

Artificial Neural Network Based Design of Governor Controller

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Abstract— This paper presents the design of Artificial Neural Network (ANN) based PID controller, to realize fast governor action in a power generation plant. The design technique is applied to single area, two area systems, to tune the parameters of the PID controller. Feed forward neural network architecture is chosen for the design of controller, which is trained by a popular back propagation algorithm. Performance of the proposed ANN based controller, is compared with conventional integral and PID controllers, through dynamic simulation. It is observed that ANN based controller provides better performance, through dynamic simulation show that the neural-network controller has quite satisfactory generalization capability, feasibility and reliability, as well as accuracy in multi area system.

Keywords: Power system, Artificial Neural Network (ANN), PID Controllers and Load Frequency Control (LFC)

I. INTRODUCTION

In electric power generation system disturbances caused by load fluctuations result in changes to the desired frequency value [1]. Load Frequency Control (LFC) is a very important issue in power system operation and control for supplying sufficient and both good quality and reliable power [2]. Power networks consist of a number of utilities interconnected together and power is exchanged between the utilities over the tie-lines by which they are connected [3]. It is therefore important to have some degree of control over the net power flow on the tie-lines [4].

Load Frequency Control (LFC) allows individual utilities to interchange power to aid in overall security while allowing the power to be generated most economically. Large scale power systems are normally composed of control areas or regions representing coherent groups of generators [5].

Area load changes and abnormal conditions lead to mismatches in frequency and scheduled power interchanges between areas [6]–[7]. These mismatches have to be corrected by Governor Control.

The key assumptions in the classical Governor Control problem are

- 1) The steady state frequency error following a step load change should vanish. The transient frequency and time errors should be reduced.
- 2) The static change in the tie power following a step load in any area should be zero, provided each area can accommodate its own load change.
- 3) Any area in need of power during an emergency should be assisted from other areas.

An integral controller provides zero steady state frequency deviation ($\Delta\omega$) but it exhibits poor dynamic performance To improve the transient response, various control techniques, such as linear feedback, optimal control and variable structure control have been proposed. Adaptive controllers with self-adjusting gain settings have also been proposed for the LFC problem [8]–[9].

The ANN is applied to self-tune the parameters The performances of the PID type controller with fixed gain, Conventional integral controller, ANN based PID controller have been compared through MATLAB Simulation results [10].

II. MODELING OF SINGLE AREA AND MULTI ARE POWER SYSTEMS

A. Single Area System Modeling

In Single area system, generation and load demand of one domain is dealt. Any load change within the area has to be met by generators in that area alone through suitable governor action. Thus we can maintain the constant frequency operation irrespective of load change

B. Generator Model

A single rotating machine is assumed to have a steady speed of ω and phase angle δ_0 . Due to various electrical or mechanical disturbances, the machine will be subjected to differences in mechanical and electrical torque, causing it to accelerate or decelerate. We are mainly interested in the deviations of speed, $\Delta\omega$, & and deviations in phase angle $\Delta\delta$, from nominal. This can be expressed in Laplace transform operator notation as

$$\Delta P_{\text{mech}} - \Delta P_{\text{elec}} = M s \Delta\omega \quad (1)$$

Equation (1) can be represented as shown in Figure 1

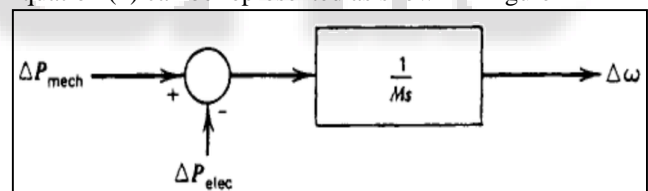


Fig. 1: Relationship between mechanical and electrical power and speed change

C. Load Model

The load on a power system comprises of a variety of electrical devices. Some of them are purely resistive. Some are motor loads with variable power frequency characteristics, and others exhibit quite different characteristics. Since motor loads are a dominant part of the electrical load, there is a need to model the effect of a change in frequency on the net load drawn by the system. The relationship between the changes in load due to the change in frequency is given by

$$\Delta P_L(\text{freq}) = D\Delta\omega \quad (\text{or}) \quad D = \Delta P_L(\text{freq}) / \Delta\omega \quad (2)$$

