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Load Frequency Control Of An Interconnected Power System Using Thyristor Controlled Phase Shifter (TCPS)

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Abstract---In an Interconnected power system, as a power demand varies randomly, both area frequency and tie-line power interchange also vary. Load frequency control (LFC) is **of** importance in electric power system operation to damp frequency and voltage oscillations originated from load variations or sudden changes in load demands. The objectives of load frequency control(LFC) is to minimize the transient deviations in these variables (area frequency and tie-line power interchange) and to ensure their steady state errors to be zeros. The control error signal in LFC is called area control error (ACE) which is a linear combination of net tie-line power error and frequency error. This paper presents the analysis of the load frequency control (LFC) of a realistic two area interconnected power system having diverse sources of power generation. A Thyristor Controlled Phase Shifter (TCPS) is used in series with AC tie line for improving the dynamic performance of the LFC system. The power system simulation is done using MATLAB Simulink and control problem is solved using MATLAB programming. An optimal integral controller with and without TCPS are obtained following a step load perturbation in either of the areas using Particle Swarm Optimization (PSO) algorithm with a strong ability to find the most optimistic results. Simulation results show that due to the presence of TCPS, the dynamic performance in terms of settling time and overshoot is greatly improved. The system with TCPS is capable of suppressing the area frequency and tie line power deviations more effectively under the occurrence of area load perturbations.

Keywords---Load Frequency Control, Matlab Simulink, Integral Controller, Particle Swarm Optimization, Thyristor Controlled Phase Shifter.

I. INTRODUCTION:

LOAD frequency control (LFC) is of importance in electric power system operation to damp frequency and voltage oscillations originated from load variations or sudden changes in load demands. In a deregulated environment load-frequency control (LFC) is very important in order to supply reliable electric power with good quality and to provide better conditions for the electricity trading.

The main goal of LFC is to maintain zero steady state errors for frequency deviation and good tracking load demands in a multi-area power system, it is treated as an ancillary service essential for maintaining the electrical system reliability at an adequate level.

The main goal of LFC of a power system within specified tolerance is to maintain the frequency of each area and tie- line power flow by adjusting the MW outputs of generators so as to accommodate fluctuating load demands.

Load Frequency Control (LFC) in a multi-area interconnected power system has four principal objectives when operating in either the so-called normal or preventive operating states:

- Matching total system generation to total system load
- Regulating system electrical frequency error to zero
- Distributing system generation amongst control areas so that net area tie flows match net area tie flow schedules
- Distributing area generation amongst area generation sources so that area operating costs are minimized, subject to appropriate security and environmental constraints.

Frequency deviation is a direct result of the imbalance between the electrical load and the power supplied by the connected generators, so it provides useful index to indicate the generation and load imbalance. LFC provides an effective mechanism for adjusting the generation to minimize the area frequency deviation and regulate tie line power flows. The concept of power system with multi-source power generation in each area is taken for the simulation of this interconnected power system. In this paper, a two area interconnected power system model comprising Hydro, Thermal with Reheat turbine and Gas units in each area as shown in Figure. TCPS is connected in series with the AC tie line for stabilizing the area frequency and tie line power deviations. The linearized models of governors, reheat turbines, Hydro turbines and Gas turbines are used for simulation of the proposed power system. The Flexible AC Transmission Systems (FACTS) devices provide more flexibility in power system operation and control. TCPS is an effective FACTS device for the tie line power flow control of an interconnected power system. The TCPS device is modeled and used in series with tie lines to improve the dynamic performance of LFC of the interconnected power systems.

In this paper, the dynamical response of the LFC problem is improved with a practical point of view by considering the output feedback control strategy using TCPS. Practically, access to all of the state variables of a system is limited and measurement of all of them is not feasible and also costly. An

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output feedback control strategy is presented in this paper to overcome this problem. Literature survey shows that most of the researchers applied optimal control theory on thermal - thermal power systems. Some researchers have studied the LFC of thermal-thermal or hydro-thermal power systems considering TCPS but surprisingly there is hardly any literature that applies optimal output feedback control strategy for the LFC of realistic interconnected power system considering TCPS.

