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Improvement of Dynamic Performance of AGC of Hydrothermal System Employing Capacitive Energy Storage and TCPS

C.Srinivasa Rao (Corresponding author)
EEE Department, G.Pullaiah College of Engineering and Technology
Nandikotkur Road, Kurnool, Andhra Pradesh, India
Tel: 91+9849627163 E-mail: csr_bit@yahoo.co.in

Abstract

This paper presents the analysis of Automatic generation control (AGC) of a two-area hydrothermal system under traditional scenario by considering the effect of Capacitive Energy Storage (CES) and Thyristor Controlled Phase Shifter (TCPS). The Combined 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 these components in the system. Computer simulations reveal that due to the presence of both TCPS and CES the dynamic performance of the system in terms of settling time, overshoot and peak time is greatly improved.

Keywords: Automatic Generation control, CES, TCPS, hydrothermal system

1. Introduction

Large scale power systems are normally composed of control areas or regions representing coherent groups of generators. In a practically interconnected power system, the generation normally comprises of a mix of thermal, hydro, nuclear and gas power generation. However, owing to their high efficiency, nuclear plants are usually kept at base load close to their maximum output with no participation in the system AGC. Gas power generation is ideal for meeting the varying load demand. Gas plants are used to meet peak demands only. Thus the natural choice for AGC falls on either thermal or hydro units. Literature survey shows that most of earlier works in the area of AGC pertain to interconnected thermal systems and relatively lesser attention has been devoted to the AGC of interconnected hydro-thermal system involving thermal and hydro subsystem of widely different characteristics. Concordia and Kirchmayer [1] have studied the AGC of a hydro-thermal system considering non-reheat type thermal system neglecting generation rate constraints. Kothari, Kaul, Nanda [2] have investigated the AGC problem of a hydro-thermal system provided with integral type supplementary controllers. The model uses continuous mode strategy, where both system and controllers are assumed to work in the continuous mode. Perhaps Nanda, Kothari and Satsangi [3] are the first to present comprehensive analysis of AGC of an interconnected hydrothermal system in continuous-discrete mode with classical controllers.

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 [4]. A Thyristor Controlled Phase Shifter (TCPS) 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. Literature survey shows ample applications of TCPS for the improvement of dynamic and transient stabilities of power systems.

The addition of a small capacity CES unit to the system significantly improves the transient performance and the frequency and tie-line power oscillations are practically damped out. Tripathy et al. [5] has shown the improvement of the transient responses of a wind-diesel power system when capacitive energy storage is included.

In view of this the main objectives of the present work are:

1. To develop the two area simulink model of hydrothermal system
2. To develop the model of TCPS and CES
3. To study the improvement of dynamic performance of the system through TCPS and CES

2. Dynamic Mathematical Model

Electric power systems are complex, nonlinear dynamic system. The load frequency controller controls the control valves associated with High Pressure (HP) turbine at very small load variations [6]. The system under investigation has tandem-compound single reheat type thermal system. Each element (Governor, turbine and power system) of the system is represented by first order transfer function at small load variations in according to the IEEE committee report [6]. Two system nonlinearities likely Governor Deadband and Generation Rate Constraint (GRC) are considered here for getting the realistic response. Governor Deadband is defined as the total magnitude of the sustained speed change within which there is no change in the valve position [6]. It is required to avoid excessive operation of the governor. GRC is considered in real power systems because there exits a maximum limit on the rate of change in the generating power. Figure 1 shows the transfer function block diagram of a two area interconnected network .The parameters of two area model are defined in Appendix.