The net change in Pelec in figure 1 is incorporated in the figure 2

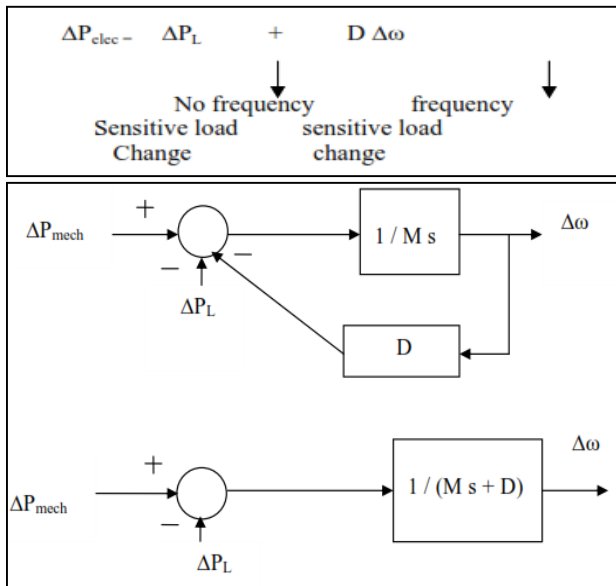


Fig. 2: Block diagram of rotating mass on load as seen by prime-mover output

D. Prime Mover Model

The prime mover driving a generator unit may be a steam turbine or a hydro turbine. The models for the prime mover must take account of the steam supply and boiler control system characteristics in the case of a steam turbine, or the penstock characteristics for a hydro turbine. Here only the simplest prime-mover model, the non-reheat turbine, is considered. The model for a non-reheat turbine shown in figure 3, relates the position of the valve that controls emission of steam into the turbine to the power output of the turbine as shown in figure 4.

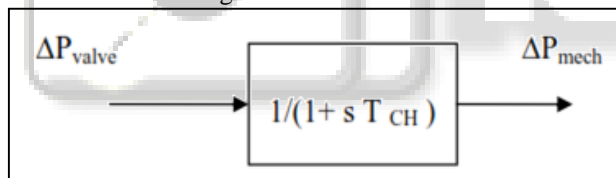


Fig. 3: Prime mover model

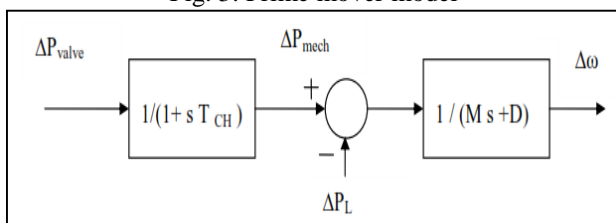


Fig. 4: Prime mover Generator load model

E. Governor Model

When the generator load is suddenly increased the electrical power exceeds the mechanical power input. This power deficiency is supplied by kinetic energy stored in rotating system. The reduction in K.E causes the turbine speed, generator frequency to fall. The change in speed is sensed by turbine governor which acts to adjust turbine input valve to change the mechanical power output to bring the speed to steady state. Basic block representation of speed governing system for steam turbine as represented in figure 5. The steady state characteristics of such a governor is shown below in figure 6

