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Design of Artificial Inteligence-Based Load Frequency Controller for a Two Area Power System with Super Conducting Magnetic Energy Storage Device

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Superconducting Magnetic Energy Storage (SMES) unit with a self-commutated converter is capable of controlling both active and reactive power simultaneously and quickly; increasing attention has been focused recently on power system stabilization by SMES control. In this study, a self-tuning control scheme for SMES is proposed and applied to Automatic Generation Control (AGC) in power system. The system is assumed to be consisting of two areas. The proposed self-tuning control scheme is used to implement the AGC for Load Frequency Control (LFC) application adding to conventional control configuration. The effects of the self tuning configuration with Artificial Neural Network (ANN) in AGC on SMES control for the improvement of LFC is compared with that of Conventional Integral controller, PI controller, Fuzzy Proportional Integral Controller (FPIC). 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 Integral controller, PI and FPIC controlled SMES in AGC control.

Keywords: *Superconducting magnetic energy storage (SMES), Self-tuning control scheme, Automatic generation control (AGC), Load frequency control (LFC), Area control error (ACE).*

1.0 INTRODUCTION

Automatic Generation Control (AGC) is very important in power system operation for supplying sufficient and reliable electric power. In an interconnected power system, as the load demand varies randomly, the area frequency and tie-line power interchange also varies. The Load Frequency Control (LFC), by only a governor control, imposes a limit on the degree to which the deviations in frequency and tie-line power exchange can be decreased. However, as the LFC is fundamentally for the problem of an instantaneous mismatch between the generation and demand of active power, the incorporation of a fast-acting energy storage device in the power system can improve the performance under such conditions. To achieve a better performance, many control strategies are proposed in literature [1–3]. Because of non-linear nature of power system, the controller designed for operation around a point based on a linear model obtained by linearization is insufficient. The operation point of a power system may change because of changing loads during the day period. In this situation, a fixed gain controller that is optimal at an operating point may not be suitable in another operating point [3]. Therefore, variable structure controller [4,5] has been proposed for AGC. For designing these control techniques, the perfect model is required which can track the state variables and satisfy system constraints. Therefore, it is difficult to apply these adaptive control techniques to AGC in practical implementations. When a small load disturbance in any area of the interconnected system occurs, tie-line power deviations and

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power system frequency oscillations continue for a long duration, even in the case with optimized gain of integral controllers. 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 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).

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

where the suffix i refers to the control area and j refers to the number of generators.

As the dynamic performance of the AGC would obviously depend 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 details of the performance index are 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 Figure 1 that in the absence of Dead-Band (DB) and Generation Rate Constraints (GRC), the value of integral controller gain KI = 0.34, and frequency bias factors, β =0.4, occurs at ISE=0.0009888.

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

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

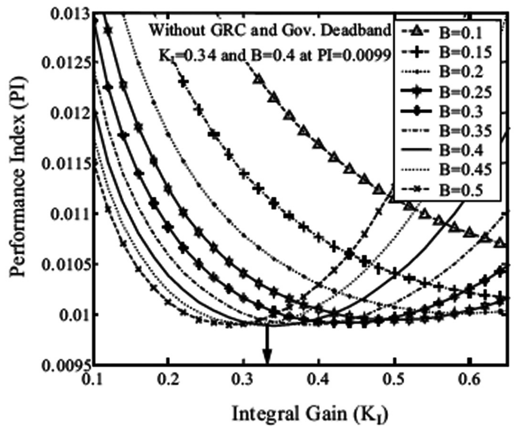


FIG. 1 THE OPTIMAL INTEGRAL CONTROLLER GAIN, KI AND FREQUENCY BIAS FACTOR, B WITHOUT DB AND GRC

2.0 THE TWO-AREA 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 Figure 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 of speed 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

