# Load Frequency Control of an Interconnected Power System under Unequal Loading

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***Abstract:*** *This paper present the use of Artificial Intelligent and conventional (PI & PID) controller to study the load frequency control of an interconnected power system under unequal loading. Unequal loading means the percentage change in load side power is not same. In the proposed scheme, control methodology developed using Artificial Neural Network and conventional controller for thermal-thermal and hydro thermal power system. The control strategies guarantee that the steady state error of frequencies and nonchalant interchange of tie-line power are maintained in given tolerance limitations. The performance of these controllers is simulated by using MATLAB/SIMULINK. A comparison of conventional controller and ANN controller based approaches shows the transcendence of proposed ANN based approach upon conventional controller. The simulation results are tabulated as a relative performance in view of settling time and peak overshoot.*

***Keywords:*** *Load Frequency Control (LFC), ANN controller, Conventional (PI & PID) Controller, Area Control Error, Tie-Line.*

## I. INTRODUCTION

In power system operation and control for procuring plenty and reliable electric power with good power quality, Load Frequency Control is a very important issue. An interconnected power system can be considered as being divided into control areas, all generators are assumed to form a coherent group [1]. In the steady state operation of power system, the load demand is increased or decreased in the form of kinetic energy stored in the generator prime over set, which results the variation of speed and frequency accordingly. Therefore, the control of load frequency is essential to have safe operation of the power system [2]-[4]. Load Frequency Control (LFC) is defined as, the regulation of power output of controllable generators within a given area in response to change in system frequency, tie-line loading, or a relation of these to each other, so as to sustain the schedules system frequency and /or the established interchange with other areas within predetermined limits [5]. Therefore, a control strategy is needed that not only maintains constancy of frequency and desired tie-power flow but also achieves zero steady state error and inadvertent interchange. Among the various types of load frequency controllers, the most widely employed is the conventional proportional integral (PI) controller. The PI controller is very simple for implementation and gives better dynamic response. But their performances deteriorate when the complexity in the system increases due to disturbances like load variation boiler dynamics [6-7]. Therefore, there is need of controller which can overcome this problem.

The Artificial Intelligent Controller like Neural Network Control approach is more suitable in this respect [8]. The silent Feature of these techniques is that they provide a model free description of control systems and do not require model identification. An ANN controller which is an advance adaptive control configuration is used because the controller provides faster control than the other [9].

An artificial neural network controller for two area interconnected hydro thermal and thermal-thermal plant is proposed to enhance the performance of conventional controller (PI &PID) and neural controller sliding surface is included. The sliding concept arises due to variable structure concept. The objective of VSC has been greatly extended from stabilization to other control functions. The most distinguished feature of VSC is its ability to result in very robust control systems, in many cases it results invariant control system. The term invariant means that the system is completely insensitive to parametric uncertainty and external disturbances [10-11].

## II.THE INVESTIGATED POWER SYSTEM

The detailed block diagram modelling of two area thermal-thermal and hydro thermal power system for load frequency control investigated is shown in Fig 1 and Fig 2. An enhanced power system can be echeloned in to a number of load frequency control areas interconnected by means of tie lines, without loss of universality one can consider a two area case connected by single tie line.

The control objectives are as follows

(i) Each control area as for as possible should supply its own load demand and power transfer through tie line should be on mutual agreement.

(ii) Both control areas should controllable to the frequency control. In an isolated control area case the incremental power was considered for by the rate of increase of stored kinetic energy and increase in area load caused by increase in frequency. Hence a tie line carries power in or out of an area, this fact must be considered for in the incremental power balance equation of each area [12-14].