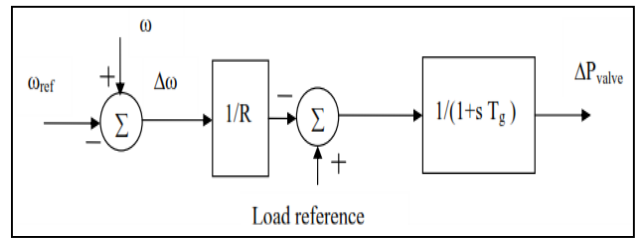


Fig. 5: Block diagram of governor with droop

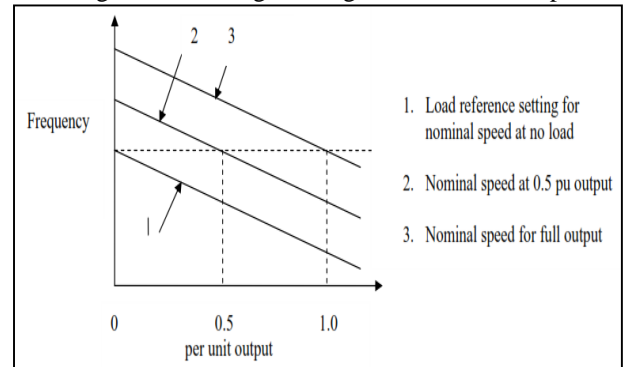


Fig. 6: Governor characteristics

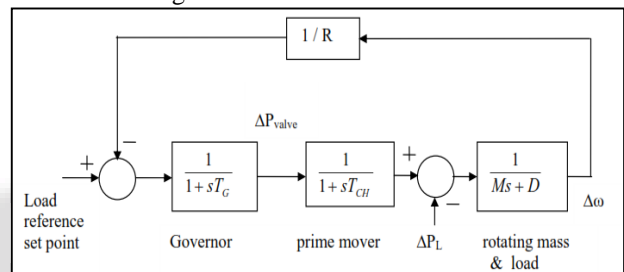


Fig. 7: Block diagram of single area system

The combined block diagram of single area system with, governor prime mover - rotating mass/load model is shown in figure 7.

Suppose that this generator experience a step increase in load

$$\Delta P_L(s) = \frac{\Delta P_L}{s}$$

The transfer function relating the load change ΔP_L , to the frequency change $\Delta \omega$ is

$$\Delta \omega(s) = \Delta P_L(s) \left[\frac{\frac{-1}{Ms+D}}{1 + \frac{1}{R} \left(\frac{1}{1+sT_G} \right) \left(\frac{1}{1+sT_{CH}} \right) \left(\frac{1}{Ms+D} \right)} \right] \quad (3)$$

The steady state value of $\Delta \omega(s)$ may be found by

$$\Delta \omega \text{ steady state} = \lim_{s \rightarrow 0} [s \Delta \omega(s)]$$

$$\Delta \omega \text{ steady state} = \frac{-\Delta P_L}{\frac{1}{R} + D} \quad (4)$$

F. Multi Area System Modeling

In multi area system load change in one area will affect the generation in all other interconnected areas. Tie line power flow should also be taken into account other than change in frequency. We will discuss two area systems in the following session.

G. Two Area System

In two-area system, two single area systems are interconnected via the tie line. Interconnection established increases the overall system reliability. Even if some generating units in one area fail, the generating units in the other area can compensate to meet the load demand.

H. Tie Line Model

The power flowing across a transmission line can be modeled using the DC load flow method as

$$P_{tieflow} = \frac{1}{X_{tie}} (\beta_1 - \beta_2) \quad (5)$$

This tie flow is a steady-state quantity. For purposes of analysis here, we will perturb the above equation to obtain deviations from nominal flow as a function of deviations in phase angle from nominal.

$$\begin{aligned} P_{tieflow} + \Delta P_{tieflow} &= \frac{1}{X_{tie}} [(\beta_1 + \Delta\beta_1) - (\beta_2 + \Delta\beta_2)] \\ &= \frac{1}{X_{tie}} (\beta_1 - \beta_2) + \frac{1}{X_{tie}} (\Delta\beta_1 - \Delta\beta_2) \end{aligned} \quad (6)$$

Then

$$\Delta P_{tieflow} = \frac{1}{X_{tie}} (\Delta\beta_1 - \Delta\beta_2)$$

where $\Delta\beta_1$ and $\Delta\beta_2$ are equivalent to $\Delta\delta_1$ and $\Delta\delta_2$

Then equation (6) can be expressed as,

$$\Delta P_{tieflow} = \frac{T}{s} (\Delta\omega_1 - \Delta\omega_2)$$

Where, T is "tie-line stiffness" coefficient and, $T = (2 \times 3.14 \times 50) \times 1 / X_{tie}$ (for a 50-Hz system).

Suppose now that we have an interconnected power system broken into two areas each having one generator. The areas are connected by a single transmission line. The power flow over the transmission line will appear as a positive load to one area and an equal but negative load to the other, or vice versa, depending on the direction of flow. The direction of flow will be dictated by the relative phase angle between the areas, which is determined by the relative speed -deviations in the areas.

