GLOBAL JOURNAL OF ENGINEERING, DESIGN & TECHNOLOGY
(Published By: Global Institute for Research & Education)
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LOAD FREQUENCY CONTROL OF MULTI AREA INTERCONNECTED SYSTEM WITH TCPS AND DIVERSE SOURCES OF POWER GENERATION

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Abstract

This paper presents the analysis of Load Frequency Control (LFC) of multi area system consisting of diverse sources of power generation. A two area power system model consisting of thermal and gas sources has been employed in this work. The speed governors are fitted to all the power generating units. FACTS devices like Thyristor Controlled Phase Shifter (TCPS) have also been employed to further increase the dynamic performance of the system in terms of peak time, overshoot and settling time. 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 TCPS the dynamic performance of the system in terms of settling time, overshoot and peak time is greatly improved.

Keywords: Load frequency Control, TCPS, Multi area system, dynamic performance, diverse sources.

I. 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.

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

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

II. 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 system consisting of thermal and gas power plants. The parameters of all the models are given in the Appendix.

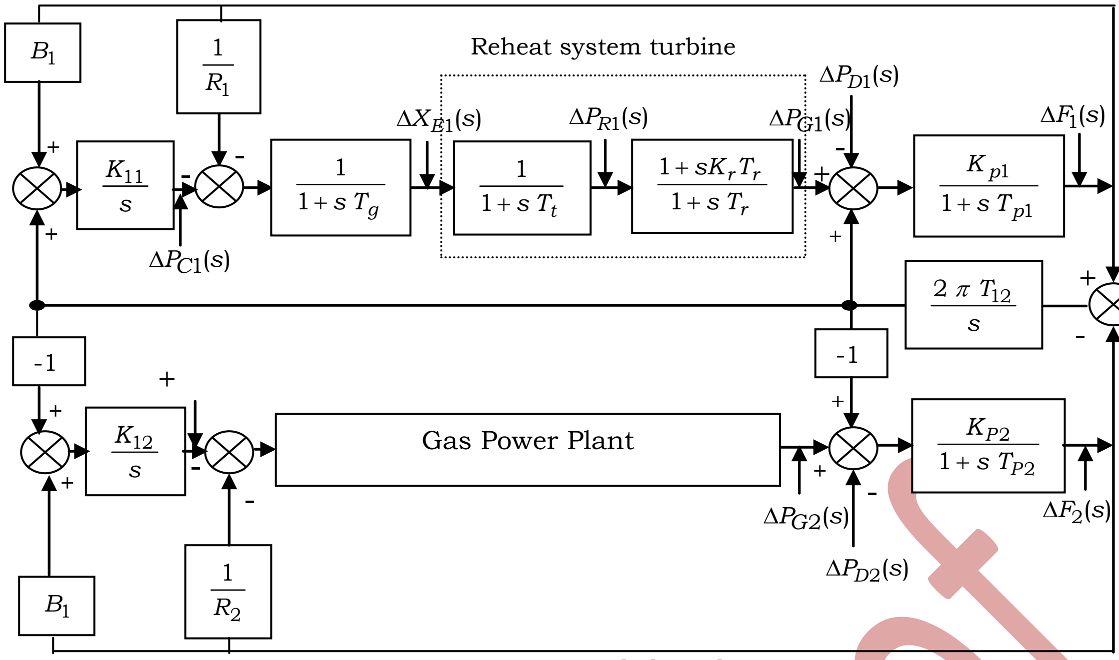


Fig. 1 Two Area Interconnected Thermal-Gas system

The block diagram of Gas power plant is shown in Fig 2

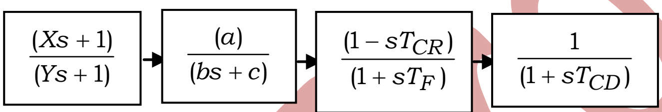


Fig. 2 Block diagram of Gas Power plant

A performance index considered in this work to compare the performance of proposed methods is given by $J=\int_0^t\left(\alpha\cdot\Delta f_1^2+\beta\cdot\Delta f_2^2+\Delta P_{tie12}^2\right)$. 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.

