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NEURAL NETWORK BASED LOAD FREQUENCY CONTROL FOR RESTRUCTURING POWER INDUSTRY

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Abstract

In this study, an artificial neural network (ANN) application of load frequency control (LFC) of a Multi-Area power system by using a neural network controller is presented. The comparison between a conventional Proportional Integral (PI) controller and the proposed artificial neural networks controller is showed that the proposed controller can generate an improved dynamic response for a step load change. The same technique is then applied to control a system compose of two single units tied together though a power line. Electric load variations can happen independently in both units. Both neural controllers are trained with the back propagation-through-time algorithm. Use of a neural network to model the dynamic system is avoided by introducing the Jacobian matrices of the system in the back propagation chain used in controller training. For this application, MATLAB-Simulink software is used.

Keywords: load frequency control, power system, controller, artificial neural network, frequency response

1. Introduction

Control and stability enhancement of synchronous generators is of major importance in power systems. Different types of controllers based on "classical" linear control theory have been developed in the past. In a power system, load-frequency control (LFC) plays an essential role to allow power exchanges and to supply better conditions for the electricity trading. Also, time delays in such systems can reduce system performance and even cause system instability on frequency or other parameters[1]. Load frequency control in power systems is very important in order to supply reliable electric power with good quality. The goal of the LFC is to maintain zero steady state errors in a multi area interconnected power system. In addition, the power system should fulfill the proposed dispatch conditions. Power systems are divided into control area connected by tie lines. All generators are supposed to constitute a coherent group in each control area. From the experiments on the power system, it can be seen that each area needs its system frequency to be controlled. In this study, a two area power system is chosen and load frequency control of this system is made by a ANN controller and a conventional PI controller.

Basically, power system consists of a governor, a turbine, and a generator with feedback of regulation constant. System also includes step load change input to the generator. This work mainly, related with the controller unit of a two area power system.

A lot of studies have been made in the past about the load frequency control. In the literature, some control strategies have been suggested based on the conventional linear control theory [4]. These controllers may be unsuitable in some operating conditions due to the complexity of the power system such as nonlinear load characteristics and variable operating points. To some authors, variable structure control [5] maintains stability of system frequency.

However, this method needs some information for system states, which are very difficult to know completely. Also, the growing needs of complex and huge modern power systems require optimal and flexible operation of them. The dynamic and static properties of the system must be well known to design an efficient controller. On the other hand, to handle such a complex system is quite complicated [6]. Recently the LFC systems use the proportional integral (PI) controllers in practice [7]. Since the dynamic behavior even for a reduced mathematical model of a power system is usually nonlinear, time-variant and governed by strong cross-couplings of the input variables, special care has to be taken for the design of the controllers. Gain scheduling is a controller design technique used for non-linear systems. Therefore, a gain scheduling controller can be used for this purpose. In this method, since parameter estimation is not required, control parameters can be changed very quickly. In addition, gain scheduling application is easier than both automatic tuning and adaptation of controller parameters methods [2]. However, the transient response for this controller can be unstable because of abruptness in system parameters. Besides, it cannot obtain accurate linear time of variant models at variable operating points [2]. To solve all these problems in the above mentioned papers, an ANN controller is proposed in this study. The ANN controller has been established to apply a single area power system in the different operating points under different load disturbances by using the learning capability of the neural Networks to improve the stability of the overall system and also its good dynamic performance achievement [8].

2. Artificial Neural Network Controller

The ANN controller architecture employed here is a Model Reference Neural technique. The Model Reference Adaptive Control configuration uses two neural networks: a controller network and a model network. The Model network can be trained off-line using historical plant measurements. 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 Reference Model Neural Network and applying to the power system with step response lead disturbance. After a series of modifications, the ANN architecture shown the fig. 1 provides the improved performance. It is a three-layer perception with five inputs in the ANN controller. Also, in the ANN Plant model, it is a three-layer perception with four inputs, 10 neurons in the hidden layer, and one output. The activation function of the networks neurons is hyperbolic tangent. The proposed network has been trained by using back-propagation algorithm. The root mean equal (RMS) error criterion is being used to evaluate the learning performance. Learning algorithms cause the adjustment of the weights so that the controlled system gives the desired response [8].

