COMPARISON OF PERFORMANCE OF TCPS AND SMES IN AUTOMATIC GENERATION CONTROL OF REHEAT THERMAL SYSTEM

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ABSTRACT

This paper presents the analysis of Automatic Generation Control (AGC) of a two-area reheat thermal system under traditional scenario by considering the effect of Superconducting Magnetic Energy Storage (SMES) and Thyristor Controlled Phase Shifter (TCPS). Both these devices are modeled and an 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 these components in the system. Computer simulations reveal that due to the presence of SMES the dynamic performance of the system in terms of settling time, overshoot and peak time is greatly improved than that of TCPS.

Keywords: *Automatic Generation Control, SMES, TCPS, thermal 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.

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 [3]. 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. The proposed control strategy will be a new ancillary service for the stabilization of frequency oscillations of an interconnected power system. Literature survey shows ample applications of TCPS for the improvement of dynamic and transient stabilities of power systems.

The reported works [4-6] further shows that, SMES is located in each area of the two-area system for AGC. With the use of SMES in both the areas, frequency deviations in each area are effectively suppressed. However, it may not be economically feasible to use SMES in every area of a multi-area interconnected power system. Therefore, it is advantageous if an SMES located in an area is available for the control of frequency of other interconnected areas. Further, literature survey shows that, no work has been carried out for the AGC of thermal power system considering an SMES unit. In view of this the main objectives of the present work are:

1. To develop the two area simulink model of reheat thermal system
2. To develop the model of TCPS and SMES
3. To compare the improvement of dynamic performance of the system through TCPS and SMES

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 [7]. 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 [7]. 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 [7]. 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.

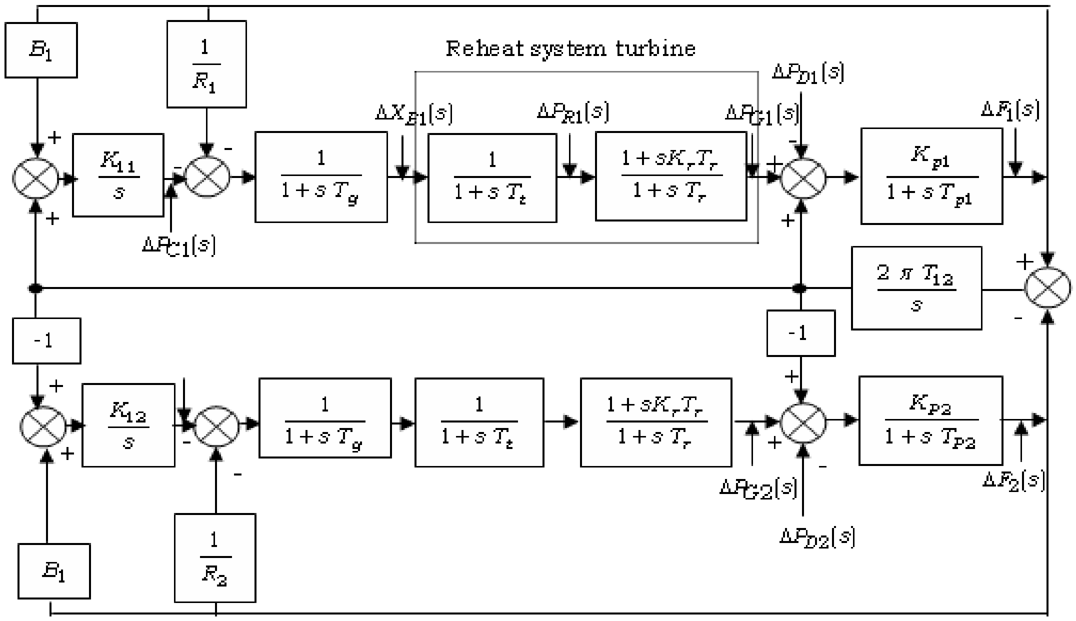

Fig. 1 Two area Reheat Thermal system

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.