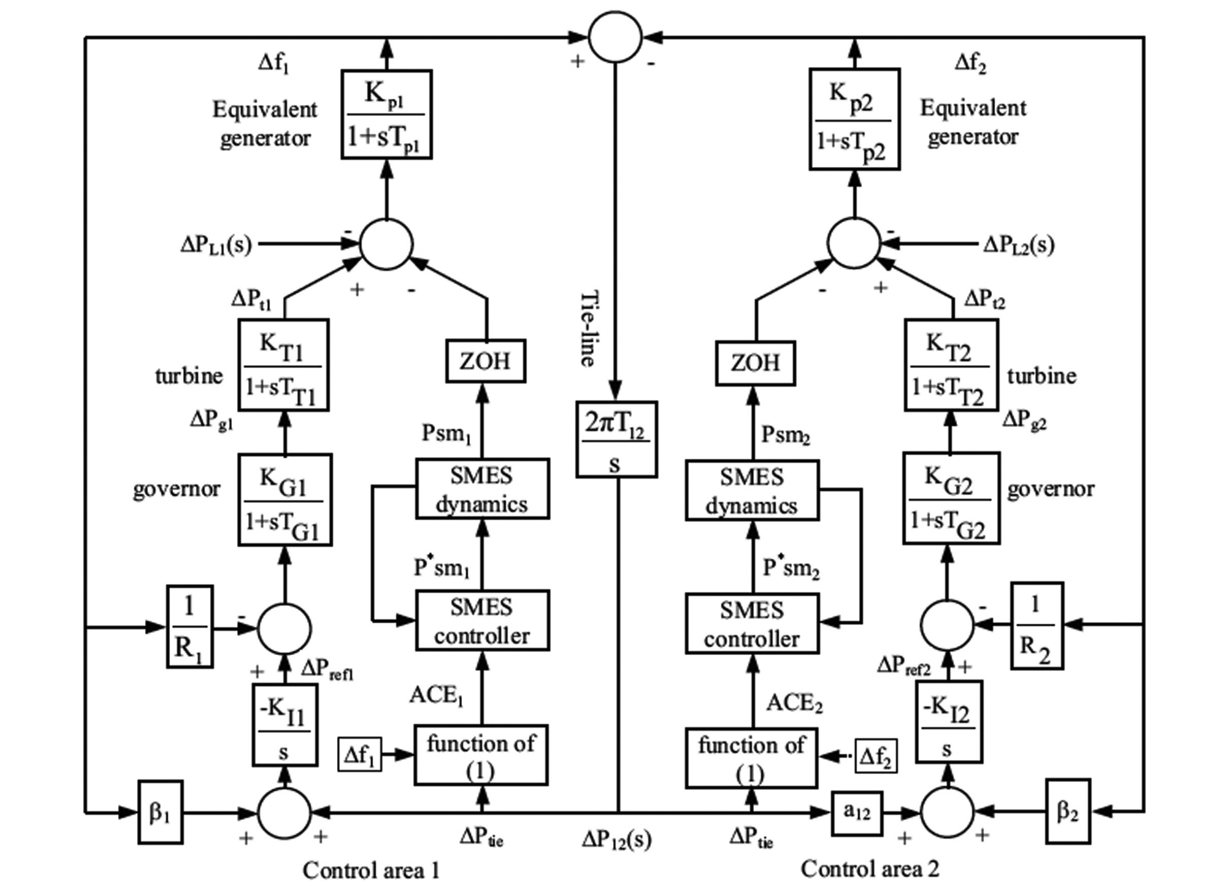


FIG. 2 TYPICAL SIMULATION MODEL OF TWO-AREA SYSTEM

be required in the analysis [7]. The presence of Zero-Hold (ZOH) device in Figure 2 implies the discrete mode control characteristic of SMES. All parameters are same as those used in [6].

3.0 SMES SYSTEM

The schematic diagram in Figure 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.

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.

