynamic performance of the system in terms of settling time, overshoot is greatly improved than that of without SSSC.

***Keywords**: Static Synchronous Series Compensator, Thyristor Controlled phase Shifter, hydrothermal system, AGC*

1. 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 [1-2].

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 [3]. The concept of independent system operator (ISO) as an unbiased coordinator to balance reliability with economics has also emerged [4-5]. The assessment of Automatic Generation control in a deregulated environment is given in detail in [6] and also provides a detailed review over this issue and explains how an AGC system could be simulated after deregulation.

On the other hand, the concept of utilizing power electronic devices for power system control has been widely accepted in the form of Flexible AC Transmission Systems (FACTS) which provide more flexibility in power system operation and control [7,8]. A Static Synchronous Series Capacitor is expected to be an effective apparatus for the tie-line power flow control of an interconnected power system in the analysis of an interconnected power system. The proposed control strategy will be a new ancillary service for the stabilization of frequency oscillations of an interconnected power system. Static Synchronous Series Compensator is one of the important members of FACTS family which can be installed in series with the transmission lines. With the capability to change its reactance characteristic from capacitive to inductive, the SSSC is very effective in controlling power flow.

This paper addresses the AGC with interconnected systems along with the incorporation of FACTS devices. The transient performance of these systems are compared to establish their effectiveness one over another to suppress the area frequency oscillation and tie-line power exchange after the step load perturbation. In the view of the above, the objectives of the paper are as follow:

- To model a hydrothermal system under deregulated scenario
- To investigate the impacts of devices like Static Synchronous Series Capacitor and Thyristor controlled phase shifter

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2. Dynamic Mathematical Model

The Automatic Generation Control 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. Fig. 1 is the block diagram of two-area hydrothermal system under deregulated 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. A performance index given by $J = \int_0^t \left(\alpha \cdot \Delta f_1^{\,2} + \beta \cdot \Delta f_2^{\,2} + \Delta P_{tie12}^2\right)$ has been considered to compare the performance of SSSC and TCPS.

