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Two-Area Frequency and Tie-Line Power Flow Control by Coordinated AGC with TCPS with PI&Fuzzy

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Abstract: Large scale power systems are normally composed of control areas or regions representing coherent groups of generators. Frequency deviations and inter-area tie-power fluctuations from their respective scheduled values following a local load disturbance are a source of great concern in interconnected power system operation and control. A new method to minimize such deviations and thereby enhance the performance of Automatic Generation Control (AGC) of an interconnected power system is to be determined. The coordinated operation of a Thyristor-Controlled-Phase-Shifter (TCPS), in an area and in series with the tie-line with supplementary controller for the improvement of Load Frequency Control (LFC) was studied..

Keywords: Automatic generation control, load frequency control, multi-area power system, thyristor-controlled-phase-shifter (TCPS), and PI&FUZZY gain scheduled AGC-TCPS combination.

I. INTRODUCTION

Automatic generation control is one of the most important issues in electric power system design and operation. The objective of the AGC in an interconnected power system is to maintain the frequency of each area and to keep tie-line power close to the scheduled values by adjusting the MW outputs of the AGC generators so as to accommodate fluctuating load demands. The automatic generation controller design with better performance has received considerable attention during the past years and many control strategies have been developed [1-2] for AGC problem. The availability of an accurate model of the system under study plays a crucial role in the development of the most control strategies like optimal control. However, an industrial process, such as a power system, contains different kinds of uncertainties due to changes in system parameters and characteristics, loads variation and errors in the modelling. On the other hand, the operating points of a power system may change very much randomly during a daily cycle. Because of this, a fixed gain controller based on classical theory [3-4] is certainly not suitable for AGC problem in all operating conditions. Thus, some authors have suggested a variable structure [5] and adaptive methods [6-7] for dealing with parameter variations. But all the proposed methods are based on the state-space approach and require Information about the system states which are not usually known or available. On the other hand, due to the requirement of a prefect model which has to track the state variables and satisfy system constraints, it is rather difficult to apply these adaptive control techniques to AGC in practical implementations.

In two-area power system, if a load variation occurs at any one of the areas in the system, the frequency related with this area is affected first and then that of other areas are also affected from this perturbation through tie-lines. When a small load disturbance occurs, power system frequency oscillations continue for a long duration, even in the case with optimized gain of supplementary controllers [8]. So, to damp out the oscillations in the shortest possible time, the fast acting energy storage devices are expected to be the most effective countermeasure [8-9]. However, it may not be economically feasible to use these devices in every area of a two--area interconnected power system because obviously it increases the overall cost.

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. This extra flexibility permits the independent adjustment of certain system variables such as power flows, which are not normally controllable. Athyristor-controlled-phase-shifter is expected to be an effective apparatus for the tie-line power flow control of an interconnected power system. In an interconnected power system, some areas are considered to be the channels of disturbances and in this situation, the conventional governor control system with optimized fixed gain integral controller may fail to attenuate the large frequency oscillations due to its slow response. At the same time, tie-line power flow control by TCPS installed in series with a tie-line in between the two areas of an interconnected power system has the possibility to control the system frequency effectively. Many applications of TCPS for the improvement of dynamic and transient stabilities of power systems have been reported in the past [8,9-12]. However, no attempt has been made to improve the performance of AGC-TCPS combination with FGS supplementary controller.

Using fuzzy logic, the integrator gain (K_{Ii}) of supplementary controller with TCPS is so scheduled that it compromise between fast transient. recovery and low overshoot in dynamic response of the system. Finally, it is seen that with the coordinated operation of FGS-AGC with TCPS performs more effective primary frequency control compared to OFG-AGC with TCPS.

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Considering these viewpoints, the proposed system can be a good tool for LFC of multi-area power system.

II. POWER SYSTEM MODEL FOR SIMULATION ANALYSIS

The AGC system investigated comprises of an interconnection of two areas, both areas comprising of a non- reheat thermal units. Fig. 1 shows the schematic of two-area interconnected thermal power system with TCPS.