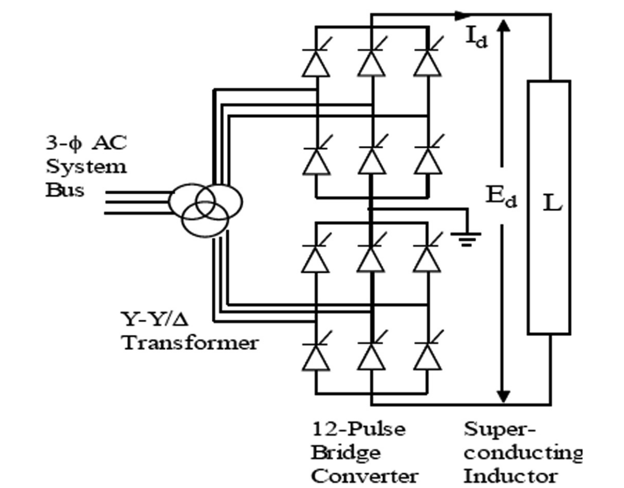


FIG. 3 THE SCHEMATIC DIAGRAM OF SMES UNIT

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 E_d appearing across the inductor to continuously vary 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 as

$$E_d = 2V_{d0} \cos\alpha \; 2I_dR_C \tag{3}$$

where E_d is DC voltage applied to the inductor (kV); α is firing angle (°); I_d is current flowing through the inductor (kA); R_c is equivalent commutating resistance (Ω) and V_{d0} 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).

3.1 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. Figure 4 shows the block diagram of SMES unit.

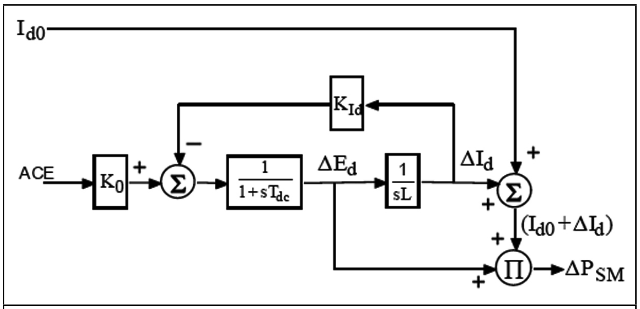


FIG. 4 BLOCK DIAGRAM OF SMES UNIT

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

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

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

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/unit ACE) and L_i is inductance of the coil (H). The deviation in the inductor real power of SMES unit is expressed in time domain as

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

This value is assumed positive for transfer from AC grid to DC. The energy stored in SMES at any instant of time is given as follows:

$$W_{smi}(t) = \frac{L_iI_{di}^2}{2}\text{(MJ); i = 1,….3} \tag{7}$$

4.0 CONVENTIONAL PI AND FPIC SYSTEM

The general practice in the design of an LFC is to utilize a PI controller. A typical conventional PI control system is shown in Figure 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 [8–10].

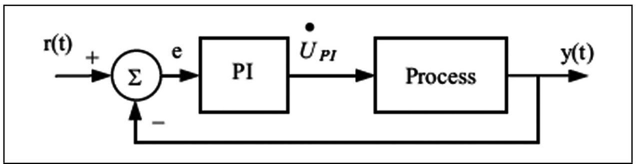


FIG. 5 A TYPICAL CONVENTIONAL PI CONTROLLER

The advantage of AGC-based FPIC 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. Hence, a fuzzy controller is designed that possesses fine characteristics of the PI controller by using ACE and (ΔACE). Here, an integrator is serially connected to the output of the fuzzy controller (Figure 6).

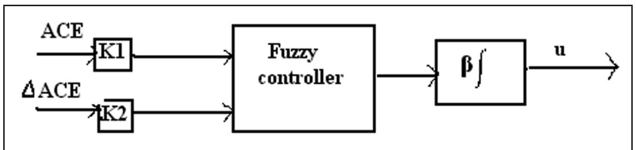


FIG. 6 THE PI-TYPE FUZZY CONTROLLER

The control input to the plant can be approximated by

$$u = \beta \int u_t dt \tag{8}$$

where β is the integral constant, or output scaling factor. Hence, the fuzzy controller becomes a parameter time-varying PI controller. The performance of FPIC given in [6] is better compared to PI controller.

In this paper, self-tuning configuration with Artificial Neural Network (ANN) in AGC on SMES control is proposed which is very effective in damping out of the oscillations caused by load disturbances in one or both of the areas compared to integral controller, PI and FPIC.