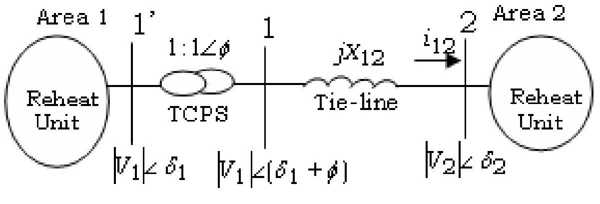

Fig. 2 TCPS in series with tie line

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

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

where T_{12} is the synchronising constant without TCPS and $\Delta F_1(s)$, $\Delta F_2(s)$ are the frequency deviations in area 1 and area 2 respectively. When a TCPS is placed in series with the tie line as in Fig. 2, current flowing from Area 1 to Area 2 is

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

and

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

Separating the real part of Eqn. (3)

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

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

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

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

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

$$\Delta P_{tie12}=T_{12}^{'}(\Delta\delta_1-\Delta\delta_2+\Delta\phi) \tag{7}$$

where $$T_{12}^{'}=\frac{|V_1||V_2|}{X_{12}}\cos(\delta_1^o-\delta_2^o+\phi^o) \tag{8}$$

$$\Delta P_{tie12}=T_{12}^{'}(\Delta\delta_1-\Delta\delta_2)+T_{12}^{'}\Delta\phi \tag{9}$$

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

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

The Laplace transform of Eqn. (11) is

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

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

$$\Delta\phi(s) = K_\phi C(s)\Delta Error_1(s) \tag{13}$$

and $C(s) = \dfrac{1}{1 + sT_{ps}}$ (14)

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

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

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, Eqn. (12) can be rewritten as

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

3.1. Logic of TCPS control, strategy

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

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

The above logic can be demonstrated as follows

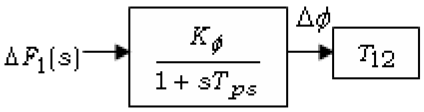

Fig. 3 Logic of TCPS in series with tie line

4. SUPERCONDUCTING MAGNETIC ENERGY STORAGE

In the SMES unit, a dc magnetic coil is connected to the ac grid through a Power Conversion System (PCS) which includes an inverter/rectifier. The superconducting coil is contained in a helium vessel.