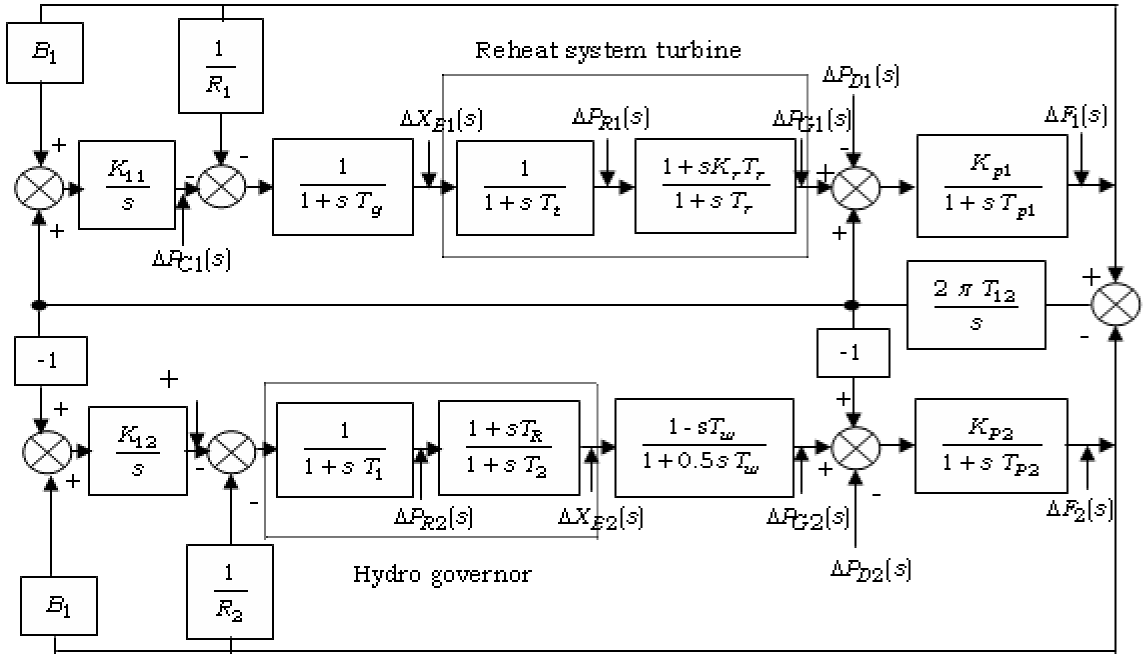

Figure 1. Two Area hydrothermal system.

3. Tie line Power flow with TCPS

The recent advances in power electronics have led to the development of the Flexible Alternating Current Transmission Systems (FACTS). FACTS devices are designed to overcome the limitations of the present mechanically controlled power systems and enhance power system stability by using reliable and high-speed electronic devices. One of the promising FACTS devices is the Thyristor Controlled Phase Shifter (TCPS). A TCPS is a device that 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. In this study, a two-area hydrothermal power system interconnected by a tie line is considered.

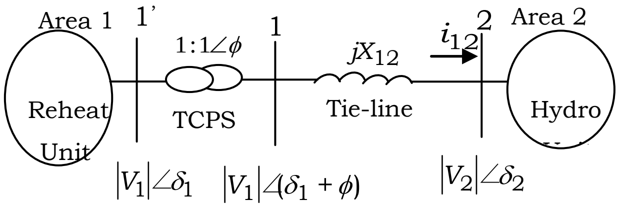

Figure 2. TCPS in series with Tie line .

Without TCPS, the incremental tie-line power flow from Area 1 to Area 2 in a traditional system can be expressed as

$$\Delta P_{tie12}(s) = \frac{2\pi T_{12}}{s}(\Delta F_1(s) - \Delta F_2(s)) \qquad (1)$$

Where T_{12} is the synchronising constant without TCPS. When a TCPS is placed in series with the tie line as in Fig 2, current flowing from Area 1 to Area 2 is

$$i_{12} = \frac{|V_1|\angle(\delta_1 + \phi) - |V_2|\angle\delta_2}{jX_{12}} \qquad (2)$$

$$P_{tie12} - jQ_{tie12} = |V_1|\angle - (\delta_1 + \phi)\left(\frac{|V_1|\angle(\delta_1 + \phi) - |V_2|\angle\delta_2}{jX_{12}}\right) \qquad (3)$$

Separating the real part of Eqn. (3)

$$P_{tie12} = \frac{|V_1||V_2|}{X_{12}}\sin(\delta_1 - \delta_2 + \phi) \qquad (4)$$

But in Eqn. (4) perturbing δ_1, δ_2 and ϕ from their nominal values δ_1^o, δ_2^o and ϕ^o respectively

$$\Delta P_{tie12} = \frac{|V_1||V_2|}{X_{12}}\cos(\delta_1^o - \delta_2^o + \phi^o)\sin(\Delta\delta_1 - \Delta\delta_2 + \Delta\phi) \qquad (5)$$

