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On The Design of Artificial Intelligence Based Load Frequency Controller for A Two Area Power System With Super Conducting Magnetic Energy Storage Device

B.Vidhya[1], R.Jayashree[2]
[1]M.Tech (Power System), Final Year, B.S.Abdur Rahman University, Chennai
[2]Professor, Electrical Engg, B.S.Abdur Rahman University, Chennai

Abstract:- This study presents a method based on Artificial intelligence techniques (FPIC, ANN) for Automatic generation control (AGC) of power system including superconducting magnetic energy storage units. The technique is applied to control system two area tied together through power lines. As a consequence of continually load variation, the frequency of the power system changes over time. In conventional studies, frequency transients are minimized by using conventional integral and proportional controllers aiming of secondary control in AGC and zero steady-state error is obtained after sufficient delay time. In this paper, instead of this method, the configuration of FPIC, ANN is proposed. The results obtained by using ANN outperform than those of FPIC and PI controllers as settling time and overshoot as shown at simulation .The effectiveness of the SMES control technique is investigated when Area Control Error (ACE) is used as the control input to SMES. The computer simulation of the two-area interconnected power system shows that the self tuning ANN control scheme of AGC is very effective in damping out of the oscillations caused by load disturbances in one or both of the areas and it is also seen that the ANN controlled SMES performs primary frequency control more effectively compared to PI and FPIC controlled SMES in AGC control

Index Terms:- Proportional Integral (PI) controller, Fuzzy PI controller (FPIC), Artificial Neural Network (ANN), Automatic Generation Control, Area Control Error (ACE), Load frequency control and multi area power system

I. INTRODUCTION

Power system stability issue has been studied widely. The dynamic behavior of many industrial plants is heavily influenced by disturbances and in particular, by changes in operating point. Load Frequency Control (LFC),or automatic generation control,is a very important issue in power system operation and control for supplying sufficient and reliable electric power[1]. Many investigation in the area of automatic generation control (AGC) of isolated and of interconnected power systems have been reported in the past and a number of control strategies have been proposed to achieve improved performance[2]. In electric power generation,system disturbances caused by load fluctuation,result in changes in the desired frequency value. The conventional control strategy for LFC problem is to take the integral of control error as the control signal [3]. The proportional integral (PI) control approach is successful in achieving zero steady-state error in the frequency of the system,but it exhibits relatively poor dynamic performance as evidenced by large overshoot and transient settling time is relatively large. To damp out the oscillations in the shortest possible time, automatic generation control including SMES unit is used.

In the proposed self tuning system, the effect of ANN in AGC on SMES control is investigated for the improvement of LFC. This is met when the control action maintains the frequency and the tie-line power interchange at the scheduled values. For this, the area control error (ACE) is used as the input to the SMES controller. The ACE is obtained from tie line power flow deviation and the frequency deviation weighted by a bias factor β as shown in (1).

$$ACE_i = \Delta P_{tie,i\,j} + B_i * \Delta f \qquad (1)$$

Where the suffix i refer to the control area and j refer to the number of generator.

As the dynamic performance of the AGC system would obviously depends on the value of frequency bias factors, β,and integral controller gain value, KI, the optimal values of the integral gain of the integral controllers are obtained using Integral Squared Error (ISE) technique as shown in (2), where the detail of the performance index is explained in [6]. A characteristic of the ISE criterion is that it weights large errors heavily and small errors lightly. The quadratic performance index is minimized for 1% step load disturbance in either of the areas for obtaining the optimum values of integral gain settings. In this study, it is seen from Fig. 1 that, in the absence of dead-band and generation rate constraints, the value of integral controller gain, KI = 0.34, and frequency bias factors, β=0.4, occurs at ISE = 0.0009888.

$$ISE = \int_0^T \left(\Delta P_{tie}^2 + \Delta f_1^2 + \Delta f_2^2 \right) dt \qquad (2)$$