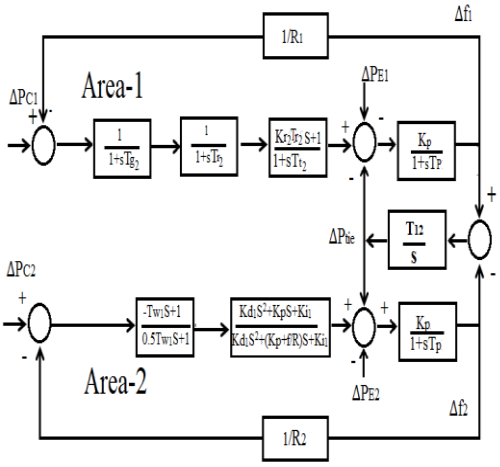


**Figure1: Block diagram of two area thermal- thermal power system**

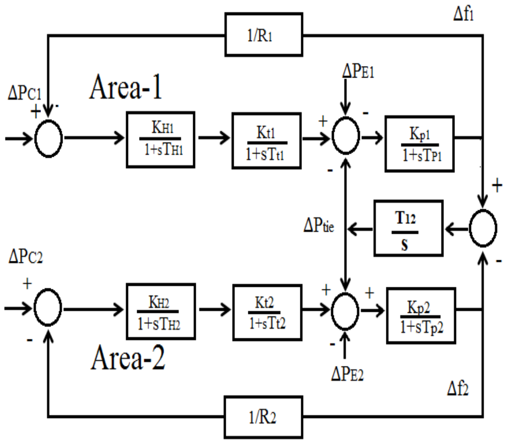


**Figure2: Block diagram of two area hydro-thermal reheat power system**

The transfer functions of different blocks used in power system model are given below. Transfer function (T/F) of hydraulic turbine is

$$\frac{-T_w.s+1}{0.5T_w.s+1}$$

T/F of hydraulic governor is

$$\frac{K_d.s^2+K_p.s+K_i}{K_d.s^2+(K_p+f/R_2).s+K_i}$$

T/F of governor (thermal plant) is

$$\frac{1}{T_g.s+1}$$

T/F of steam turbine is

$$\frac{K_r.T_r.s+1}{T_r.s+1}$$

T/F of re-heater is

$$\frac{1}{T_t.s+1}$$

And transfer function of generator load is

$$\frac{K_p}{T_p.s+1}$$

2.1 MODELLING OF TIE-LINE

The power transfer equation through tie line is ,

$$P_{12} = \frac{|V_1||V_2|}{x}\sin(\delta_1 - \delta_2) \qquad (1)$$

Considering area 1 has surplus power and transfers to area 2 $P_{12} =$ Power transferred from area 1 to 2 through tie line.

$$P_{12} = \frac{|V_1|.|V_2|}{X_{12}}\sin(\delta_1 - \delta_2) \qquad (2)$$

Where

$\delta_1$ and $\delta_2$ = Power angles of end voltages $V_1$ and $V_2$ of equivalent machine of the two area respectively.

$X_{12}$ = reactance of tie line.

The order of the subscripts indicates that the tie line power is define positive in direction 1 to 2.

For small deviation in the angles and the tie line power changes with the amount i.e. small deviation in $\delta_1$ and $\delta_2$ changes by $\Delta\delta_1$ and $\Delta\delta_2$ ,

Power $P_{12}$ changes to $P_{12} + \Delta P_{12}$

Therefore, Power transferred from Area 1 to Area 2 as given in is

$$\Delta P_{12}(s) = \frac{2\pi T^0}{s}(\Delta f_1(s) - \Delta f_2(s)) \qquad (3)$$

$T^0$ = Torque produced

The above equation can be represented as in Figure3

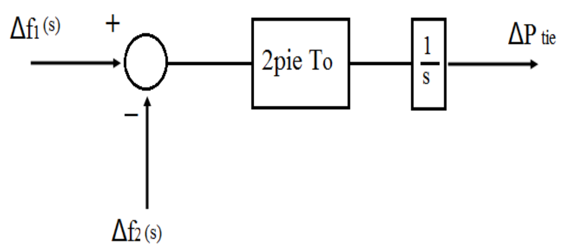


**Figure3: Block diagram representation of a tie line**

Tie- line bias control is used to eliminate steady state error in frequency in tin-line power flow. This states that the each control area must allow their part to frequency control in addition for taking care of their own net interchange.