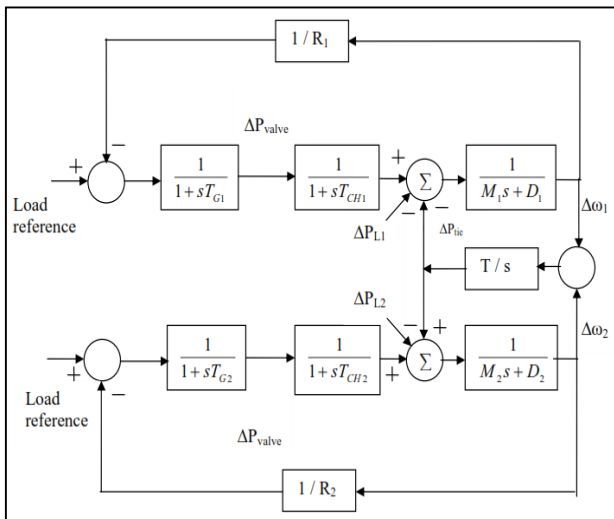


Fig. 8: Block diagram of interconnected areas

A block diagram representing this interconnection can be drawn as in figure 8 and the parameters are in table 1.

Parameters	Single area system	Two area system	
		Area 1	Area 2
Turbine time constant (T_{CH})	0.5s	0.5s	0.6s
Governor time constant (T_G)	0.2s	0.2s	0.3s
Generator angular momentum (M)	10 MJ rad/s	10 MJ rad/s	8 MJ rad/s
Governor speed regulation (R)	0.05	0.05	0.0625
Load change for frequency change of 1 %	0.8%	0.6%	0.9%
$D = \Delta p / \Delta \omega$	0.8	0.6	0.9
Turbine rated output	250 MW	250MW	250 MW
Tie line stiffness (T) Coefficient	-	2 rad/s/ Ω	

Table 1: Power system Parameters

It should be noted that the tie power flow was defined as going from area 1 to area 2. Therefore, the flow appears as a load to area 1 and a power source (negative load) to area 2. If one assumes that mechanical powers are constant, the rotating masses and tie line exhibit damped oscillatory characteristics are known as synchronizing oscillations.

It is quite important to analyze the steady-state frequency deviation, tie-flow deviation and generator outputs for an interconnected area after a load change occurs. Let there be a load change ΔP_L in area 1. In the steady state after all synchronizing oscillations have damped out, the frequency will be constant and equal to the same value on both areas.

Then

$$\begin{aligned} \Delta\omega_1 - \Delta\omega_2 &= \Delta\omega \quad \text{and} \\ \frac{d(\Delta\omega_1)}{dt} &= \frac{d(\Delta\omega_2)}{dt} = 0 \end{aligned} \quad (7)$$

Finally we have,

$$\Delta\omega = \frac{-\Delta P_{L1}}{\frac{1}{R_1} + \frac{1}{R_2} + D_1 + D_2} \quad (8)$$

$$\Delta P_{tie} = \frac{-\Delta P_{L1} \left(\frac{1}{R_2} + D_2 \right)}{\frac{1}{R_1} + \frac{1}{R_2} + D_1 + D_2} \quad (9)$$

The new tie flow is determined by the net change in load and generation in each area. We do not need to know the tie stiffness to determine this new tie flow, although the tie stiffness will determine how much difference in phase angle across the tie will result from the new tie flow.

III. CONTROLLERS CLASSIFICATION

Controllers can be divided into two main groups, conventional controllers and unconventional controllers. P, PI, PD, PID are different types of conventional controllers. However, it is known that a good many nonlinear processes

can satisfactorily controlled using PID controllers providing that controller parameters are tuned well. Practical experience shows that this type of control has a lot of sense since It is simple and based on 3 basic behavior types: proportional (P), integrative (I) and derivative (D).

A. Integral Controller

An integral controller provides zero steady state frequency deviation ($\Delta\omega$) but it exhibits poor dynamic performance. To improve the transient response, various control techniques, such as linear feedback, optimal control and variable structure control have been proposed. Adaptive controllers with self-adjusting gain settings have also been proposed for the LFC problem.