The main contributions of the present work are:

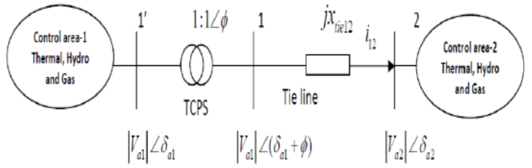
- Simulation of a realistic power system with TCPS using MATLAB Simulink tool and MATLAB coding for solving the controller design problem.
- Improvement of the dynamic response of LFC system in a realistic two area interconnected power system considering TCPS in series with tie line.
- Comparison of the dynamic responses of the LFC of the power system with and without TCPS.

The recent advances in power electronics have led to the development of the flexible alternating current transmission systems (FACTS). These devices are playing an increasing and major role in the operation and control of power systems. FACTS devices are utilized both in controlling the power flow in the transmission networks and improving transient and dynamic performances of a power system. Among the different features presented by the FACTS devices the improvement of electromechanical oscillation damping is considered as one of the main tasks of FACTS devices installed in power systems.

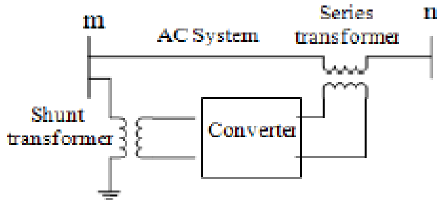
The Thyristor controlled phase shifter (TCPS), called also Thyristor controlled power angle regulator (TCPAR) belongs to the group of FACTS of special consideration. The main function of a TCPS is to enforce a desired distribution of power flows between parallel lines linking two areas of a power system in order to increase the overall power transfer capability between the areas. The ability of effective damping of electromechanical oscillation is also an important feature of the TCPS.

The recent advances in power electronics have led to the development of the flexible alternating current transmission systems (FACTS). FACTS 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 considerable attention has been directed to analysis and realization of various TCPS schemes. However, a relatively little work in TCPS control aspects has been reported in the literature. In their control scheme the phase shift angle is determined as a nonlinear function of rotor angle and speed. However, in real life power system with a large number of generators, the rotor angle of a single generator measured with respect to the system reference will not be very meaningful.

II. THYRISTOR CONTROLLED PHASE SHIFTER



Schematic of interconnected power system considering TCPS in series with tie line



A simple single machine infinite bus system with a TCPST; (a) single line diagram; (b) equivalent circuit

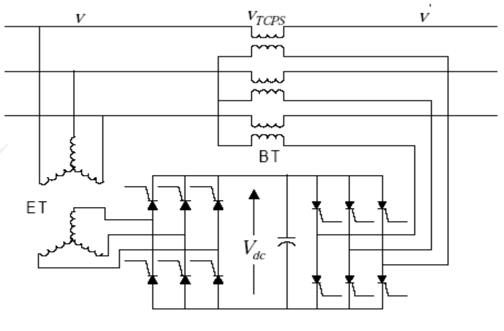


Fig. 2: The configuration of TCPS

III. TCPS CONTROL STRATEGY

Error signal to TCPS can be any signal such as the area frequency deviation or area control error to control the TCPS phase shifter angle. If the frequency deviation of area-1 is sensed as error signal, it can be used as the control signal to the TCPS unit to control the TCPS phase shifter angle which results in controlling the tie line power flow.

$$\Delta\phi(s) = \frac{\bar{K}_{\Phi}}{(1+sT_{\Phi})}\Delta F_1(s)$$

and

$$\Delta\tilde{P}_{tie12}(s) = \frac{2\pi\tilde{T}_{12}}{s}\left[\Delta F_1(s) - \Delta F_2(s)\right] + \tilde{T}_{12}\frac{K_{\Phi}}{(1+sT_{\Phi})}\Delta F_1(s)$$

A. *Power System Model of TCPS*

A single area power system with hydro, the hydro, thermal and gas power generation sources is thermal and gas power generation sources is considered for the study. considered for the study.

Load Frequency Control is applied only to Load Frequency Control is applied only to thermal and gas power generating units thermal and gas power generating units.

Hydro is allowed to operate at its scheduled Hydro is allowed to operate at its scheduled generation level with only speed governor generation level with only speed governor control. Integral (I) load frequency control is applied to thermal and gas power generating units. Common LFC for both thermal and gas power generating units. Individual LFC for thermal and gas power generating units.