But for a small change in real power load, the variation of bus voltage angles and also the variation of TCPS phase angle are very small. As a result ($\Delta\delta_1 - \Delta\delta_2 + \Delta\phi$) is very small and hence, sin($\Delta\delta_1 - \Delta\delta_2 + \Delta\phi) \approx (\Delta\delta_1 - \Delta\delta_2 + \Delta\phi)$. So Eqn. (5) can be written as

$$\Delta P_{tie12} \approx \frac{|V_1||V_2|}{X_{12}}\cos(\delta_1^o - \delta_2^o + \phi^o)(\Delta\delta_1 - \Delta\delta_2 + \Delta\phi) \qquad (6)$$

$$\Delta P_{tie12} = T'_{12}(\Delta\delta_1 - \Delta\delta_2 + \Delta\phi) \qquad (7)$$

Where $$T'_{12} = \frac{|V_1||V_2|}{X_{12}}\cos(\delta_1^o - \delta_2^o + \phi^o) \qquad (8)$$

$$\therefore \quad \Delta P_{tie12} = T'_{12}(\Delta\delta_1 - \Delta\delta_2) + T'_{12}\Delta\phi \qquad (9)$$

But $\Delta\delta_1 = 2\pi\int\Delta f_1 dt$ and $\Delta\delta_2 = 2\pi\int\Delta f_2 dt$ (10)

Eqn. (9) can be modified as

$$\Delta P_{tie12} = 2\pi T'_{12}(\int\Delta f_1 dt - \int\Delta f_2 dt) + T'_{12}\Delta\phi \qquad (11)$$

The Laplace transform of Eqn. (11) is

$$\Delta P_{tie12}(s) = \frac{2\pi T'_{12}}{s}\left[\Delta F_1(s) - \Delta F_2(s)\right] + T'_{12}\Delta\phi(s) \qquad (12)$$

As per Eqn. (12), it can be observed that the tie-line power flow can be controlled by controlling the phase shifter angle $\Delta\phi$. Assuming that the control input signal to the TCPS damping controller is $\Delta Error_1(s)$ and that the transfer function of the signaling conditioning circuit is $K_\phi C(s)$, where K_ϕ is the gain of the TCPS controller

$$\Delta\phi(s) = K_\phi C(s)\Delta Error_1(s) \qquad (13)$$

And $$C(s) = \frac{1}{1 + sT_{ps}} \qquad (14)$$

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, Eqn. (12) can be rewritten as

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

A. Logic of TCPS Control Strategy

$\Delta Error_1$ can be any signal such as the thermal area frequency deviation Δf_1 or hydro area frequency deviation Δf_2 or ACE of the thermal or hydro area to the TCPS unit to control the TCPS phase shifter angle which in turn controls the tie-line power flow. Thus, with $\Delta Error_1 = \Delta f_1$, Eqn (13) can be written as

