International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-1, October, 2019

Performance Evaluation of Neuro-Fuzzy Clustering for Hydro Thermal Power System

Ajay Kumar Maurya, G.K. Banerjee, Piush Kumar

Abstract: *To meet increasing power demands and reduce carbon emission additional renewable sources of power are added to existing thermal unit. Even network frequency change by 1% due to change in speed, may result in loss of synchronization with the rest of power system and finally resulting in power system black-out. Inter-connection of hydro units to existing thermal system can allow to transmission system to operate at full capacity. The paper investigates LFC by adding non-linearity's to the thermal and hydro-thermal systems. Further PID and Neuro-Fuzzy Controllers are compared for these systems. A multi section steam turbine with re-heater was used for a single area system modeled in MATLAB, later two single area systems were combined to create a two area system, and its dynamics are studied by creating load perturbations. Form simulation studies it is shown that the proposed Neuro-Fuzzy controller was able to attain a setting time of 10 Sec which is comparatively lower than other existing speed controllers. The time domain response result of hydropower system proves that it provides more rapid output response and minimal overshoot.*

Keywords **:** *Adaptive Fuzzy, Frequency Control, Fuzzy Control, Neuro-Fuzzy Control, Speed Control, Steam Turbine Speed, Two Area System.*

I. INTRODUCTION

A. Overview

The steam turbine is the prime mover for synchronous generators in thermal power stations. The speed in which the turbine rotates is controlled by a governor and it associated control system, this decides the output frequency of the generator (Fig. 1). The frequency of electric power generated is related to the speed of the turbine by the expression, Ns=120 *F/P, Where, Ns is the speed of the turbine, P is the number of poles and F is the frequency.

Load Frequency Control of a power system is concerned with the following objectives:

- Match the power generation as per the load
- Maintain the System frequency (F)
- Maintain Tie line power scheduled within the restraining values

The steam inlet level is adjusted by the control value, thereby controlling the speed of the turbine. Due to the complexity involved in steam turbine control and the related electrical generator, conventional speed regulation systems can no longer afford fast dynamic response. This has led to the design of robust controllers with superior dynamic response.

In general, the mechanical and electrical measured parameters used to identify the model of steam power plant are translated into suitable transfer functions for various components in the power plant [1]. The model selected in this investigation is the turbine speed control system presented in a two-area system i.e. the turbine generator system is electrically tied to a similar system through a tie-line. Each area has a number of steam turbine coupled generators which operate as a coherent group, i.e. all generator of the area responds in unison to external disturbances.

B. Objectives of the Proposed Work

The foremost Contribution of this investigation on speed controllers are,

- To develop a Neuro-Fuzzy Controller with fine speed response to track load demands and reject disturbance, with a reduced settling time and acceptable overshoots.
- Ensure zero steady state error after frequency deviations created due to disturbances.
- Evaluate the performance of the designed Adaptive Neuro-Fuzzy Controller (ANFC) with PID and Fuzzy controller modes.

Prior works by a number of control engineers, namely Bode, Nyquist, and Black, has established links between the frequency response of a control system and its closed-loop transient performance. A major issue in the design of the controllers for thermal power systems is the parametric uncertainties. These uncertainties have been taken into account by several authors and concepts like variable-structure systems have been suggested to handle these issues [2, 3].

Studies carried out on classical control approaches reveal that it would result in reasonably large overshoots and transient frequency deviation [4-6]. Further, in these reported works the settling time of the system frequency deviation is relatively long, of the order of 20–40 seconds. Various methods of speed control cited in literature are can be classified as Conventional and Intelligent Methods.

1) Conventional control methods

- LQR based controlling techniques
- Proportional, Derivative, Integral controlling techniques

Revised Manuscript Received on October 30, 2019.

* Correspondence Author

Ajay Kumar Maurya*, PhD Scholar, Department of Electrical Engineering, IFTM University, Moradabad, Uttar Pradesh. Email: ajaykumarmauryaeee@gmail.com.

G.K. Banerjee, Professor, Department of Electrical Engineering, IFTM University, Moradabad, Uttar Pradesh.

Dr. Piush Kumar, Associate Professor, Department of Electrical and Electronics Engineering, Future College of Engineering and Technology, Bareilly, Uttar Pradesh, India .

2) Adaptive and Variable structure methods,
3) Robust controller approaches
4) Artificial Intelligence (AI) methods [7- 18]
Fuzzy logic - Based on Fuzzy rules
Neural network – Machine learning, Parameter Identification
Genetic Algorithm – Used to tune PID Parameters
Particle Swarm – Used to tune PID Parameters

Among these control algorithms like Fuzzy and Neuro-Fuzzy are hot research topics in the start-of-the-art algorithm development for nonlinear control system. The subsequent section describes the modeling of thermal power system and it components used for the simulation studies in MATLAB.