Two areas are connected by a weak tie-line. TCPS is placed in series with the tie-line near area-1. A TCPS is a device that changes the relative phase angle between the system voltages [8]. Therefore, the real power flow can be regulated to mitigate the frequency oscillations and enhance power system stability.

The small perturbation transfer function block diagram of Fig. 1 is shown in Fig. 2. When there is sudden rise in power demand in a control area, the governor control mechanism starts working to set the power system to the new equilibrium condition. Similar action happens when there is a sudden decrease in load demand. Basically, the operation speed of governor-turbine system is slow compared with that of the excitation system. As a result, fluctuations in terminal voltage can be corrected by the excitation system very quickly, but fluctuations in generated power or frequency are corrected slowly.

Since load frequency control is primarily concerned with the real power/frequency behaviour, the excitation system model will not be required in the approximated analysis [9]. This important simplification paves the way for constructing the simulation model shown in Fig. 2. The basic objective of the supplementary control in Fig. 2 is to restore balance between each area load and generation for a load disturbance. This is met when the control action maintains the frequency and the tie-line power interchange at the scheduled values. Thus supplementary controller with integral gain KIi is therefore made to act on area control error (ACE), which is a signal obtained from tie-line power flow deviation added to frequency deviation weighted by a bias factor β as in (1).

$$ACE_i = \sum_{j=1}^{n} \Delta P_{tie,ij} + \beta_i \Delta f_i \qquad (1)$$

where the suffix i refer to the control area and j refer to the number of generator. The nominal parameters of the system are same as those used in [8].

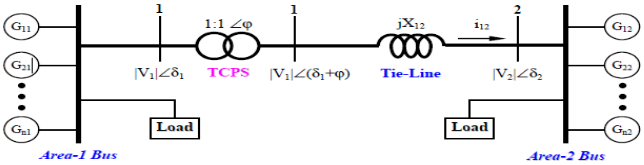


Fig1: two-area thermal power system with TCPS

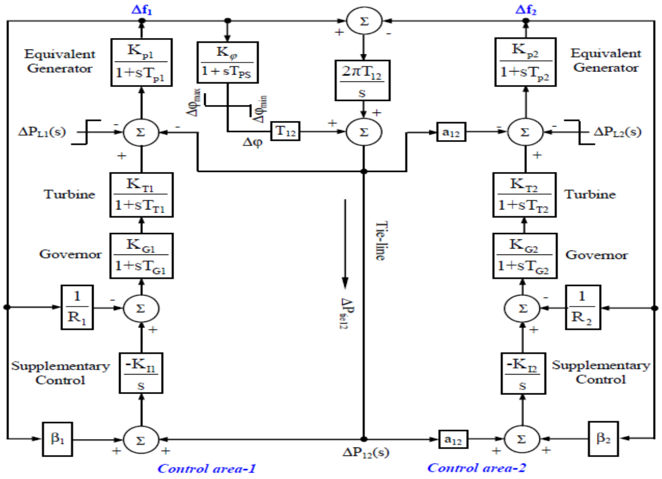


Fig2: Block diagaram for the two-area power system with TCPS

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

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

where $T12$ is the synchronizing constant without TCPS and $\Delta F1(s)$, $\Delta F2\ (s)$ 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. 3, current flowing from Area 1 to Area 2 is

$$i_{12} = \frac{|V_1|\angle(\delta_1+\Phi) - |V_2|\angle\delta_2}{JX_{12}} \qquad (3)$$

And

$$P_{tie12} - jQ_{tie12} = |V_1|\angle-(\delta_1+\Phi)\left[\frac{|V_1|\angle(\delta_1+\Phi) - |V_2|\angle\delta_2}{JX_{12}}\right] \qquad (4)$$