Let ACE1 = area control error of area 1

ACE2 = area control error of area 2

In this control, ACE1 and ACE2 are made linear combination of frequency and tie line power error [11].

$$ACE1 = \Delta P_{12} + b_1 \Delta f_1$$

$$ACE2 = \Delta P_{21} + b_2 \Delta f_2$$

Where the constant $b_1 \,\&\, b_2$ are called frequency bias of area 1 and area 2 respectively.
Now

$$\Delta PR1 = -K_{i1} \int_0^t (\Delta P_{12} + b_1 \Delta f_1) dt \qquad (6)$$

$$\Delta PR2 = -K_{i2} \int_0^t (\Delta P_{21} + b_2 \Delta f_2) dt \qquad (7)$$

Taking Laplace transform of the above equation we get

$$\Delta PR1_{(s)} = \frac{-K_{i1}}{s} \int_0^t [\Delta P_{12}(s) + b_1 \Delta f_1(s)] \qquad (8)$$

$$\Delta PR2_{(s)} = \frac{-K_{i2}}{s} \int_0^t [\Delta P_{21}(s) + b_2 \Delta f_2(s)] \qquad (9)$$

The step changes $\Delta PD_1$ and $\Delta PD_2$ are applied simultaneously in control area 1 and 2 respectively. When steady state conditions are reached, the output signals of all integrating blocks will be constant and their input signal must become zero. i.e.

$\Delta P_{12} + b_1 \Delta f_1 = 0$ (Input of integrating block $\frac{-K_{i1}}{s}$ ) (10)

$\Delta P_{21} + b_2 \Delta f_2 = 0$ (Input of integrating block $\frac{-K_{i2}}{s}$ ) (11)

$\Delta f_1 - \Delta f_2 = 0$ (Input of integrating block $-\frac{2\pi T_{12}}{s}$ (12)

$\Delta P_{12} = \Delta P_{tie,1}$ and $\Delta P_{21} = \Delta P_{tie,2}$

Therefore $\frac{\Delta P_{tie,1}}{\Delta P_{tie,2}} = -\frac{\Delta P_{12}}{\Delta P_{21}} = -\frac{1}{a_2}$ = constant (13)

Hence $\Delta P_{tie,1} = \Delta P_{tie,2} = 0$

$\Delta PR1 = \Delta PR2,$

And $\Delta f_1 = \Delta f_2 = 0$

Thus, under steady condition change in the tie-line power and frequency of each area is zero. This is achieved by integration of ACEs in the feedback loops of each area [12-14]. Control methodology used (PI, PID & ANN) is mentioned in the next preceding sections.

**Conventional Integral Controller**

When an integral controller is added to each area of the uncontrolled plant in forward path the steady state error in the frequency becomes zero. The task of load frequency controller is to generate a control signal u that maintains system frequency and tie-line interchange power at predetermined values.
The block diagram of PI controller is shown in Fig 4 where, the control input

$$ui = -K_1 \int_0^t (ACEi) dt = -Ki \int_0^\tau (\Delta P_{tie,1} + bi \Delta f_1) dt \qquad (14)$$

Conventional proportional plus integral controller (PI) provides zero steady state frequency deviation, but it exhibits poor dynamic performance (such as more number of oscillation and more settling time), especially in the presence of parameters variation and non-linearity.

In PI controller proportionality constant provides simplicity, reliability, directness etc. The disadvantage of offset in it is eliminated by integration but this system will have some oscillatory offset.

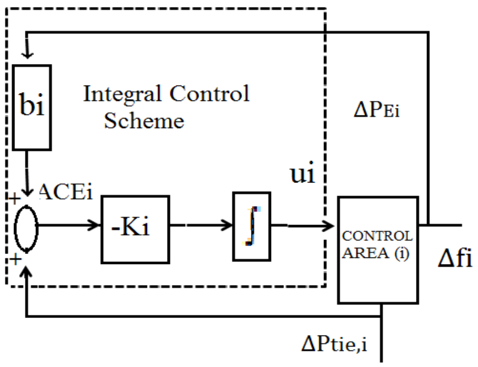


**Figure4: Conventional PI controller**

## III.ARTIFICIAL NEURAL NETWORK (ANN) CONTROLLER

ANN is information processing system, in this system the element called as neurons process the information. The signals are transmitted by means of connecting links. The links process an associated weight, which is multiplied along with the incoming signal (net input) for any typical neural net [15-17]. The output signal is obtained by applying activations to the net input. The field of neural networks covers a very broad area.