B. PID Controller

PID is an acronym for proportional integral and derivative. Thus, the PID controller algorithm is described by a weighted sum of three time functions where the three distinct weights are: the proportional gain (K_P) that determines the influence of the present error-value on the control mechanism, the integral gain (K_i) that decides the reaction based on the area under the error-time curve up to the present point and the derivative gain (K_d) that accounts for the extent of the reaction to the rate of change of the error with time. Thus, the superposition of these three actions constitutes the mechanism for adjustment of plant performance.

Derivative mode improves stability of the system and enables increase in gain K and decrease in integral time constant K_i , which increases speed of the controller response. Engineers prefer PID controls over untested solutions. Control signal of PID controller is,

$$u(t) = K \left[e(t) + \frac{1}{T_i} \int_0^t e(\Gamma) d\Gamma + T_d \frac{de(t)}{dt} \right], \quad \text{OR}$$

$$u(t) = K e(t) + K_i \int_0^t e(\Gamma) d\Gamma + K_d \frac{de(t)}{dt},$$

Where,

$$K_i = \frac{K}{T_i} \text{ gain (reset) of integral part of the controller,}$$

$$K_d = K T_d \text{ gain of derivative part of the controller.}$$

C. Single and Two Area Power System Using PID Controller

In Single area system, generation and load demand of one domain is dealt. Any load change within the area has to be met by generators in that area alone through suitable governor action. Thus we can maintain the constant frequency operation irrespective of load change.

Single area system with governor control using PID controller is shown in figure 9. Modeling of single and two area systems are based on transfer function.

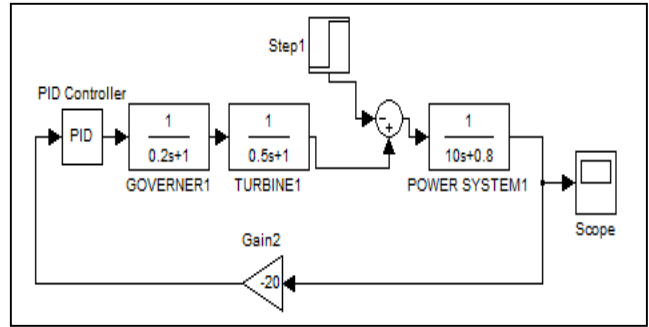


Fig. 9: Single area system with governor control using PID controller

Two area system with governor control using PID controller is shown in figure 10. Tie line control system must use two pieces of information: the system frequency and the net power flowing in or out over the tie lines.

- 1) If frequency decreased and net interchange power leaving the system increased, a load increase has occurred outside the system.
- 2) If frequency decreased and net interchange power leaving the system decreased, a load increase has occurred inside the system.

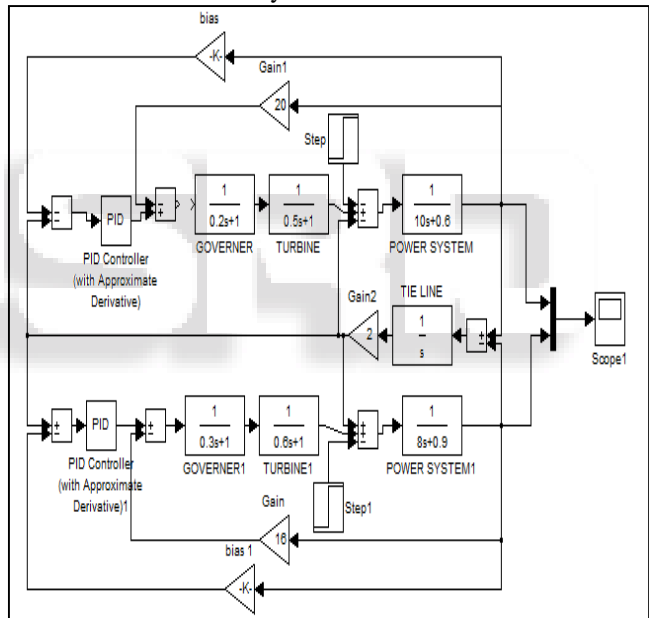


Fig. 10: Two area system with governor control using PID controller

Normal PID controller will work with fixed constants K_P , K_I , K_D . The parameter values are chosen based on the Routh Hurwitz criterion and by comparing the performance of conventional integral controller. Good performance is achieved for all load disturbances ΔP_L compared to conventional integral controller.