Separating the real part of eqn(3)

$$P_{tie12} = \frac{|V_1||V_2|}{X_{12}}\sin(\delta_1-\delta_2+\Phi) \qquad (5)$$

But in Eqn. (4) perturbing $\delta_{1,}\delta_2$ and Φ from their nominal values $\delta_{1,}^{o}\delta_2^{o}$ and Φ^{o} respectively

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

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

III. 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.

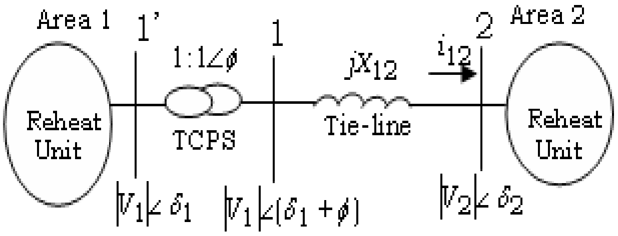


Fig3: TCPS in series with tie line

very small and hence,

$\sin(\Delta\delta_1 - \Delta\delta_2 + \Delta\Phi) = (\Delta\delta_1 - \Delta\delta_2 + \Delta\Phi)$. so eqn (6)

Can be written as

$$\Delta P_{tie12} = \frac{|V_1||V_2|}{X_{12}}\cos(\delta_1^o - \delta_2^o + \Phi)(\Delta\delta_1 - \Delta\delta_2 + \Delta\Phi) \quad (7)$$

$$\Delta P_{tie12} = T_{12}^{'}(\Delta\delta_1 - \Delta\delta_2 + \Delta\Phi) \quad (8)$$

Where

$$T_{12}^{'} = \frac{|V_1||V_2|}{X_{12}}\cos(\delta_1^o - \delta_2^o + \Phi) \quad (9)$$

$$\Delta \text{Ptie12} = T_{12}^{'}(\Delta\delta_1 - \Delta\delta_2) + T_{12}^{'}\Delta\Phi \quad (10)$$

But $\Delta\delta_1 = 2\pi\int\Delta f_1\,\mathrm{dt}$ and $\Delta f_2 = 2\pi\int\Delta f_2\,dt$ (11)

Eqn (9) can be modified as

$$\Delta P_{tie12} = 2\pi T_{12}^{'}\left(\int\Delta f_1\,\mathrm{dt} - \int\Delta f_2\,dt\right) + T_{12}^{'}\Delta\Phi \quad (12)$$

The laplace transform of eqn(11) is

$$\Delta P_{tie12}(s) = \frac{2\pi T_{12}^{'}}{s}[\,\Delta \mathrm{F}_1(\mathrm{s}) - \Delta \mathrm{F}_2(s) + T_{12}^{'}\Delta\Phi\,(\mathrm{s}) \quad (13)$$

$$\Delta\Phi\,(\mathrm{s}) = K_\emptyset C(s)\Delta error_1\,(s) \quad (14)$$

And $C(s) = \frac{1}{1+sT_{ps}}$ (15)

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

$$\Delta\emptyset(s) = \frac{K_\emptyset}{1+sT_{ps}}\Delta error_1(s) \quad (16)$$

Where $K_\emptyset$ and Tps are the gain and time constants of the TCPS and $\Delta Error1(s)$ is the control signal which controls the phase angle of the phase shifter. Thus, Eqn. (12) can be rewritten as

$$\Delta P_{tie12}(s) = \frac{2\pi T_{12}^{'}}{s}[\,\Delta \mathrm{F}_1(\mathrm{s}) - \Delta \mathrm{F}_2(s) + T_{12}^{'}\frac{K_\emptyset}{1+sT_{ps}}\Delta error_1(s) \quad (17)$$