$$\Delta\phi(s) = \frac{K_\phi}{1 + sT_{ps}}\Delta F_1(s) \qquad (17)$$

The above logic can be demonstrated as follows

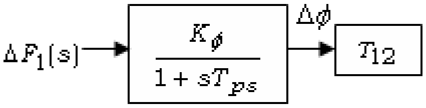

Figure. 3 Logic of TCPS in series with tie line

4. Capacitive Energy Storage

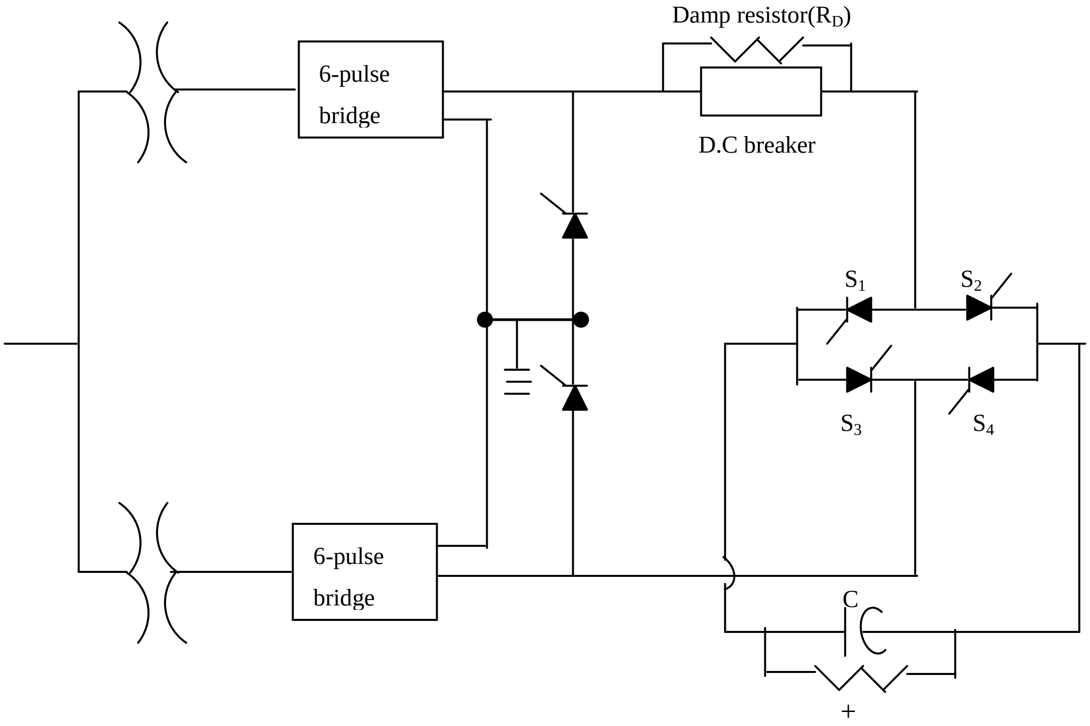

Figure. 4 Capacitive Energy Storage

Fig 4 depicts the basic configuration of a CES unit. The storage capacitor is connected to the AC grid through a Power Conversion System (PCS) which includes a rectifier/inverter system. The storage capacitor may consist of many discrete capacitors connected in parallel, having a lumped equivalent capacitance C as shown in Fig. 2. Resistance R which is connected in parallel to the capacitor C is the equivalent resistance of the capacitor bank to represent its leakage and dielectric loss. During normal operation of the grid, the capacitor can be charged to a net value of voltage from the utility grid. A reversing switch arrangement using gate turnoff thyristors (GTO) is provided to accommodate the change of direction of current in the capacitor during charging and discharging modes, as the direction of current through the bridge converters cannot change. When there is a sudden rise in the demand of load, the stored energy is almost immediately released through the PCS to the grid. As the governor and other control mechanisms start working to set the power system to the new equilibrium condition, the capacitor charges to its initial value of voltage. Similar is the action during sudden release of loads. The capacitor is charged immediately towards its full value, thus absorbing some portion of the excess energy in the system and as the system returns to its steady state, the absorbed excess energy is released and the capacitor voltage attains its normal value. Data for CES is given in the Appendix. Assuming the losses to be negligible, the bridge voltage Ed is given by

$$E_d = 2E_{do}\cos\alpha - 2I_d R_D \tag{18}$$

The normal operating point of the capacitor can be such that the maximum allowable energy absorption equals the maximum allowable energy discharge. This will make the CES unit very effective in damping the oscillations created by sudden increase or decrease in load. If E_{do} denotes the set value of voltage and $E_{d\max}$ and $E_{d\min}$ denote the maximum and minimum limits of voltage respectively, then

$$\frac{1}{2}CE_{d\max}^2 - \frac{1}{2}CE_{do}^2 = \frac{1}{2}CE_{do}^2 - \frac{1}{2}CE^2{}_{d\min} \tag{19}$$

The capacitor voltage should not be allowed to deviate beyond certain lower and upper limits. During a sudden system disturbance, if the capacitor voltage goes too low and if another disturbance occurs before the voltage returns to its normal value, more energy will be withdrawn from the capacitor which may cause discontinuous control. To overcome this problem, a lower limit is imposed for the capacitor voltage and in the present study, it is taken as 30 % of the rated value.