B. *Mathematical Modelling*

Under normal operating conditions there is no mismatch between generation and load. The total generation is given by,

$$P_G = P_{Gth} + P_{Ghy} + P_{Gg} \qquad \text{---- (i)}$$

Where

Area thermal power generation, $P_{Gth} = K_{th} P_G$
Area hydro power generation, $P_{Ghy} = K_{hy} P_G$
Area gas power generation, $P_{Gg} = K_g P_G$

$$K_{th} + K_{hy} + K_g = 1.0 \qquad \text{----- (ii)}$$

K_{th}, K_{hy} and K_g represent the share of the power generation by thermal, hydro and gas sources to the total area power generation respectively.

For small perturbation equation (i) can be written as

$$\Delta P_G = \Delta P_{Gth} + \Delta P_{Ghy} + \Delta P_{Gg} \qquad \text{----- (iii)}$$

Common Load Frequency Controller

$$\Delta P_C = K_P \Delta f + K_I \int \Delta f\, dt$$

Individual Load Frequency Controller

$$\Delta P_{Cth} = K_{Pth} \Delta f + K_{Ith} \int \Delta f\, dt$$
$$\Delta P_{Cg} = K_{Pg} \Delta f + K_{Ig} \int \Delta f\, dt$$

The optimum values of K_p and K_I increase whereas K_{Pth} and K_{Ith} decrease and K_{Ig} increase with decrease in gas power generation to match the decrease in operating load.

Individual LFC provides better response that common LFC, Performance of the system improves as gas power generation decreases.

C. *Steady State Response*

Let the step changes in loads ΔP_{D1} and ΔP_{D2} be simultaneously applied in areas 1 and 2 respectively. When steady state conditions are reached, the output signals of all integrating blocks will become constant and their input signals must become zero.

$\Delta P_{tie\ 1} + b_1 \Delta f_1 = 0$
$\Delta P_{tie\ 2} + b_2 \Delta f_2 = 0$
$\Delta f_1 - \Delta f_2 = 0$
$\Delta P_{tie\ 1} / \Delta P_{tie\ 2} = -a12$ = constant
$\Delta P_{tie\ 1} = \Delta P_{tie\ 2} = 0$
And $\Delta f_1 = \Delta f_2 = 0$

Under steady condition change in tie line power and frequency of each area is zero.

D. *Tie Line Bias Control of Two Area Systems*

The control strategy is termed as tie line bias control and is based upon the principle that all operating pool members must contribute their share to frequency control in addition to taking care of their own net interchange. It is possible to divide an extended power system (say, national grid) into sub-areas in which the generators are tightly coupled together so as to form a coherent group, i.e., all the generators respond in unison to changes in load or speed changer settings. Such a coherent area is called a control area in which the frequency is assumed to be the same throughout in static as well as dynamic conditions. A control area is interconnected not only with one tie-line to one neighbouring area, but with several tie lines to neighbouring areas in the power pool.

Area control error, $ACE_i = \sum_{j=1}^{m} \Delta Pij + b\Delta fi$

The Net interchange = $\sum_{j=1}^{m} \Delta Pij$

The reset control is implemented by sampled data techniques. At sampling intervals of one second, all tie-line power data are fed into the central energy control area, where they are added and compared with predetermined power. Now this error is added with biased frequency error, to give ACE results. Under normal operating condition, each control area should have the capacity to meet its own load from its own spinning generator, plus the scheduled interchange between the neighbouring areas. Under emergency condition, the energy can be drawn from the spinning reserves of all the neighbouring areas immediately due to the sudden loss of generating unit.

The Load frequency control involves the sensing of the bus bar frequency and compares with the tie-line power frequency. The difference of the signal is fed to the integrator and it is given to speed changer which generates the reference speed for the governor. Thus, the frequency of the tie-line is maintained as constant.