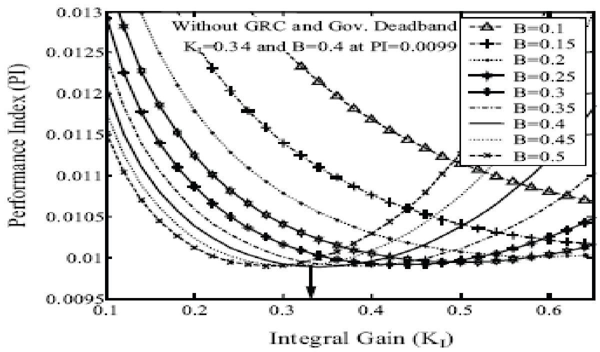


Fig.1. The optimal integral controller gain, KI and frequency bias factor, B without DB and GRC

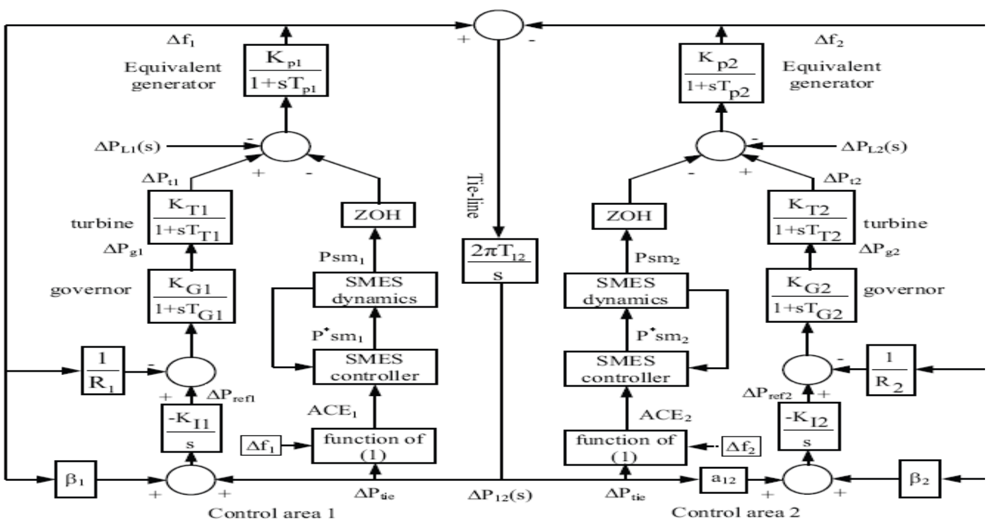


Fig 3 Typical simulation model of two-area system

For PI controller, the integrator gain (KIi) of the supplementary controller is chosen as the fixed optimized value. And in FPIC and ANN technique the supplementary controller output (ΔPref) is scheduled to optimized value with fuzzy logic controller and ANN controller according to load disturbance. So it compromise between fast transient recovery and low overshoot in dynamic response of the system. It is seen that SMES with FPIC and ANN performs primary frequency control more effectively in AGC compared to that with fixed gain PI controller for load frequency control of multi-area power system.

II. THE MODEL SYSTEM CONFIGURATION

The model of a two-area power system suitable for a digital simulation of AGC is developed for the analysis as shown in Fig. 2. Two areas are connected by a weak tie-line. When there is sudden rise in power demand in one area, the stored energy is almost immediately released by the SMES through its power conversion system. As the governor control mechanism starts working to set the power system to the new equilibrium condition, the SMES coil stores energy back to its nominal level. Similar is the action when there is a sudden decrease in load demand. Basically, the operation speed of governor-turbine system is slow compared with that of the excitation system. As a result, fluctuations in terminal voltage can be corrected by the excitation system very quickly, but fluctuations in generated power or frequency are corrected slowly

Since load frequency control is primarily concerned with the real power/frequency behavior, the excitation system model will not be required in the analysis [7]. This important simplification paves the way for the required digital simulation model of the example system of Fig. 4. The modeling and control design aspects of SMES are separately described in detail. The presence of zero-hold (ZOH) device in Fig.2 implies the discrete mode control characteristic of SMES. All parameters are same as those used in [6].