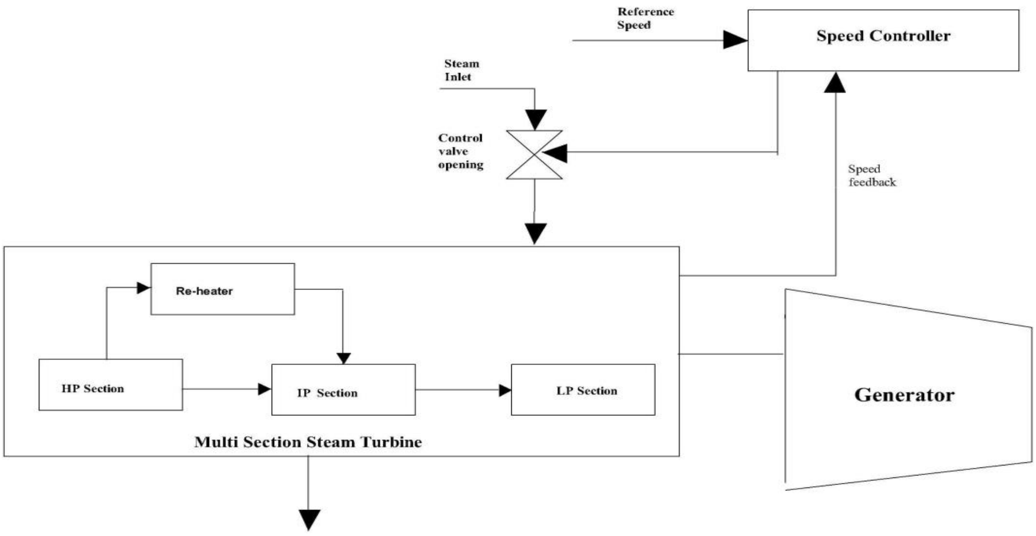

Fig.1. Steam Turbine Control System

This paper is organized as follows; in section 2 the open loop response of a interconnected two area thermal system is done. In section 3 two thermal and one hydro unit is modeled. The Neuro-fuzzy controller application is presented in section 4. The comparison of neuro fuzzy with PID for thermal and hydro-thermal systems is given in section 5. The final section 6 presents the conclusion of this article.

II. TWO AREA STEAM TURBINE CONTROL SYSTEM MODELING

Two commonly employed models in study of speed dynamics are,

1. Transfer function approach.
2. State variable equations.

The transfer function method was used in this work. Each component in the LFC (Load Frequency Control) system is modeled in block diagram with the help of transfer functions of multi section steam turbine, re heater & generator. The speed control loop performance analysis is done using this comprehensive two area power system. The incremental power mismatch is given as in Eq. (1).

$$(\Delta P_m - \Delta P_l) = 2Hd(\Delta f)/dt + D\Delta f \ldots\ldots\ldots (1)$$

Where,
ΔPm is Mechanical Power,
ΔPl is the Load change,
Δf is the Frequency deviation,
H is the Inertia Constant,
Now, D the Load Damping Coefficient of Eq. (1) can be modified as,

$$Gp = 1/(2Hs+D) \ldots\ldots\ldots (2)$$

Discrepancies occurs in development of the mathematical model for the Steam Turbine coupled with generator owing to the parameter variations, un-modeled dynamics and approximation made in these models. Any controller designed must be robust in order to lessen the effect of these mismatches. In this work conventional PID controller designs are compared with Neuro-Fuzzy based controller for the steam turbine speed control. The simplified model of the Single Area Multi Section Steam Turbine is presented in Fig. 2 and the Bode Plot Response of the same obtained from the transfer functions of the Mechanical and electrical systems given in Fig. 3.

III. CONTROLLER FOR TWO AREA SYSTEM

The Ziegler and Nichols proposed the well-known Ziegler-Nichols technique to tune the coefficients of a PID controller. Tuning parameters of PID controller decides the error and other time domain response characteristics. This method despite of its simplicity, cannot guarantee to provide the best controller parameters, hence the Simplex method was preferred in this research

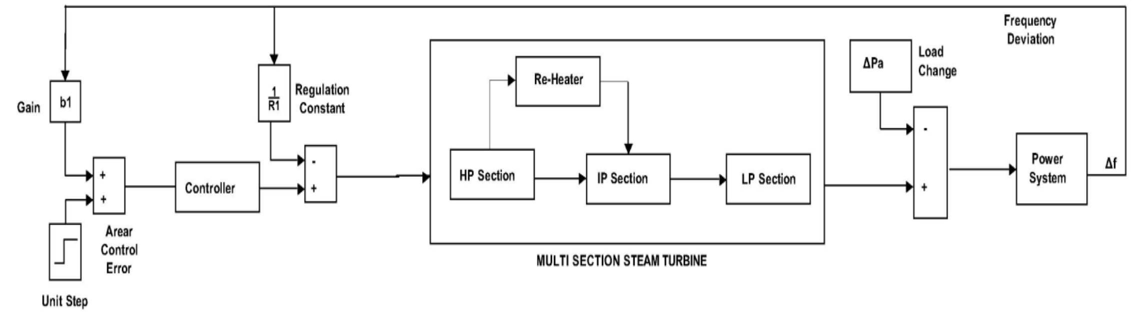

Fig. 2. Single Area Power System Block Diagram

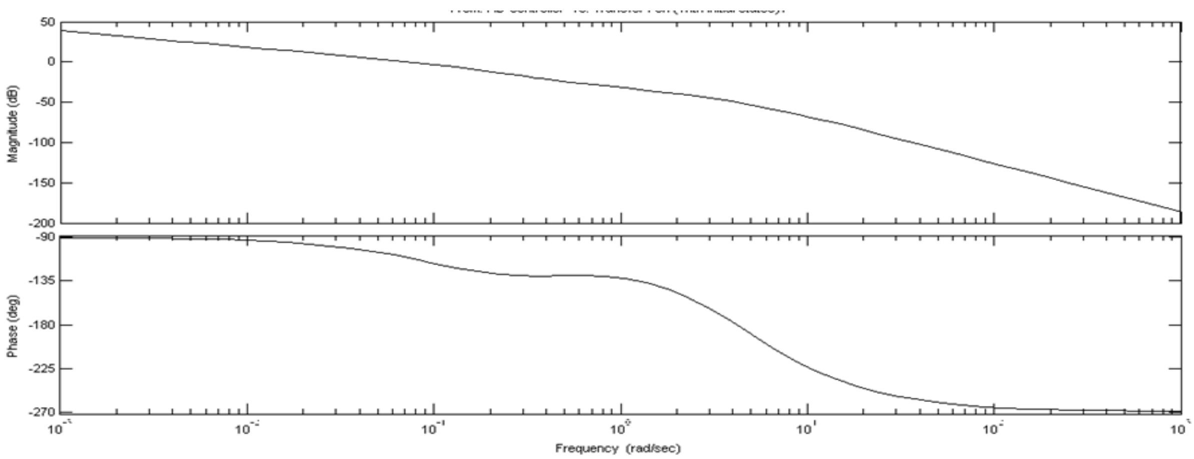

Fig.3. Bode Plot of the Single Area Systems with PID Controller

In Nelder-Mead algorithm (NM) or (simplex search) method a simplex s in Rn is defined as the convex hull of n+1 vertices a0 ………an ∑ Rn. In our case the PID parameters KP, KI and KD constitute a tetrahedron then, the algorithm selects a new test position by extrapolating the objective function and the advancement is based on the replacement of the test point. The creation of new simplex is based the mathematical model of PID controller given by Eq. (3).

$$Y(t) = KP\ e(t)+Ki\int_0^t e(t)\ dt+KD\ \frac{de(t)}{dt} \quad ...(3)$$

Where,

Y(t)……… controller output.