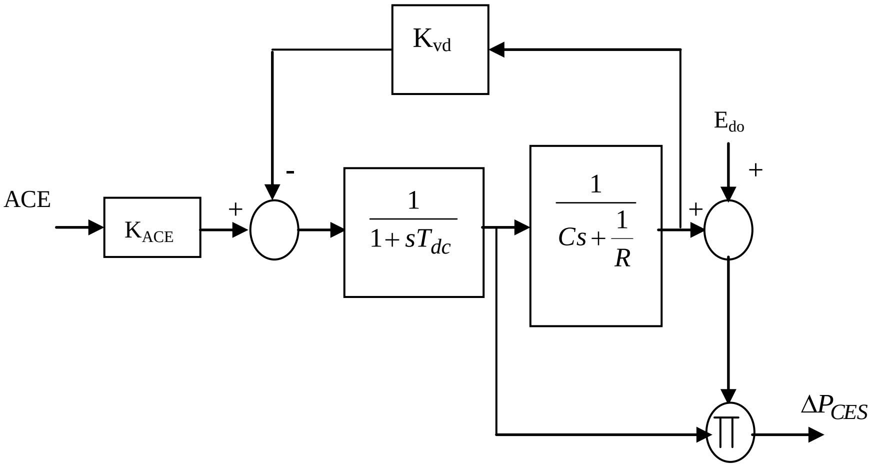

Figure. 5 Control of CES Unit

The set value of the CES voltage has to be restored at the earliest, after a load disturbance so that the CES unit is ready to act for the next load disturbance. For this, the capacitor voltage deviation can be sensed and used as a negative feedback signal in the CES control loop so that fast restoration of the voltage is achieved as shown in Fig. 5.

A performance index considered in this work to compare the performance of proposed methods is given by

$$J = \int_0^t \left(\alpha \cdot \Delta f_1^2 + \beta \cdot \Delta f_2^2 + \Delta P_{tie12}^2\right) \tag{20}$$

The ISE criterion is used because it weighs large errors heavily and small errors lightly. Even though

Δf_1 and Δf_2 have very close resemblance, separate weighing factors i.e., α and β are considered for each of them respectively so as to obtain better performance. The parameters α and β are weighing factors which determine the relative penalty attached to the tie-line power error and frequency error. A value of 0.65 has been considered in this work as the value for both α and β.

5. Results and Discussions

The proposed system in modeled in MATLAB/SIMULINK environment and the results have been presented. A load change of 0.04 p.u M.W has ben considered to study the effect of both TCPS and CES. Table 1 shows the performance of the system in area 1 when both CES and TCPS are present during a load disturbance of 0.0.04 p.u MW. A value of 0.6 has been considered as the value of integral controller in both the areas.

Table 1**:** Performance of area -1

	Peak time	Overshoot	Settling time
Without CES and TCPS	0.705	0.0084784	4.085
With CES and TCPS	0.285	0.0039932	0.535

Table 2 shows the performance of the system in area 2 when both CES and TCPS are present during a load disturbance of 0.0.04 p.u MW. Table 3 shows the performance index of the system when both CES and TCPS are present during a load disturbance of 0.04 p.u MW

Table 2: Performance of area -2

	Peak time	Overshoot	Settling time
Without CES and TCPS	0.78	0.0105568	4.22
With CES and TCPS	0.35	0.004607	1.78

Table 3: Performance Index of the system

	Performance Index
Without CES and TCPS	3.811×10^{-5}
With CES and TCPS	1.496×10^{-5}

Figure 6 shows the various frequency deviations and tie line power deviations in both the areas during a load change of 0.04p.u MW. It can be seen from the figures that the system with CES and TCPS has better performance in terms of peak time, overshoot and settling time than that of the system without TCPS and CES.

