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Automatic Generation Control of Multi Area Power System using ANN Controller

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***Abstract*— In this paper an Artificial Neural Network (ANN) based controller is presented for the Automatic Generation Control (AGC) of a five area interconnected power system with reheat turbines. The control scheme guarantees that steady state error of the area frequencies and inadvertent interchange of tie-lines are maintained in a given tolerance limit. ANN controller controls the inputs of each area in the power system together. In this study, back propagation algorithm is used as neural network learning rule. The performance of the power system is evaluated by comparing with conventional Integral controller. The ANN controller gives much better results as compared to that of Integral controller.**

***Index Terms*— Automatic Generation Control (AGC), Artificial Neural Network (ANN), Back Propagation Algorithm and Power System**

I. INTRODUCTION

IN actual power system operations, the load changes continuously and randomly. As a result the power demands on the power system are never steady, but continuously vary with the rising or falling trend. The power generations must change accordingly to match the load perturbations. AGC is very essential for successful operation of interconnected power system [1]. To accomplish this task, it becomes necessary to automatically regulate the operations of main stream valves or hydro gates in accordance with a suitable control strategy, which in turn controls the real power output of electric generators. The problem of controlling the output of electric generators in this way is termed as AGC [2]. The AGC plays an important role in the automation of power system. The main purpose of AGC is to maintain system frequency very close to a specified nominal value, to maintain generation of individual generating units at the most economical value and to keep the correct value of tie line power between different areas. The literature survey shows that a lot of work pertaining to secondary control aspect of AGC has been reported. Secondary controllers are designed to regulate the area control errors to zero effectively. The AGC problem has been augmented with the valuable research contributions from time to time, like LFC regulator designs incorporating parameter variations/uncertainties, load characteristics, excitation control and parallel ac/dc transmission links. The most recent research trend in this area is the application of artificial intelligence techniques such as neural networks, fuzzy logic, genetic algorithm, PSO, BF etc. to tackle difficulties associated with the design of regulators with nonlinear models. Some researchers [3] have presented basic important works on tie-line power and frequency control and tie line bias control in interconnected systems. The investigations carried out by a number of control engineers using classical control approaches revealed that it would result in relatively large overshoots and frequency deviation [4].

The advent of artificial intelligence (AI) techniques, such as neural networks, has solved this problem to a great extent. The neural technology offers many more benefits in the area of nonlinear control problems, particularly when the system is operating over the nonlinear operating range. Work has also been done in using an ANN based frequency controller design for Multi area AGC scheme in deregulated electricity market [5],[6]. Several work has been [7] presented that deals with the development of nonlinear neural network controller using a generalized neural network. Artificial neural network (ANN) have been used for pattern recognition, function approximation, time series prediction and classification problems for quite some time. Due to their learning capability, ANN is also used for applications requiring intelligence. Artificial neural networks have been successfully applied to the AGC problem with rather promising results [8], [9], [10]. In [11], fuzzy neural network is used to study AGC problem in

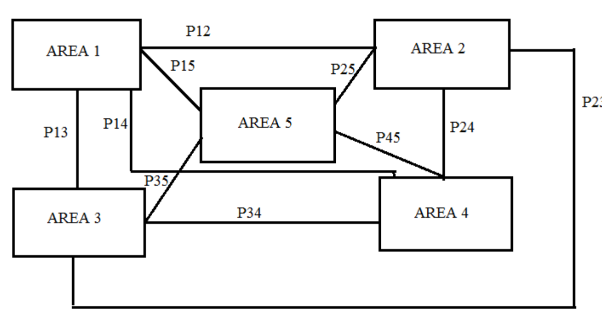

Fig. 1: Basic Block Diagram of Five area interconnected system

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a two area interconnected reheat power system with both areas including reheat turbine.

In this paper, a five area interconnected power system [13] is chosen and load frequency control of this system is made by an ANN controller [10], [11], [15]. The areas are interconnected by tie-lines. From experiments on power system, it is seen that each area needs its system frequency to be controlled [12], [17], [18]. The reason for the proposed technique is that firstly it adapts to changing operating points and calculates optimal control commands, it can also perform effectively with nonlinearities, it can function even if system inputs are temporarily lost or errors are introduced. ANN controller continues to function without needing any decision support software in case of a failure. For comparison, the AGC of considered power system is accomplished using:

(i) Conventional Integral controller

(ii) ANN Controller

In this paper a five area interconnected power system [13] is taken for the study of AGC. ANN controller is presented for the load frequency control. The superiority of the controller is established by making the comparison of its performance with that of conventional Integral controller.

II. MODELLING AND SIMULATION WITH CONVENTIONAL INTEGRAL CONTROLLER

In five area system, five single area systems are interconnected via tie-line. Interconnections 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. The basic block diagram of five area interconnected power system is shown in Fig.1.