III. SMES SYSTEM

The schematic diagram in Fig.3 shows the configuration of a thyristor controlled SMES unit. The SMES unit contains a DC superconducting coil and a 12-pulse converter, which are connected by Y–Δ/Y–Y transformer. The superconducting coil is contained in a helium vessel. Heat generated is removed by means of a low-temperature refrigerator. The energy exchange between the superconducting coil and the electric power system is controlled by a line commutated converter

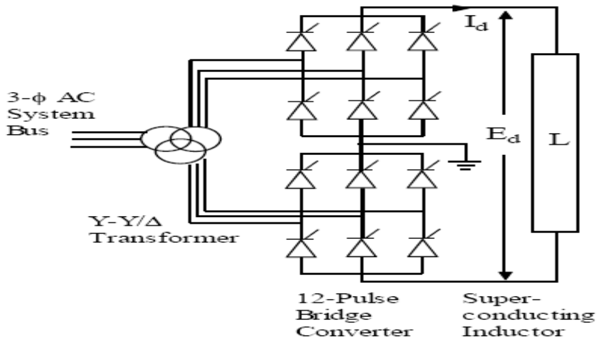


Fig.3 The schematic diagram of SMES unit

The superconducting coil can be charged to a set value from the grid during normal operation of the power system. Once the superconducting coil gets charged, it conducts current with virtually no losses, as the coil is maintained at extremely low temperatures. When there is a sudden rise in the load demand, the stored energy is almost released through the converter to the power system as alternating current. As the governor and other control mechanisms start working to set the power system to the new equilibrium condition, the coil current changes back to its initial value. Similarly, during sudden release of loads, the coil immediately gets charged towards its full value, thus absorbing some portion of the excess energy in the system and as the system returns to its steady state, the excess energy absorbed is released and the coil current attains its normal value The control of the converter firing angle provides the dc voltage Ed appearing across the inductor to be continuously varying within a certain range of value, it is maintained constant by reducing the voltage across the inductor to zero since the coil is superconducting. Neglecting the transformer and the converter losses, the DC voltage is given

$$\mathbf{E_d = 2V_{d0}\cos\alpha - 2I_dR_C} \qquad (3)$$

Where E_d is DC voltage applied to the inductor (kV), α is firing angle (°), Id is current flowing through the inductor (kA). Rc is equivalent commutating resistance (Ω) and Vd0 is maximum circuit bridge voltage (kV).

Charge and discharge of SMES unit are controlled through change of commutation angle α If α is less then 90°,converter acts in converter mode and if α is greater than 90°, the converter acts in an inverter mode (discharging mode).

Control of SMES unit

In LFC operation, the dc voltage E_d across the superconducting inductor is continuously controlled depending on the sensed Area Control Error (ACE) signal. In this study, inductor voltage deviation of SMES unit of each area is based on ACE of the same area in power system Moreover; the inductor current deviation is used as a negative feedback signal in the SMES control loop. So, the current variable of SMES unit is intended to be settling to its steady state value. If the load demand changes suddenly, the feedback provides the prompt restoration of current.

The inductor current must be restored to its nominal value quickly after a system disturbance, so that it can respond to the next load disturbance immediately. Fig. 4 shows the block diagram of SMES unit.

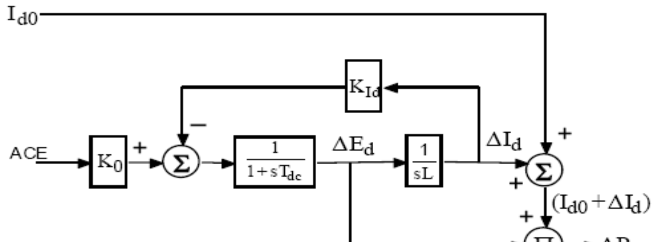


Fig.4 Block diagram of SMES unit

The equations of inductor voltage deviation and current deviation of SMES unit of area i (i=1,2,…N) in Laplace domain are as follow

$$\Delta E_{di}(s) = K_{0i}\frac{1}{1+sT_{dci}}[B_i\Delta f_i(s)+\Delta P_i(s)] - K_{Idi}\frac{1}{1+sT_{dci}}\Delta I_{di}(s) \quad \textbf{(4)}$$

$$\Delta I_{di}(s) = \frac{1}{sL_i}\Delta E_{di}(s) \quad \textbf{(5)}$$

Where ΔE_{di} is the incremental change in converter voltage (kV), ΔI_{di} is the incremental change in SMES current (kA), K_{Idi} is the gain for feedback ΔI_{di} (kV/kA), T_{dci} is converter time delay(s), K_{0i} is gain constant (kV/unitACE) and Li is inductance of the coil (H). The deviation in the inductor real power of SMES unit is expressed in time domain as

$$\Delta P_{smi}(t) = \Delta E_{di} I_{di0} + \Delta I_{di}\Delta E_{di} \quad \textbf{(6)}$$