E(t)……... error signal.

Kp, Ki, Kd……proportional, integral and derivative gains.

For realization of the controller in an embedded system the PID controllers are preferred in industries. Perhaps the use of Neuro-Fuzzy controllers can be simplified by the advent of

Hardware-In-Loop features in software like MATLAB.

PID controller are preferred in industries as they can be easily implemented via PLC (programmable logic controllers) or using embedded processor, the foremost task in implementation of PID controller is the tuning of the parameters to obtain the desired response. The trial and error adjustment was carried by means of the following criteria

a) Higher value of Kp results in decrease of rise time and steady state error but oscillation may increase.

b) Derivative control KD was used to trim down the system oscillation, thereby providing reasonable over shoots.

c) When KP and KD are fixed then the value of KI can be adjusted to provide rational settling time.

The response of the PID system under external disturbances, for Frequency deviation and Speed deviation is presented in Fig. 4 and Fig. 5 respectively. From the response characteristic it's obvious that a setting time of 15 Sec can be obtained by proper tuning of the PID parameters. The hydro system consists of the hydro turbine, with its governor and associated electric systems. The non-linearity of the hydro system creates large overshoots and longer settling times. To study the behavior of the hydro turbine a 1% disturbance was fed to the SIMULINK model presented in Fig. 6. The resulting transients are presented in Fig. 7. These hydro and thermal areas are interconnected by a tie line. The Load disturbances are expressed in delP11 and delP2 in thermal and hydro area respectively. R1 and R2 represent frequency bias in area 1 and area 2 respectively.

