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LFC DYNAMIC RESPONSE IMPROVEMENT USING FUZZY LOGIC BASED CONTROL OF TCPS IN DEREGULATED POWER SYSTEM

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Abstract- This paper deals with application of load frequency control (LFC) to deregulated power system and makes a maiden attempt to provide a new practical AGC model to cater to the needs of a modern restructured hydrothermal power system. FACTS device like TCPS can be used to regulate the power flow in the tie-lines of interconnected power system. A simple fuzzy logic controller is designed to help damping of frequency and tie line power oscillations due to different load disturbances.

Keywords: TCPS, Fuzzy Control, LFC, Deregulation.

I. INTRODUCTION

In a deregulated environment, any power system control such as frequency, will serve as an ancillary service. Thus, stabilization of frequency oscillations in an interconnected power system becomes challenging when implemented in the future competitive environment. A new frequency stabilization service which emphasizes not only efficiency, reliability and economics, but also, advanced and improved controls for satisfying the requirements of power system operation, is much in demand. 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. 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 [1].

II. INCREMENTAL MODELING OF TIE LINE POWER FLOW CONSIDERING TCPS

Figure 1 shows a two-area multi-machine power system interconnected by a tie-line in which two TCPS are placed in series with tie-line (resistance=0) near control areas 1 and 2. Without TCPS, incremental tie-line power flow from area 1 to area 2 can be expressed as [2]:

$$\Delta P_{tie-1,2} = \frac{2\pi T_{12}}{s}(\Delta f_1 - \Delta f_2) \tag{1}$$

When two TCPS are placed in series with the tie-line, as shown in Figure 1, the power flowing from area 1 to area 2 will be written as:

$$\Delta P_{tie-1,2}(s) = \frac{2\pi T_{12}}{s}[\Delta F_1(s) - \Delta F_2(s)] + \\ T_{12}\Delta\varphi_1(s) - T_{12}\Delta\varphi_2(s) \tag{2}$$

The last equation shows that the tie-line power flow can be controlled by phase shifter angles $\Delta\varphi_1$ and $\Delta\varphi_2$. The phase shifter angle $\Delta\varphi_i(s)$ can be represented as [3]:

$$\Delta\varphi_i(s) = \frac{K_{\varphi i}}{1+sT_{PSi}}\Delta Error_i(s) \quad , \quad i = 1,2 \tag{3}$$

where $K_{\varphi i}$ and T_{PSi} are gain and time constants of the TCPS, respectively. Therefore, (2) can be rewritten as:

$$P_{tie-1,2}(s) = \frac{2\pi T_{12}}{s}[\Delta F_1(s) - \Delta F_2(s)] + \\ T_{12}\frac{K_{\varphi 1}}{1+sT_{PS1}}\Delta Error_1(s) - T_{12}\frac{K_{\varphi 2}}{1+sT_{PS2}}\Delta Error_2(s) \tag{4}$$

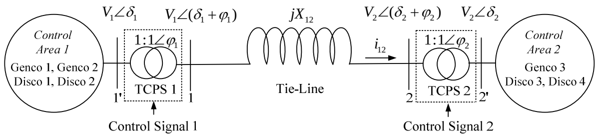

Figure 1. Schematic of two area interconnected hydrothermal power system with two TCPS in series with tie-line in a restructured environment

III. CONTROL STRATEGY OF TCPS

The frequency deviation of each control area i (Δf_i) can be used as the control signal for the nearby TCPS unit in order to control the TCPS phase shifter angle which in turn, controls the tie-line power flow. Hence:

$$\Delta\varphi_i(s) = \frac{K_{\varphi i}}{1+sT_{PSi}}\Delta F_i(s) \quad , \quad i = 1,2 \tag{5}$$

By using a simple but effective Fuzzy Logic Controller (FLC) for controlling the TCPS unit, the dynamic performance of the system may be improved.

IV. SYSTEM INVESTIGATED

The AGC system investigated is composed of an interconnection of two areas. Area 1 comprises of a non reheat and a reheat thermal system. Moreover, area 2 consists of a hydro system. Both areas have two Discos. The dynamic responses of the system with the presence of GRC have larger overshoots and longer settling times, compared to the system without considering GRC [4]. The detailed small perturbation transfer function block diagram model of the two-area hydrothermal system along with the incremental model of the TCPS in series with the tie-line and a fuzzy logic controller is shown in Figure 2 [8-11].