IV. INTRODUCTION TO NEURAL NETWORK

A. Introduction

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large

number of highly interconnected processing elements (neurons) working in unison to solve specific problems. Artificial neural networks are computers whose architecture is modeled after the brain. They typically consist of many hundreds of simple processing units which are wired together in a complex communication network. Each unit or node is a simplified model of a real neuron which fires (sends off a new signal) if it receives a sufficiently strong input signal from the other nodes to which it is connected.

B. Design of ANN Controller in Tuning PID Controller Parameters

Neural Network (NN) TOOL method provides the facility to train through one of the methods Say conjugate gradient method, Leven berg-Marquardt method for back propagation. It is superior to approximate steepest descent method. Hence at first training is carried out using the NN tool method. In the neural network we have employed TANSIG as transfer function in the hidden layer and PURELIN in the output layer. Then they obtained weights and biases are chosen as the initial weights and biases.

Now the training is carried out using the first method. All results such as the updating of weights and biases from the initial set values, sensitivities, trained data, coordination between the target and trained data can be obtained in figure 11.

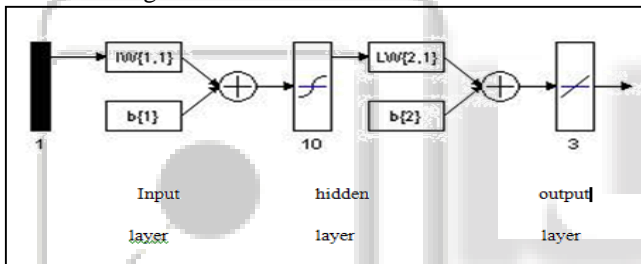


Fig. 11: Neural network for the design of ANN based PID controller

The error signal is given as input to the neural network using MATLAB function. Desired target for each input value is obtained. The fresh neural network is written as program and is incorporated in the MATLAB function tool, in SIMULINK diagram. Thus for each error signal fed as input, trained PID controller parameters K_P , K_I , K_D are given back as output to called MATLAB function tool in SIMULINK diagram.

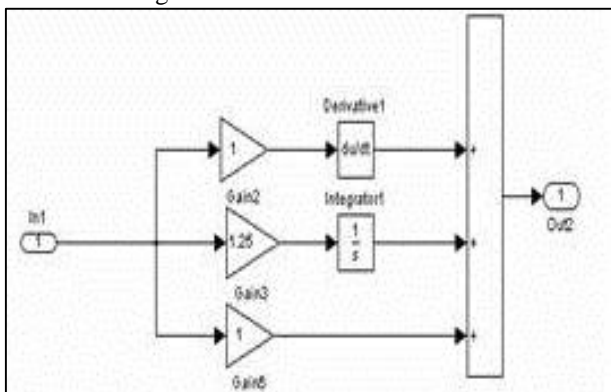


Fig. 12: PID controller

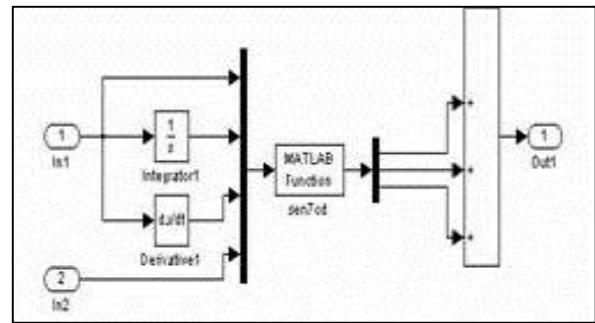


Fig. 13: ANN based PID controller

For any load change, the required change in generation, called the area control error or ACE, represents the shift in the areas generation required to restore frequency and net interchange to their desired values. Maximum and minimum values of ACE occur in transient state and steady state respectively. Parameter Comparison of PID controller figure 12 and ANN based PID controller figure 13 for maximum ACE and minimum ACE is carried out and listed in table 2.

Parameters	PID Controller		ANN based PID Controller	
	ACE (min)	ACE (max)	ACE (min)	ACE (max)
K_P	1	1	0.95	1.35
K_I	1.25	1.25	1.2	1.6
K_D	1	1	0.95	1.35

Table 2: Parameter comparison of PID controller and ANN based PID controller

C. Training Procedure

Import inputs to the network & corresponding targets either from current workspace or from a file.

