LOAD FREQUENCY CONTROL OF COORDINATED HYDRO AND THERMAL POWER PLANT USING ANN BASED PID CONTROLLERS

[1] Jagdeep Singh, [2]Amninder Singh
[1]Student, [2]Assistant Professor,
[1] Department of Electrical Engineering
[1] Guru Kashi University, Bathinda, India

Abstract: The main objective of automatic generation control (AGC) is to balance the total system generation against system load losses so that the desired frequency and power interchange with neighbouring system is maintained. Any mismatch between generation and demand causes the system frequency to deviate from the nominal value. This high frequency deviation may lead to system breakdown. AGC comprises a load frequency control (LFC) loop and an automatic voltage regulator loop. Interconnected power systems regulate power flows and frequency by means of an AGC. LFC system provides generator load control via frequency zero steady-state errors of frequency deviations and optimal transient behaviour are objectives of the LFC in a multiarea interconnected power system. In this paper, artificial neural network (ANN) and PID based adaptive approach is used to automatic generation control of two unequal area thermal power systems. The proposed ANN-PID controller combines the advantages of PID controller as well as quick response and adaptability nature of ANN. Area 1 and area 2 consist of thermal reheat power plant . Performance evaluation is carried out by using ANN and PID control approaches. To enhance the performance of intelligent controller, adaptive ANN is used which adaptively trains itself on each iteration of running of simulation. The performances of the controllers are simulated using MATLAB/SIMULINK software. Three different case studies are taken in experimentation in which area one is altered with 0, 0 .01 and 0.015 per unit load change whereas area two keeps running at the same load. A comparison of ANN and PID approaches shows the superiority of proposed ANN over PID for change in frequency and tie-line power deviation in two area interconnected power system. Proposed ANN system also have less settling time than the PID based controllers.

***Index Terms* - ANN & PID Controllers, Area Control Error (ACE), Load Frequency Control (LFC), MATLAB/SIMULINK**

I. Introduction

Modern electric power systems consist of many power system units interconnected by a network of transmission and distribution lines. With the increase of energy consumption, power systems become increasingly complex in order to satisfy the power needs of consumers. A power system is interconnected to the others in neighboring areas through tie lines [1]. North India's power system is distributed throughout many different regions. Each interconnection acts as a large machine and each generator within a region works in tandem with the others in other regions to supply electricity. A disturbance in one area will cause a frequency deviation in that area as well as in neighboring areas. Frequency error is the frequency deviation from normal frequency. Tie-line power error is proportional to the integral of frequency error. A conventional area control error is the linear combination of frequency error and tie-line power error [2]. The frequency of the power system must be maintained at 50 or 60 Hz. If the generation does not match the load changes, the frequency will deviate from its desired value. "Off-normal frequency can impact power system operation and system stability. A large frequency deviation can damage equipment, cause the instability of the equipment, affect the life of equipment, cause the transmission line to be overloaded, interfere with the system protection schemes, and will ultimately lead to power system's instability"[3]. To solve this problem, load frequency control has been introduced to the power system. Load frequency control (LFC) is used to control the generation and frequency of the power system. It is a major part of automatic generation control, and has been one of the most important control efforts in electric power system design and operation.

II. Existing Control Methods for LFC

LFC has two goals. One goal is to maintain the load frequency at a desired value, and the other goal is to maintain the interchange power between tie-lines at an expected value. The LFC method has been developed for more than thirty years. A survey of LFCs for both continuous and discrete models of power system is conducted in [4].

Both centralized and decentralized LFCs have been introduced in the literature. The LFC design based on an entire power system model is considered to be a centralized control method. Since the 1960s, centralized control methods have been used for LFC. A typical centralized LFC based on linear matrix inequalities with communication delays is reported in [5]. Though centralized control method has advantages of low cost and high reliability, it can also cause communication delays for interconnected power systems. Another drawback of the centralized control method is that it requires high computational and storage complexities along distant geographical territories.