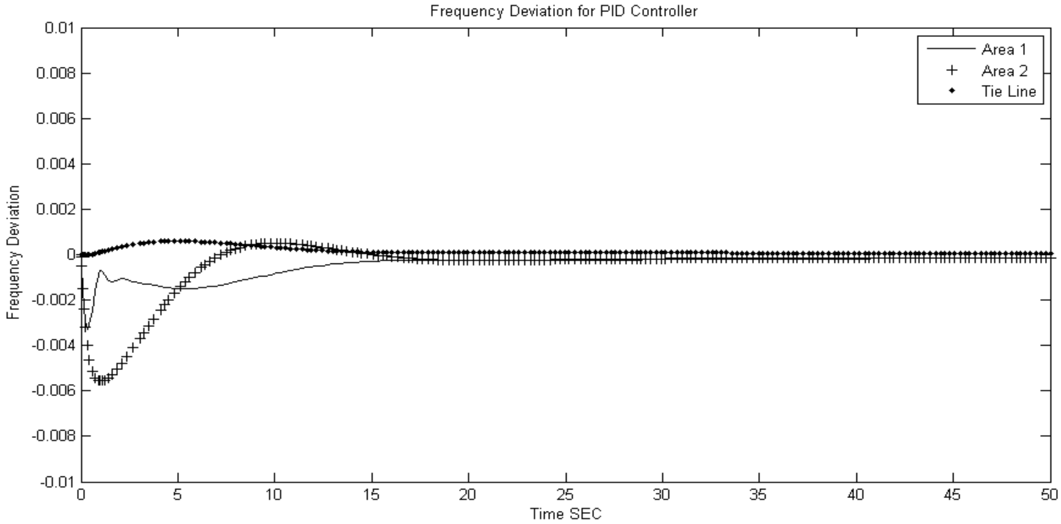

Fig.4. Response of PID Controller - Frequency Deviation in Area One and Two

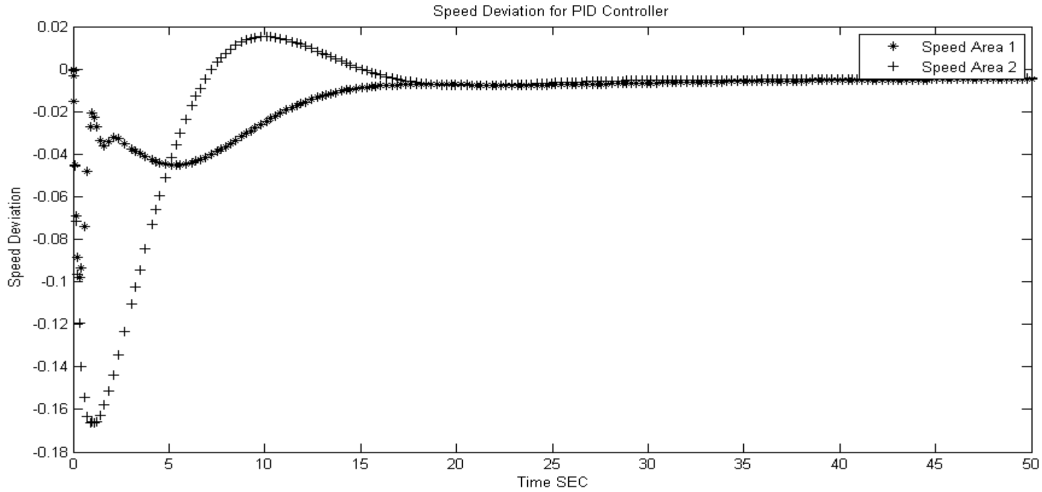

Fig.5. Response of PID Controller - Speed Deviation in Area One and Two

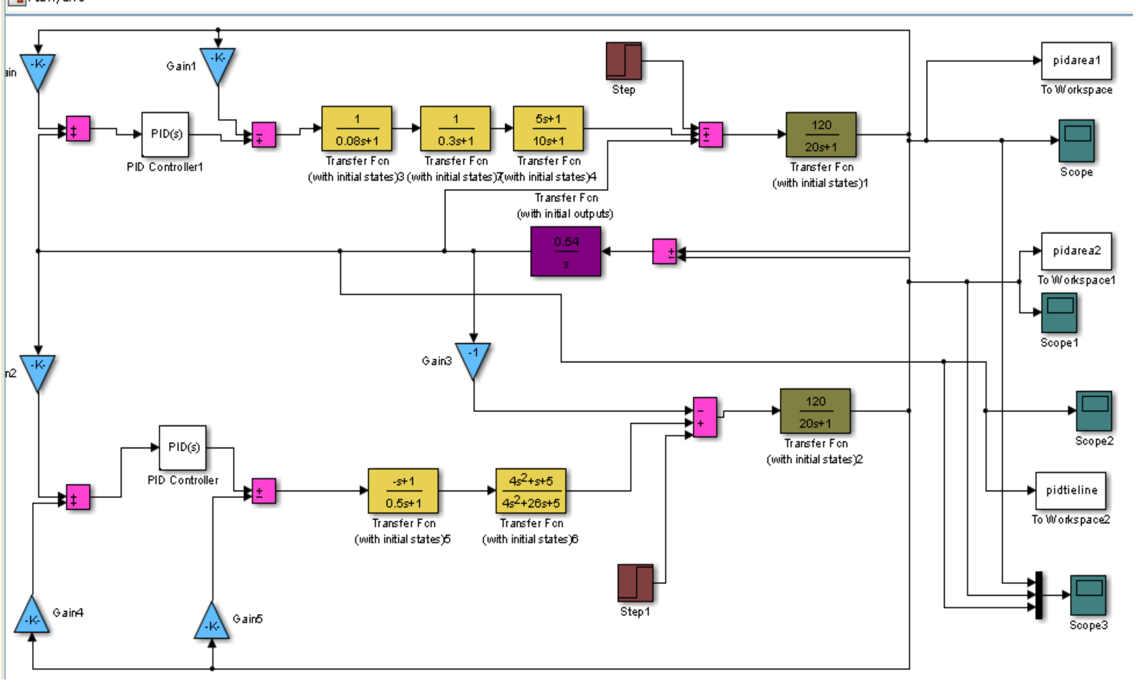

Fig.6. MATLAB model for Thermal-hydro interconnected system

These transfer equations described in this model has been investigated by other researchers as well. The role made by the authors in this work is the devise of a Neuro-fuzzy controller.

IV. FUZZY AND NEURO-FUZZY CONTROLLERS

Fuzzy is a problem solving algorithm used in control systems when the inputs are imprecise or when the mathematical model of the plant is not present. Ross TJ (1995) defined the fuzzy as the process of making crisp quantity into fuzzy variables. The fuzzy variables are uncertain, imprecise or vague and represented by the fuzzy membership function. The purpose of using NFC is to suppress the frequency oscillations in each individual area as well as the tie lines.

V. DESIGN OF NEURO-FUZZY CONTROLLER (NFC)

The use of Neuro–fuzzy is justified by the following points,

1. Addition of new source of power like hydro or solar into the existing network configuration needs an adaptive and efficient controller.
2. The basic Fuzzy logic controllers are based on the rules defined from the user experience. Further the tuning of membership functions are done by a trial and error process. In a Neuro-fuzzy system a neural network optimizes the fuzzy membership functions based on the set of input/output data.

A. Clustering Algorithm for controller

In order to start the modeling process, an initial fuzzy model has to be derived this initial fuzzy model can be selected based on the fuzzy rules framed using clustering technique. The clustering technique called as subtractive clustering is used in this work. For a set of n data points {a1, a2 ….an} in an M dimensional space these data points are normalized in the range 0 to 1. Initially each data point is considered to be a potential cluster center and Fi is a measure of the potential of the data point Xi to serve as a center, which is shown in Eq. (4)

$$Fi = \sum_{k=1}^{n} \sum_{xi\, \varepsilon\, Ck} Uik\,(\gamma)^{\wedge}2 \quad \ldots\ldots\ldots\ldots..(4)$$

and γ = || Xi - Xk|| is the Euclidean distance,

$$Cj = \frac{\sum_{x \in Cj} Uik * X}{\sum_{x \in Cj} Uik}$$

Here the degree of belonging, Uik is linked inversely to the distance from x to the cluster center.

$$Uik = \left[\frac{1}{\sum_{i=1}^{k} \frac{(|xi-Cj|)}{(|Xi-Ck|)}}\right] ^{\wedge} \left[\frac{2}{m-1}\right] \quad \ldots\ldots\ldots(5)$$

Where,

m……. fuzzifier (between 1 and ∞),

Uik……degree to which an observation,

Xk …… center of cluster k.

The cluster center derived using the above equation describes the input–output relationship of the fuzzy system being modeled.

Table-1: Parameters of the Neuro-fuzzy Controller

Parameter Name	Value
Maximum Number of Epochs	100
Error tolerance	0.001
Shape of the Membership Function (MF)	Gaussian MF
Training Algorithm	Back Propagation

Procedure to implement adaptive neural Fuzzy inference start with the collection of data set for training, the flow diagram of the entire process is given in Fig. 8. Herein the two area system with PID controller model was used to collect the training set. The neural controller adjusts the membership functions in the infernce system to match the target value.