The power transfer through tie line for the model is given by:

$$Ptie_{ij} = \frac{V1V2}{X}\sin(\theta 1 - \theta 2) \quad (1)$$

where $\theta 1$ and $\theta 2$ are power angles of end voltages V_1 and V_2. The transfer function model for reheat turbine is given by:

$$\frac{del\ Pt}{del\ Pr} = \frac{(1+Kr.Tr.s)}{(1+Tr.s)} \quad (2)$$

A conventional integral controller is used on a reheat power system model. The integral controller improves steady state error simultaneously allowing a transient response with little or no overshoot. As long as error remains, the integral output will increase causing the speed changer position, attains a constant value only when the frequency error has reduced to zero. The SIMULINK model of a five area interconnected power system with reheat turbine using integral controller is shown in Fig. 2.

III. ARTIFICIAL NEURAL NETWORK

ANN are relatively crude electronic models based on the neural structure of the brain. The brain learns from experience. ANN try to mimic the functioning of brain. The brain stores information as patterns. Some of these patterns are very complicated and allow us the ability to recognize individual faces from many different angles [10], [11], [15]. This process of storing information as patterns, utilizing those patterns and then solving the problems encompassed a new field in computing, which does not utilize traditional programming but involves the creation of massively parallel networks and training of those networks to solve specific problems. The most basic element of the human brain is a specific type of cell, called 'neuron'. These neurons provide the abilities to remember think and apply previous experiences to our every action. The neurons are the structural constituents of the brain, which are highly complex non-linear and parallel processing systems [10], [11], [15].

ANNs are massively parallel-interconnected networks of simple elements known as artificial neurons and their connectivity is intended to interact with the objects of the real world, in a similar manner as the biological nerves systems do.

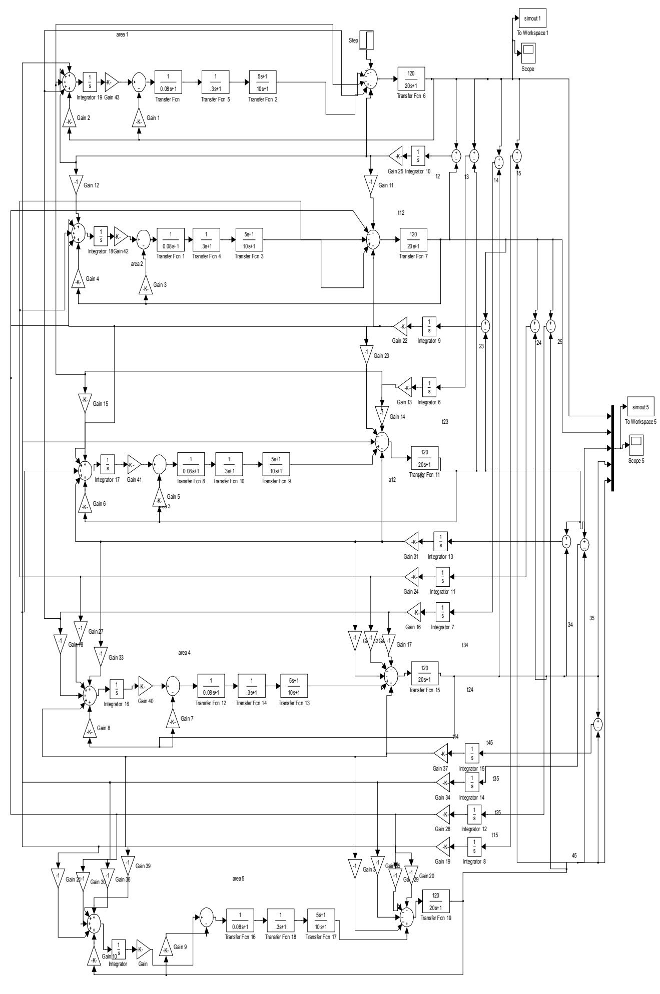

Fig. 2: MATLAB SIMULINK model of five area power system with conventional integral controller

The basis features of neural networks are [14]:

(i) High computational rates due to the massive parallelism.

(ii) Fault tolerance

(iii) Learning or training

(iv) Goal -seeking

(v) Primitive computational elements

Only one artificial neural network (ANN) controller, which controls the inputs of each area in the power system together, is considered. In this paper a three layer feed forward neural network is considered. The best value for controller parameters is obtained by training the ANN off line at different load parameters through Back propagation algorithm (BPA). The controller has designed by taking one hundred forty neurons in hidden layer and five neurons in the output layer. The ANN controller is trained by using back propagation algorithm which is well explained in [15].