III. Control Employing 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.

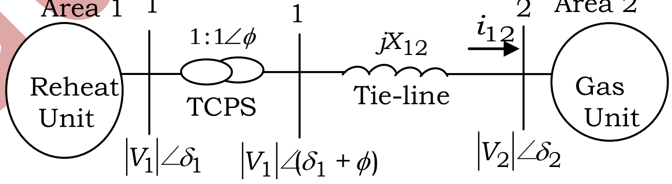


Fig. 3 TCPS in series with tie line

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. When a TCPS is placed in series with the tie line as in Fig 2, current flowing from Area 1 to Area 2 is

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

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

Separating the real part of Eqn. (3)

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

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

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

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

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

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

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

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

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

$$\Delta P_{tie12} = 2\pi T_{12}^{'}(\int\Delta f_1 dt-\int\Delta f_2 dt)+T_{12}^{'}\Delta\phi \quad (11)$$

The Laplace transform of Eqn. (11) is

$$\Delta P_{tie12}(s) = \frac{2\pi T_{12}^{'}}{s}[\Delta F_1(s)-\Delta F_2(s)]+T_{12}^{'}\Delta\phi(s) \quad (12)$$

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

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

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

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

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

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

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

A. Logic of TCPS Control Strategy

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

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

The above logic can be demonstrated as follows

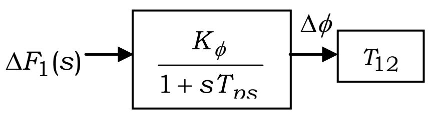


Fig 4 Logic of TCPS in series with tie line

V. Result and Discussion

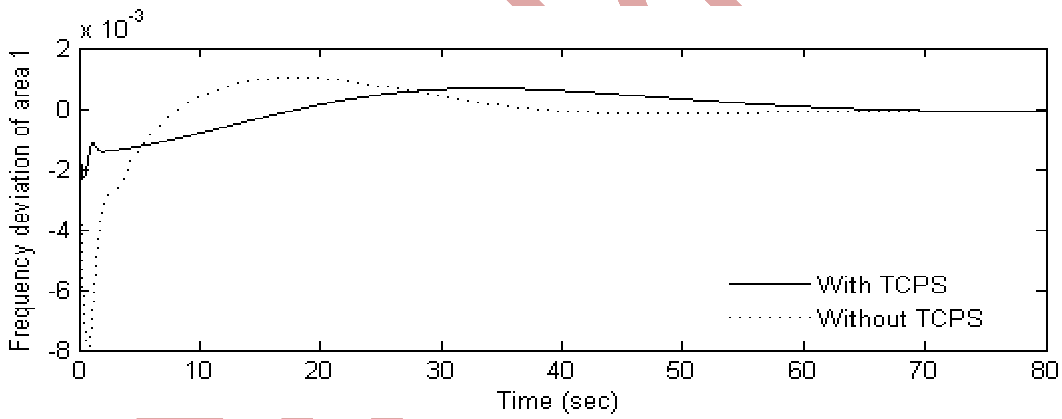
The proposed system in modeled in MATLAB/SIMULINK environment and the results have been presented. A load change of 0.04 p.u M.W in each area has been considered to study the comparison between the performance of the systems. A value of 0.5 has been considered as the gain of integral controller. Table 1 shows the comparison of both types of systems in thermal and gas area. Table 2 represents the performance index of both the systems. It can be observed that the system with TCPS gives better performance than the system without TCPS. Figure 5 represents the comparison between the frequency deviation and tie line error deviation for both the areas. The comparison between the systems in terms of performance index is represented in Figure 6. It can be observed that the system with TCPS has less performance index as compared to the system without TCPS.

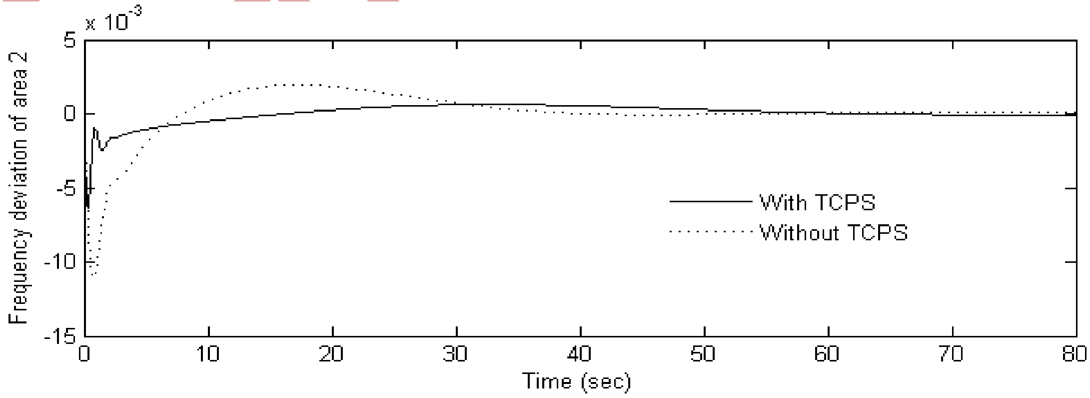
Table1: Comparison of system performance with and without TCPS.