3. A Two Area Interconnected Power Model

An interconnected power system is divided into two control areas connected by a tie line. In each control area, all generators are supposed to constitute a coherent group. A two- area interconnected power system of a thermal plant is used to explain motivation of the proposed method [9]. Lets assume that large load with sudden charges, such as large steel mills, arc furnace factories, cement manufacturing company etc, have been placed in both areas. The frequency deviation in both areas severely affect the production quality of frequency sensitive industries such as the spinning and weaving industry, petrochemical industry, pulp and paper industry, semiconductor industry, etc. Furthermore, the lifetime of machine apparatuses on the load side will be reduced.

The tie-line power flow and frequency of the area are affected by the load charges. Therefore,

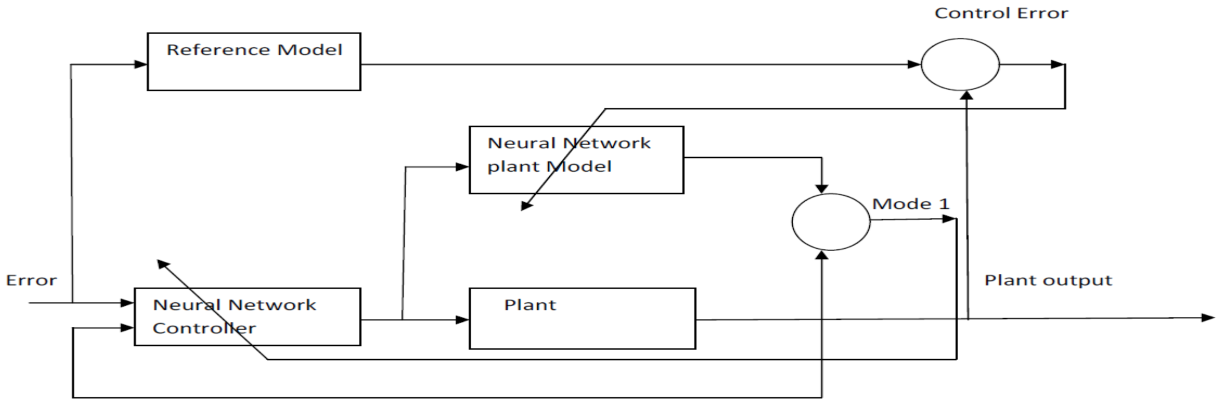

Figure 1. The System added Artificial Neural Network Architecture

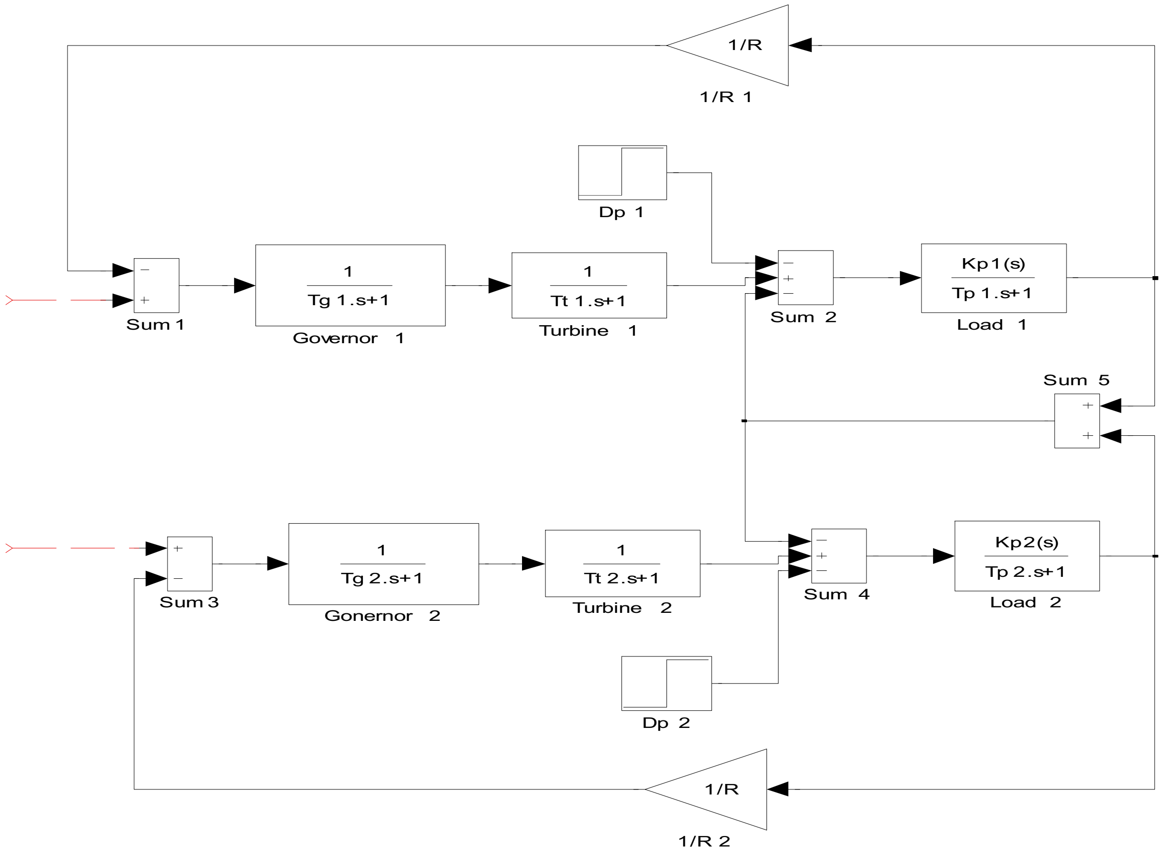

Figure 1: Interconnected power systems.

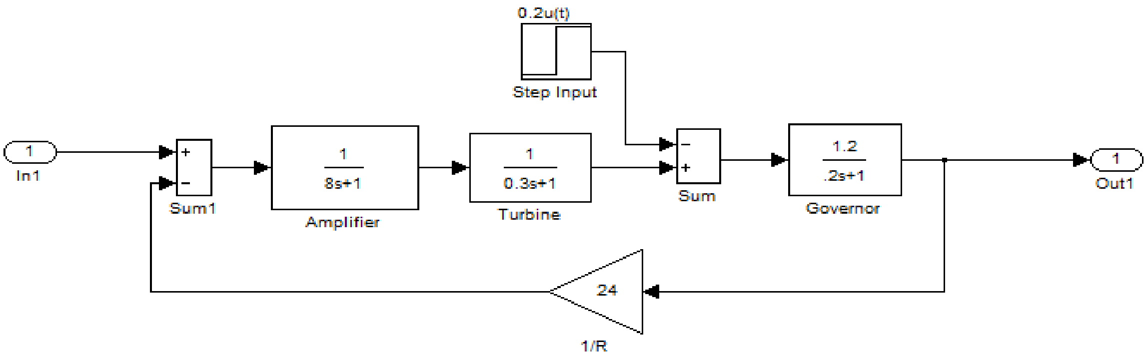

Figure 2: Single area power system with controller in the subsystem.