To solve this problem, decentralized control method was first proposed in the 1980s. The decentralized LFC is constructed on a local power area. Since the tie-line interface between different power areas can be considered as a weak coupled term, the large-scale power system can be decentralized into small subsystems by treating tie line signals as disturbances. Each area executes its decentralized control based on locally available state variables. Decentralized feedback control can achieve the same performance as the centralized control method does [6]. The most traditional decentralized control methods for LFC are PI control [6] and PID control [8]. PI control has the benefit of a simple controller structure. But it can produce a long settling time and a large overshoot in transient response [4]. PID controller is an effective LFC when the system is operating in the vicinity of the nominal operating point. However, the operating points could deviate from their nominal values significantly due to the variations of power consumptions, system uncertainties, and the change of the number of power plants in different control areas [7]. The performance of a PI or PID controller would be significantly degraded due to a large deviation of operating points from their nominal values. In order to overcome the drawbacks of PI or PID control methods, advanced control methods are developed for the power system to reject disturbance, improve the robustness against uncertainties in the system, maintain power quality in a wide range of operation, and improve the system's transient response [8]. The advanced control methods include robust control ,fuzzy logic control algorithm, neural network control , model predictive control ,optimal control ,adaptive power control ,artificial intelligent control, Active Disturbance Rejection Control (ADRC), and so on. Traditionally, the LFC is based on a linear model of the power system. However, in practice, a large load change stemming from deregulated operation or frequent on-off control of a large load, can cause overshoot and oscillation on the governor valve. Therefore, the limits of valve position should be considered to avoid overshoot and oscillation. In addition, the generation rate constraint (GRC) should be considered because the power generation changes at a specified maximum rate. A linear or linearized model of the power system cannot represent the real power system, especially due to a large deviation from the operating point of the power system. A robust LFC is essential for a power system to regulate the frequency deviation, and to improve the operating quality of the power system. For its practicality, the LFC has to be simulated on a nonlinear model of the power system.

III. Present work

A two-area interconnected power systems with different units are considered here. Figure 1 shows the representation of the two-area interconnected power systems. The two areas may have the combinations of different units. (Thermal-Hydro units). The detailed transfer function models of speed governors, thermal nonreheat turbines and hydro turbines are developed. Governors are the units that are used in power systems to sense the frequency bias caused by the load change and it can be cancelled by varying the inputs of the turbines. The transfer function of governor unit is given by [9]:

$$G_g(S) = \frac{\Delta P_e(s)}{\Delta P_v(s)} = \frac{1}{T_{g1}s+1} \tag{1}$$

where ΔPe—change in electrical power; ΔP_v—Change in gate/valve position; T_{g1}—Governor time constant. A turbine unit in power systems is used to transform the natural energy, such as the energy from steam or water, into mechanical power that is supplied to the input of the generator. In LFC model, there are three kinds of commonly used turbines: non-reheat, reheat and hydraulic turbines, all of which can be modeled by transfer functions. The transfer function of the non-reheat turbine is represented as follows:

$$G_{NR}(S) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{T_{t1}s+1} \tag{2}$$

where ΔPm—change in mechanical power; T_{t1}—Time delay.