- 1) Step 1: Choose new network icon in the box to create a new neural network.
- 2) Step 2: Creation of New Network In this box we can choose the number of layers, number of neurons in each layer and input ranges.
- 3) Step 3: Initialization of the network
- 4) Step 4: Simulation of the neural network
- 5) Step 5: Training the neural network
- 6) Step 6: Adaptation of the neural network with trained data
- 7) Step 7: Required weights and biases for the neural network.

D. Adaptation of Artificial Neural Network

In a system, if inputs and the corresponding targets are identified, then we can implement the Artificial Neural Network (ANN) for the input–target pair. ANN is computationally simple, reliable, model free system. One of the main advantages of ANN is desired output can be obtained for even untrained data within the input range.

In this paper training is carried out using NNTOOL box in MATLAB software version 6.1. NNTOOL method provides the facility to train through one of the methods Say conjugate gradient method, Leven berg-Marquardt method for back propagation. In this paper Leven berg-Marquardt method is employed for its superiority in convergence.

V. SIMULATION RESULTS

Performance comparison of ANN controller, PID controller, Conventional integral controller for single area system and two area system for different load disturbances (ΔP_L) are carried out and the results are shown in figures 14, 15 and 16

A. Single Area Frequency Deviation

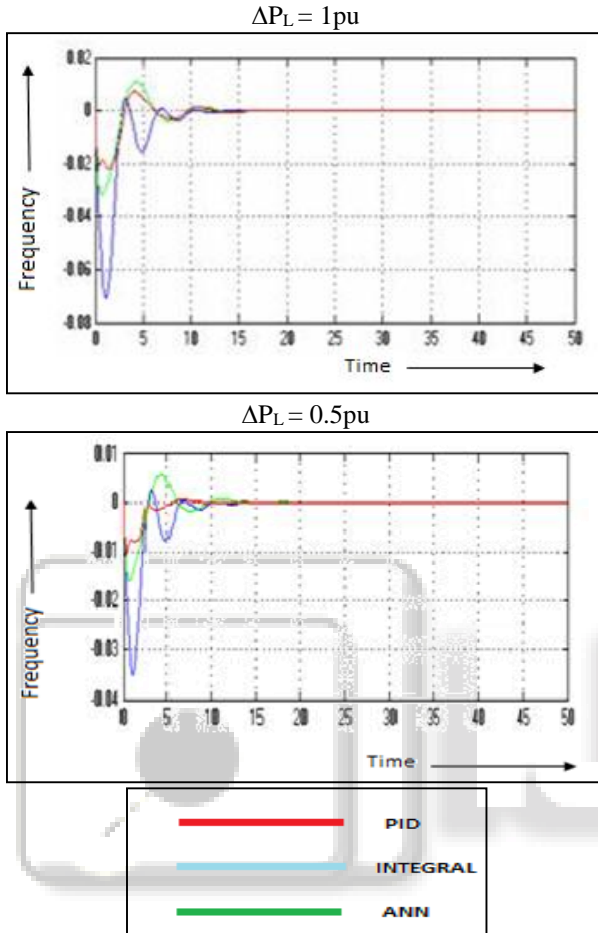


Fig. 14: Comparison of ANN controller, PID controller & conventional controller

B. Two Area System Frequency Deviation

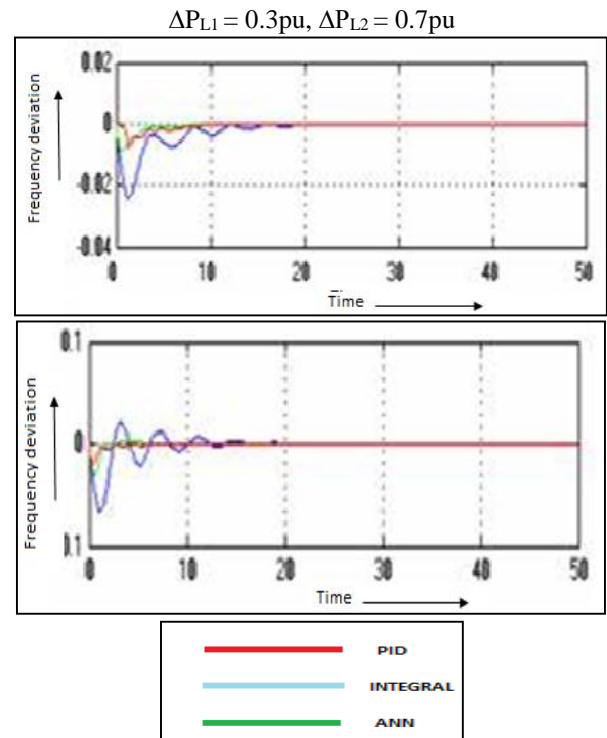
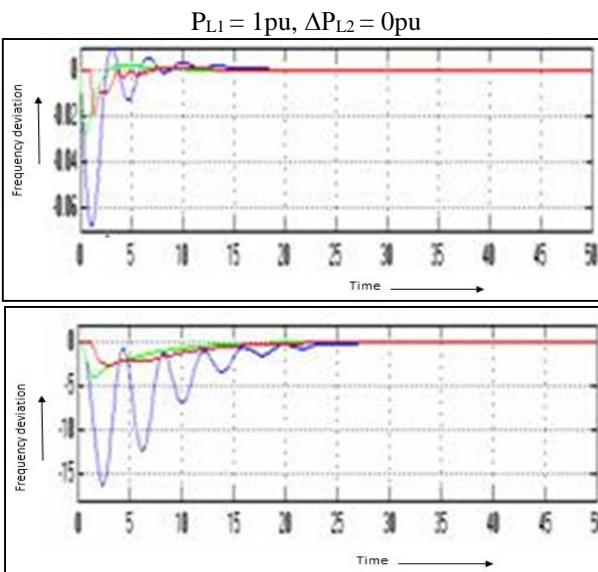


Fig. 15: Comparison of ANN controller, PID controller and conventional controller

C. Tie Line Power Flow

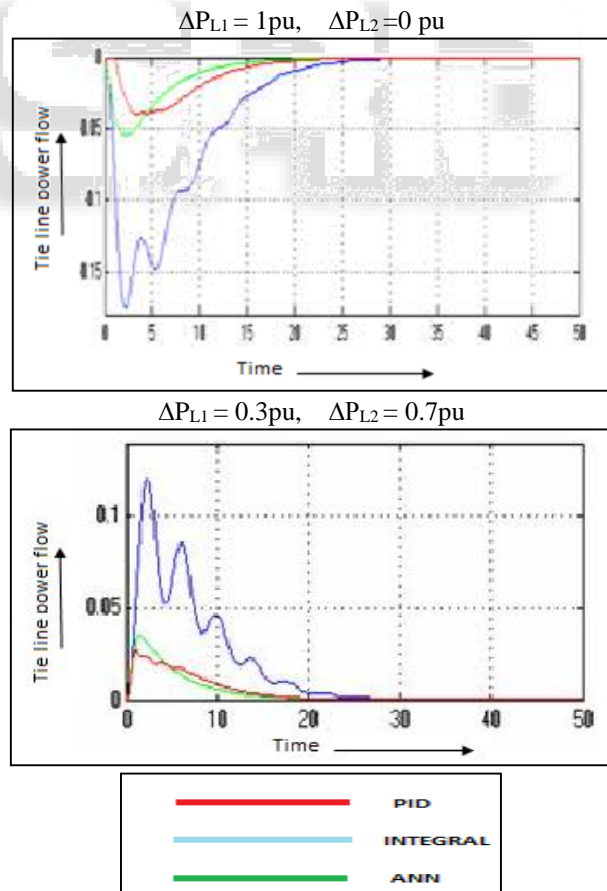


Fig. 16: Comparison of ANN controller, PID controller and conventional controller

VI. CONCLUSIONS

In this paper artificial neural network has been investigated for both single area and two area power systems. For this purpose first an ANN was designed and also conventional integral controller & PID controller was applied to the system. Comparison of responses with conventional integral controller & PID controller show that the neural network controller has quite satisfactory generalization capability, feasibility and reliability as well as accuracy in both single area system & two area system.

Simulations of the networks are carried out for different load changes and simulation results are compared highlighting the performance of ANN controller. For this application MATLAB SIMULINK software is used. In this paper PID controller parameters are continuously adjusted according to the change in area control error.

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