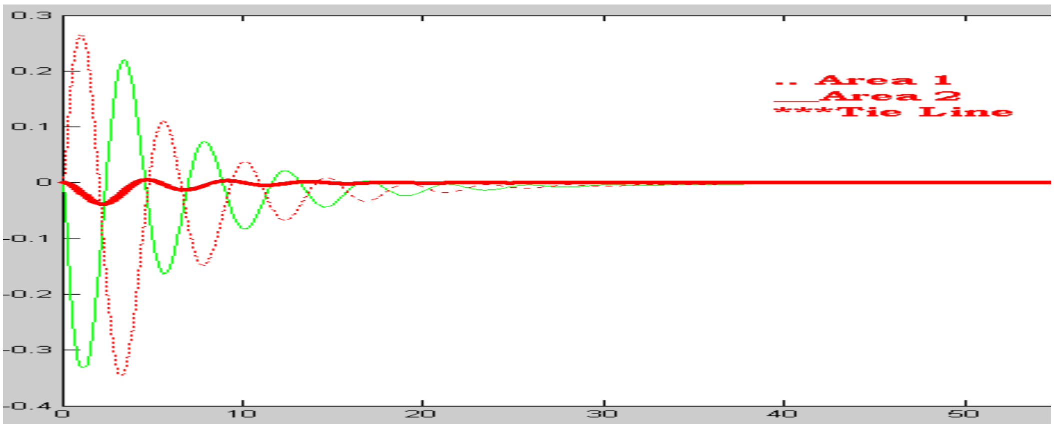

Fig. 7. Response of Two Area with Thermal and Hydro units with PID controller.

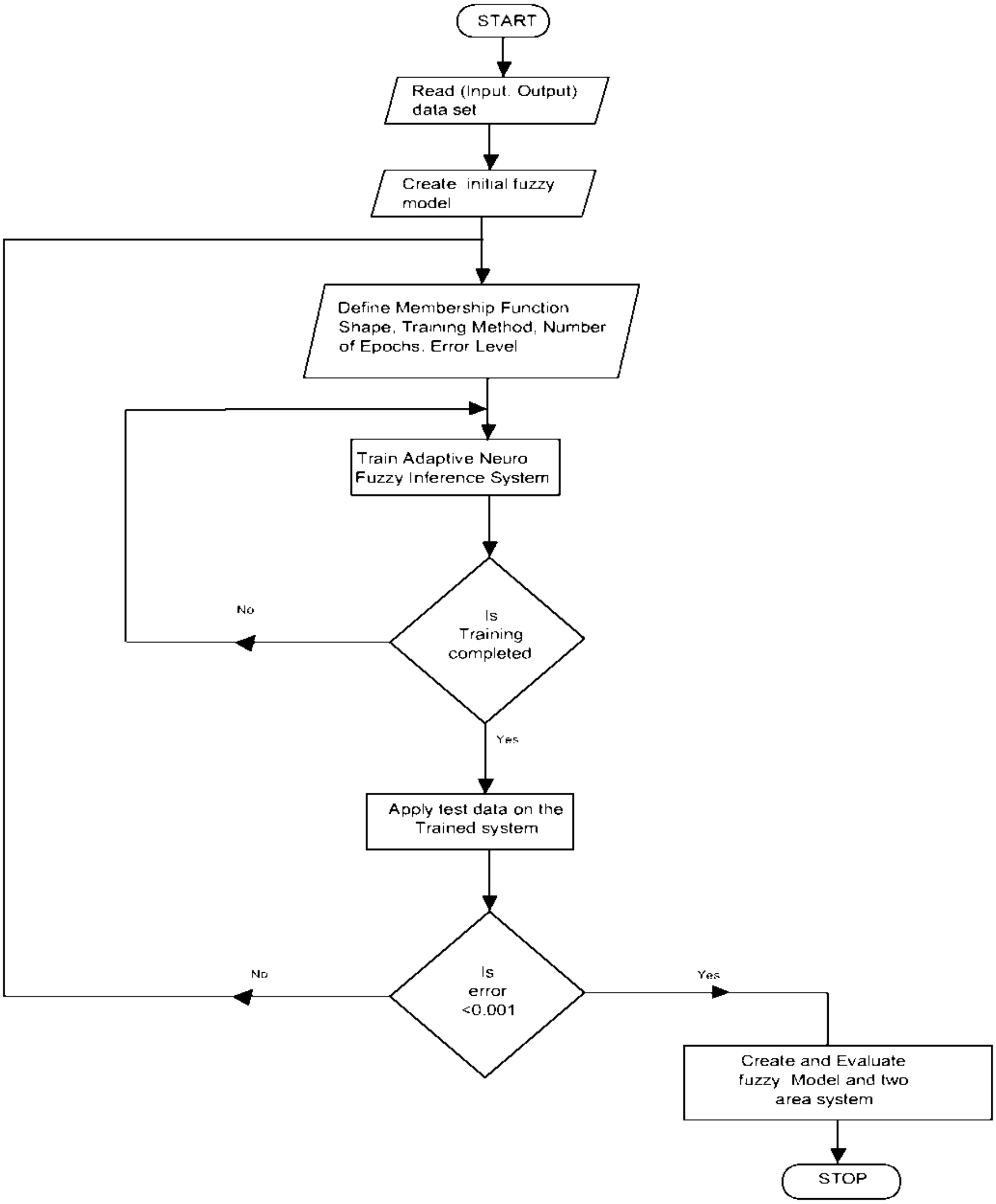

Fig. 8.

Implementation of Neuro-fuzzy

B. Performance of Neuro-fuzzy Controller

In 1970 the adaptive networks were based on the gradient descent [6] and the chain rule for learning, subsequently, these methods have been replaced by the neural based learning algorithms in this case the adaptive network is a feed forward, multi-layer neural network, contain fixed and adaptive nodes. The term Neuro-fuzzy in this article refers to the neural Network performing the adaptation task. The procedure of training is terminated when the error value is less that the error tolerance (0.001). Adaptive Network Based Fuzzy Inference System (ANBFIS) helps in constructing the fuzzy IF-Then rules with suitable membership functions. The type of training and other parameter used in creating the network are listed in table 1. The performance of the ANBFIS for an external disturbance of 0.01 is displayed in Fig. 8.

The trained network was tested (Fig. 9) using about 25% of the training data, perhaps even the entire training set can be used to validate the network.

