TIE LINE POWER OSCILLATION
CONTROL IN AN INTERCONNECTED
SYSTEM USING TWO LAYERS FUZZY
LOGIC CONTROLLERS WITH UNIFIED
POWER FLOW CONTROL

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ABSTRACT
This paper focuses on systematic approach towards damping the tie-line power oscillations in an interconnected thermal power plant using Unified Power Flow Controller (UPFC) with two layer fuzzy logic controller (FLC). Conventionally, Automatic Generation Control (AGC) is carried out by primary governor control and secondary Proportional-Integral (PI) controller. PI controller helps to damp out tie-line power and frequency oscillations when subjected to unit step load disturbance. UPFC based damping controller helps to stabilize the tie-line power oscillations of power system. The simulation indicates reduced frequency and tie-line power transient with much faster settling time is obtained by using UPFC along with two layer fuzzy logic controller.

Key words: Automatic Generation Control, Proportional-Integral Controller, Unified Power Flow Controller, fuzzy logic controller.


1. INTRODUCTION
System load changes in an interconnected power system leads to oscillations in frequency and mismatches in scheduled power interchange between the areas. AGC
helps to damp out the frequency oscillations and match the power flow between the areas within predetermined limits [1-3]. AGC scheme has two main control loops namely, primary control and secondary control [1]. During load variations, the primary speed governor control generation, to match with the demand. With the help of speed controller, various generators in the control area track the load variations and share the load in proportion to their capacities. The secondary controller will fine tune the frequency and tie line power. As per Cohn control strategy, the power flow control among the areas becomes a joint undertaking for the control areas [4].

The control areas may contain thermal, hydro, nuclear or gas turbine plant. The inter connection between these areas of any combination is made by tie line.

In this paper, two area thermal power systems are considered. Depending upon the turbine type, the primary control loop responds within few seconds. Though, primary AGC match generation with demand, there will be a dip in frequency. The speed changer setting control by secondary controller is used to resets the error to zero in few minutes. This fine adjustment carried out through integral action by controlling the speed changer setting is considerably slower and goes into action only after the primary control loop has completed its job [1-3].

Mostly as secondary controller, PI controller is employed [4-9]. The PI controller is tuned using various techniques [5-8]. Further improvement in the tie line power flow is achieved using Flexible AC Transmission System (FACTS) devices. The Superconducting Magnetic Energy Storage (SMES) [15] appreciably improves the frequency oscillations but the tie line power variations are not much improved [16]. The tie line power oscillations are much damped out using the Static Synchronous Series Compensator (SSSC) [14] [17]. The Unified Power Flow Controller (UPFC) [18-20] is used in this paper for damping the tie line power oscillations.

This paper describes about two area thermal power in section 2. Two layer fuzzy logic Controller and its tuning are explained in section 3. The modeling of UPFC and its connection with two area thermal power system is furnished in section 4. The performance of UPFC along with FLC controller is described in section 5.

2. MODEL OF TWO AREA THERMAL PLANT – PRIMARY CONTROL

2.1. Speed Governing System
Speed-governor in thermal power plant controls the turbine speed with the help of fly ball and speed Changer mechanism. The steam input valve to the turbine is controlled by speed governor. The speed control in turn controls the active power output of the system. During load variations, by controlling the steam the real power is made to match with the demand. The governor indirectly measures the mismatch between generation and demand by sensing the change in frequency. Though, primary AGC match generation with demand, there will be error in frequency. Fine tuning of frequency is carried out by secondary controller which in turn controls the speed changer setting.

2.2. Hydraulic Valve Actuator
Very large mechanical forces are needed to position the valve against the high steam pressure inlet to turbine. These forces are obtained via hydraulic amplifier
2.3. Turbine-Generator Response
The prime mover driving a generator unit is a steam turbine of thermal power plant. The turbine power is directly proportional to the flow of the steam. Here, a non-reheat type turbine is used. It relates the position of the valve that controls the emission of steam into turbine to the power output of the turbine. The turbine power output is given as the input to the generator which in turn provides electrical power to the power system.

2.4. Tie-line
Practically, all power systems are tied together with neighbouring areas. The problem of load-frequency control becomes a joint undertaking in controlling the power flows on the inter-ties. In this paper, a two-area thermal power plant is connected by a tie-line as shown in Fig. 1.

The interconnected thermal power plant is subjected to a unit step load disturbance, the system frequency and tie-line power deviations are controlled.

![Figure 1 Block Diagram of Two Area Interconnected Power Plant](image)

Primary AGC mathematical model of a two-area thermal power plant is used for simulation as shown in Fig. 2.