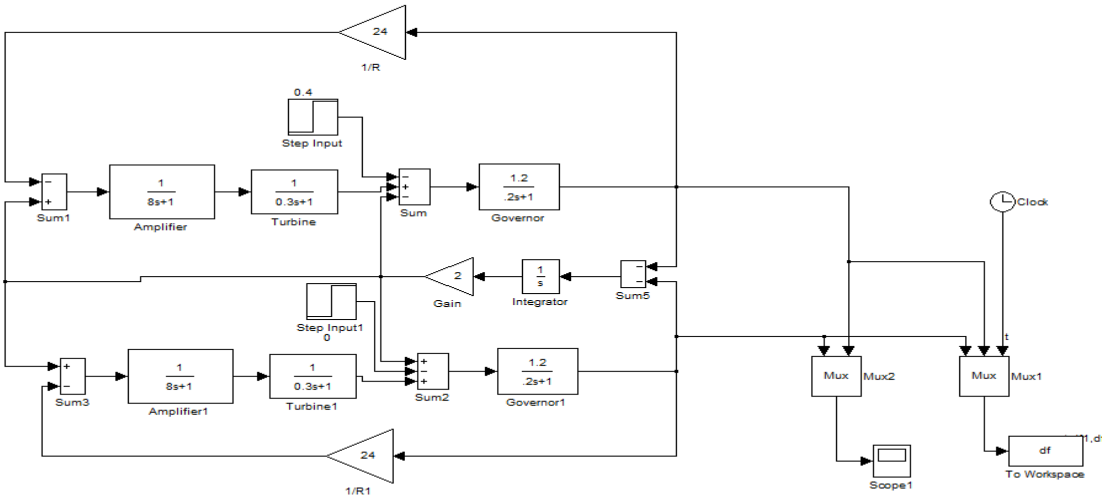

Figure 3: Two area-power System with controller (conventional controller).

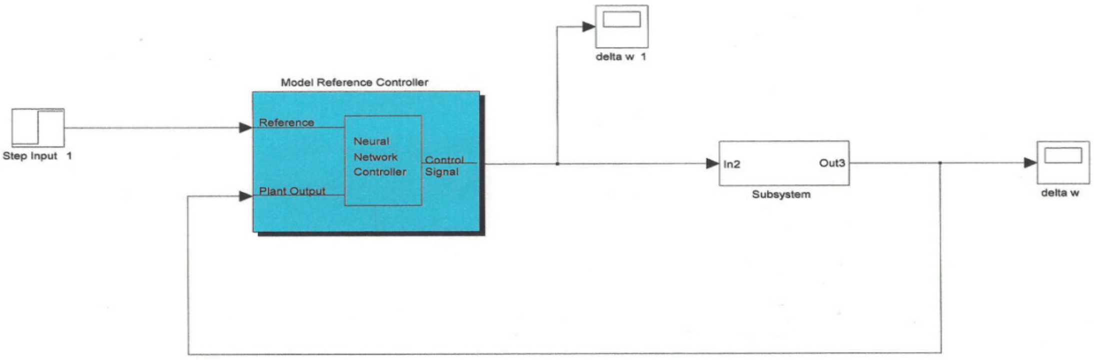

Figure 4: System block scheme for simulation using Neural Network.