C. Implementation of Neuro-Fuzzy Controller

The flow sequences to design a Fuzzy Logic Sliding mode controller as shown in Fig. 8 are as follows,

1. Selection the input and output variables; the error and the change in error. These may be recorded from experiments or simulated from a PID controller

2. Selecting proper initial Membership Functions to represent fuzzy input and output variables,

3. Apply Fuzzification on the crisp input variable,
4. Use the ANFIS tool to perform training and develop Fuzzy Inference system,
5. Apply the designed fuzzy into the actual Load Frequency Controller Model (the *.fis file).
6. The actual output of the FLC controller is studied under disturbance. For the presence of error more than 0.001 the ANFIS learning rate may be altered.

In this work the hybrid learning rule was used to identify the parameters of the adaptive network. The algorithm is implemented in two phases: in the forward pass the least squares method is used to evaluate the consequent parameters and in the backward pass the gradient descent is used find the parameters.

The membership function evaluation was done using the expression,

$$\mu A(x) = \frac{1}{1+\left[\frac{x-c1}{a1}\right]^{2b1}} \quad \ldots\ldots\ldots\ldots\ldots(7)$$

Where,

a1, b1, c1 …… adjustable parameters.

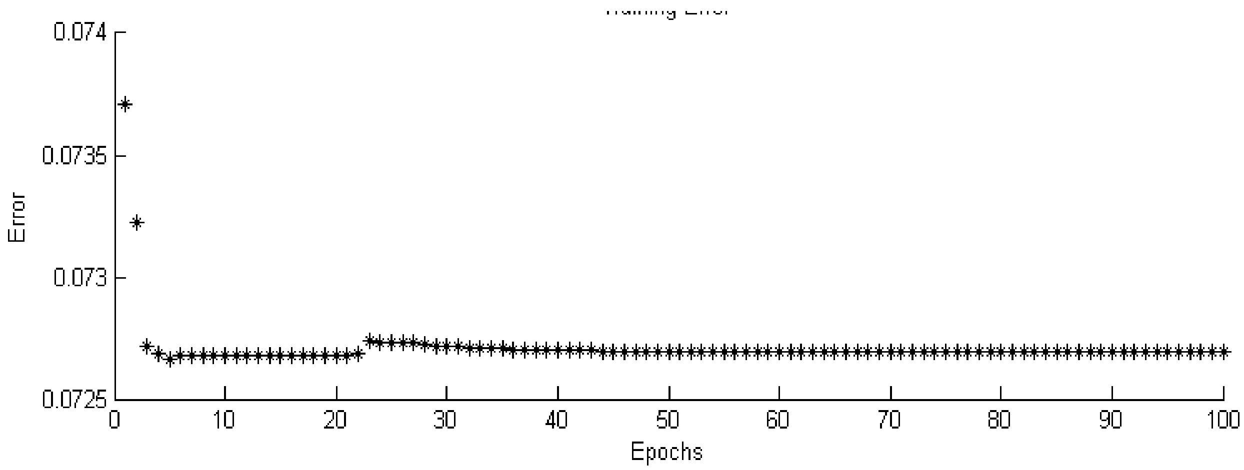

Fig. 9. Training performance of Neuro-Fuzzy

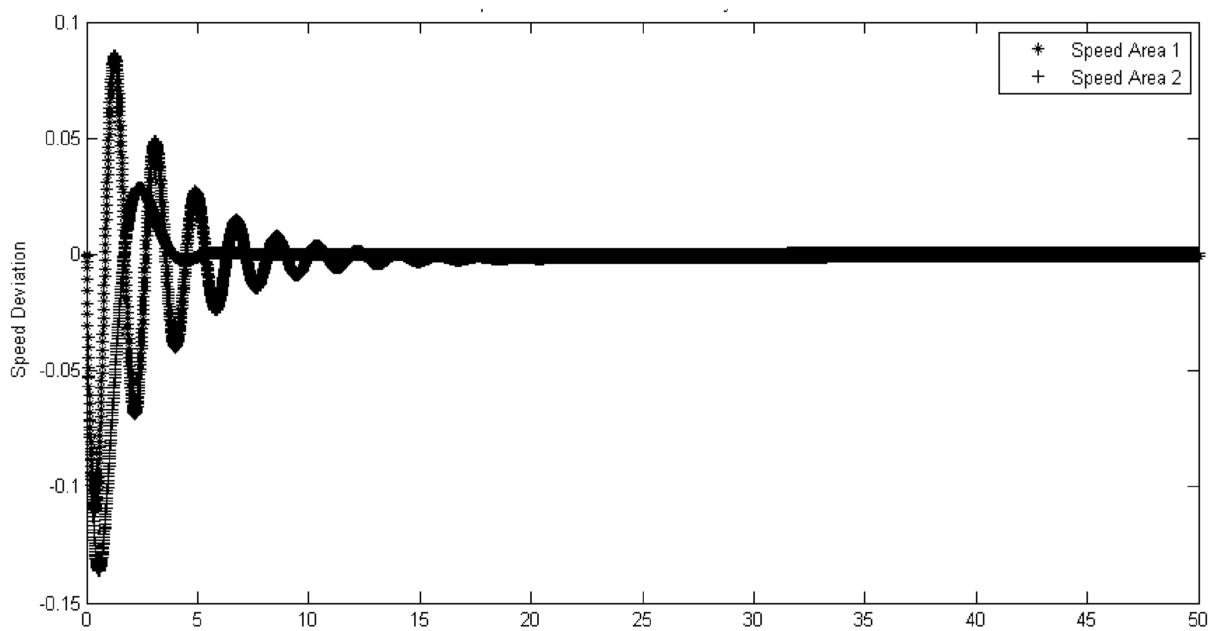

Fig.10.Adaptive Neuro-Fuzzy Controller – Frequency Deviation in a Two Thermal area system