3. DEVELOPMENT TWO LAYER FUZZY LOGIC CONTROLLER

3.1. PI controller
Conventionally, PI controller acts as secondary controller which sets the turbine reference power of each area. When a two-area thermal power plant is subjected to a unit step load disturbance, the variation in one area affects the other area via tie-line in terms of frequency and tie-line power. These two variations have to be combined
linearly as one signal which serves as the input to the secondary PI controller. The input of each controller is called as Area Control Error (ACE).

The ACE adopted in two area system is developed by Cohn [4]. The proportional control is used for increasing the loop gain to make the system less sensitive to load disturbance. The integral control is used to eliminate steady state errors [5]. The secondary PI controller resets both the frequency and tie-line power variations back to nominal values.

According to Cohn control strategy [4], all the areas in the network should control both tie-line and frequency deviations when subjected to step load disturbance.

3.2. Fuzzy Logic Controller

Fuzzy logic systems belong to the category of computational intelligence technique. One advantage of the fuzzy logic over the other forms of knowledge-based controllers lies in the interpolative nature of the fuzzy control rules. The overlapping fuzzy antecedents to the control rules provide transitions between the control actions of different rules. Because of this interpolative quality, fuzzy controllers usually require far fewer rules than other knowledge-based controllers.

![Figure 3 Block Diagram of Fuzzy Logic Controller](image)

A fuzzy system knowledge base consists of a fuzzy if then rules and membership functions characterizing the fuzzy sets. The block diagram and architecture of fuzzy logic controller is shown in fig 4. Membership Function (MF) specifies the degree to which a given input belongs to a set. Here triangular membership function have been used to explore best dynamic responses namely Negative Big (NB), Negative Small (NS), zero (ZE), Positive Small (PS), Positive Big (PB). Fuzzy rules are conditional statement that specifies the relationship among fuzzy variables. These rules help to describe the control action in quantitative terms and have been obtained by examining the output response to the corresponding inputs to the fuzzy controllers.

Defuzzification, to obtain crisp value of FLC output is done by centre of area method. The fuzzy rules are designed as shown in Table 1.

3.2 Design of a Two Layer Fuzzy Logic Controller

The aim of introducing two layered fuzzy logic controller [16] is to eliminate the steady state error and improve the performance of the output response of the system under study. The proposed control scheme is shown in Fig. 5. The controller consists
Tie Line Power Oscillation Control In An Interconnected System Using Two Layers Fuzzy Logic Controllers with Unified Power Flow Control

of two “layers”: a fuzzy pre-compensator and a usual fuzzy PI controller. The error $e(k)$ and change of error $\Delta e(k)$ are the inputs to the pre compensator.

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Table 1 Fuzzy Logic Rules for LFC

![Basic Structure of Fuzzy Pre-Compensated Pi Controller](image)

The aim of introducing two layered fuzzy logic controller [16] is to eliminate the steady state error and improve the performance of the output response of the system under study. The proposed control scheme is shown in Fig. 5.

The controller consists of two “layers”: a fuzzy pre-compensator and a usual fuzzy PI controller. The error $e(k)$ and change of error $\Delta e(k)$ are the inputs to the pre compensator. The output of the pre-compensator is $\mu(k)$.

The pre-compensation scheme [18, 19] is easy to implement in practice, since the existing PI control can be used without modification in conjunction with the fuzzy pre-compensator as shown in Fig 6. The procedure of rule generation consists of two parts (i) learning of initial rules which determines the linguistic values of the consequent variables. (ii) fine tuning adjusts the membership function of the rules obtained by the previous step. The structure of the pre-compensation rule is written as If $e$ is $Le$, and $\Delta e$ is $L\Delta e$ then $C$ is $Lc$ where $Le$, $\Delta Le$ and $Lc$ are linguistic values of $e$, $\Delta e$, and $c$ respectively. Each fuzzy variable is assumed to take 5 linguistic values $Le, \Delta Le, Lc = \{\text{NB, NS, ZE, PS, and PB}\}$. This leads to fuzzy rules, if the rule base is complete.
The proposed two layered FL Ccontroller compensates these defects and gives fast responses with less overshoot and/or undershoot. Moreover, the steady state error reduces to zero. The first layer fuzzy pre-compensator is used to update and modify the reference value of the output signals to damp out the oscillations. The fuzzy states of the input and output all are chosen to be equal in number and use the same linguistic descriptors as \( N = \text{Negative}, Z = \text{Zero}, P = \text{Positive} \) to design the new fuzzy rules. The fuzzy logic rules for pre-compensator are presented in Table 2.

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The second layer which is known as feedback fuzzy logic control reduces the steady state error to zero.