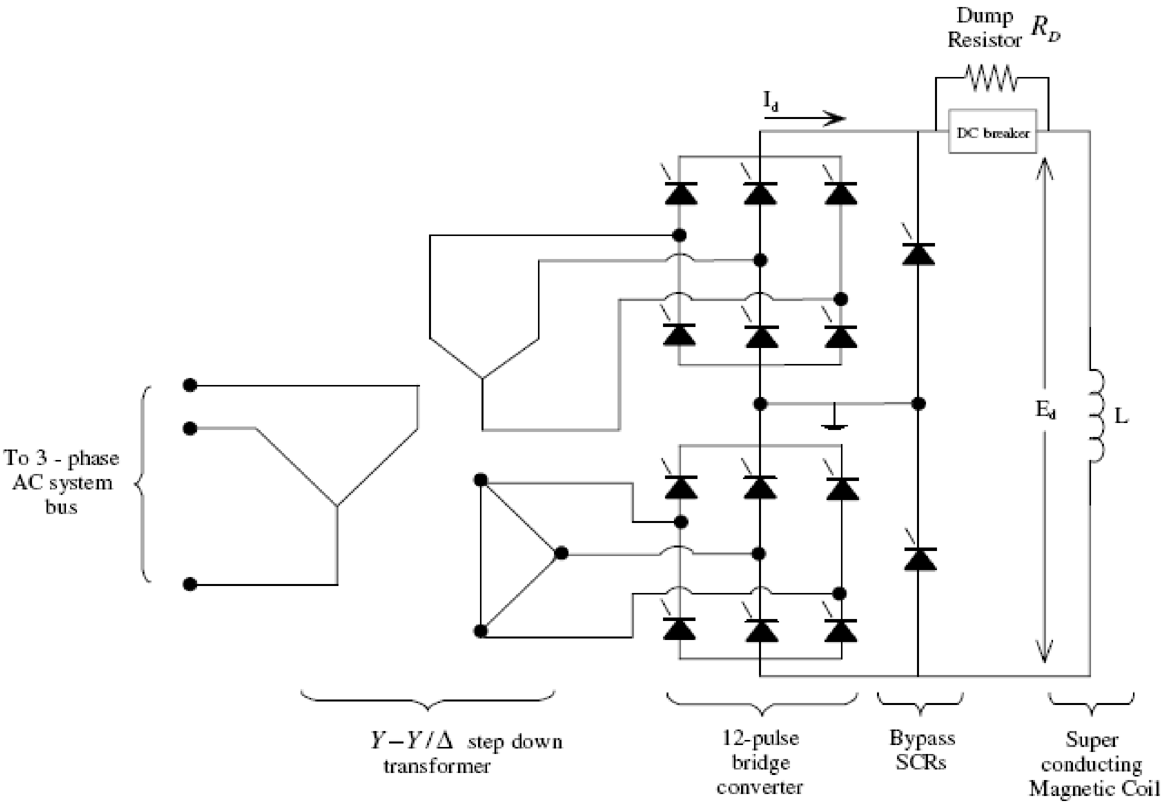

Fig. 4 Schematic of SMES

Heat generated is removed by means of a low-temperature refrigerator. Helium is used as the working fluid in the refrigerator as it is the only substance that can exist as either a liquid or a gas at the operating temperature which is near absolute zero. The current in the superconducting coil will be tens of thousands or hundreds of thousands of amperes.

No ac power system normally operates at these current levels and hence a transformer is mounted on each side of the converter unit to convert the high voltage and low current of the ac system to the low voltage and high current required by the coil. The energy exchange between the superconducting coil and the electric power system is controlled by a line commutated converter. To reduce the harmonics produced on the ac bus and in the output voltage to the coil, a 12-pulse converter is preferred. Figure 3 shows the schematic representation of SMES unit. When there is a sudden rise in the load demand, the stored energy is almost released through the PCS to the power system as alternating current. As the governor and other control mechanisms start working to set the power system to the new equilibrium condition, the coil current changes back to its initial value. Similar action occurs during sudden release of loads. In this case, the coil immediately gets charged 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 excess energy absorbed is released and the coil current attains its normal value. The control of the converter firing angle α provides the dc voltage appearing across the inductor to be continuously varying within a certain range of positive and negative values. The inductor is initially charged to its rated current I_{do} by applying a small positive voltage. Once the current reaches its rated value, it is maintained constant by reducing the voltage across the inductor to zero since the coil is superconducting. When power is to be pumped back into the grid in the case of a fall in frequency due to sudden loading in the area, the control voltage E_d is to be negative since the current through the inductor and the thyristors cannot change its direction. The incremental change in the voltage applied to the inductor is expressed as

$$\Delta E_d = \left[\frac{K_{smes}}{1+sT_{dc}}\right]\Delta Error \tag{18}$$

where, ΔE_d is the incremental change in converter voltage; T_{dc} is the converter time delay; K_{smes} is the gain of the control loop and $\Delta Error$ is the input signal to the SMES control logic. The inductor current deviation is given by

$$\Delta I_d = \frac{\Delta E_d}{sL} \tag{19}$$

In this work ACE is taken as $\Delta Error$ and is fed to the SMES unit. As a result (18) can be written as

$$\Delta E_d = \left[\frac{K_{smes}}{1+sT_{dc}}\right]B_1\Delta f_1 + \Delta P_{tie12} \tag{20}$$

But, the inductor current must be restored to its nominal value quickly after a system disturbance so that it can respond to the next load perturbation immediately. Hence, the inductor current deviation can be sensed and used as a negative feedback signal in the SMES control loop so that the current restoration to its nominal value can be enhanced. Thus the dynamic equation for the inductor voltage deviation and current deviation of the SMES unit area

$$\Delta E_d = \left[\frac{K_{smes}}{1+sT_{dc}}\right]B_1\Delta f_1 + \Delta P_{tie12} - K_{id}\Delta I_d \tag{21}$$