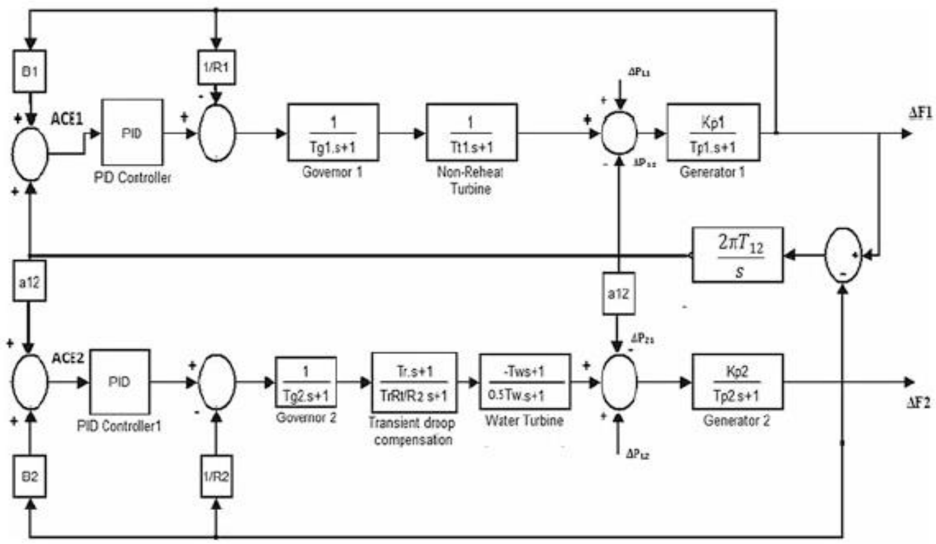

Figure 1: Two area interconnected power system with hydro and thermal units

A generator unit in power systems converts the mechanical power (ΔPm) received from the turbine into electrical power (Δf) The transfer function of the generator is represented as follows:

$$G(S) = \frac{\Delta f(s)}{\Delta P_m(s)} = \frac{K_{pi}}{T_{pi}s+1} \quad (3)$$

where K_{pi} —System gain for area i; T_{pi} —Generator time constant for area i. Hydraulic turbines are non-minimum phase units due to the water inertia. In the hydraulic turbine, the water pressure response is opposite to the gate position change at first and recovers after the transient response. Thus the transfer function of the hydraulic turbine is in the form of,

$$G_H(S) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \left(\frac{-T_w s}{0.5T_w s+1}\right) \quad (4)$$

where T_w —water starting time. For stability concern, a transient droop compensation part in the governor is needed for the hydraulic turbine. The transfer function of the transient droop compensation part is given by

$$G_{TD}(S) = \left(\frac{T_r s+1}{T_r\left(\frac{R_t}{R_2}\right)s+1}\right) \quad (5)$$

where T_r —reset time; R_t and R_2 —temporary droop and permanent droop respectively.

IV. Results and discussions

The PID and ANN based MATLAB code is developed in this work for PID controller tuning. The values of PID controller gains kp, kd and ki thus obtained are used in PID blocks of two area LFC block diagram (Fig. 1) drawn in MATLAB/Simulink. This interconnected power system having thermal generators are simulated with ANN tuned PID gains for several cases. The power system data used here are given in Table 1 and the optimized values of the PID gains based on are shown in Table 2.

Table 1: Power system data

Power System Data	Values
Steam generator time constants tg1,tg2	1s
Steam generator time constants kp1,kp2	100 s
Steam turbine time constants Tt1,Tt2	.3 s

Steam reheater time constants Tr1,Tr2	5s, 10s
Speed governor time constant for turbine	.018s
B1,B2	0.425 pu MW/hz
Speed regulation of governors R1,R2	2.4 Hz/pu MW

Table 2: Values of PID and ANN controllers for area one and two

Kp (proportional gain)	**Ki (integral gain)**	**Kd (derivative gain)**
1.931	1.978	1.831