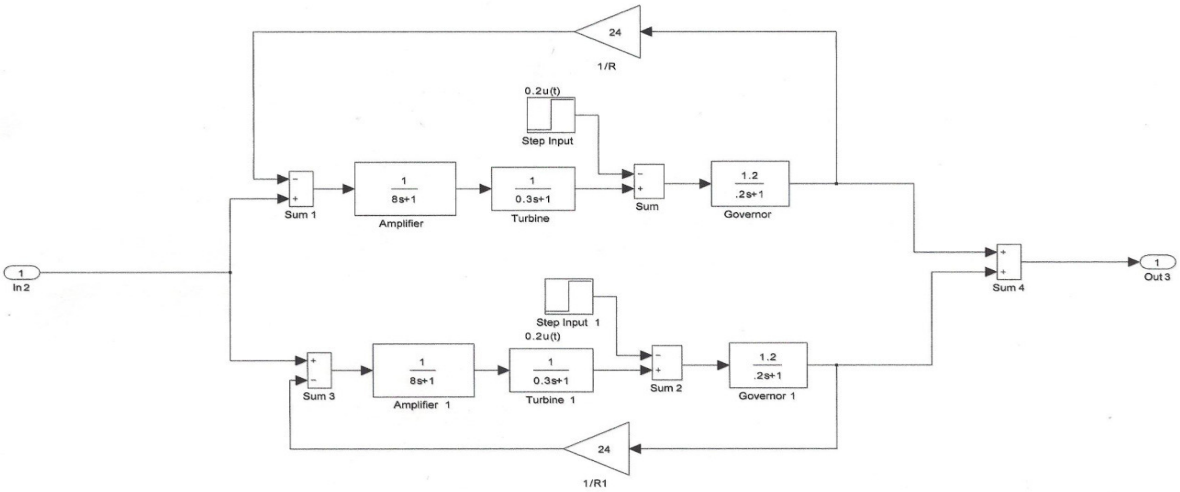

Figure 5: Two Area power System block used for simulation in the subsystem.

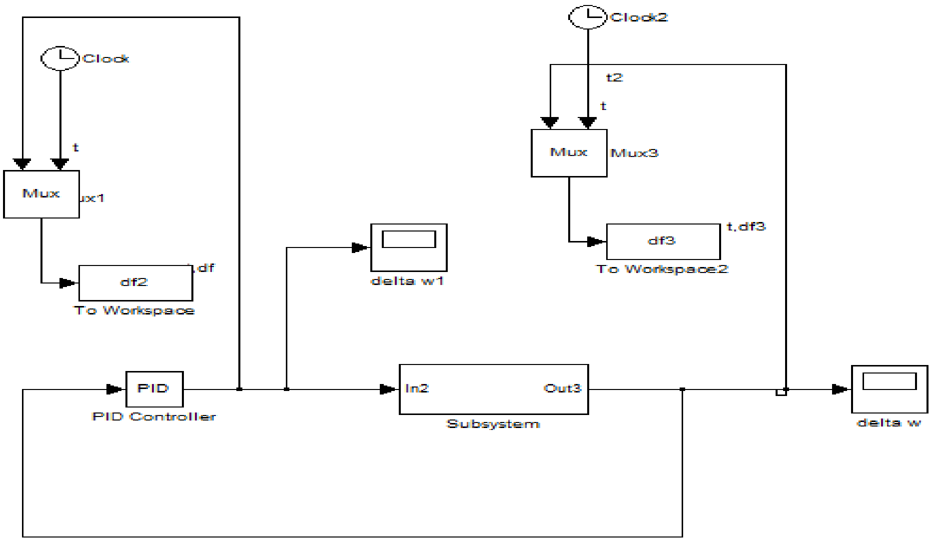

Figure 6: System block scheme for simulation using PID Controller.

it can be considered that each area needs its system frequency and tie-line power flow controlled.

A controlled two-area interconnected power system of a thermal plant is shown in Fig. 2 where D denotes deviation from the nominal values and f_1 is the system frequency (Hz), R_i is regulation constant (Hz per unit), T_{gs} is speed governor time constant (s), T_{ts} is turbine time constant (s),T_{pi} is power system time constant (s) and D_{pdi} is load demand increment.

The overall system can be modeled as multivariable system in the following form:

$$\dot{x}(t) = Ax(t) + Ld(t) \qquad (1)$$

In which A is the system matrix, B and L are input and disturbance distribution matrices, $x(t)$, $u(t)$ and $d(t)$ are state, control and load change disturbance vectors, respectively.

$$\dot{x} = [Df_1\ DP_{g1}\ DP_{v1}\ DP_{12}\ Df_2\ DP_{g2}\ DP_{v2}]^T$$

$$u(t) = [D_{pc1}\ D_{pc2}]^T = [u_1 u_2]^T$$

$$d(t) = [DP_{d1}\ DP_{d2}]^T$$

The u_1 and u_2 are the control output in Figure 2 [8].