IV. LOGIC OF TCPS CONTROL, STRATEGY

$\Delta Error1$ can be any signal such as the thermal area frequency deviation $\Delta f1$or frequency deviation $\Delta f2$ 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 $\Delta Error1 = \Delta f1$, Eqn (15) can be written as

$$\Delta\emptyset(s) = \frac{K_\emptyset}{1+sT_{ps}}\Delta F_1(s) \quad (18)$$

The above logic can be explained below

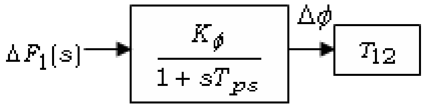


Fig4: TCPS in series with tie line

V. FUZZY GAIN SCHEDULED (FGS) INTEGRALCONTROLLER

Figure 5 shows the membership functions for PI control system with a fuzzy gain scheduler. The approach taken here is to exploit fuzzy rules and reasoning to generate controller parameters. The triangular membership functions for the proposed fuzzy gain scheduled (FGS) integral controller of the three variables (e_t, ce_t , K_I) are shown in Fig. 5, where frequency error (e_t) and change of frequency error (ce_t) are used as the inputs of the fuzzy logic controller. K_{Ii} is the output of fuzzy logic controller. Considering these two inputs, the output of gain K_{Ii} is determined. The use of two input and single output variables makes the design of the controller very straightforward. A membership value for the various linguistic variables is calculated by the rule given by

$$\mu(e_t, ce_t) = \min\,[\mu(e_t), \mu(ce_t)] \quad (19)$$

The equation of the triangular membership function used to determine the grade of membership values in this work is as follows:

$$\mathrm{A(x)} = \frac{(b-2|X-a|)}{b} \quad (20)$$

Where A(x) is the value of grade of membership, ‘b’ is the width and ‘a’ is the coordinate of the point at which the grade of membership is 1 and x is the value of the input variables. The control rules for the proposed strategy are very straightforward and have been developed from the viewpoint of practical system operation and by trial and error methods.

The fuzzy rule base for the FGS integral controller is shown in Table I. The membership functions, knowledge base and method of defuzzification determine the performance of the FGS integral controller in a multi-area power system as shown in (21).

$$K_I = \frac{\sum_{j=1}^{n}\mu_j u_j}{\sum_{j=1}^{n}\mu_j} \quad (21)$$

Table1. Fuzzy rule base for FGS controller

ce\e	NB	NS	Z	PS	PB
NB	PB	PB	PB	PS	Z
NS	PB	PB	PS	Z	NS
Z	PB	PS	Z	NS	NB
PS	PS	Z	NS	NB	NB
PB	Z	NS	NB	NB	NB

VI. SIMULATIONRESULTS

To demonstrate the usefulness of the proposed controller, computer simulations were performed using the MATLAB SIMULINK environment under different operating conditions.

The system performances with FGS-AGC including TCPS and OFG- AGC including TCPS are shown in Fig. 6 and Fig7,Fig8. The system performances without TCPS unit are also shown in the same figures.

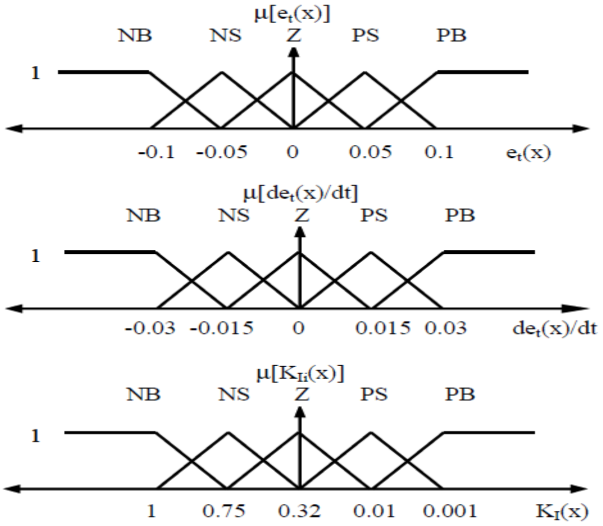
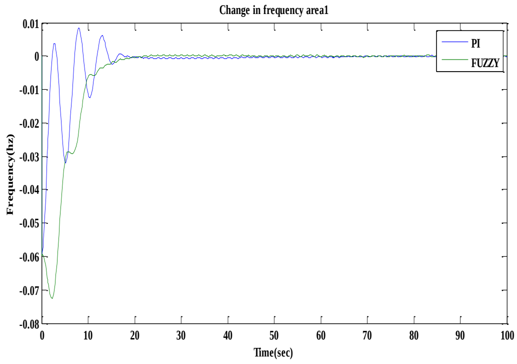