V. OPTIMIZATION OF INTEGRAL GAIN SETTINGS CONSIDERING GRC

The optimum gains for the integral controllers have been selected using ISE (Integral Square Error) criterion. The cost function J for ISE is taken as:

$$J = \int_0^\infty (\Delta f_1^2 + \Delta f_2^2 + \Delta P_{tie-1,2}^2) dt \qquad (6)$$

This performance index is minimized in the presence of GRC to obtain the optimum values of K_{I1} and K_{I2} [5]. Optimum values of integral gain settings of area 1 and area 2 with and without TCPS in series with the tie line are tabulated in Table 2. From Table 2 it is seen that the optimum values of the integral gain settings in areas 1 and 2 considering TCPS are higher than those obtained without TCPS.

Table 1. Optimum values of integral gain settings

Area	With TCPS	Without TCPS
Thermal	$K_{I1} = 0.0783$	$K_{I1} = 0.0516$
Hydro	$K_{I2} = 0.3719$	$K_{I2} = 0.118$

VI. STATE SPACE REPRESENTATION

The power system model considered being a linear continuous-time dynamic system, can be represented by the standard state space model as:

$$\dot{X} = AX + BU + \Gamma p \qquad (7)$$

where X, U, and p are the state, control and disturbance vectors respectively and A, B and Γ are the system, input and disturbance matrices respectively which are constant and of compatible dimensions associated with them which in turn depend on the system parameters and the operating point.

VII. DISCO PARTICIPATION MATRIX

The concept of Disco Participation Matrix (*DPM*) is introduced to make the visualization of contracts easier. DPM is a matrix with the number of rows equal to the number of Gencos and the number of columns equal to the number of Discos in the system. Consider the above mentioned two-area system in which area 1 has two Gencos and two Discos in it. Also, area 2 has one Genco and two Discos in it. The corresponding DPM will become:

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \end{bmatrix} \qquad (8)$$

where cpf_{ij} refers to *contract participation factor*. The diagonal blocks of DPM correspond to local demands. Off diagonal blocks correspond to the demands of Discos in one area to the Gencos in another area [6, 7].

VIII. SIMULATIONS AND DISCUSSIONS

The effect of TCPS with and without a fuzzy logic controller is considered on the dynamic responses of the system in the presence of GRC. The following two cases are considered:

A. Inner Area Contracts

Suppose that the load changes occur in both control areas 1 and 2. It is assumed that the load is demanded by all Discos. Let the value of this load demand be 0.005 pu MW for each of them. Referring to (25), DPM becomes:

$$DPM = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix}$$

Disco$_1$ and Disco$_2$ demand identically from their local Gencos, *viz.*, Genco$_1$ and Genco$_2$. Moreover, Disco$_3$ and Disco$_4$ demand all their required power from their local Genco, *viz.*, Genco$_3$. Note that all Discos demand power internally from the Gencos in the same area. Thus off diagonal blocks of the DPM are zero. Inner area contracts result in no change in the tie line power.

Figure 3 shows the results of this load changes in three cases, i.e. without TCPS, with TCPS considering FLC and in the absence of FLC: Area frequency deviations, actual power flow on the tie line (in a direction from area 1 to area 2), the generated powers of various Gencos, and the governor control signals, following a step change in the load demands of all Discos. The frequency deviation in each area goes to zero in the steady state (Figure 6(a), (b)). As the Discos in both areas demand the same power, the transient dip in frequency of area 1 and area 2 are approximately the same.

Since the off diagonal blocks of DPM are zero, i.e., there are no contracts of power between a Genco in one area and a Disco in another area, the scheduled steady state power flow over the tie line is zero. The actual power on the tie line goes to zero. The effects of GRC in the generation rate of Gencos are shown in Figure 6(d), (e) and (f). It can be seen from Figure 6 that the damping is greatly improved with the addition of the TCPS. The simple fuzzy logic controller can improve the dynamic response of the power system to some degree.

B. Between Areas Contracts

In this case the contracts are performed not only in the internal of the control areas but also in between the control areas. Suppose that the DPM is as follows:

$$DPM = \begin{bmatrix} 0.5 & 0.25 & 0.25 & 0 \\ 0.5 & 0.5 & 0.5 & 0.5 \\ 0 & 0.25 & 0.25 & 0.5 \end{bmatrix}$$

The system in Figure 5 is simulated using this data and the results are depicted in Figure 7. Figure 7(c) shows the actual power on the tie line. It is to be observed that it settles to 0.005 pu MW, which is the scheduled power on the tie line in the steady state. Figure 4(d), (e) and (f) show actual generated powers of the Gencos. The trajectories reach respective desired generations in the steady state.