This value is assumed positive for transfer from ac grid to dc. The energy stored in SMES at any instant in time in is given as follows

$$W_{smi}(t) = \frac{L_i I_{di}^2}{2} \quad \textbf{(MJ)} \quad \textbf{i=1,….3} \quad \textbf{(7)}$$

IV. CONVENTIONAL PI CONTROL SYSTEM

The general practice in the design of a LFC is to utilize a PI controller. A typical conventional PI control system is shown in Fig. 5. This gives adequate system response considering the stability requirements and the performance of its regulating units. In this case the response of the PI controller is not satisfactory enough and large oscillations may occur in the system [8-9]. For that reason, a fuzzy PI controller and Artificial Neural Network is designed and implemented in this study

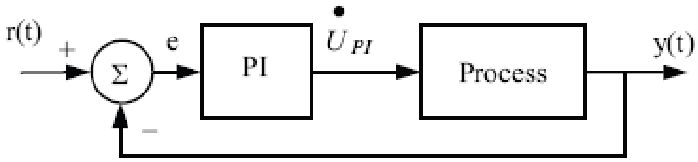


Figure 5. A typical conventional PI controller

V. FUZZY LOGIC CONTROLLER

The AGC based on FLC is proposed in this study. One of its main advantages is that controller parameters can be changed very quickly by the system dynamics because no parameter estimation is required in designing controller for nonlinear system. Therefore a FLC which represents a model-free type of nonlinear control algorithms could be a reasonable solution.

There are many possibilities to apply fuzzy logic to the control system. The fuzzy logic structure for the all controller design can be seen in fig 6. There are four main structures in a fuzzy system: the fuzzifier, the inference engine, the KB and defuzzifier.

The first stage in the fuzzy system computations is to transform the numeric into fuzzy sets. This operation is called fuzzification.From the point of view of fuzzy set theory, the inference engine is the heard of the fuzzy system. It is the inference engine that performs all logic manipulations in a fuzzy system. A Fuzzy system KB consists of fuzzy IF-THEN rules and membership functions characteristics the fuzzy sets. The result of the inference process is an output represented by a fuzzy set, but the output of the fuzzy system should be a numeric value. The transformation of a fuzzy set into a numeric value is called defuzzification. In addition, input and output scaling factor are needed to modify the universe of discourse. Their role is tune the fuzzy controller to obtain the desired dynamic properties of the process controller loop.

In this paper, the inputs of the proposed Fuzzy controllers are ACE, and change rate in ACE(ΔACE) as shown in fig.7,which is indeed error (e) and the derivation of the error($\dot{e}$) of the system, respectively. This gives us a fairly good indicator of the general tendency of the error.

Many fuzzy controller structures based on various methods have been presented. The most widely used methods in the practice is the Mamdani method proposed by Mamdani and his associates who adopted the min-max compositional rule of interference based on an interpretation a control rule as a conjuction of the antecedent and consequent. It is natural to apply the conventional theory, to solve the nonlinear problem of fuzzy controller and much work has been done in this direction.

Conventional controllers are derived from control theory techniques based on mathematical models of open-loop process to be controlled. For instance , a conventional proportional-integral(PI) controller can be described by the function

$$U= K_p e + K_i \int e dt \quad \textbf{(8)}$$

According to the conventional automatic control theory, the performance of the PI controller is determined by its proportional parameter K_p and integral parameter K_i [13]. The proportional term provides control action equal to some multiple of the error, while the integral forces the steady state error to zero.
Since the mathematical models of most process systems are type 0, obviously there would be steady-state error if classical PD fuzzy controller controls them.