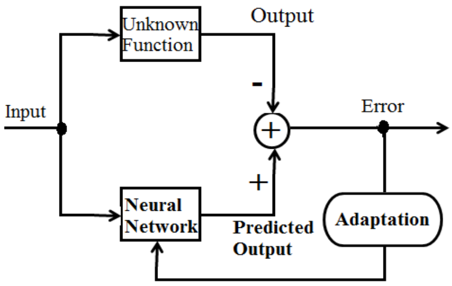


**Figure5: Neural network as function approximataor**

Neural network architecture the multilayer perceptron as unknown function are shown in Fig 5, which is to be approximated. Parameters of the network are adjusted so that it produces the same response as the unknown function, if the same input is applied to both systems. The unknown function could also represent the inverse of a system being controlled; in this case the neural network can be used to implement the controller.

## IV. NARMA-L2 CONTROL

The ANN controller architecture employed here is nonlinear auto regressive model reference adoptive controller. This controller requires the least computation of the three architectures. This controller is simply a rearrangement of the neural network plant model, which is trained offline, in batch form. It consists of reference, plant output and control signal. The controller is adaptively trained to force the plant output to track a reference model output. The model network is used to predict the effect of controller changes on plant output, which allows the updating of controller parameters. In the study, the frequency deviations, tie-line power deviation and load perturbation of the area are chosen as the neural network controller inputs.

The outputs of the neural network are the control signals, which are applied to the governors in the area. The data required for the ANN controller training is obtained from the designing the reference model neural network and applying to the power system with step response load disturbance. NARMA-L2 controller is shown in Fig 6.

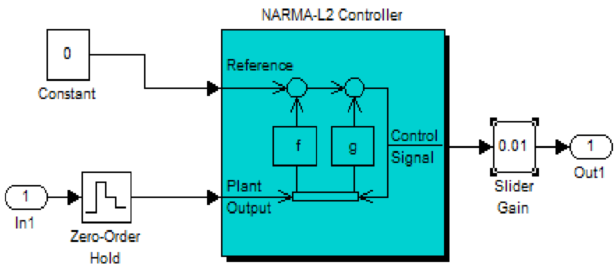


**Figure6: NARMA-L2 Controller**

After a series of trial and error and modifications, the ANN architecture provides the best performance. It is a three-layer perceptron with five inputs, 13 neurons in the hidden layer, and one output in the ANN controller. Also, in the ANN plant model, it is a three-layer perceptron with four inputs, 10 neurons in the hidden layer, and one output. The activation function of the networks neurons is trainlm function. 300 training sample has been taken to train 300 no of epochs. The proposed network has been trained by using the learning performance. Learning algorithms causes the adjustment of the weights so that the controlled system gives the desired response.

## V. SIMULATION AND RESULTS

In this work, Thermal-Thermal and Thermal-Hydro interconnected power system are considered with conventional controller and ANN controller to illustrate the performance of load frequency control. The parameters are used for simulation are as given appendix. The various Simulink models developed are shown in the Fig 7 to Fig 11. Refer to Simulink model frequency deviation plot for thermal-thermal and thermal-hydro cases are obtained separately for unequal load change in system frequency and tie-line power is shown in Fig 12 to Fig 15 respectively. With unequal load change in both cases with conventional controller and ANN controller, the steady state error is minimising to zero. Settling time and peak overshoot in transient condition for system frequency are given in table 2 to table 4 respectively.