The system output, which depends on area control error (ACE), is written as follow:

$$y(t) = \begin{bmatrix} y_1(t) \\ y_2(t) \end{bmatrix} = \begin{bmatrix} ACE_1 \\ ACE_2 \end{bmatrix} = Cx(t) \qquad (2)$$

And

$$ACE_i = DP_{12} + b_i DF_i \qquad (3)$$

Where $y(t)$ is the output vector, ACE_i is area i control error, b_i is area i frequency bias constant, Df_i is area i frequency change, DP_{12}, is the change in tie-line power and C is the output matrix.

4. Learning Algorithm

The learning process of NN for each control area is to minimize the performance function given by:

$$E = \frac{1}{2}(y_d - y)^2 = \frac{1}{2}(e^2) \qquad (4)$$

Where y_d represents the reference signals, y represents the actual output (i.e. frequency deviations of area). It is desirable to find a set of weights in dynamic and conventional neurons that minimize the E. A general and useful way to achieve this is a gradient descent method. Learning of all set weight in NN controller by employing the gradient descent method, the increment of Γ donated by $\Delta Gamma$ where Γ contain all weights in NN controller, can be obtained as,

$$\Delta\Gamma(t) = \eta \frac{\partial E(t)}{\partial \Gamma(t)} \qquad (5)$$

Where the η is learning rate given by a small positive constant, thats be noted the same η considered for learning of all parameters, and Γ is

$$\Gamma = [Wa_0 b_0 a_{ij} b_{ij}] \quad i = 1,\ j = 1, 2$$

Therefore, the learning update equation of Γ is obtained by

$$\Gamma(t+1) = \Gamma(t) + \Delta\Gamma(t) \tag{6}$$

$$\Gamma(t+1) = \Gamma(t) + \eta \frac{\partial E(t)}{\partial \Gamma(t)} r \tag{7}$$

The partial derivative of E with respect to elements of Γ, for example W, is described as follow:

$$\frac{\partial E}{\partial W^i} = \frac{\partial E}{\partial e} \frac{\partial e}{\partial t} \frac{\partial y}{\partial u} \frac{\partial u}{\partial W^i} \tag{8}$$

$$\frac{\partial E}{\partial W^i} = e(t) \times (-1) \frac{\partial y}{\partial u} \times O_1^i(t) \tag{9}$$

Where O1 and $\frac{\partial y}{\partial u}$ are the outputs of hidden layer and sensitivity of plant, respectively.

For parameters of DN, the weights of dynamic neurons can be written as follow:

$$\Delta a_0^i = \eta \delta^i(t) X_e^i(t) \tag{10}$$

$$\Delta a_{11}^i = \eta \delta^i(t) O_E^i(t-1) \tag{11}$$

$$\Delta a_{12}^i = \eta \delta^i(t) O_1^i(t-1) \tag{12}$$

Where

$$\delta^i(t) = e(t) \frac{\partial y(t)}{\partial u(t)} W^i(t) F^{\prime\prime i}(.) \tag{13}$$

Where, $F^{\prime\prime i}(.)$ is derivative of outputs of hidden layer with respect to its input.

5. Simulation Results

The two area power systems parameters are given in table 1. System block scheme and simulation results for the single area power system and two area systems are shown in Fig. 2 to 6. As can be observed, the settling time and overshoots with the proposed ANN controller are much shorter than that with the conventional PI controller.

From the fig.10 below, it is show that the settling time of conventional PI controller is much longer than the propose ANN controller and the overshoots of the proposed controller is almost 85% better than the PI controller's. Therefore, the proposed ANN controller provides better performance than conventional controller for the single area power system. In this study, it is shown that the overshoots and settling times with the proposed ANN controller are better than the outputs of the other controllers.