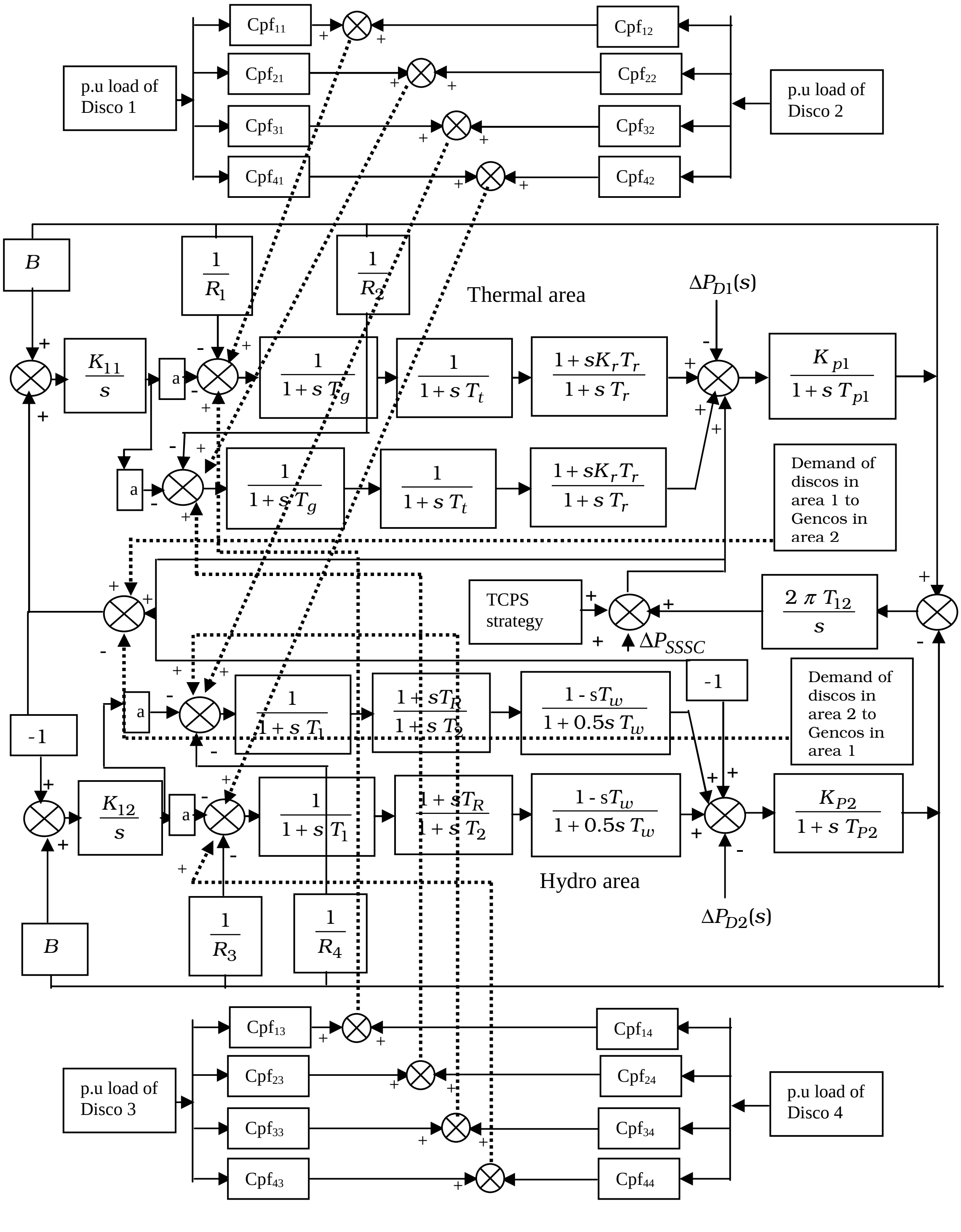

Figure1. Two area hydrothermal system under deregulated scenario

3. Modeling of SSSC and TCPS

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.

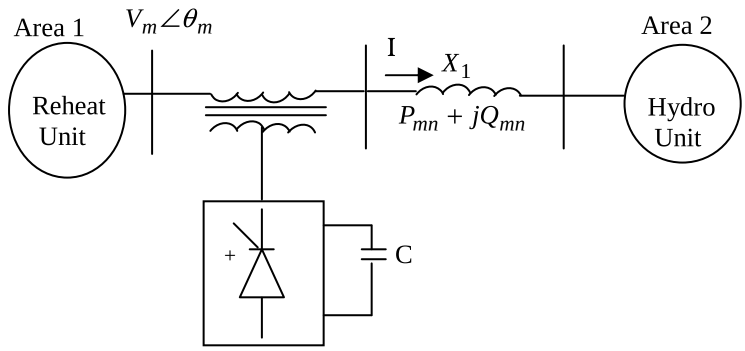

Figure 2. Schematic of SSSC applied to AGC

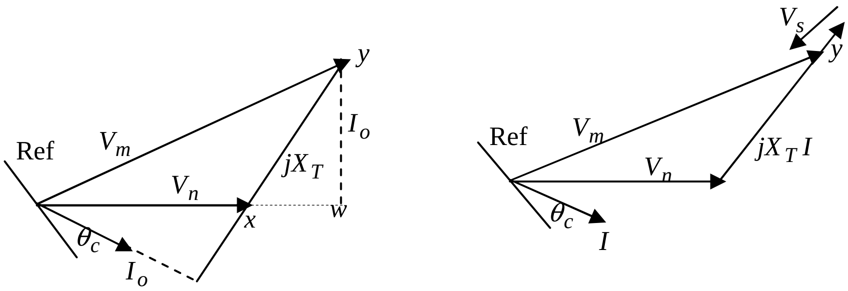

Figure 3. Phasor diagram atV_s=0 and V_s lagging I by 90^o

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

$$I_o = \frac{V_m - V_n}{jX_T} \tag{1}$$

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

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

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

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

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

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

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

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

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

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

Referring to Fig 3 it can be written as

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

and it can be seen as

$$yw = V_m \sin\theta_{mn} \quad (9)$$

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

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

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

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

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

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

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

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

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.