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

$$J = \int_0^t \left(\alpha \cdot \Delta f_1^2 + \beta \cdot \Delta f_2^2 + \Delta P_{tie12}^2\right) \tag{22}$$

The ISE criterion is used because it weighs large errors heavily and small errors lightly. Even though Δf_1 and

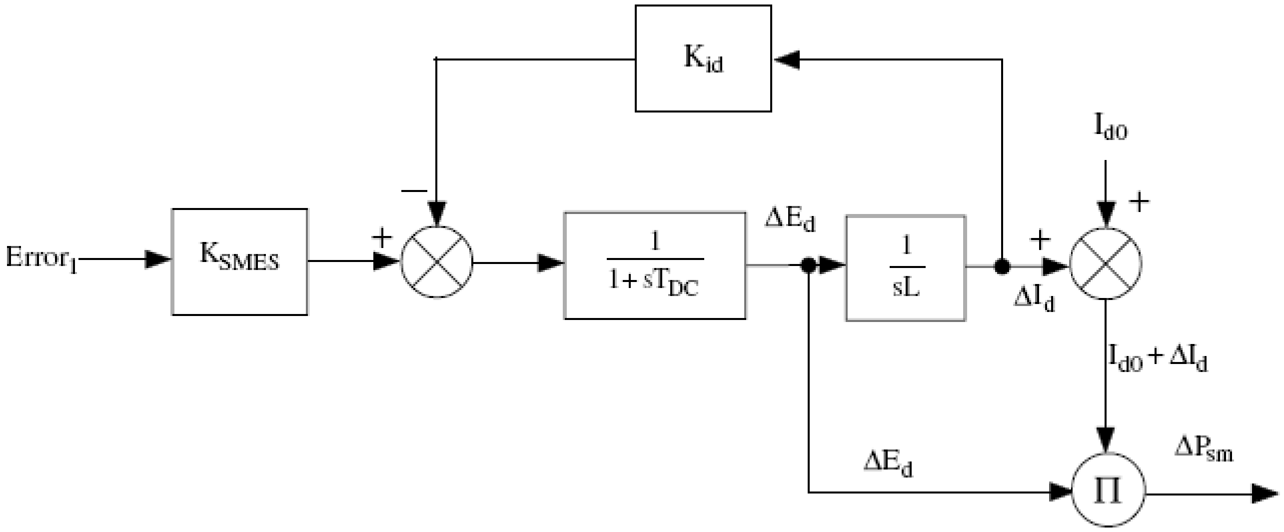

Fig. 5 Logic of implementation of SMES Block in AGC

Table 1 Comparison of performance of TCPS and SMES

	Area-1			Area-2		
	Peak Time	Overshoot	Settling Time	Peak Time	Overshoot	Settling Time
With SMES	1.885	0.012640	9.38	1.9175	0.033200	12.21
With TCPS	1.980	0.0203541	12.0476	1.995	0.044861	14.832
% Improvement	4.79	37.89	22.14	3.88	25.99	17.67

$$\text{where \% improvement} = \left(\frac{(|With\ TCPS| - |with\ SMES|)}{|With\ TCPS|}\right) \times 100$$

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

The proposed system is modeled in MATLAB/SIMULINK environment and the results have been presented. A load change of 0.01 p.u M.W has been considered to study the effect of both TCPS and SMES. A value of 0.6 has been considered as the value of integral controller in both the areas. Table 1 shows the performance of the system with TCPS and SMES. It can be seen that the performance of the system is greatly improved in the presence of SMES rather than in the presence of TCPS. It can be seen from the table that SMES gives better performance than TCPS in terms of peak time, overshoot and settling time.