5.1. System parameters and constants used for both single and two area power system

The gain and time constants of the turbine, hydraulic amplifier and generator are as follows:

All the figures from 7 to 10 are all frequency response of the power systems.

6. Conclusion

Artificial neural networks controller has been investigated for automatic load frequency control of a single area and two area power systems. For this purpose, first, a ANN controller was designed for improvement sensitivity of the system. Also, a conventional PI controller was applied to the system for comparison. It has been shown that the proposed control algorithm is effective and provides significant improvement in system performance. Therefore, the proposed ANN controller is recommended to generate good quality and reliable electric energy. In addition, the proposed controller is very simple and easy to implement since it does not require many information about system parameters. Neural networks have been successfully applied to control the turbine reference power of a computer-simulated generator unit. The same principle has been applied to a simulated two area system. The Neural Network controllers have been adapted using backpropagation through time. The frequency variations in both areas of the two area system were put into the Neural Network controller. The Neural Network controller is found very suitable for controlling the plant dynamics in relatively less time. Each neural network controller receives only local information about the system in that specific area.

Table 1: Parameters of the two area power system.

Area 1	Tg1 = 1.0	Tt = 1.0	Kp = 1.2Hz	Tp = 0.2s	T_h = 8ms	R = 24Hz
Area 2	Tg2 = 1.0	Tt = 1.0	Kp = 1.2Hz	Tp = 0.2s	T_h = 8ms	R = 24Hz

* Ki = any non-negative value.

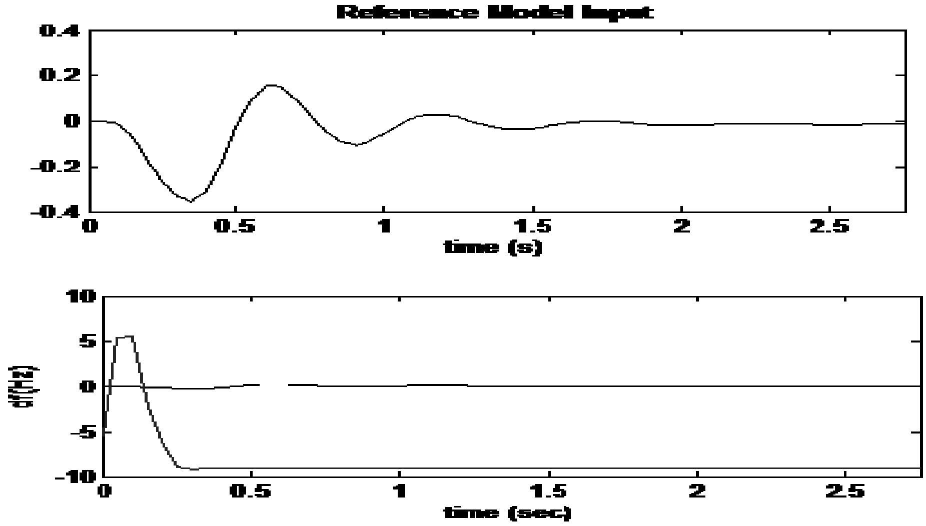

Figure 7: Neural Network frequency deviation response for two area power system compared with a conventional controller.