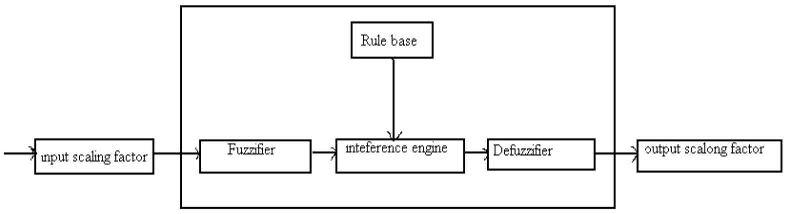


Fig.6. Component of fuzzy system

Whenever the steady-state error of the control system is eliminated, it can be imagined substituting the input (ΔACE) of the fuzzy controller behaving like a parameter time-varying PI controller; thus the steady-state error is removed by the integration action. However, these methods will be hard to apply in practice because of the difficulty of constructing fuzzy control rules.Usually,fuzzy control rules are constructed by summarizing the manual control experiences of an operator who has been controlling the industrial process skillfully and sucessfully.The operator intuitively regulates the executer to control the process by watching the error and the change rate of the error between output of the system and the set- point value given by the technical requirement. It is no practical way for operator to observe the integration of the error of the system. Therefore it is impossible to explicitly abstract fuzzy control rules from the operator's experience. Hence, it is better to design a fuzzy controller that possesses the fine characteristics of the PI controller by using only ACE and (ΔACE).

Fig.7. The PI-type fuzzy controller

One way is to have an integrator serially connected to the output of the fuzzy controller, as show in Fig.7 The control input to the plant can be approximated by

$$u = \beta \int u_t \, dt \quad (9)$$

Where β is the integral constant, or output scaling factor. Hence, the fuzzy controller becomes a parameter time-varying PI controller. The controller is called as PI-type fuzzy controller, and the fuzzy controller without the integrator as the PD-type fuzzy controller.

The type of the FLC obtained is called Mamdani type which has fuzzy rules of the form
If ACE is A_i and ΔACE is B_i THEN u is C_i = 1,2,2,…n

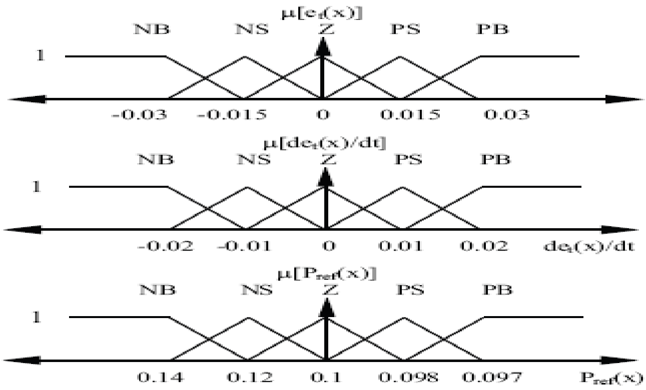


Fig.8. Membership function for the fuzzy variable

Here A_i , B_i ,C_i are the fuzzy sets. The triangle membership functions for each fuzzy linguistic values of the ACE and ΔACE are shown in Fig.8 in which NB,NS, Z,PB,PS represent negative big, negative small, zero, positive big, positive small respectively. Also set of fuzzy rules is shown in Table1.

Table1.Rule base

ΔACE/ACE	NB	NS	Z	PS	PB
NB	PS	NB	NB	NS	NS
NS	NS	NS	NB	NS	NS
Z	NB	NS	Z	NS	PB
PS	NB	Z	NS	PB	NB
PB	Z	NS	NS	NB	PB

VI. 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, Levenberg-Marquardt method for back propagation. In this paper Levenberg-Marquardt method is employed for it's superiority in convergence.

Feed forward neural network architecture is chosen for the design of controller, which is trained by a popular back propagation algorithm

In the neural network developed (Figure. 9) TANSIG is employed as transfer function in the hidden layer and PURELIN in the output layer. Then the obtained weights and biases are chosen as the initial weights and biases.

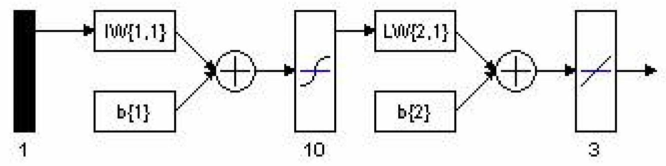


Figure.9 Neural network

TRAINING PROCEDURE:

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

Step1: Choose new network icon in the box to create a new neural network.