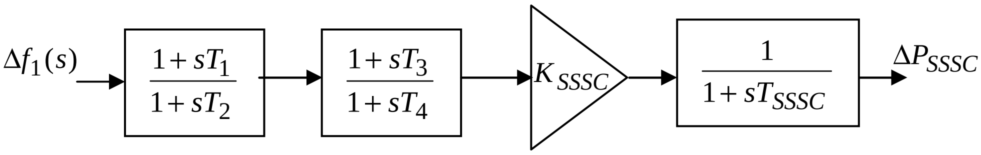

Figure 4: Structure of SSSC

Modeling 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]

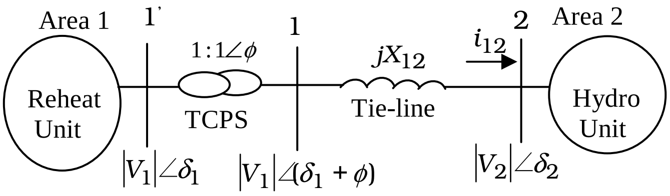

Figure.5. Schematic of TCPS in series with Tie line

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

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

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

$$\Delta P_{tie12}(s) = \frac{2\pi T'_{12}}{s}\left[\Delta F_1(s) - \Delta F_2(s)\right] + T'_{12}\frac{K_\phi}{1+sT_{ps}}\Delta Error_1(s) \tag{16}$$

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

4. Results and Discussions

The proposed techniques are applied to a two area hydrothermal system under deregulated scenario. The simulation has been conducted Simulink in MATLAB 7.1 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). 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:

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

A step load disturbance of 0.04 pu MW is considered in either of the areas(fig 6-8). Also an additional case is also considered when contract violation occurs in either area. So in this contact violation an additional load of 0.03 pu MW is considered in both the areas after the time span of 30 sec and 75 sec (fig 9-11). In this contract violation the Gencos which are present in that particular area where the violation has taken place indeed take up that extra load while the remaining generators of other area generate the power which they had been generating before. Fig 12 shows the comparison of performance index of he system during the normal case. Table 1 shows the comparison of dynamic performance of the system with SSSC and TCPS and without SSSC. Table 2 shows the performance index of the system during the normal case. It can be observed from the tables that the system with SSSC and TCPS has better dynamic performance over the system without SSSC.

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Table1. Comparison of system performance with and without SSSC

	Thermal Area			Hydro Area		
	Peak Time (sec)	Overshoot (Hz)	Settling Time (sec)	Peak Time (sec)	Overshoot (Hz)	Settling Time (sec)
With TCPS	0.575	0.0079368	3.995	0.765	0.01107	3.67
With SSSC and TCPS	0.375	0.00233921	0.615	0.31	0.0062918	1.815
% Improvement	34.78	70.52	84.60	59.47	43.16	50.54

Where % Improvement is given by

$$\left(\frac{\left(\left|corresponding\ \ parameter\ in\ with\ TCPS\right|-\left|corresponding\ \ parameter\ in\ with\ SSSC\right|\right)}{\left|Corresponding\ \ parameter\ in\ withTCPS\right|}\right)\times 100$$