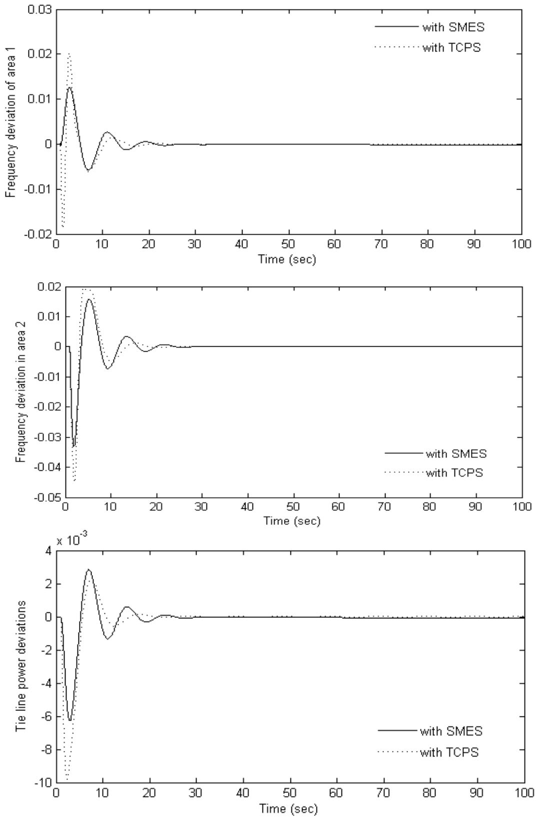

Fig. 6 Comparison of frequency and tie line power deviations in both areas with SMES and TCPS

Table 2 shows the comparison of performance index of the system in the presence of SMES and TCPS. It can be observed from the table that the system with SMES has less performance index than that of the system with TCPS which demonstrates the superiority of the system in the presence of SMES.

Table 2 Comparison of Performance Index Values

	Performance Index Value
With SMES	0.0002405
With TCPS	0.0004489

Figure 6 shows the various frequency deviations and tie line power deviations in both the areas during a load change of 0.01p.u MW. It can be seen from the figures that the system with SMES has better performance in terms of peak time, overshoot and settling time than that of the system with TCPS.

Figure 7 shows the comparison of performance index of the system when SMES and TCPS are employed. It can be seen that the performance index of the system when SMES is employed is less than that of performance index of the system when TCPS is employed.

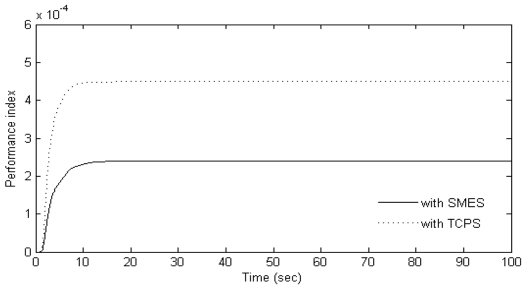

Fig. 7 Comparison of performance index of system with SMES and TCPS

6. CONCLUSIONS

A systematic method has been suggested for the design of a thyristor controlled phase shifter and SMES in order to improve the dynamic performance of a two area reheat thermal system. Analysis reveal that with the use of TCPS and SMES 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 SMES and TCPS units. Investigation has been done to find out the better device out of SMES and TCPS. Investigations also reveal that ACE signal can be provided as input to SMES and frequency deviation can be provided as input to the TCPS. The performance index of the system with SMES has less value to that of the system with TCPS which indicates better response of the system with SMES.

APPENDIX

Governor speed regulation parameter, R =2.4 Hz/p.u.MW

Load damping constant, $D = 8.33 \times 10^{-3}$ p.u. MW/Hz

Gain of turbo governor, K_g =1

Time constant of turbo governor, T_g =0.08 sec

Gain of non-reheat turbine, K_t =1

Time constant of non-reheat turbine, T_t =0.3 sec

Reheat constant, K_r =0.5

Reheat time constant, T_r =10 sec

Power system gain of both areas, K_p =120 Hz/p.u. MW

Power system time constants of both areas, T_p =:20 sec

Frequency bias constant, B =0.425 p.u. MW/Hz

Gain of TCPS controller, K_ϕ =:1.5 rad/Hz

Time constant of TCPS, T_{ps} =0.01 sec

Weighing factors, α , β =:0.065

$L = 2.65H, T_{dc} = 0.03\,\text{sec}$

$K_{smes} = 100 kv / unitMW$

$K_{id} = 0.2 kv / kA, \quad I_{do} = 4.5 kA$

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