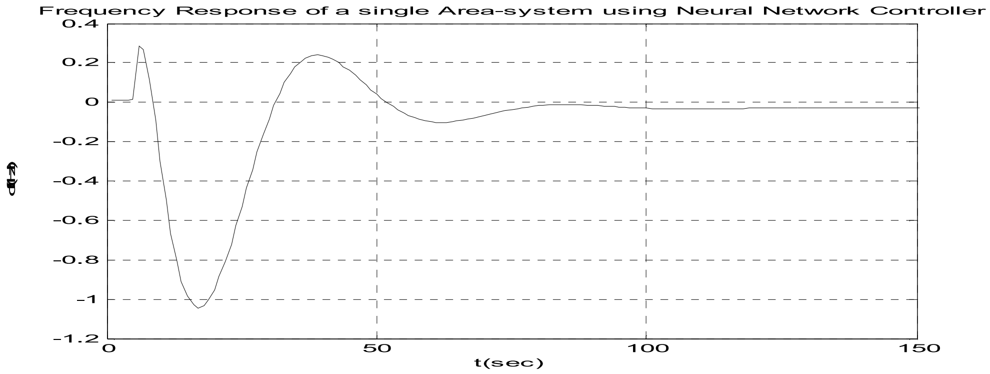

Figure 8: Frequency response of a single area power system using NN.

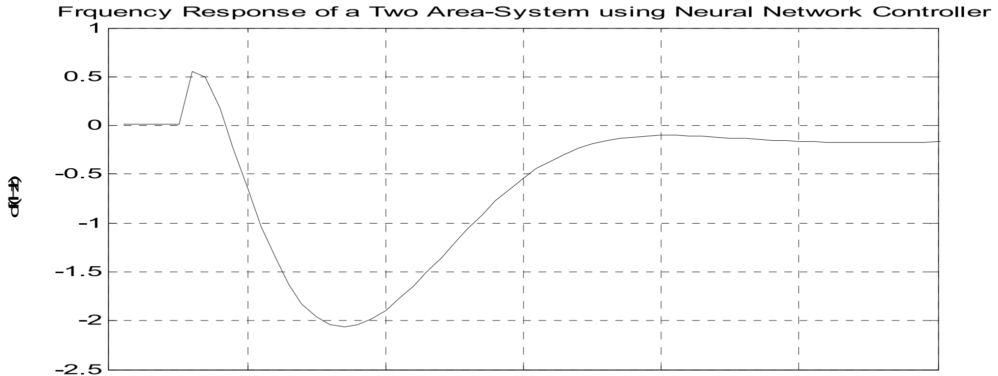

Figure 9: Frequency response of a two area power system using NN.

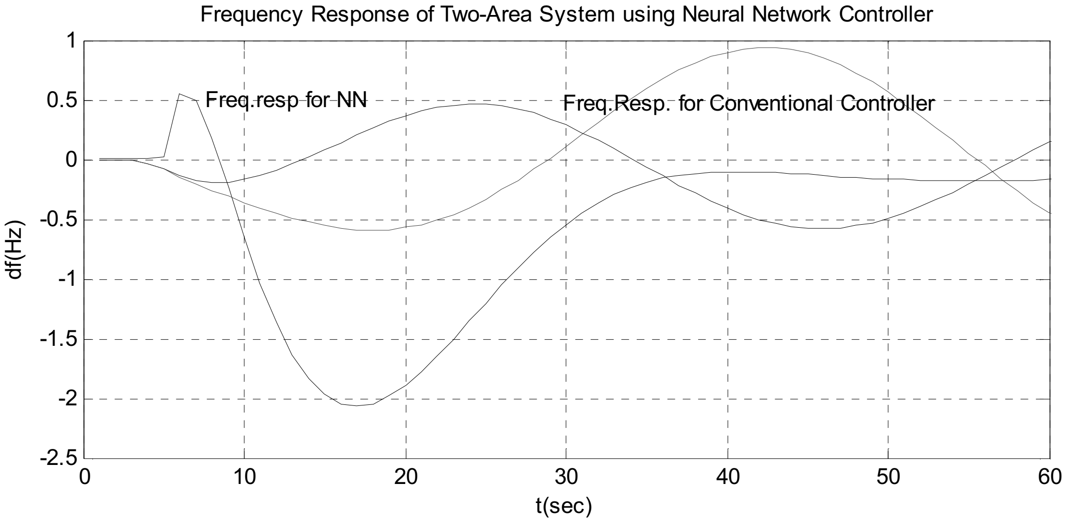

Figure 10: Showing the frequency response of both Neural Network Controller and a Conventional Controller.

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