Fig5: Membership functions for the fuzzy variables

for different step load increase is applied to each area (ΔP_{L1}=0.01 pu MW & ΔP_{L2}=0.015 pu MW). It is seen from Fig. 4 that, the tie-line power deviation are more reduced with the FGS-AGC including TCPS than the OFG-AGC including TCPS. Performance of the tie-line power deviation without TCPS is also shown in the same figure. It can be observed from Fig.6&7 that with the addition of FGS-AGC and TCPS units, system frequency deviation reduced significantly and responses have become much smoother. Further, the peak deviations have reduced to a great extent and settling time is less. Though TCPS unit is placed in area-1, performance of system frequency deviations in both areas is also improved with OFG-AGC with TCPS compared to without TCPS. As each area is loaded by the different load increase, each area adjusts their own load and FGS integral controllers of both the loaded areas determine the integral gain Ki to a scheduled value to resotore the frequency to its nominal value. Thus, the damping of the system frequency is not satisfactory in the case with the OFG-AGC including TCPS, but the proposed FGS-AGC including TCPS significantly improves the system performances. In the light of the above facts, it may be concluded that, a coordinated FGS-AGC and TCP Scombination is very effective in wiping out the oscillations in area frequencies and tie-power oscillations following momentary deflections in the load, improving the LFC of multi-area power systems.

Area1



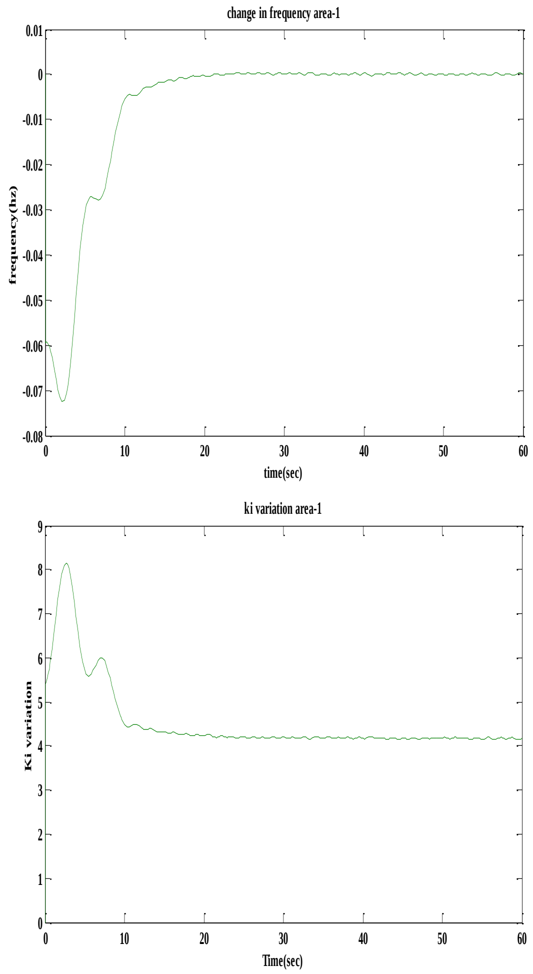
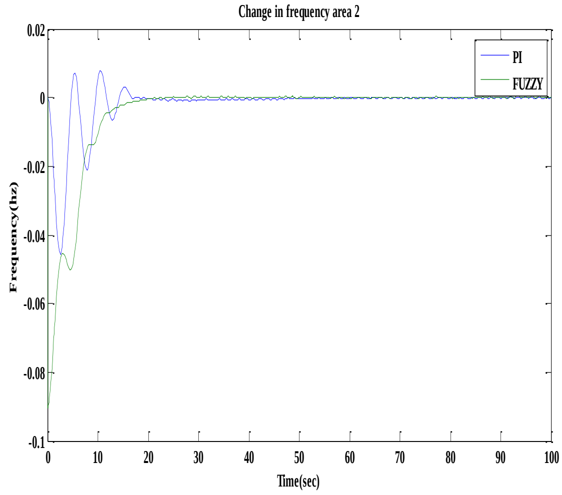