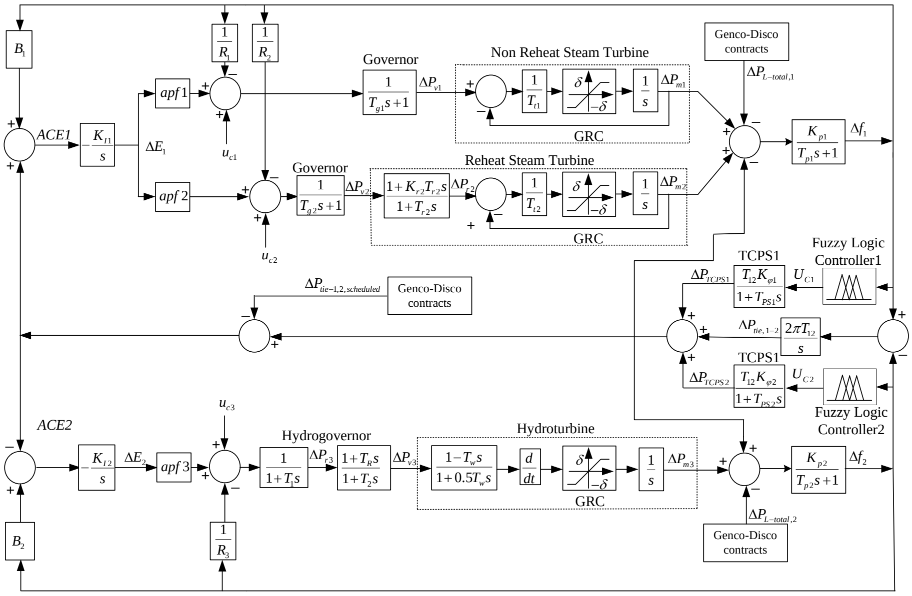

Figure 2. The two-area hydrothermal system along with the incremental model of the TCPS in series with the tie-line and fuzzy logic controller

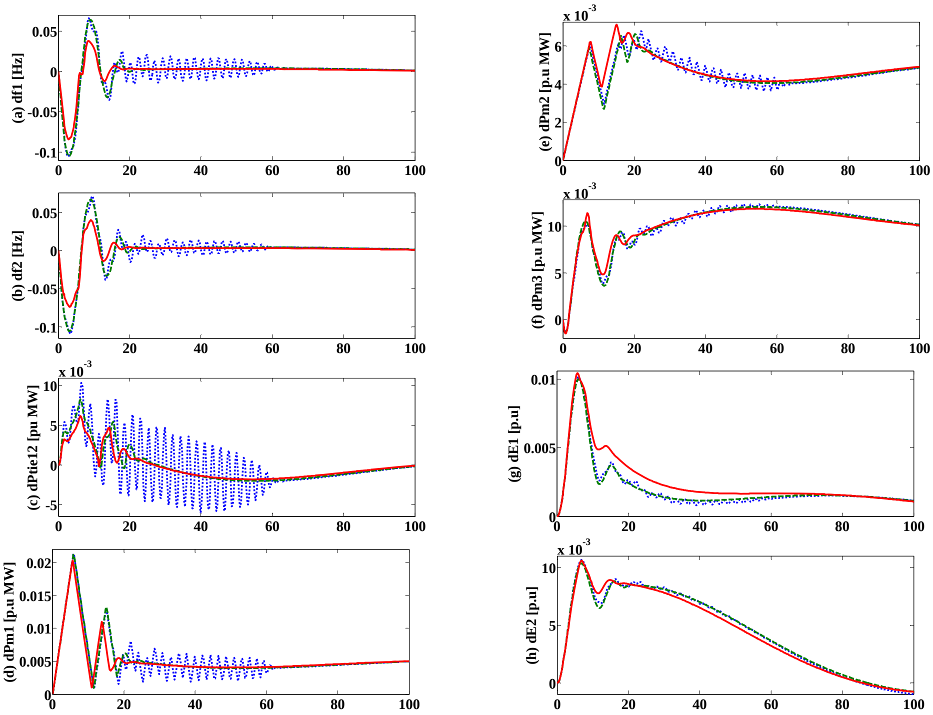

Figure 3. The simulation results in internal contract case for (a) Δf_1 [Hz], (b) Δf_2 [Hz], (c) $\Delta P_{tie,1-2}$ [pu MW], (d) ΔP_{m1} [pu MW], (e) ΔP_{m2} [pu MW], (f) ΔP_{m3} [pu MW], (g) ΔE_1 [pu], (h) ΔE_2 [pu]; .... curves are in the absence of TCPS; -------- and ——— curves are in the presence of TCPS without and with FLC, respectively; horizontal axes are time in second