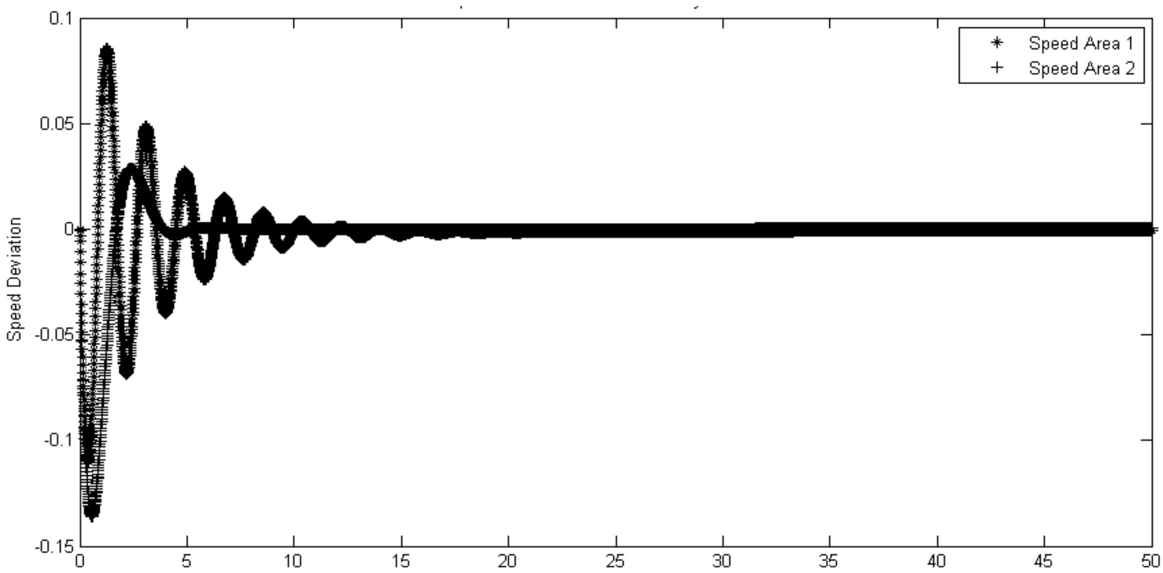

Fig.11. Adaptive Neuro-Fuzzy Controller – Speed Deviation in a Two Thermal area system

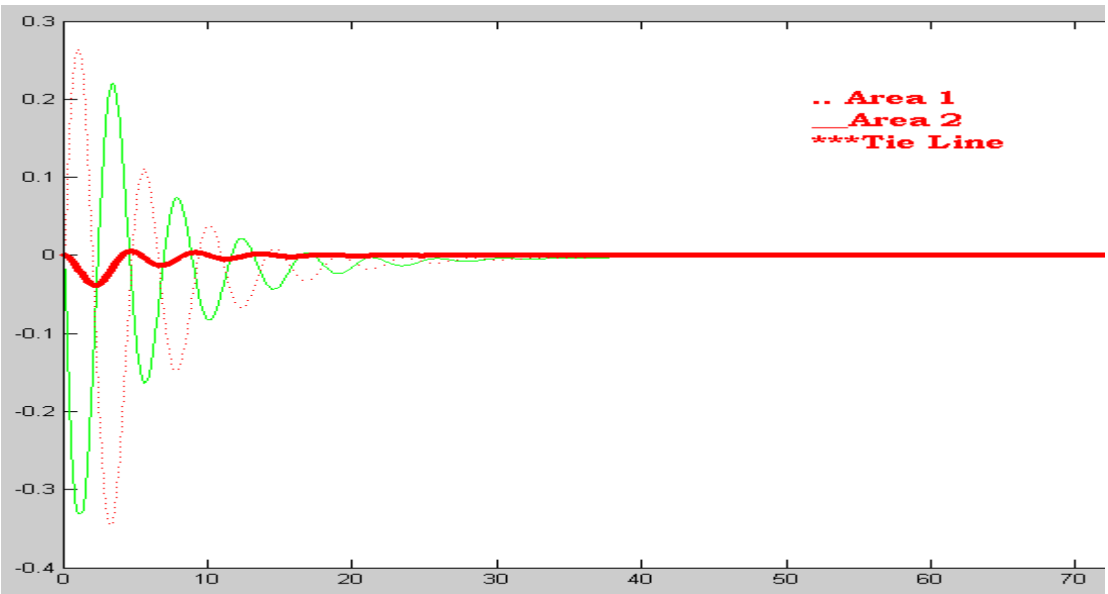

Fig. 12. Adaptive Neuro-Fuzzy Controller Based LFC - Frequency Deviation with Hydro and Thermal Units

Table 2 Performance of Different Speed Controllers

Type of Controller	Peak Overshoot Area 1	Settling Time Area 1 (Sec)	Peak Overshoot Area 2	Settling Time Area 2 (Sec)	Peak Overshoot Tie Line	Settling Time Tie Line (Sec)
PID Only Thermal	6 %	15	5%	15	6%	20
Neuro-Fuzzy Only Thermal	3%	7	3%	7	3%	10
PID based Hydro thermal	25%	22	15%	20	8%	30
Neuro-Fuzzy based Hydro Thermal	20%	20	12%	20	7%	20

VI. CONCLUSIONS

The performance of speed and Frequency controllers likes PID and Neuro-Fuzzy were investigated in this work. Among these, the performance of Neuro-Fuzzy Controller developed using clustering approach was found to provide better response with reduced settling time (as in Table 2). In fuzzy clustering, data points can potentially belong to multiple clusters. The settling time for the PID controller was 20 seconds and that of Neuro-fuzzy Controller was found to be less than 10 seconds. The peak overshoot for the PID controller was 6 % and that of Neuro-fuzzy controller was found to be 3% (as in Fig.10 & 11). Similarly, for the hydro-thermal interconnected system the overshoot of 8% on the tie-line was reduced to 7% when using the Neuro-fuzzy Controller as shown in Fig. 12.