Fig6: System performances for a step load increase ΔP_{L1}=0.01 pu MW in area-1

VII. CONCLUSIONS

The LFC performance of a two-area interconnected power system was investigated in the presence of a coordinated AGC and TCPS combination. Online adaptation of Fuzzy controller gain associated with TCPS simulated at different operating conditions. it is observed from the simulations the fuzzy controller resulted in better transient and steady state response conventional PI controller .

Area 2



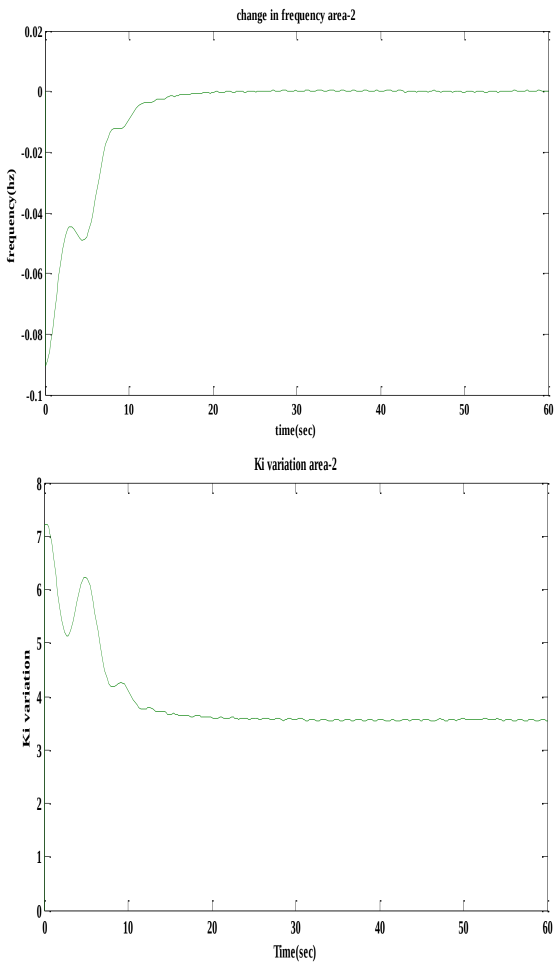


Fig7: System performances for a step load increase ΔPL1=0.015 pu MW in area-2

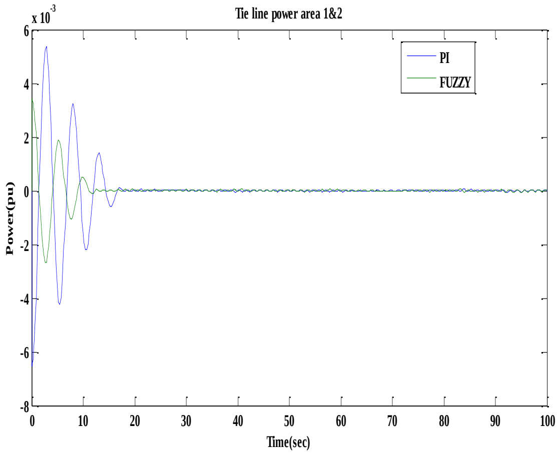


Fig8: Performances of tie power deviation for a step load increase ΔPL1=0.01 pu MW in area-1 & ΔPL2=0.015 pu MW in area-2

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