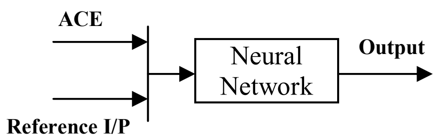

Fig. 3: ANN Controller

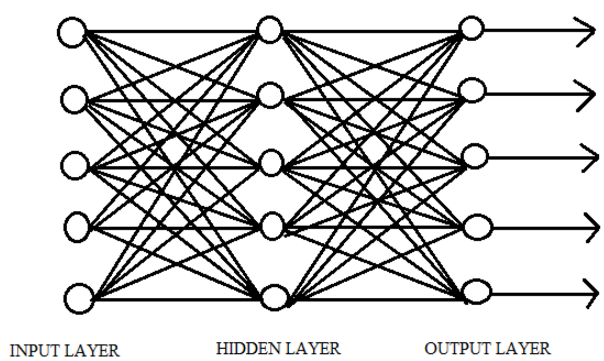

Fig. 4: Multilayer Feed Forward Network

A. Multi-Layer Feed Forward Network

This type of network (Fig.4) consists of one or more hidden layers, whose computation nodes are called hidden neurons or hidden units. The function of hidden neurons is to interact between the external input and network output in some useful manner and to extract higher order statistics. The source nodes in input layer of network supply the input signal to neurons in the second layer (1st hidden layer). The output signals of 2nd layer are used as inputs to the third layer and so on. The set of output signals of the neurons in the output layer of network constitutes the overall response of network to the activation pattern supplied by source nodes in the input first layer.

Short characterization of feed forward networks:

1. typically, activation is fed forward from input to output through 'hidden layers', though many other architectures exist.
2. mathematically, they implement static input-output mappings.
3. most popular supervised training algorithm :back-propagation algorithm
4. have proven useful in many practical applications as approximators of nonlinear functions and as pattern classificators.

IV. BACK PROPAGATION (BP) ALGORITHM

The BP algorithm is perhaps the most popular and widely used neural paradigm [10], [11], [15]. The BP algorithm is based on the generalized delta rule proposed by the PDP research group in 1985 headed by Dave Rumelhart based at Stanford University, California, U.S.A. The BP algorithm overcame the limitations of the perceptron algorithm. Among the first applications of the BP algorithm is speech synthesis called NETalk developed by Terence Sejnowski. The BP algorithm created a sensation when a large number of researchers used it for many applications and reported its successful results in many technical conferences [10], [11], [15], [16].

A. Algorithm

1. Read the data for ANN parameters, plant parameters, change in load value.
2. Initialize the NN weight matrices with random values.
3. Set the initial state vector of the plant and the desired target vector.
4. Set condition for exiting iteration loop (con = 0); and set the initial value for iteration counter (iter =0)
5. Execute the forward run calculations for the neural network controller using the formulas given for a static back-propagation algorithm.
6. Apply the output of the controller to the plant (i.e, in the plant equations).
7. Find the error at the plant output at the final time K.
8. Find the equivalent error at the controller output by multiplying the error matrix of the plant with the Jacobian matrix of the plant. The Jacobian matrix is the derivative of the plant outputs with respect to its inputs.
9. If the error is below the specified error criterion or maximum number of iteration is reached, then set con=1 (to exit the iteration loop).
10. If the above condition is not true, then execute the back-propagation calculations and calculate the local gradients as per the formulas given for static Back-propagation algorithm for the final time instant of the controller.
11. Find the equivalent errors for the previous instants' plant output and the controller, (say K-1), in the same way as done in 7. Note that the plant error for this instant will be the local gradients at the input of the controller block which was previously calculated, (say K).
12. Find the change in weights for every instant controller blocks and add them together with the original weights of the network.
13. Repeat the steps 5 to 12 until the con = 1.
14. Plot the change in frequency in Hz vs time in seconds.

V. SIMULATION RESULTS AND COMPARATIVE ANALYSIS

The simulation results with ANN controller are shown in Fig. 5 and Fig. 6. The test system for AGC as shown in Fig. 2 consists of five control areas and the parameters are given in the Appendix-B. The considered system is controlled using conventional Integral controller and ANN controller separately. 1% Step load perturbation is given in area-1. The simulations results show that the dynamic responses obtained using ANN controller satisfy the AGC requirements. For demonstration, area frequency deviation responses are shown in Fig.5. It is evident that all area frequency deviations settle very fast with zero steady state error. The dynamic response using ANN controller and Integral controller is shown in Fig. 6. The quantitative comparison between the two controllers is given in Table 1. This shows that the settling time and undershoots are improved significantly with ANN controller.