**4. UNIFIED POWER FLOW CONTROLLER**

Unified Power Flow Controller (UPFC), the FACTS device is a fast acting compensator. It controls the power system parameters in terms of voltage, phase angle and impedance. It can be used not only for power flow control but also for stabilizing the power system [18]. UPFC improves both steady state and dynamic performance of the system. UPFC with damping controller further improves the dynamic performance of the system [19]. UPFC with damping controller is connected in series with the transmission line or in a tie-line. It provides damping of tie-line power oscillations with fast control of voltage in maintaining the stability of the system. Schematic block of UPFC based damping controller is shown in Fig. 5.
UPFC comprises of high pass filter known as signal wash-out which prevents steady changes in frequency by modifying input parameters. The wash out time constant $T_w$ is not sensitive and could lie in the range of 1s to 20s. $T_w$ of 10s is taken as wash-out time constant. The phase compensator is a lead compensator whose time constants are chosen so that the system is fully compensated. The damping controller parameters are determined by means of phase compensation technique [19]. The UPFC based damping controller relates

5. SIMULATION RESULTS
The two area thermal power plant shown in Fig. 2 is developed using MATLAB / Simulink, and is subjected to a unit step load disturbance in area 1 alone. The response shows steady state error pertaining to oscillations in frequency and tie-line power.

Later, secondary PI controller, is discussed in section 3.1 is included to the two-area thermal power plant as shown in Fig. 2. The interconnected thermal plant is subjected to a unit step load disturbance in area 1 alone. The response with secondary PI controller provides better result with reduced peak overshoot attaining zero steady state error, when compared with the open loop response as shown in Fig. 8.

Further, the secondary PI controller is replaced by VSS controller as shown in Fig. 2 is simulated. The response of the plant with secondary PI controller and FLC controller is compared and furnished in Fig. 9.
FLC controller relatively reduces the transients in frequency and tie-line power with zero steady state error at faster rate.

From the Fig. 9, it shows the oscillation in tie-line power still persists for a while. Therefore, FLC controller with UPFC damping controller is included in two-area thermal power plant subjected to step load disturbance in area 1 alone as its comparison response is shown with VSS controller in Fig. 10.

![Figure 9 Change In Tie Line Frequency](image)

![Figure 10 change in area 2 frequency](image)

6. CONCLUSION

The systematic procedure for improving the system dynamic performance of an interconnected thermal power plant is presented in this paper. Two-area thermal power plant when subjected to unit step load disturbance lead to frequency and tie-line power oscillations with steady state error and transient overshoots. The transient oscillation in frequency and tie-line power is reduced using ZN tuned secondary PI controller. In secondary PI controller, a high proportional gain results in a large change in the output during the steady state and high integral gain results overshoot during the transient period.

Thus, it is overcome by using FLC controller. As FLC controller switches in between P and PI controller, it helps in achieving improved system frequency and tie-line power response. But, the transient tie-line power oscillation persists for a while which is not desirable. Therefore, UPFC connected in interconnected tie-line helps to stabilize the system tie-line power oscillations at a faster rate. The two-area thermal power plant with FLC controller and UPFC yields much better faster response in terms of reduced peak overshoot, controls the transient frequency oscillation and reduces the tie-line power oscillations with zero steady state error.

LIST OF SYMBOLS
- $R_1, R_2$: Speed regulation of thermal system; $= \text{2Hz/pu MW}$
- $TH$: Hydraulic amplifier time constant; $= 0.08$ sec
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- $TT$: Non-reheat turbine time constant; = 0.3 sec
- $KP$: Power system gain constant; = 100
- $TP$: Power system time constant; = 20 sec
- $PD_1, PD_2$: Change in load demand power in area1 and area2 respectively; =0.01 p.u.
- $A12$: Synchronizing power coefficient; = -1
- $\delta_{12}$: Operating voltage angle of the tie-line; = 450
- $T$: Synchronizing coefficient; =10% of area capacity = 0.1 Cos $\delta_{12}$ = 0.0707
- $B1, B2$: Frequency bias constant; = 0.425 p.u. MW/Hz
- $Pref_1, Pref_2$: Change in reference power in p.u;
- $P_g$: Change in governor power of the thermal system in p.u;
- $PH$: Change in hydraulic valve power of the thermal system in p.u;
- $PT$: Change in turbine power of the thermal system in p.u;
- $f1, f2$: Change in frequency of area 1 and 2 respectively in Hz;
- $P_{tie12}$: Change in tie-line power in p.u;
- $s$: Laplace operator;
- $K$: Constants of the UPFC based damping controller;

**REFERENCE**