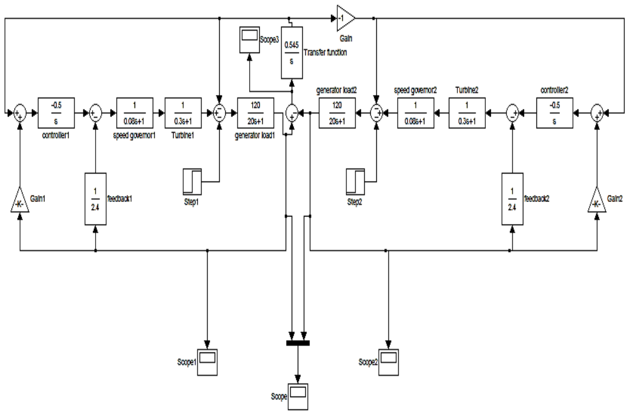

**Figure7: Simulink Model of the Two Area Thermal-Thermal Interconnected with PI Controller**

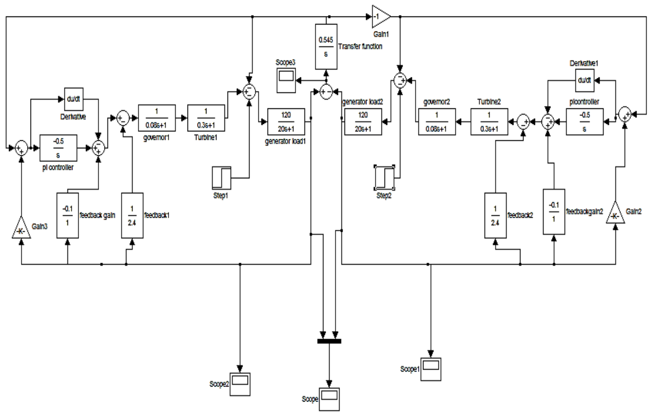

**Figure8: Simulink Model of Two Area Thermal-Thermal Interconnected with PID Controller**

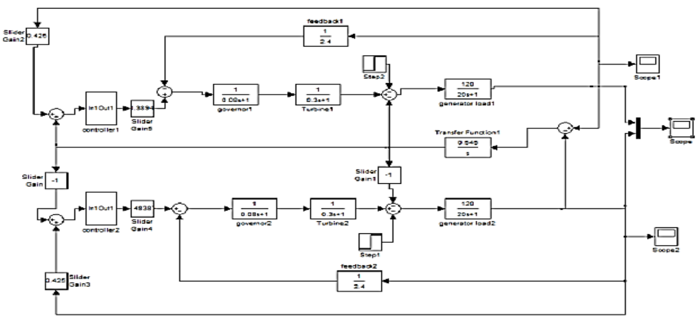

**Figure9: Simulink Model of Two Area Thermal- Thermal Interconnected with ANN Controller**

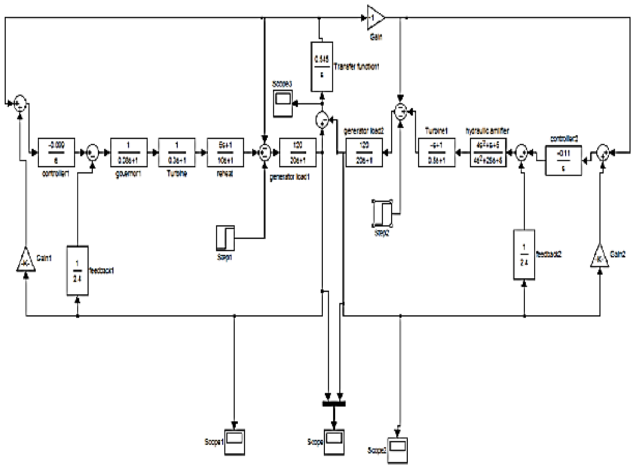

**Figure10: Simulink Model of Two Area Interconnected Hydro-Thermal Reheat Plant with PI Controller**

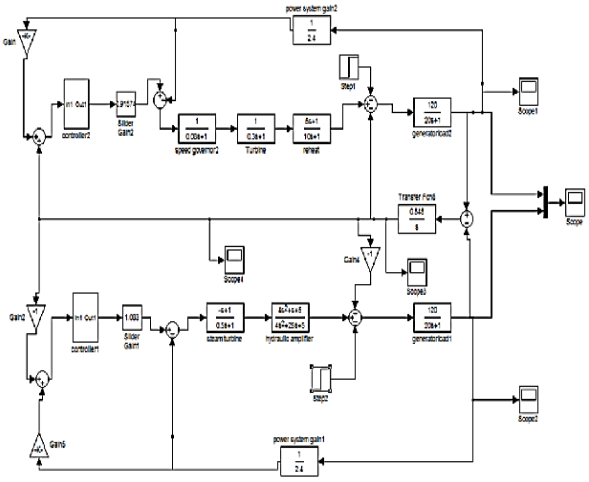

**Figure11: Simulink Model of Two Area Interconnected Hydro-Thermal Reheat Plant with ANN Controller**

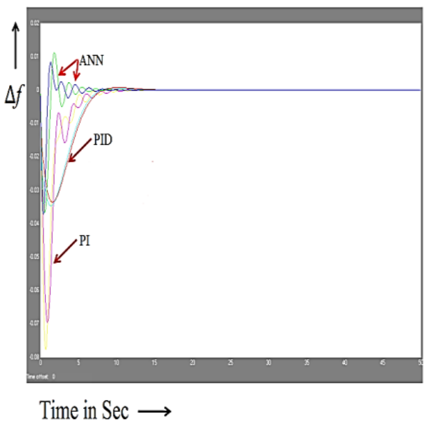


**Figure12: Response of PI, PID and ANN Controller with Two Area Thermal –Thermal Plant (1%-2%)**

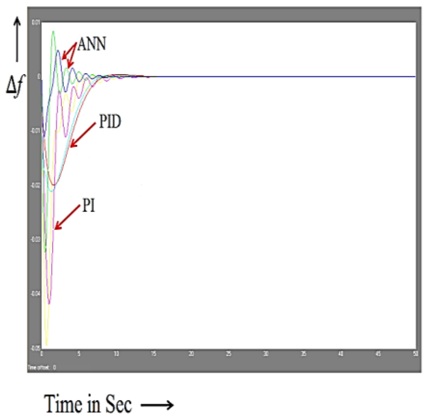


**Figure13: Response of PI, PID and ANN Controller with Two Area Thermal-Thermal Plant (2%-3%)**

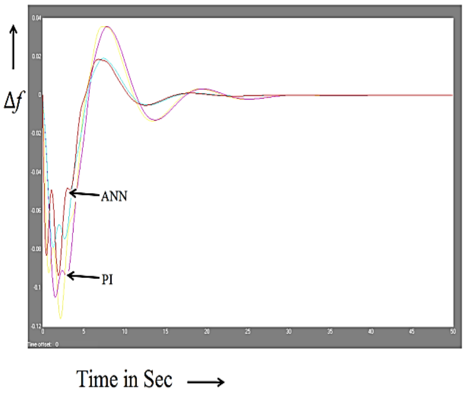