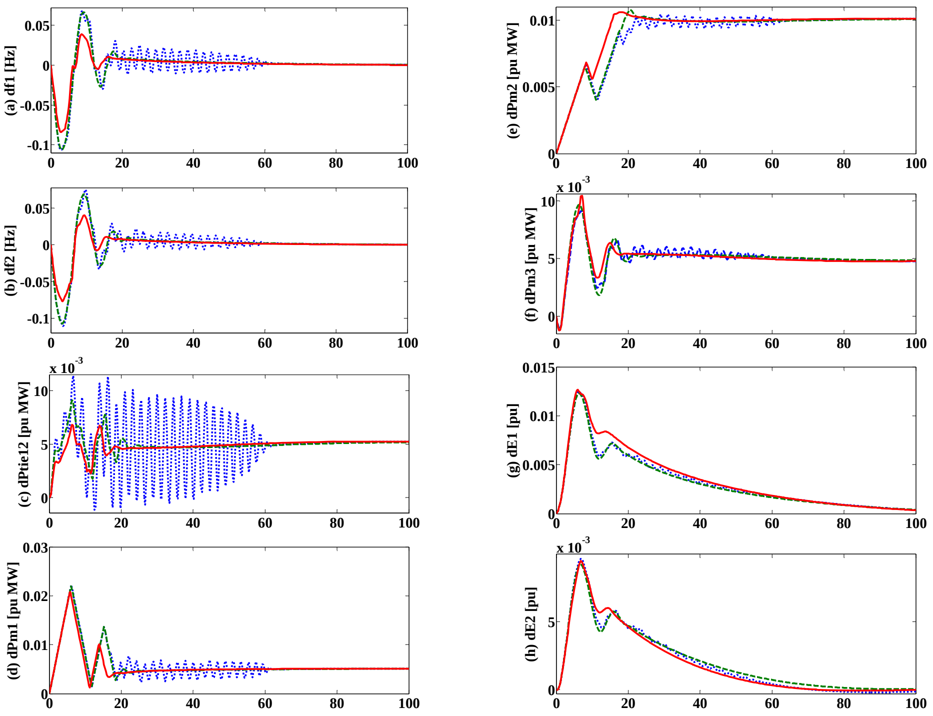

Figure 4. The simulation results in case of between areas contract for (a) Δf_1 [Hz], (b) Δf_2 [Hz], (c) $\Delta P_{tie,\,1-2}$ [pu MW], (d) ΔP_{m1} [pu MW], (e) ΔP_{m2} [pu MW], (f) ΔP_{m3} [pu MW], (g) ΔE_1 [pu], (h) ΔE_2 [pu]; .... curves are in the absence of TCPS; -------- and ——— curves are in the presence of TCPS without and with FLC respectively; horizontal axes are time in second

IX. CONCLUSIONS

It has been observed in the present work that a TCPS with a simple fuzzy logic controller can effectively reduce frequency and tie line power oscillations following sudden small load disturbances arising from bilateral transactions. It may be therefore concluded that, the tie-line power flow control by a TCPS can be expected to be utilized as a new ancillary service for stabilization of frequencies and tie-power oscillations in the deregulated environment of power systems.

Gain settings of the integral controllers are optimized using ISE technique in the presence of GRC by minimizing a quadratic performance index. The concept of a DPM is introduced to make the visualization of contracts easier. A new block diagram is formulated for a two-area AGC system in the deregulated scenario considering bilateral transactions and TCPS.

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BIOGRAPHIES

Navid Taghizadegan received his B.E. degree from Tabriz University (Tabriz, Iran) in 1989 and his M.E. degree from Tehran University (Tehran, Iran) in 1994 and his Ph.D. degree from Tabriz University in 2008 all in Electrical Engineering. His research interests are power system planning and control, and electrical machines. He is the author of many international papers, and several books in above mentioned subjects. He were also directed some research projects in Azerbaijan Electric Utility in Iran. He joined to Azarbaijan Higher Educational and Research Complex (Tabriz, Iran) in 1995 and since he is doing lecturing and research duties in there.

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