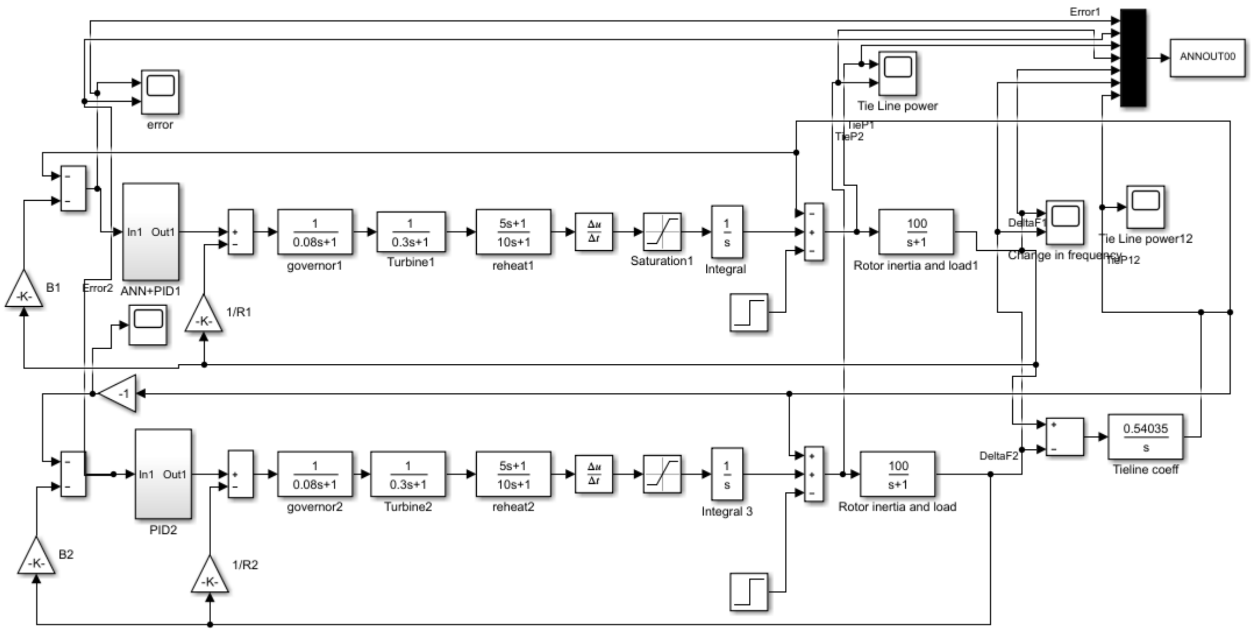

Figure 2: Simulation model designed in matlab/simulink

Study of Effects of Sudden Change of Load in Both Areas

The transient behavior of actual tie line power deviations due to sudden change of load in area1 is observed. As per contracts made in deregulated environment, the scheduled tie line power deviation due to the said load changes in area1 is 0.01 pu and .015 pu which is met by both the systems at steady state condition. Though the PID based system has lower overshoots, ANN-PID based system gives better response in terms of settling time. Also the numbers of oscillations are quite less in case of latter system.

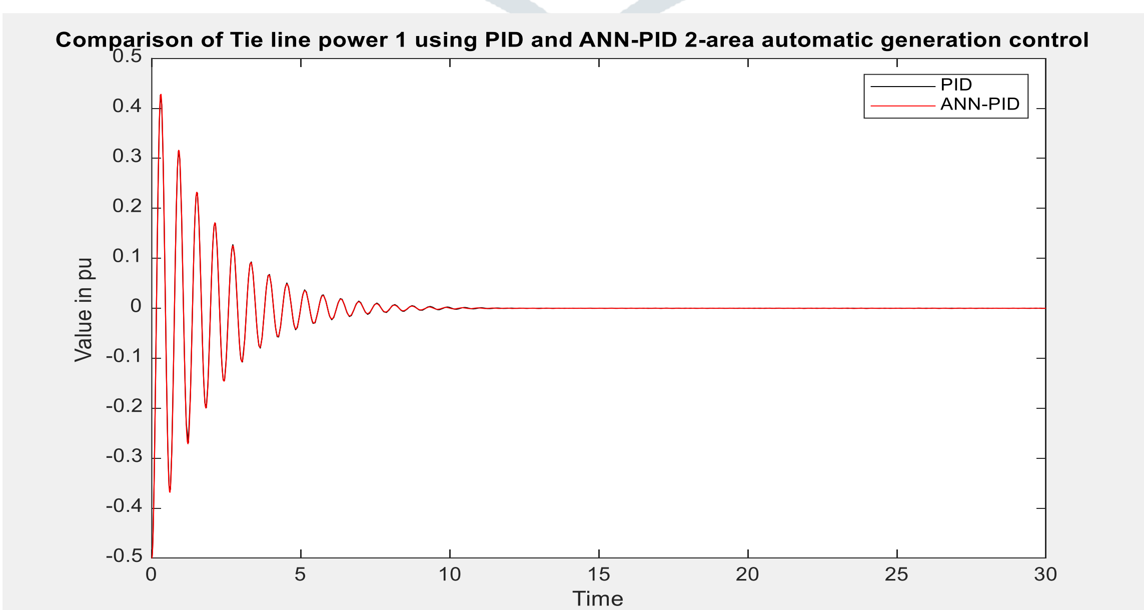

Figure 3: Comparison of tie line power (1 and 2) using PID and ANN-PID 2-area automatic generation control with zero percent change in load of area 1