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 .

Step 3: Initialization of the network

Step 4: Simulation of the neural network

Step 5: Training the neural network

Step 6: Adaptation of the neural network with trained data

Step 7: Required weights and biases for the neural network

VII. DESIGN OF ANN CONTROLLER

The range over which error signal is in transient state, is observed. Corresponding values of the proportional, integral constants are set. This set is kept as target. Range of error signal is taken as the input. This input – target pair is fed and new neural network is formed using “nntool” in the MATLAB Simulink software. Updated weights and biases are given to a fresh neural network. Now the neural network is ready for operation.
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.

As the neural network developed is purely dependant on the area control error signal, the network trained can be used for two area systems. Further as the neural network is independent of the time instant, the trained network is more reliable for all disturbances which may occur at different time instances.
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.

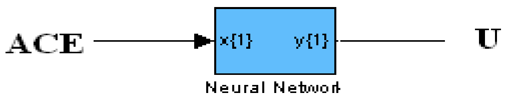


Figure 10. Artificial Neural Network

VIII. SIMULATION RESULTS

Performance comparison of ANN controller, PI controller, Conventional integral controller for two area system with SMES unit for different load disturbances (ΔP_L) are carried out and the results are shown in figures 11 to 12.
Two case studies are conducted.
Case -1: a step load increase of ΔP_{L1}=0.1 p.u. MW is applied in area 1 only.
Case-2: same step load increase $\Delta P_{L1} = \Delta P_{L2}$=0.1 p.u. MW in both areas.

Area 1

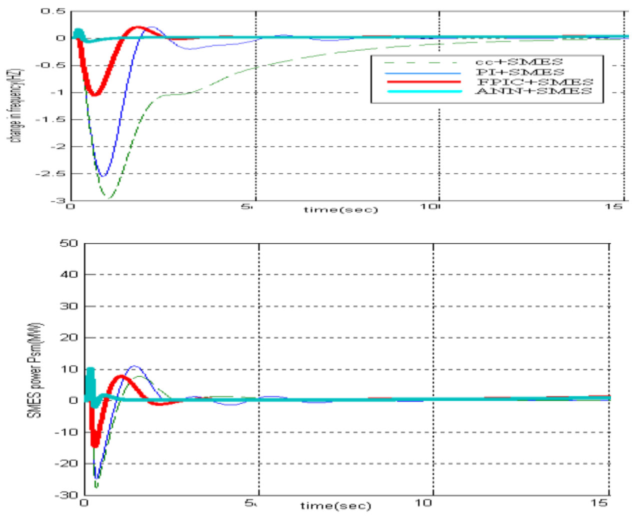
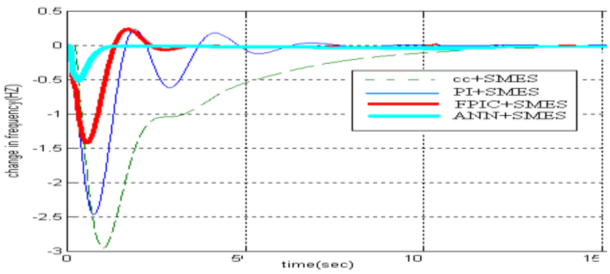


Fig 11. System performances for a step load increase ΔP_{L1}= 0.1 p.u. MW in area-1 [Case-I] with SMES unit