Table 2: Comparison of Performance Index Values

	Performance Index Value
With SSSC and TCPS	1.435×10^{-5}
With TCPS	3.742×10^{-5}

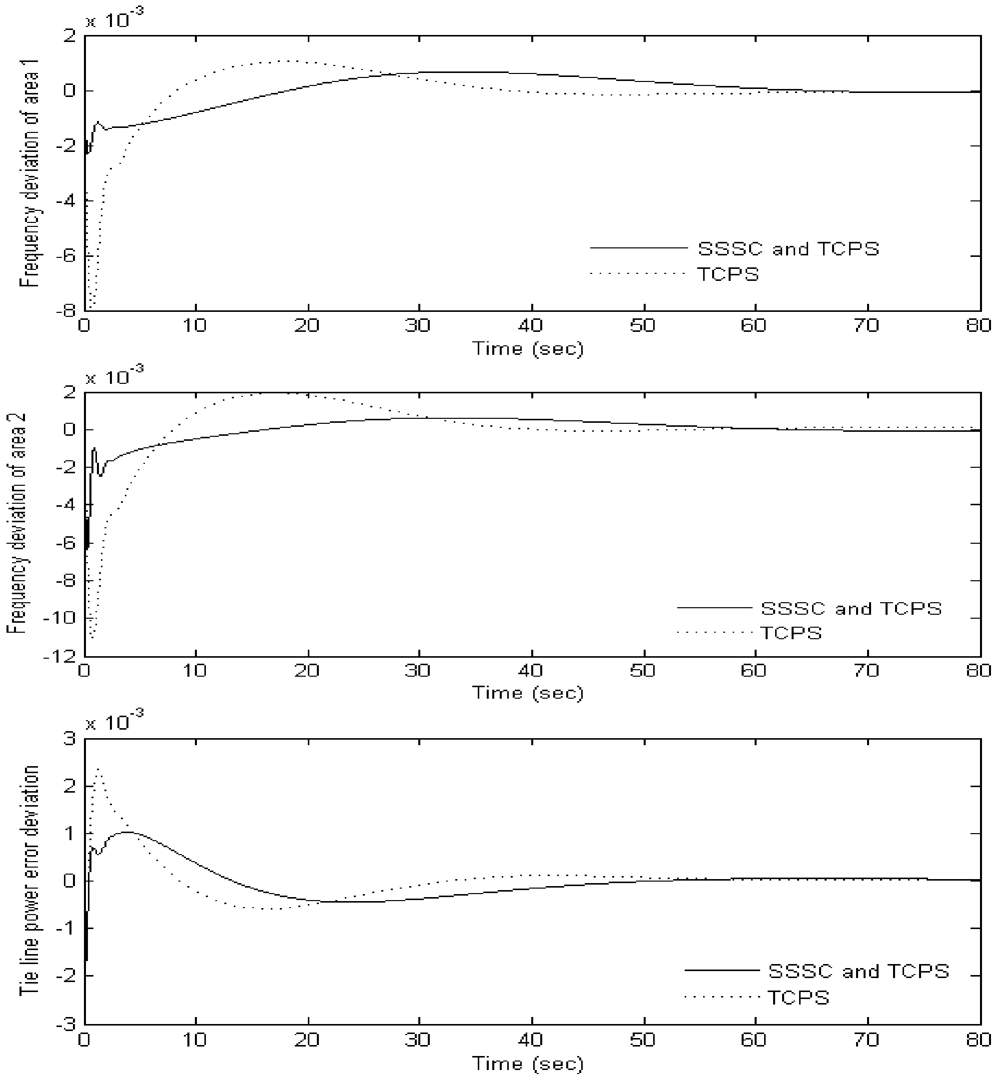

Figure 6**.** Frequency and tie line power deviations during normal case

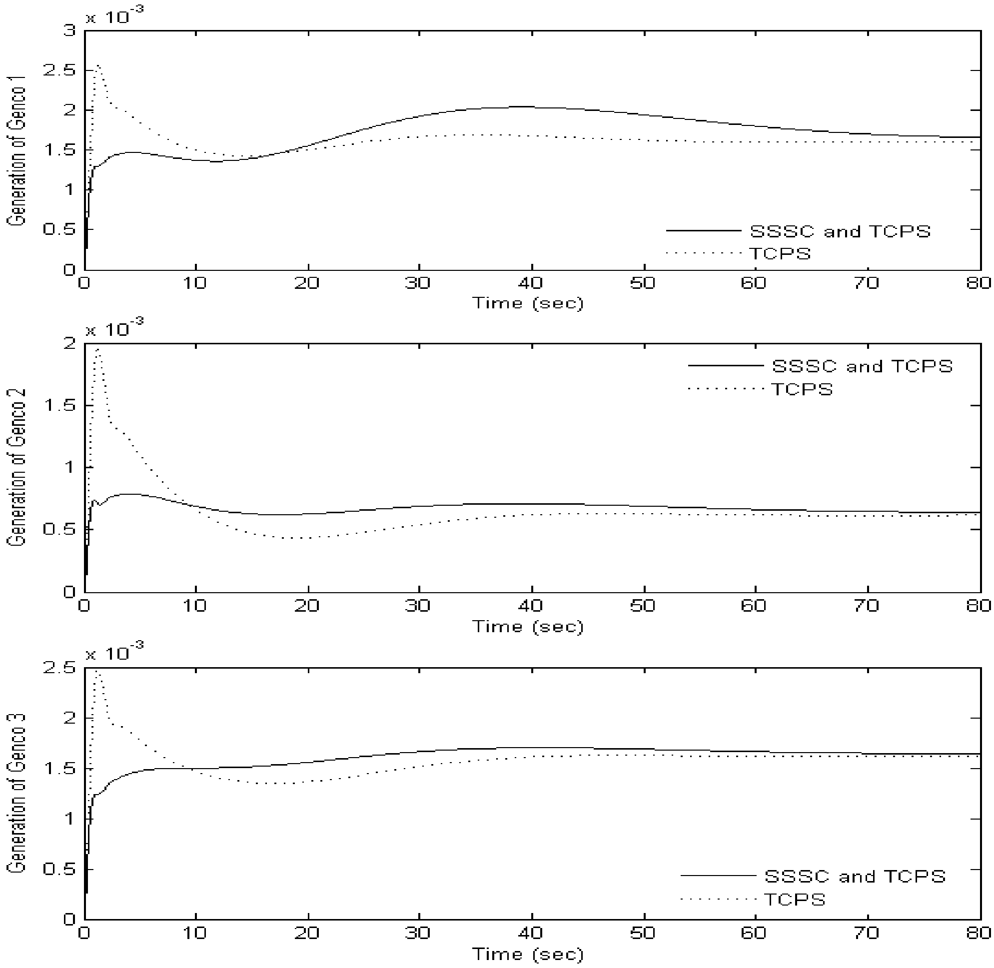

Figure 7. Generation of Gencos in area 1

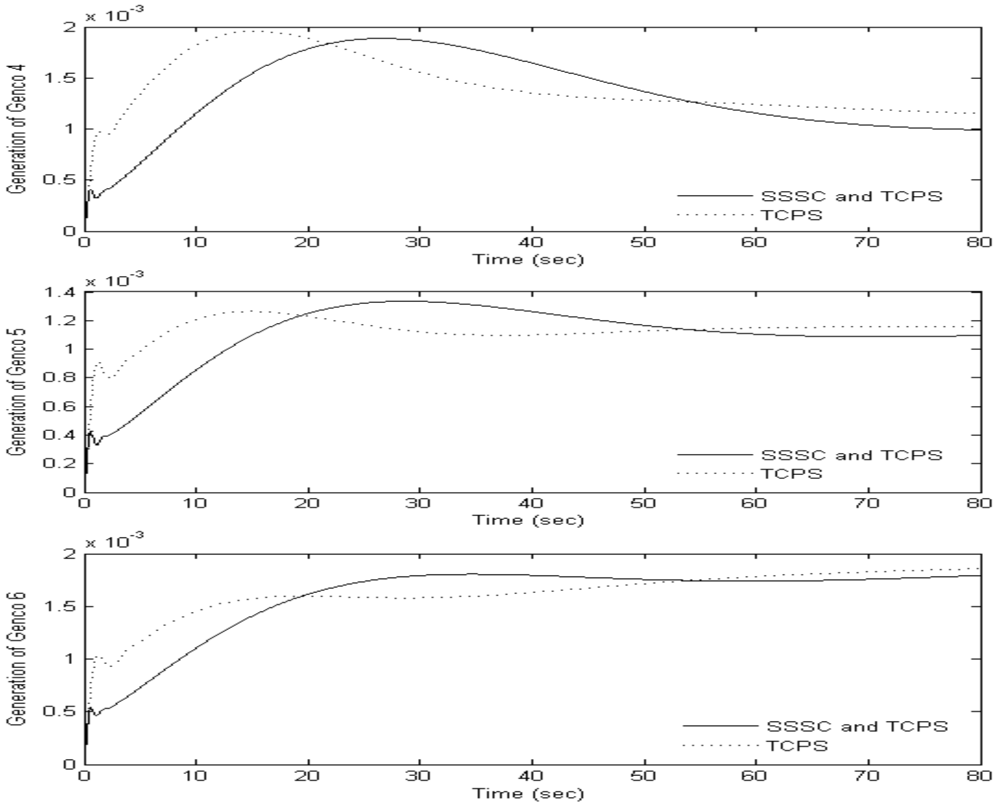