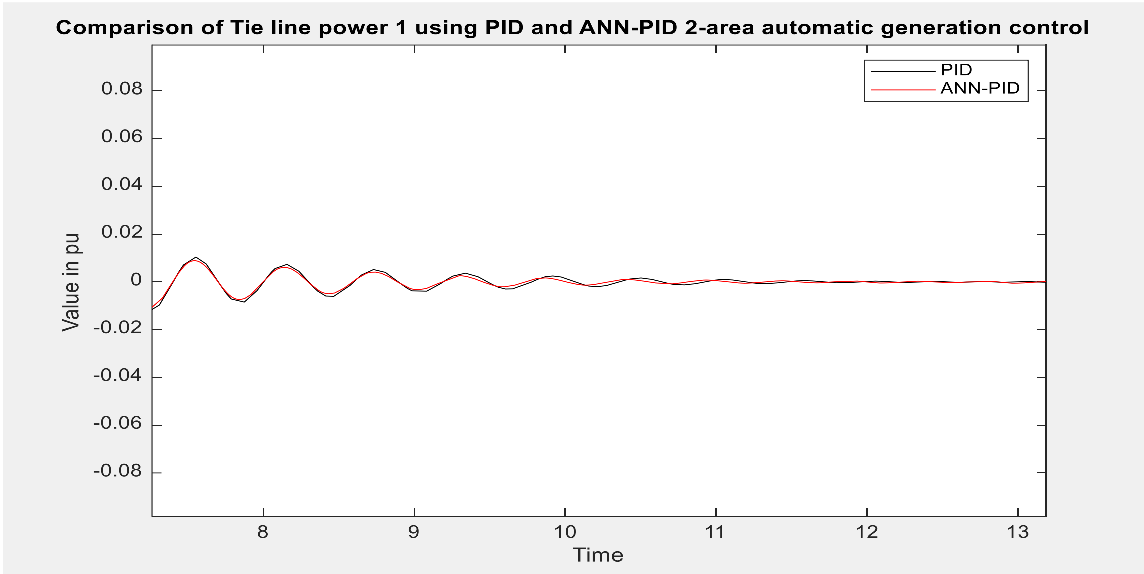

Figure 4: Zoomed view of tie line power with zero percent change in load of area 1