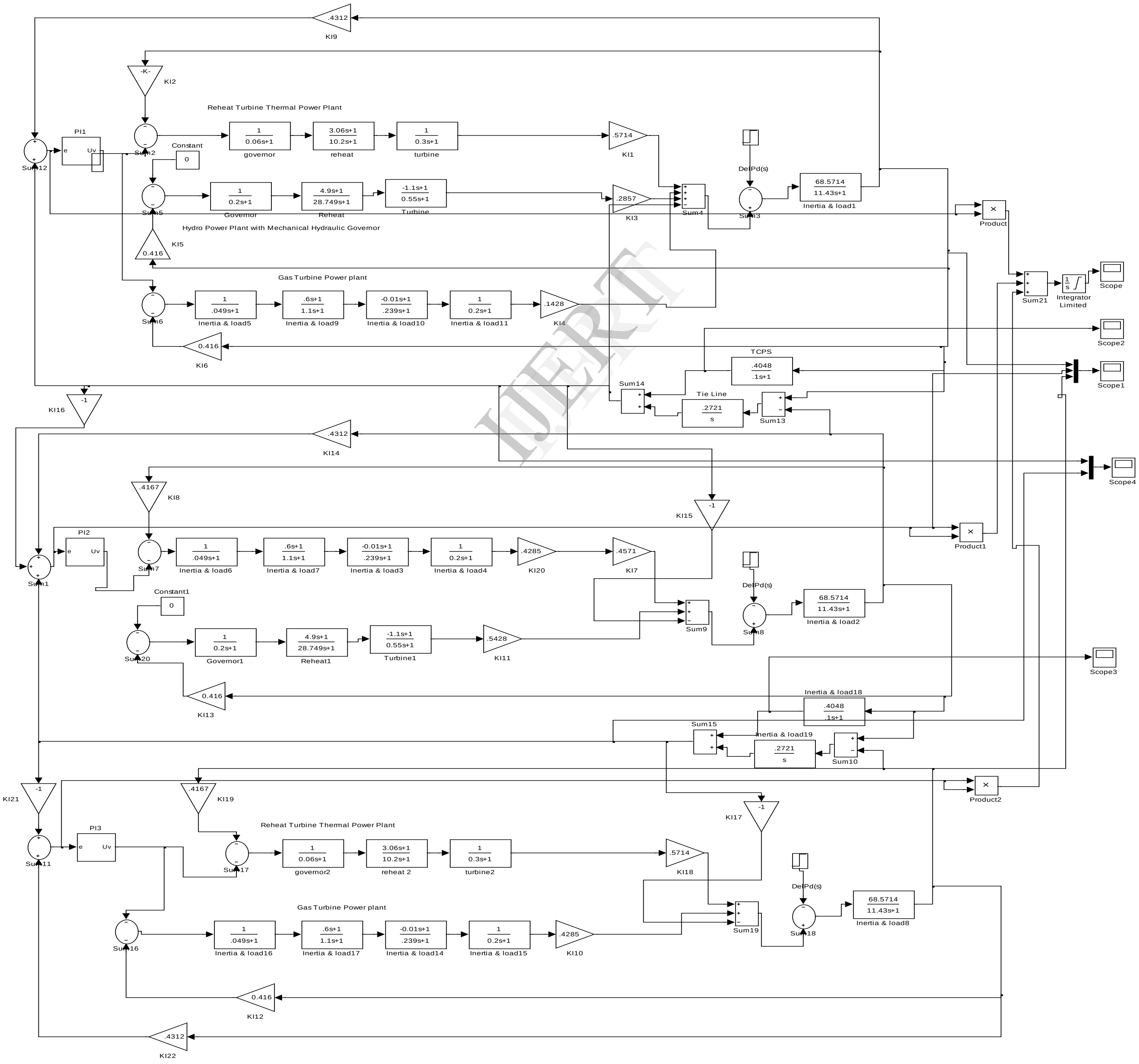
Primary Control: The speed change from synchronous speed initiates the governor control action resulting in all the participating generator – turbine units taking up the change in load, and stabilizes the system frequency.

Secondary Control: It adjusts the load reference set points of selected turbine – generator units so as to give nominal value of frequency.