Figure 8.: Generation of Gencos in area 2

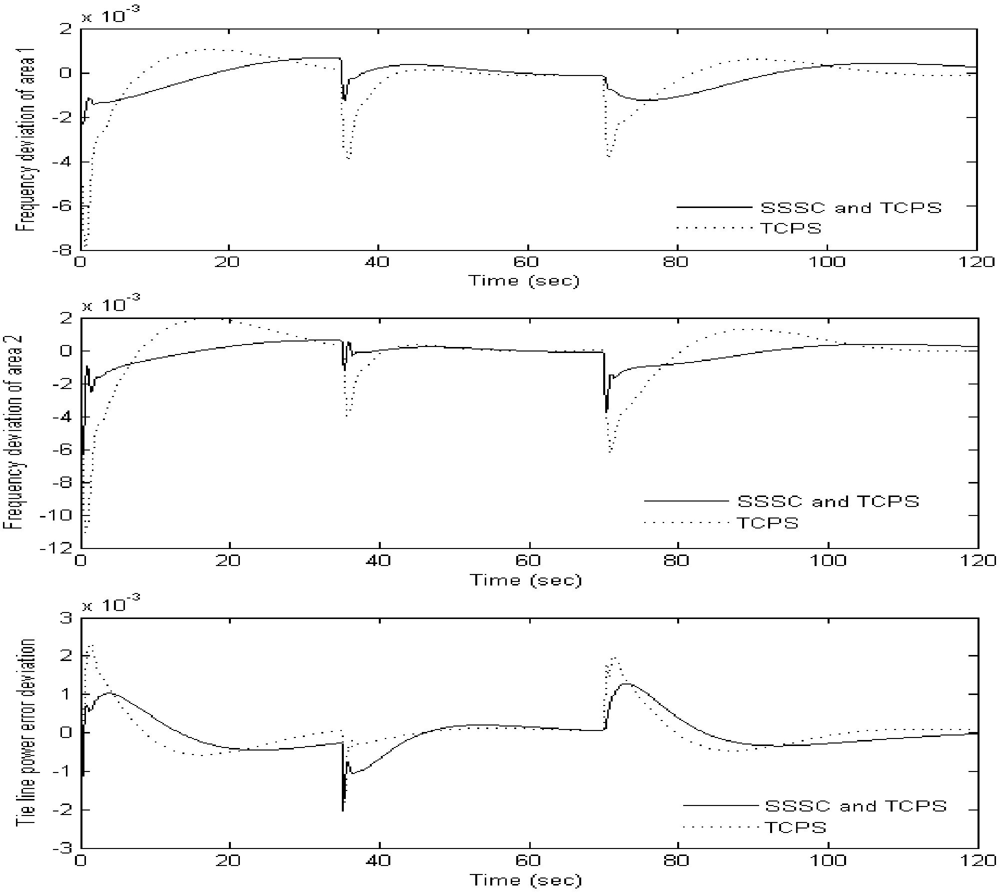

Figure 9. Frequency and tie line power deviations during contract violation case

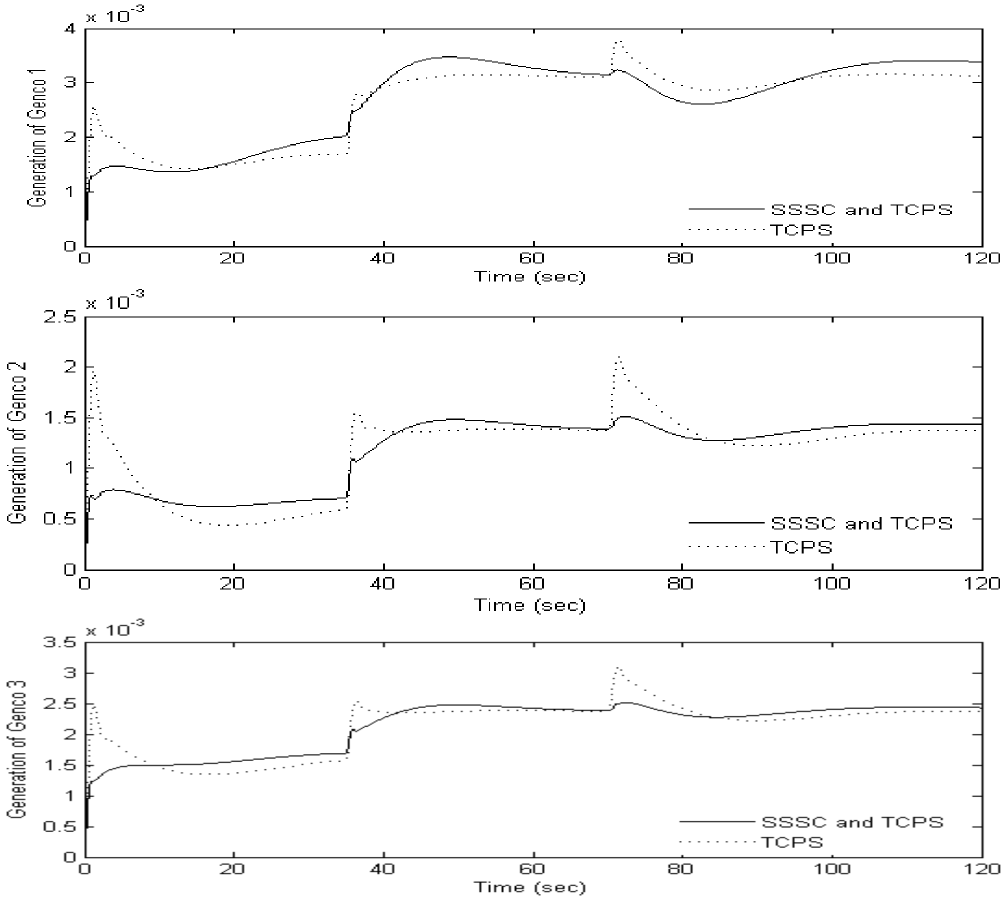

Figure 10. Generation of Gencos in area 1during contract violation case

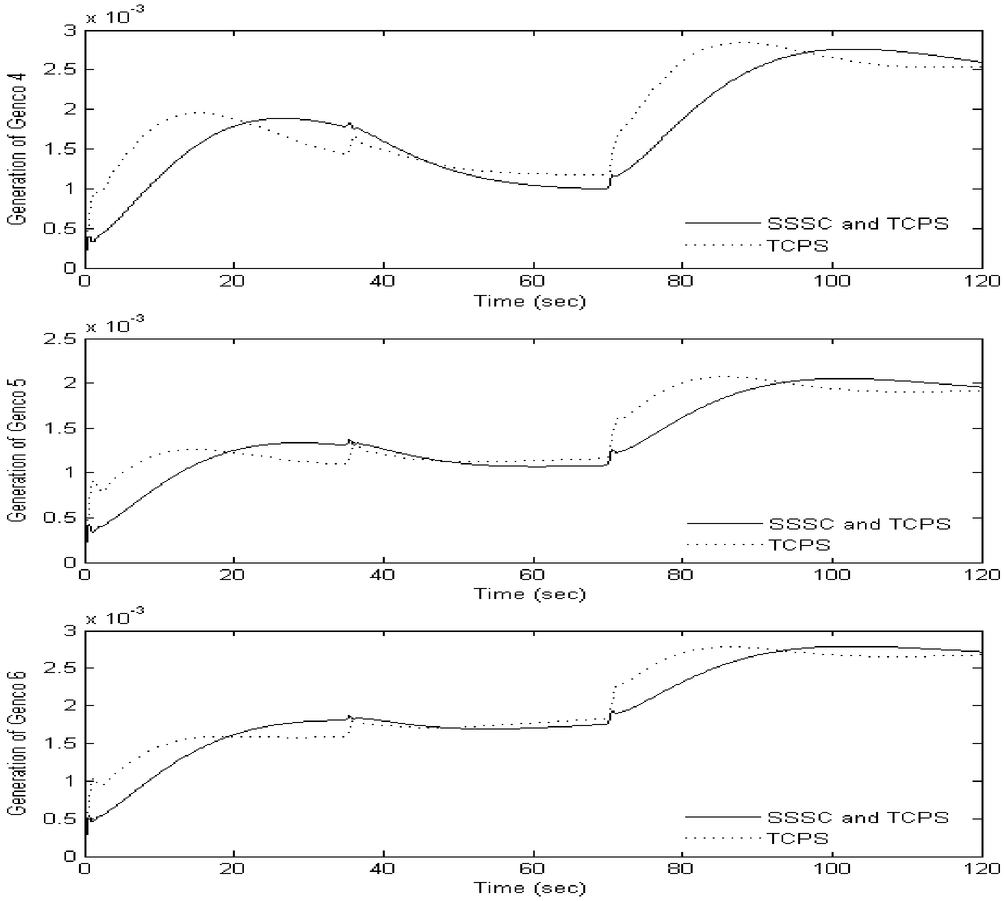

Figure 11. Generation of Gencos in area 2 during contract violation case