	Thermal area			Gas area		
	Peak time (sec)	Overshoot	Settling Time (sec)	Peak time (sec)	Overshoot	Settling Time (sec)
With TCPS	0.735	0.007936	3.995	0.765	0.01107	5.065
Without TCPS	0.375	0.002339	0.615	0.31	0.006291	1.815
% Improvement	48.97	70.52	84.60	45.5	43.17	64.16

Table 2: Comparison of Performance Index Values.

	Performance Index Value
With TCPS	1.435×10^{-5}
Without TCPS	3.742×10^{-5}





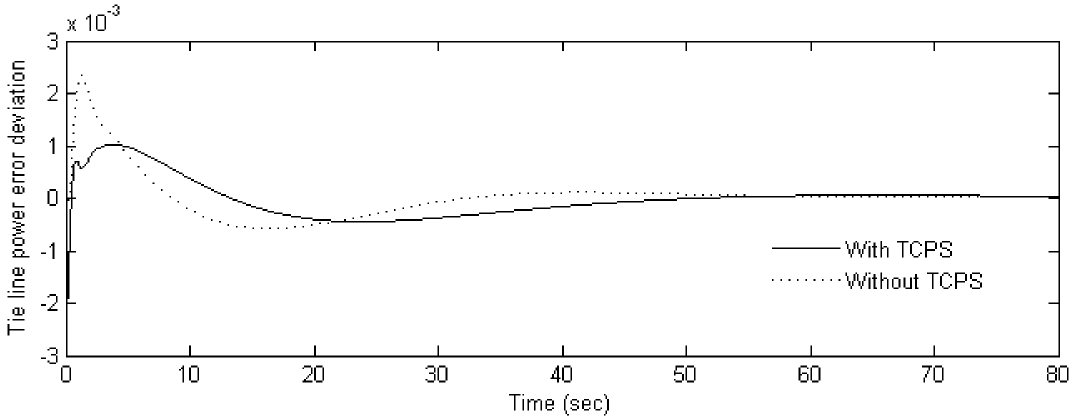


Figure 5: Comparison of Frequency and tie line power deviations with and without TCPS.

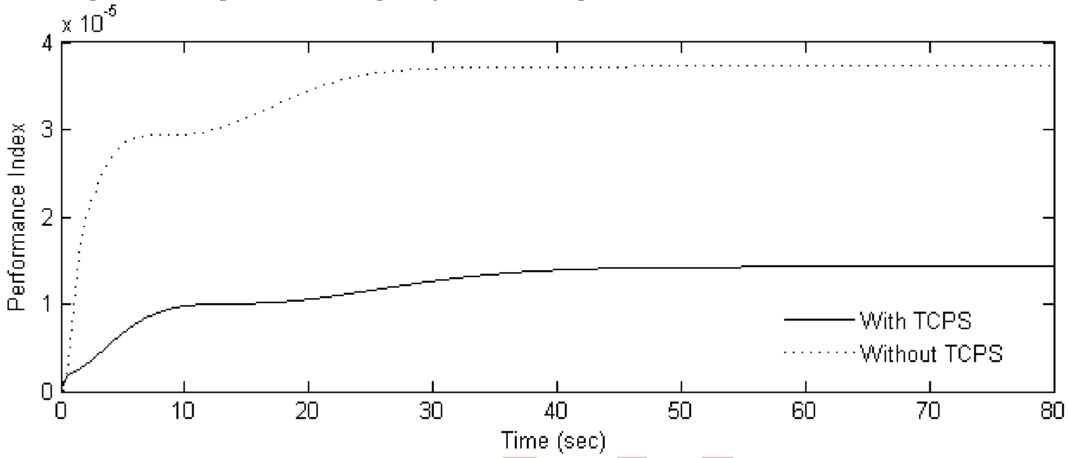


Figure 6: Comparison of Performance Index of both the systems.

VI. Conclusion

A systematic method has been suggested for the design of a Thyristor Controlled Phase shifter for a two-equal-area gas thermal system. This paper has also investigated the performance of the system with and without TCPS with respect to reduction of frequency deviations and tie line power deviations during a load change on a two area gas thermal 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 TCPS is less than the system without TCPS which indicates the superiority of the proposed method.

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