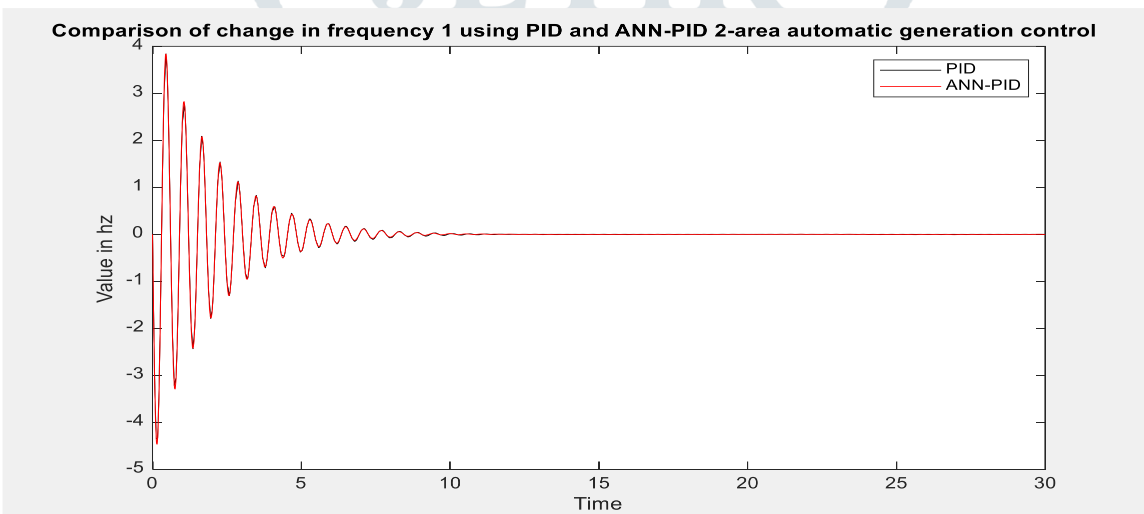

Figure 5: Comparison of change in frequency using PID and ANN-PID 2-area automatic generation control with zero percent change in load of area 1

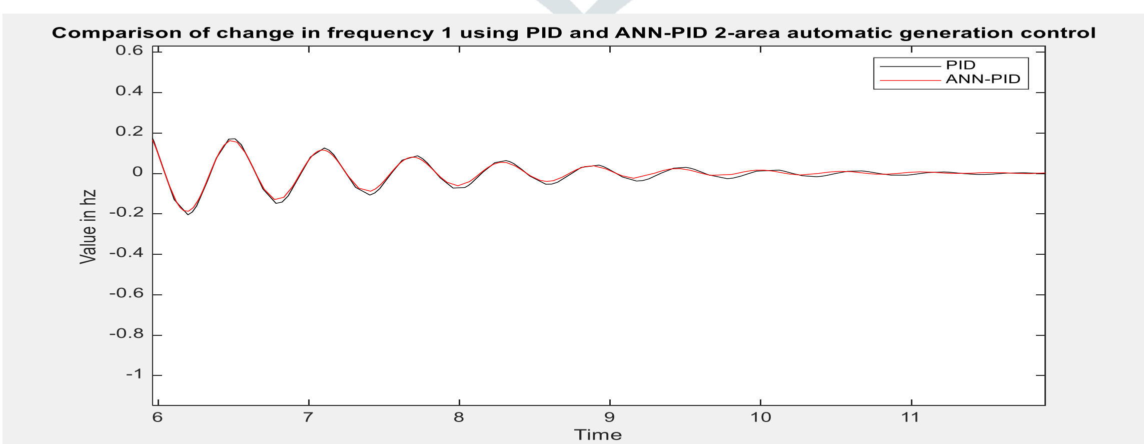

Figure 6: Zoomed view of change in frequency with zero percent change in load of area 1 (area2)