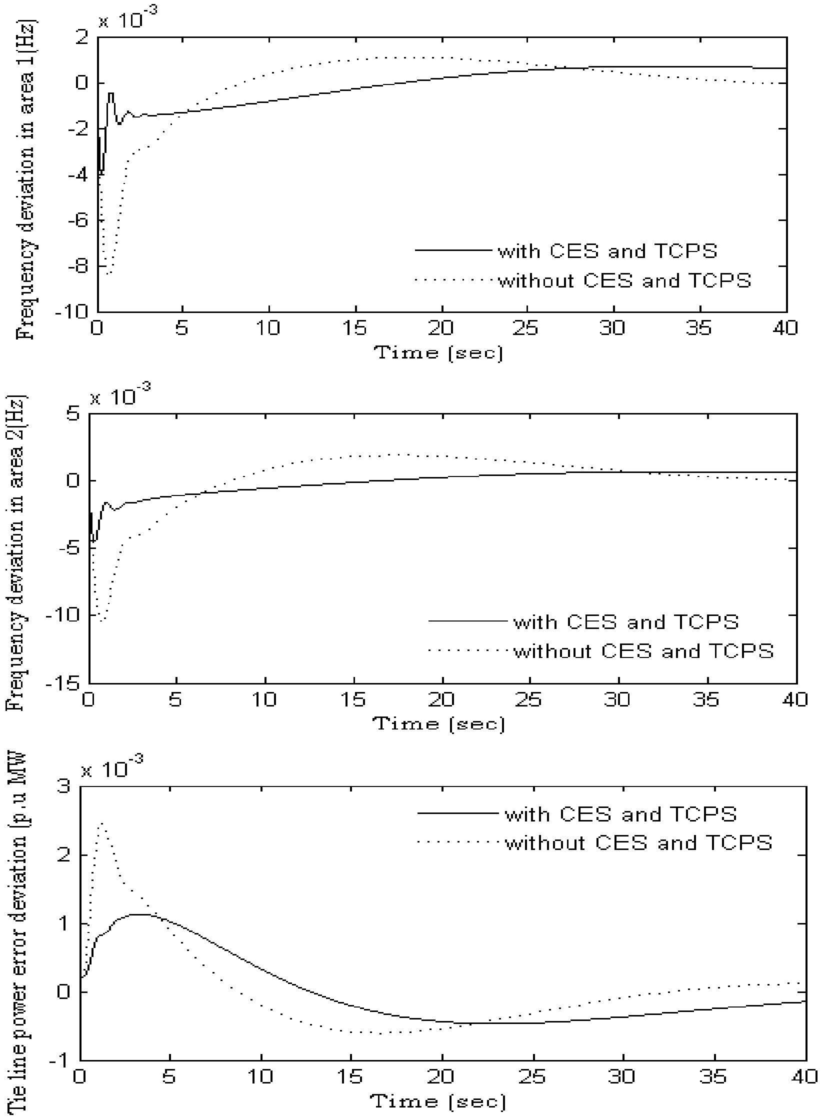

Figure 6: Frequency and tie line power error deviations in both the areas

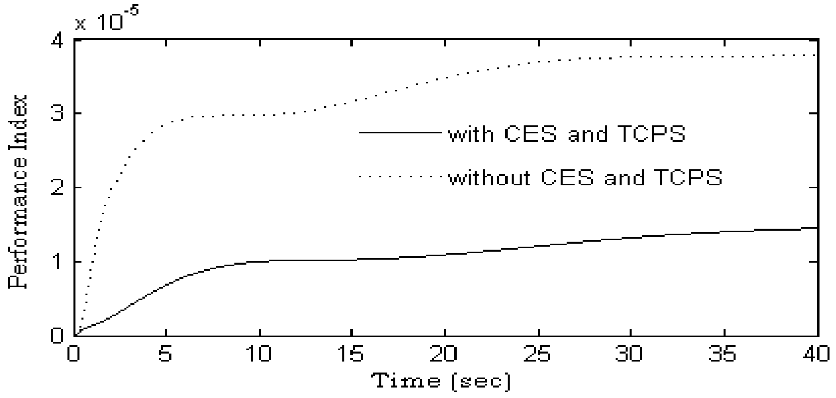

Figure 7: Performance index of the system with and without CES and TCPS

6. Conclusions

A systematic method has been suggested for the design of a thyristor controlled phase shifter and CES in order to improve the dynamic performance of a two area hydrothermal system. Analysis reveal that with the use of TCPS and CES units, the oscillations are practically damped out and also the amplitudes of the deviations in frequency and tie-line power are reduced considerably when compared to those without CES and TCPS units. Investigations also reveal that ACE signal can be provided as input to CES and frequency deviation can be provided as input to the TCPS. The performance index of the system with TCPS and CES also has less value to that of the system without TCPS and CES which indicates better response of the system with TCPS and CES.

Appendix

R =2.4 Hz/p.u.MW, $D = 8.33\times10^{-3}$ p.u. MW/Hz; K_g =1; T_g =0.08 sec; K_t =1 ; T_t =0.3 sec ; K_r =0.5 ; T_r =10 sec ; T_1, T_2, T_R =41.6, 0.513, 5 sec ; T_w =1 sec ; K_p =120 Hz/p.u. MW; T_p =:20 sec ; B =0.425 p.u. MW/Hz; K_ϕ =:1.5 rad/Hz; T_{ps} =0.01 sec; α , β =:0.065

Capacitive Energy Storage Data:

C=1.0F; R=100 Ω ; $T_{DC} = 0.05s$; $K_{ACE} = 70$ kA/unitMW; $K_{vd} = 0.1$ kA/kV; $E_{do} = 2$ kV

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