In frequency bias tie-line control, the ACE comprises both the area frequency deviation and tie-line power deviation. Hence, both the deviations are brought to zero under steady state. Proper section of the frequency bias factors B1 and B2 is important form the dynamic performance considerations. The performance of this mode of integral control is examined for different settings of area frequency bias factors and the selection of B = β. The basic role of Automatic Load Frequency Control(ALFC) is to maintain desired megawatt output of a generator unit and assist in controlling the frequency of the larger interconnection. Static response of an ALFC loop will inform about frequency accuracy, whereas, the dynamic response of ALFC loop will inform about the stability of the loop.

IV. TRANSFER FUNCTION OF REALISTIC POWER SYSTEM MODEL WITH TCPS

The two area interconnected power system model with TCPS is shown in Figure 1. The realistic two area interconnected power system with TCPS which comprises more practical combination of generating units in each area is simulated using MATLAB Simulink. As shown in Figure 1, each area comprises Reheat thermal, Hydro and Gas generating units and the two equal areas are interconnected. The simulation of this interconnected power system in a new power system environment is based on the concepts of considering variety of generators with their corresponding participation rates in each area and TCPS. The governor turbine dynamic models of Reheat thermal, Hydro and Gas generating units taken for simulation are described in Furthermore, in the new environment, generators may or may not participate in the LFC task and participation rates are not the same for all participant generators. Let the participation factor of kth generator unit and ith area. In a given control area, the sum of participation factors is equal to 1. The system parameter values are given in Appendix. The nominal loading of each area is taken 1740MW with the power generation scheduling and generator participation factors.



TRANSFER FUNCTION BLOCK DIAGRAM OF A POWER SYSTEM HAVE THERMAL, HYDRO AND GAS POWER STATIONS

V. SIMULATION RESULTS AND DISCUSSION

The optimum values of the K of the output feedback controller for the simulated ower system are obtained using MATLAB code. The optimal value of K for the power system with TCPS in series with AC tie line.

Dynamic responses of the system are obtained for 1% SLP in the area-1. The Eigen values of the system with open and closed secondary loop are given in Table 2. The closed loop Eigen values have negative real parts and satisfy the system stability conditions. The frequency deviation responses of area-1 and area-2 are shown in Figures. The tie line power deviation response is shown in Figure 5. It is observed that the output feedback controller considering TCPS in power system gives better dynamic responses having relatively smaller peak overshoot and lesser settling time with zero steady state error as compared to the power system without TCPS. The quantitative comparison is made in Tables 1 and 2 where percentage reduction in the overshoot (OS) of Δf1, Δf2 and becoming 35.16, 51.27 and 40, respectively and the settling time of Δf1, Δf2 and becoming 34.11, 53.29 and 74.29, respectively. The phase angle deviation of TCPS in response to 1% SLP in area-1 is shown in Figure 6 where maximum phase angle deviation on positive side is 1.270 and on negative side is 1.760.