**Figure14: Response of Hydro-Thermal Reheat Plant with PI and ANN Controller (1%-2%)**

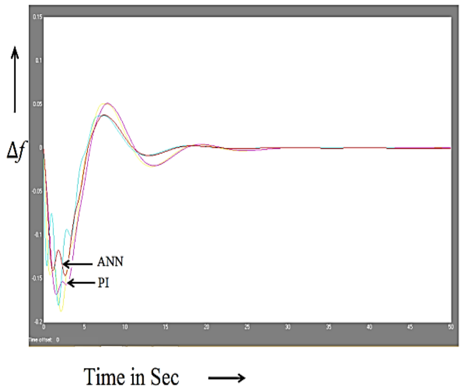


**Figure15: Response of Thermal-Hydro Reheat Plant with ANN and PI Controller (2%-3%)**

## VI. CONCLUSIONS

With unequal load variation (1%-2% & 2%-3%) in power system the following results are obtained the intelligent control approach with inclusion of slider gain provides better dynamic performance and reduces the oscillations of the frequency deviation and the tie-line power flow in each area in thermal-thermal and thermal-hydro combination.

**Table1: Comparative Study of Settling Time for Thermal-Thermal Plant**

| Controller | Steady State Error | Settling Time | |
|---|---|---|---|
| | | $\Delta f_1$ | $\Delta f_2$ |
| PI (1%-2%) | 0 | 25 | 26 |
| PI (2%-3%) | 0 | 26 | 25 |
| PID (1%-2%) | 0 | 21 | 20 |
| PID (2%-3%) | 0 | 20 | 22 |
| ANN (1%-2%) | 0 | 16 | 15 |
| ANN (2%-3%) | 0 | 16 | 17 |