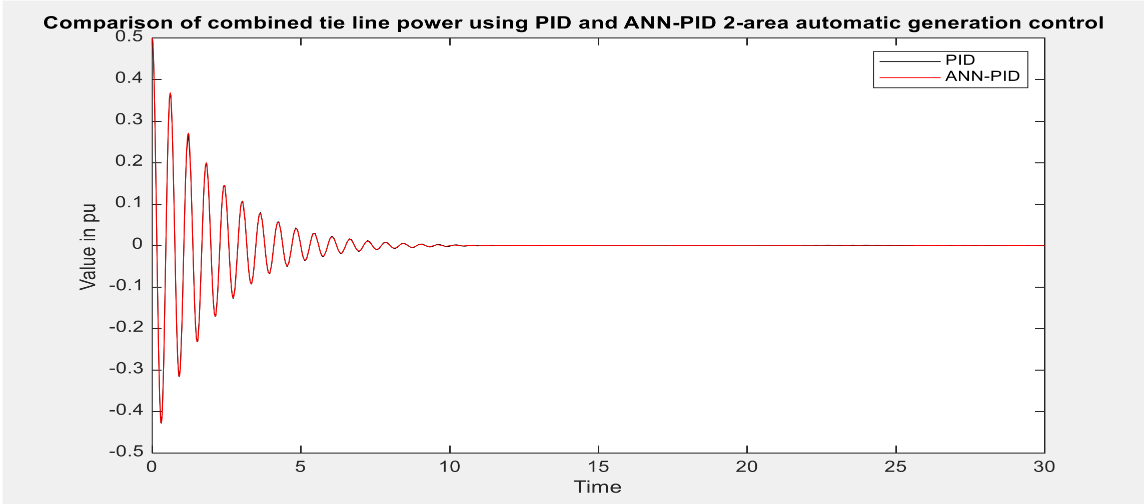

Figure 7: Comparison of combined tie line power using PID and ANN-PID 2-area automatic generation control

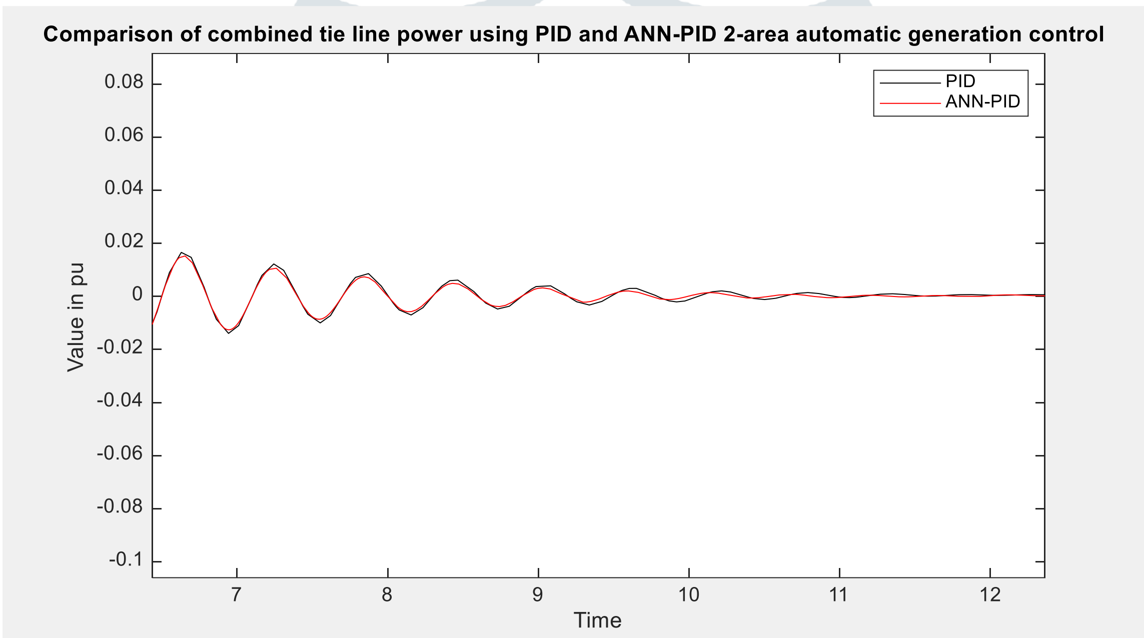

Figure 8: Zoomed view of combined tie line power with zero percent change in load of area 1

Table 3: Performance Study

0 pu load change						
parameters	**Delta F1**		**Delta F2**		**DeltaP$_{tie12}$**	
	PID	ANN-PID	PID	ANN-PID	PID	ANN-PID
Settling time (s)	12.02	11.15	2.02	11.15	12.02	11.15
Rise time (s)	.4493	.4459	.1511	.1248	.3682	..3579
Peak over-shoot (%)	3.839/50 =7.68	3.835/50= 7.67	4.463/50=8 .93	4.353/50=8. 71	61.06	62.74
1 pu load change						
parameters	Delta F1		Delta F2		DeltaP$_{tie12}$	
	PID	ANN-PID	PID	ANN-PID	PID	ANN-PID
Settling time (s)	20.34	15.14	20.34	15.14	20.34	15.14
Rise time (s)	0.4317	.4432	1.405	.1401	.3674	.3674
Peak over-shoot (%)	7.27	7.38	8.87	8.86	60.71	60.71
1.5 pu load change						
parameters	Delta F1		Delta F2		DeltaP$_{tie12}$	
	PID	ANN-PID	PID	ANN-PID	PID	ANN-PID
Settling time (s)	14.5	13.03	14.5	13.03	14.5	13.03
Rise time (s)	.4457	.4442	.1399	.1389	.6153	.5971
Peak over-shoot (%)	7.25	7.24	8.848	8.832	36.46	36.46