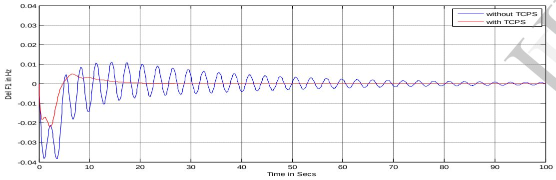


Fig: 1 Change in frequency and time with TCPS and without TCPS in area 1

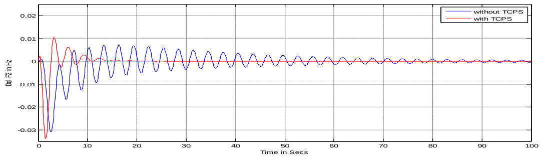


Fig: 2 Change in frequency and time with TCPS and without TCPS in area 2

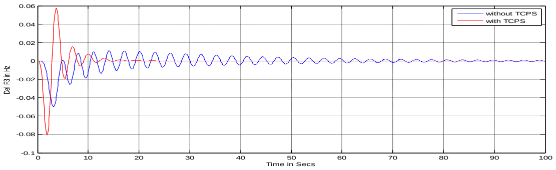


Fig: 3 Change in frequency and time with TCPS and without TCPS in area 3

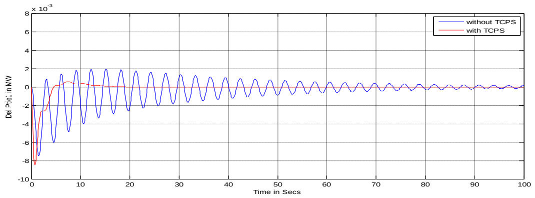


Fig: 4 – Change in tie line power and time with TCPS and without TCPS in area 1

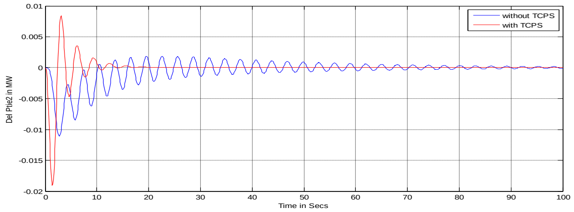


Fig: 5 Change in tie line power and time with TCPS and without TCPS in area 2

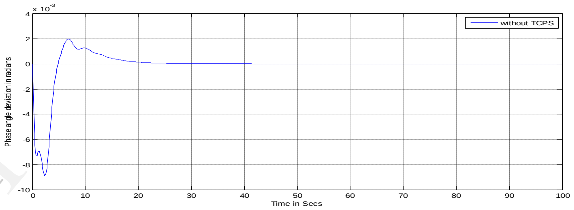


Fig: 6 Change in phase angle and time with TCPS and without TCPS in area 1

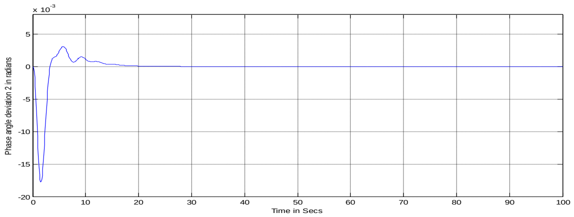


Fig: 7 Change in phase angle and time with TCPS and without TCPS in area 2

Settling Time					
Description	DelF1	DelF2	DelF3	Ptie1	Ptie2
Without TCPS	95.6	98.3	83.4	96.2	95
With TCPS	25.6	29.6	19.9	17.4	18.6

	Peak over shoot				
Description	DelF1	DelF2	DelF3	Ptie1	Ptie2
Without TCPS	0.0155	0.007	0.008	0.00194	0.00189
With TCPS	0.00452	0.01	0.056	0.0005	0.0087

Overall Performance Measure of ISE

Gain Value				
	PI	I1	I2	I3
Without TCPS	4.397968647	0.20254	0.00541	0.040687
With TCPS	2.851779265	0.54159	0.95898	0.001603
Percentage Reduction of ISE	35.156			

VI. CONCLUSION

This paper presents a mathematical model of a Thyristor Controlled Phase Shifter (TCPS) in a simple power system to investigate the dynamic behaviour of the system. The voltage magnitude and angle of the bus at which the TCPS is connected are expressed in terms of the control parameters of the TCPS. This allows expressing the output power of the generator in a much simpler way. The above model of TCPS is then used to investigate the damping improvement of the system. Simulation results indicated that the TCPS is capable of significantly improving the damping of the system. However, the degree of improvement depends of the size or rating of the TCPS.

APPENDIX

P_n = 2000 MW (Rated capacity of each area)
P_L^o = 1740 MW (Nominal load of each area)
F = 60Hz, H=5 MWsec/MVA,
D=0.0145 pu MW/Hz,
K_{PS} = 68.9655 Hz/pu MW, T_{PS} = 11.49 sec,
T_{SG} = 0.06 sec, T_T = 0.3 sec, T_{12} = 0.0433
$R_{TH} = R_{HY} = R_G$ = 2.4 Hz / puMW
B = 0.4312, a_{12} = -1, K_R = 0.3, T_R = 10.2 sec,
T_W = 1.1 sec, T_{RS} = 4.9 sec, T_{RH} = 28.749 sec,
T_{GH} = 0.2 sec, X_G = 0.6 sec, Y_G = 1.1 sec
Cg = 1, b_g = 0.049 sec, T_F = 0.239 sec,
T_{CR} = 0.01 sec, T_{CD} = 0.2 sec
TCPS parameters
K_Φ = 1.5 rad/Hz, T_Φ = 0.1 sec
Φ_{max} (positive) = 10^0, Φ_{max} (negative) = -10^0

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