The Neuro-Fuzzy controller needs only the limits (upper and lower bound) of the unknown parameter. The exact mathematical model of the plant is not needed; hence the system can endure parameter uncertainties. As presented, the rule base obtained for the Neuro-Fuzzy Controller can be applied to a real plant due to its simple structure. Further the projected method can be extended to real time implementation using the Real Time Workshop features present in current release of MATLAB/SIMULINK. The proposed controller is adaptive in nature hence can be extended to four area systems also.

APPENDIX A

The various parameters used in the simulation are below,
F = 50 HZ, $R_1 = R_2$ = 2.4HZ/per unit MW. T_g = 0.08Sec, T_p = 20Sec, Ptie Max = 200MW, T_r =10 Sec, K_r = 0.5, $P_{r1} = P_{r2}$ = 2000MW, T_t = 0.3Sec.

REFERENCES

1. J. Faiz, G. Shahgholian, and M. Arezoomand, "Analysis and simulation of the AVR system and parameters variation effects", *IEEE/POWRENG*, pp. 450-453, April 2007.
2. V. Vesely and A.D. Rosinov, "Robust PID-PSD Controller Design: BMI Approach", *Asian Journal of Control*, Vol 15, No. 2, pp. 469–478, 2013.
3. N.N. Bengiamin and W.C Chan, "Variable Structure Control of electric power generation", *IEEE Transactions on Power Apparatus and Systems*, 1982, pp. 376- 380.
4. D.R. Chaudhary, "*Modern control engineering*", PHI, Private Limited, 2005.
5. P. Kundur, "*Power System stability and control*", TMH Publication, 322. 2004.
6. W Tan, J.Z Liu, F Fang and Y. Q Chen, "Tuning of PID controllers for boiler-turbine units". *ISA Trans.*, 43 (4):571–583, 2004.
7. E. Bonabeau, M. Dorigo, and G. Theraulaz, *Swarm Intelligence: From Natural to Artificial Systems*, Oxford University Press, 1999.
8. K Deb, *Optimization for Engineering Design*, Prentice-Hall, New Delhi, 1995.
9. D.E. Goldberg, *Genetic Algorithms in Search, Optimization and Machine Learning, Reading, Mass*, Addison Wesley, 1989.
10. J. Kennedy, R. Eberhart and Y. Shi, *Swarm Intelligence*, Academic Press, 2001.
11. D. Devaraj and J.P. Roselyn, "Genetic Algorithm Based Reactive Power Dispatch for Voltage Stability Improvement", *Electric Power Energy System*, 32: 1151-1156, 2010.
12. X.S. Yang, *Nature-Inspired Meta heuristic Algorithms*, Luniver Press, UK, 2008.
13. J.C. Bansal and K. Deep, "Optimization of Directional Over-Current Relay Times by Particle Swarm Optimization", *Swarm Intelligence Symposium (SIS 2008)*, IEEE Publication, pp. 1-7.
14. C.A. Floudas and P.M. Pardolos, *Encyclopedia of Optimization*, 2nd Edition, Springer, 2009.
15. R.S. Parpinelli and H.S. Lopes, "New Inspirations in Swarm Intelligence: a survey", *International Journal of Bio-inspired computation*, 3, 1-16, 2011.
16. X.S. Yang, *Engineering Optimization: An introduction with Meta heuristic Applications*, John Wiley and Sons, USA, 2010.
17. X.S. Yang, "A New Meta heuristic Bat-Inspired Algorithm, in: Nature Inspired Cooper-Active Strategies for Optimization (NICSO 2010)", *Springer, SCI* 284, 65-74.
18. A.H. Gandomi, X.S. Yang and A.H. Alavi, "Cuckoo Search Algorithm: A Meta heuristic Approach to Solve Structural Optimization Problems", *Engineering with Computers*, 27, 2011, Article DOI 10.1007/ S00366-011-0241.
19. L.A. Zadeh, "Fuzzy Sets", *Information on control*, Vol.8, pp. 338-353, 1965.

AUTHORS PROFILE

Ajay Kumar Maurya was born in Gorakhpur, Uttar Pradesh, India on July 07, 1981. He received his B.Tech degree in Instrumentation and Electronics Engineering from Meerut Institute of Engineering and Technology, Meerut in 2003 and M.Tech degree in Electrical Engineering (Control and Instrumentation) from Motilal Nehru National Institute of Technology, Allahabad, India in 2006. Currently He is pursuing Ph.D. degree from the Department of Electrical Engineering, Institute of Foreign Trade and Management (IFTM) University Moradabad, Uttar Pradesh, India. He is having 12 years teaching Experience (8 years in India, 4 Years in Ethiopia). His area of interest is Power System, Control System, Artificial Neural Network and Fuzzy Logic.

Professor GK Banerjee was born in Raipur in 1947. He received his B.Sc. Engg. (Electrical) degree in 1968 from AMU Aligarh, M.Sc. Engg. (Electrical) in 1983 from AMU, Aligarh and Ph.D in electrical engineering from G.B. Pant University of Agriculture & Technology Pantnagar in 1998. He was at Pantnagar during 1984-2011 and retired from Pantnagar as a Professor. After retiring from Pantnagar he joined IFTM University, Moradabad as a Prof & Head, Department of Electrical Engineering. At present, he is Dean, school of Engineering & Technology. He has published two books and 13 papers and edited three Laboratory manuals. His areas of interest include electrical machines & instrumentation engineering.

Dr. Piush Kumar graduated from Karnataka University Dharwad India, with Electrical and Electronics Engineering in 1998. He received his master's degree in Power Electronics and Drives, from M.M.M. Engineering College, Gorakhpur in 2003. He completed his PhD degree in Electrical Engineering from Motilal Nehru National Institute of Technology, Allahabad, India in 2010. He is working as a Associate Professor in Future College of Engineering and Technology, Bareilly. His area of interest is Power Electronics and Drives, Control System, Power System, Fuzzy Logic and Neural Network. His total Experience is 21 Years (3 years in Industry, 6 Years in Research and 12 years in Teaching).