**Table2: Comparative Study of Peak Overshoot for Thermal-Thermal Plant**

| Controller | Peak Overshoot in pu | |
|---|---|---|
| | Area1 | Area 2 |
| PI (1%-2%) | -0.0416 | -0.048 |
| PI (2%-3%) | -0.068 | -0.076 |
| PID (1%-2%) | -0.019 | -0.025 |
| PID (2%-3%) | -0.032 | -0.033 |
| ANN (1%-2%) | -0.01 | -0.03 |
| ANN (2%-3%) | -0.036 | -0.037 |

**Table3: Comparative Study of Settling Time for Thermal-Hydro Reheat Plant**

| Controller | Steady State Error | Settling Time | |
|---|---|---|---|
| | | $\Delta f_1$ | $\Delta f_2$ |
| PI(1%-2%) | 0 | 40 | 40 |
| PI(2%-3%) | 0 | 41 | 42 |
| ANN(1%-2%) | 0 | 25 | 26 |
| ANN (2%-3%) | 0 | 26 | 26 |

**Table4: Comparative Study of Peak Overshoot for Thermal-Hydro Plant**

| Controller | Peak Overshoot in pu | |
|---|---|---|
| | Area 1 | Area 2 |
| PI (1%-2%) | -0.104 | -0.114 |
| PI (2%-3%) | -0.168 | -0.188 |
| ANN (1%-2%) | -0.078 | -0.092 |
| ANN(2%-3%) | -0.14 | -0.180 |

From the above table it is clear that responses obtained, reveals that ANN controller with sliding gain provides better settling time and peak overshoot performance over conventional controller. Therefore intelligent control approach using ANN concept is more accurate and faster over conventional control scheme even for complex dynamical system.

**APPENDIX**

Parameters are as follows

$f = 60Hz\ R_1 = R_2 = R_3 = R_4 = 2.4Hz / per\ unitMW,\ T_{gi} = 0.08\sec,\ T_{p1} = 20\sec;$

$P_{tie,\max} = 200MW;\ Tr = 10\sec;\ Kr = 0.5,\ H_1 = H_2 = H_3 = H_4 = 5\sec;\ P_{ri} = 2000MW,$

$T_{ti} = 0.3\sec;\ K_{p1} = K_{p2} = K_{p3} = K_{p4} = 120 Hz.p./MW;$

$K_p = 1,\ K_d = 4.0;$

$Ki = 5.0;\ Tw = 1.0\sec;\ Di = 8.33*10^{-3}\ p.uMW / Hz.;\ B_1 = B_2 = B_3 = B_4 = 0.425\ p.u.MW / hz;$

$a_i = 0.545;\ a = 2*Pi*T_{12} = 2*Pi*T_{23} = 2*Pi*T_{34} = 2*Pi*T_{41} = 0.545,\ delP_{di} = 0.01$

$\Delta Pd_1 = 0.01 = 1\%,\ \Delta Pd_2 = 0.02 = 2\%$

$\Delta Pd_3 = 0.03 = 3\%$

Nomenclature

$i$ : Subscript referring to area (i=1,2,3,4)

$f$ : Nominal system frequency

$H_i$ : Inertia constant; $\Delta P_{Di:}$ Incremental load change

$\Delta Pg_i$ : Incremental generation change

$Di = \frac{\Delta P_{Di}}{\Delta fi}$; $T_r$ : Reheat time constant

$T_g$ : Steam governor time constant; $K_r$ : Reheat constant

$T_t$ : Steam turbine time constant;

$B_i$ : Frequency bias constant

$R_i$ : Governor speed regulation parameter

$T_{pi}$ : 2Hi/f*Di, $K_{pi}$ : 1/Di

$K_t$ : Feedback gain of FLC

$T_w$ : Water starting time, ACE: Area control error

$P$ : Power, E: Generated voltage

$V$ : Terminal voltage, $\delta$ angle of the Voltage V

$\Delta\delta$ : Change in angle, $\Delta P$ : Change in power

$\Delta f$ : Change in supply frequency;

$\Delta Pc$ : Speed changer position

$R$ : Speed regulation of the governor

$K_H$ : Gain of speed governor

$T_H$ : Time constant of speed governor

$K_p$ : 1/B=Power system gain

$T_p$ : $2H/Bf_0$=Power system time constant

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