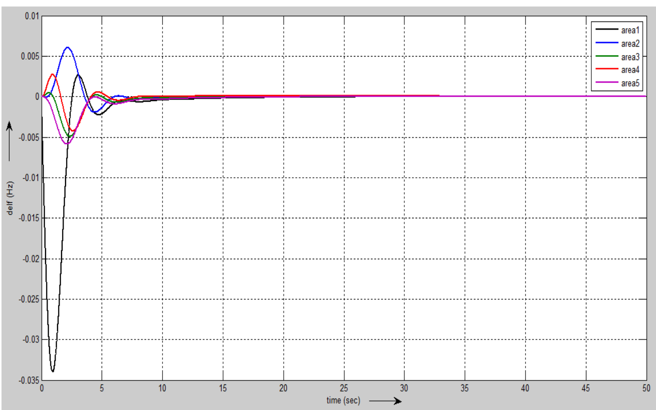

Fig. 5: Area Frequency Deviation Response of five area power system considering reheat turbine with ANN controller

Table 1: Comparison of Integral and ANN controller in terms of frequency deviation response

	Integral controller response	**ANN controller response**
Step Load perturbation (pu)	0.01	0.01
Settling time(sec)	35	15
First Peak overshoot (Hz)	-0.035	-0.033

VII. CONCLUSION

In this paper, an artificial neural network (ANN) based controller using Back Propagation Algorithm (BPA) is presented for the AGC of five areas. To improve the controller performance, the proposed controller makes use of the load perturbation as input control signal, which is not used in the

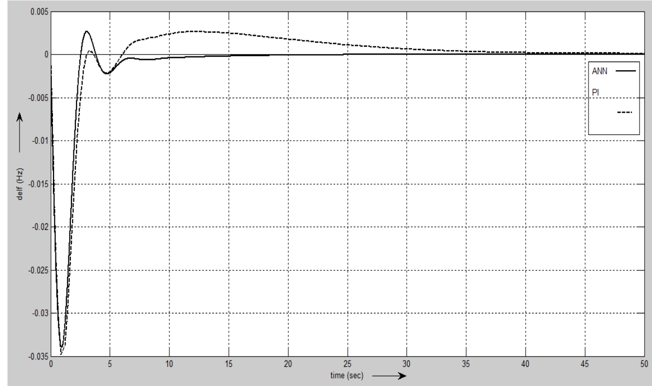

Fig. 6: Comparison of Integral and ANN controller showing frequency response of area-1 of the five area power system

conventional integral controller. Back Propagation algorithm is worked out and the controller is shown to be viably applicable to practical power systems. It is concluded that ANN controller performance is better than that of integral controller in terms of peak overshoot, settling time. The superiority of ANN controller is established on a five area test system. The ANN controller gives robust dynamic performance which satisfies the requirement of AGC.

Appendix-A

Nomenclature:

del F1,delF2,delF3,delF4,delF5 = change in frequency
del Pe = load increment
R= speed regulation
Kg1,Kg2,Kg3,Kg4,Kg5 = gain of speed governor
Tg1,Tg2,Tg3,Tg4,Tg5 = time constant of governor
Kt1,Kt2,Kt3,Kt4,Kt5 = gain of turbine
Tt1,Tt2,Tt3,Tt4,Tt5 = time constant of turbine
Kr1,Kr2,Kr3,Kr4,Kr5 = gain of reheat turbine
Tr,Tr1,Tr2,Tr3,Tr4,Tr5 = time constant of reheat turbine
Kps1,Kps2,Kps3,Kps4,Kps5 = gain of generator
Tps1,Tps2,Tps3,Tps4,Tps5 = time constant of generator
Ts = sampling time
Δ Pg1,ΔPg2,ΔPg3,ΔPg4,ΔPg5= governor output
Δ Pt1,ΔPt2,ΔPt3,ΔPt4,ΔPt5 = turbine output
Δ Pr1,ΔPr2,ΔPr3,ΔPr4,ΔPr5 = reheat turbine output
P12,P13,P14,P15,P23,P24,P25,P34,P35,P45 = tie line power
T12,T13,T14,T15,T23,T24,T25,T34,T35,T45 = tie line time constant
Ki = integral controller gain
b1,b2,b3,b4,b5 = bias factor

Appendix-B

Nominal parameters of the system investigated
F=60Hz,Tg1=Tg2=Tg3=Tg4=Tg5=0.08s,
Tr1=Tr2=Tr3=Tr4=Tr5=10 s,
H1=H2 =H3=H4=H5=5,

Tt1=Tt2=Tt3=Tt4=Tt5=0.3 s,Kr1=Kr2=Kr3=Kr4=Kr5=0.5Hz/puMW, Ptiemax=200MW,Tps1=Tps2=Tps=Tps3=Tps4=Tps5=20s, Kps1=Kps2=Kps3=Kps4=Kps5=120Hz/p.uMW; T12=0.08674; Ki=0.1,Ts=0.01, max_iter=2, K=5000

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