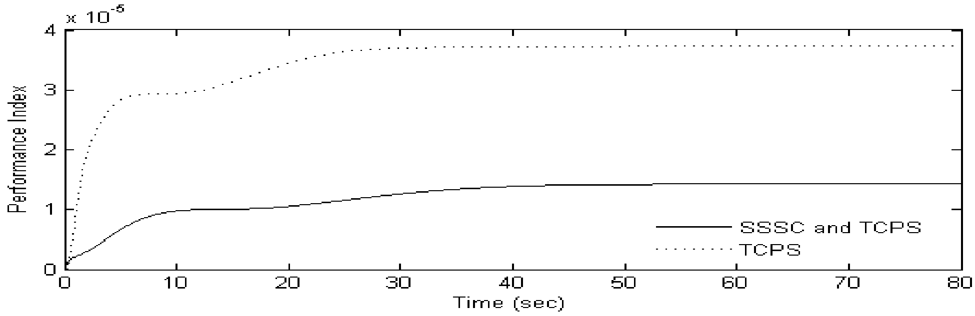

Figure 12.: Comparison of performance Index

5. Conclusions

A systematic method has been suggested for the design of a static synchronous series compensator for a two-equal-area hydrothermal system under deregulated scenario. This paper has also investigated the performance of the system with SSSC and with TCPS with respect to reduction of frequency deviations and tie line power deviations during a load change on a two area hydrothermal system. 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 is less than the system without SSSC which indicates the superiority of the proposed method.

Appendix

All the notations carry the usual meanings

(a) System data

T_{p1}, T_{p2} = 20s; K_{p1}, K_{p2} = 120 Hz/p.u.Mw; P_{r1}, P_{r2} = 1200 Mw; T_t = 0.3s; T_g = 0.08s, T_w = 1s; $T_r = 5s$, $T_1 = 41.6s$,

T_2 =0.513s; R_1, R_2 = 2.4Hz/pu Mw; T_{12} = 0.0866s; B_1, B_2 = 0.4249p.u Mw/Hz;

$T_1 = 0.279; T_2 = 0.026;\ T_3 = 0.411;\ T_4 = 0.1; K_{SSSC} = 0.1808; T_{SSSC} = 0.0386$

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