Area 2



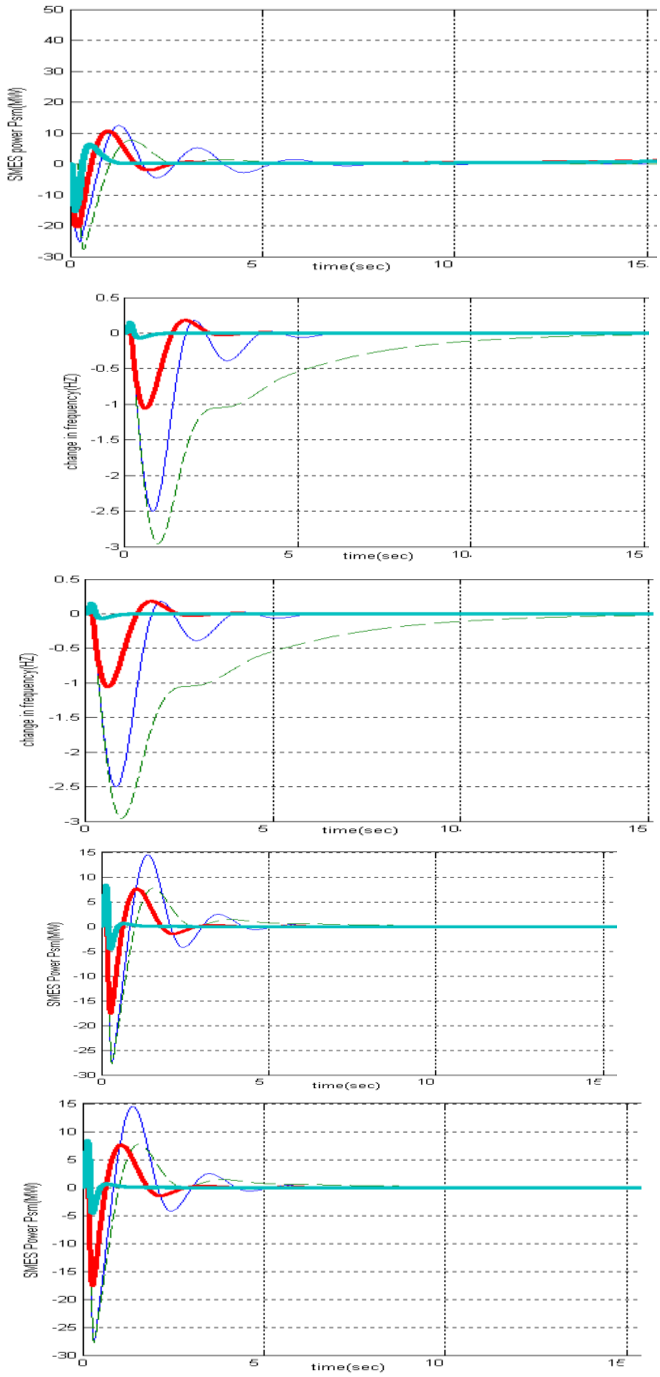


Fig. 12. System performances for a step load increase ΔP_{L1}=ΔP_{L2}= 0.1 p.u. MW in both areas [CaseII] with SMES unit

Table 1. Shows the comparison of performances between the ANN controller, FPIC controller, PI controller and conventional integral controller with SMES unit

Controller	**Settling time(sec)**	**Area control error(MW)**
Conventional integral controller	**14.8**	**-0.002362**
PI controller	**6.5**	**-0.008022**
FPIC	**3**	**-0.0836**
ANN	**1.9**	**-0.0000272**

Using of ANN control the settling time is reduced to 1.9s and the Area control error becomes -0.0000272 MW.

IX. CONCLUSION

The simulation studies have been carried out on a two-area power system to investigate the impact of the proposed intelligently controlled AGC including SMES units on the power system dynamic performance. The results show that the Neural Network Controller has quite satisfactory generalization, capability, feasibility, reliability ,accuracy and it is very powerful in reducing the frequency deviations under a variety of load perturbations. Using ANN controller, the online adaptation of integral controller output (ΔP_{ref}) associated with SMES makes the proposed intelligent controllers more effective and are expected to perform optimally under variety of load disturbance when ACE is used as the input to SMES controller

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ABOUT THE AUTHORS

Ms.Vidhya .B

Received her B.E. degree in Electrical and Electronics Engineering from Sasurie College of Engineering & Technology in the year 2009 from Anna University. She is currently pursuing her M.Tech. Degree in Power System Engineering in the Department of Electrical and Electronics Engineering of B.S. Abdur Rahman University. Her area of interests include Power systems and load frequency control.

R.Jayashree

Received her B.E. degree in Electrical and Electronics Engineering from Madurai Kamaraj University, India in 1990.She received M.E in Power System Engineering in 1992 from Anna university, India and She received her Ph.D in Power System Engineering from Anna University. She is working as a Professor in B.S.A Crescent Engg College (Affiliated to Anna University) , Chennai, India. Her research interests include ATC, congestion management in deregulated Power Systems and load frequency control.