Table 3 depicts the comparative study of transient responses of two systems. As per desired response, the frequency deviation is nullified in case of both areas. The PID based system has lower peak overshoot compared to the other and lesser settling times. It is observed that the transient plot of frequency deviation of area2 less number of oscillations compared to area1.The generation capacities of all generators are assumed to be equal. ANN based PID tuning of area 1 and 2 ensures better response because the thermal generators have to generate less. Also there are less settling times when ANN-PID controller is used as compared to PID controllers.

V. Conclusion

The aim of control areas in Load Frequency Control (LFC) is such that each control area as far as possible should supply its own load demand, and power transfer through tie-line should be on mutual agreement and each control area should be controllable to the frequency control. Most of the earlier work in the area of LFC pertains to interconnected thermal system and relatively lesser attention has been devoted to the LFC of multi-area interconnected hydro-thermal system. The proportional & integral (PI) and proportional, integral & derivatives (PID) controllers are very simple for implementation and gives better dynamic response, but their performances deteriorate when the complexity in the system increases due to non-linearity, disturbances like load variation boiler dynamics. Therefore, a controller is needed which can overcome this problem. The artificial intelligent controllers like neural control approaches are more suitable in this respect. ANN system has been applied to the LFC problems with rather promising results. ANN is an 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. The output signal is obtained by applying activations to the net input. The field of neural networks covers a very broad area.The simulation results obtained above reveals that the steady state error is minimized to zero using ANN-PID based controllers. Settling time and maximum peak overshoot in transient condition for both change in system frequency and change in tieline power are improved with proposed ANN-PID controller when 0 pu, 0.01 pu and 0.15 pu load variations are introduced in area one.

References:

[1] M. Saif, "Optimal Load Frequency Control: A multilevel hierarchical approach," M.S. thesis, Department of Electrical and Computer Engineering, Cleveland State University, Cleveland, Ohio,1984.

[2] T. Jawat and A. B. Fadel, "Adaptive fuzzy gain scheduling for load frequency control," IEEE Transactions on PAS, vol. 14, no. 1, pp. 145-150, February 1999

[3] H. Bevrani, Robust Power System Frequency Control, 1st ed, Springer, 2009.

[4] H. Shayeghi, H. A. Shayanfar and A. Jalili, "Load frequency strategies: a state of the art survey for the researcher," Energy Conversion and Management, vol. 50, no. 2, pp. 344-353, February 2009

[5] X. Yu and K. Tomsovic, "Application of linear matrix inequalities for load frequency control with communication delays," IEEE Transactions on Power System, vol. 19, no. 3, pp. 1508-1511, August 2004.

[6] Bheem Sonker, Deepak Kumar, Paulson Samuel, Dual loop IMC structure for load frequency control issue of multi-area multi-sources power systems, International Journal of Electrical Power & Energy Systems, Volume 112, 2019, Pages 476-494

[7] Dipayan Guha, Provas Kumar Roy, Subrata Banerjee, Application of backtracking search algorithm in load frequency control of multi-area interconnected power system, Ain Shams Engineering Journal, Volume 9, Issue 2, 2018, Pages 257-276

[8] W. Tan, "Unified tuning of PID load frequency controller for power systems via IMC," IEEE Transactions on Power Systems, vol. 25, no. 2, pp. 341–50, 2010

[9] Sahaj Saxena, Yogesh V. Hote, Decentralized PID load frequency control for perturbed multi-area power systems, International Journal of Electrical Power & Energy Systems, Volume 81, 2016, Pages 405-415,