5.0 ADAPTATION OF ARTIFICIAL NEURAL NETWORK

In a system, if inputs and the corresponding targets are identified, then we can implement the ANN for the input–target pair. ANN is computationally simple, reliable, and model-free system. One of the main advantages of ANN is that 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 and 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 [11].

In the neural network developed (Figure 7), 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.

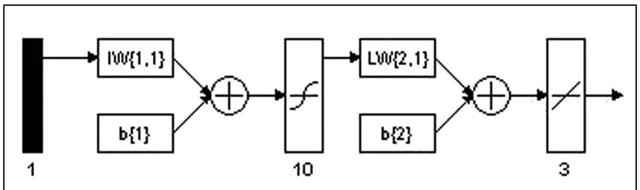


FIG. 7 NEURAL NETWORK

6.0 TRAINING PROCEDURE

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

Step 1: Choose new network icon in the box to create a new neural network

Step 2: Creation of New Network in this box. 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

7.0 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 value 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 dependent on the Area Control Error signal (Figure 8), 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.

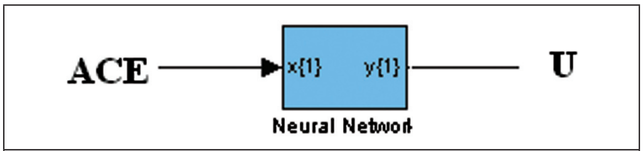


FIG. 8 ARTIFICIAL NEURAL NETWORK

8.0 SIMULATION RESULTS

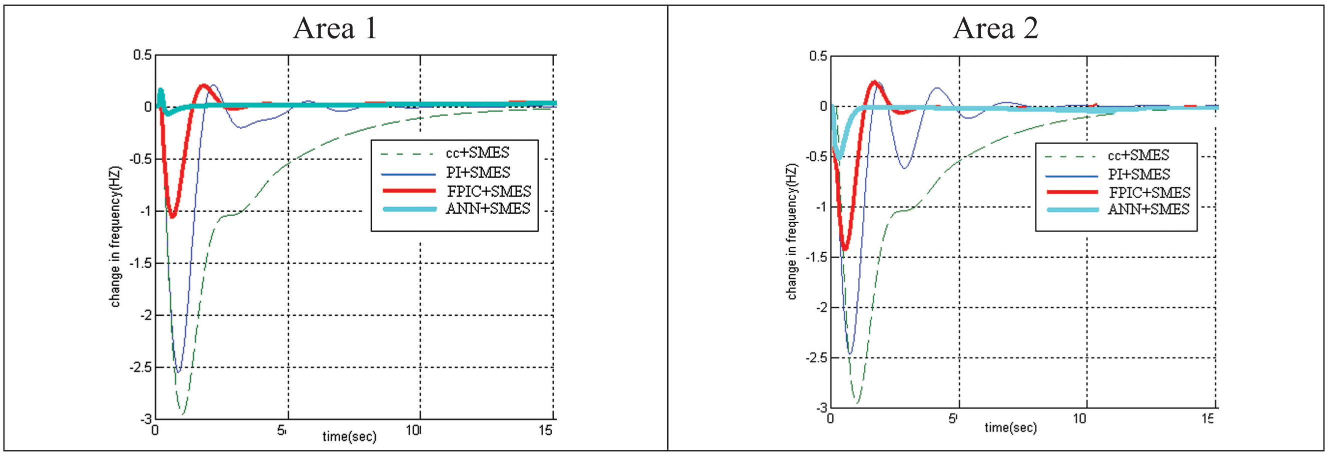
Performance comparison of ANN controller, Conventional Integral Controller, PI controller, FPIC for two-area system with SMES unit for load disturbances (ΔP_L) in areas 1 and 2 are carried out and the results are shown in Figures 9 and 10.

The following 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: a same step load increase

$\Delta\Delta P_{L1} = \Delta\Delta P_{L2}$ = 0.1 p.u MW in both areas.



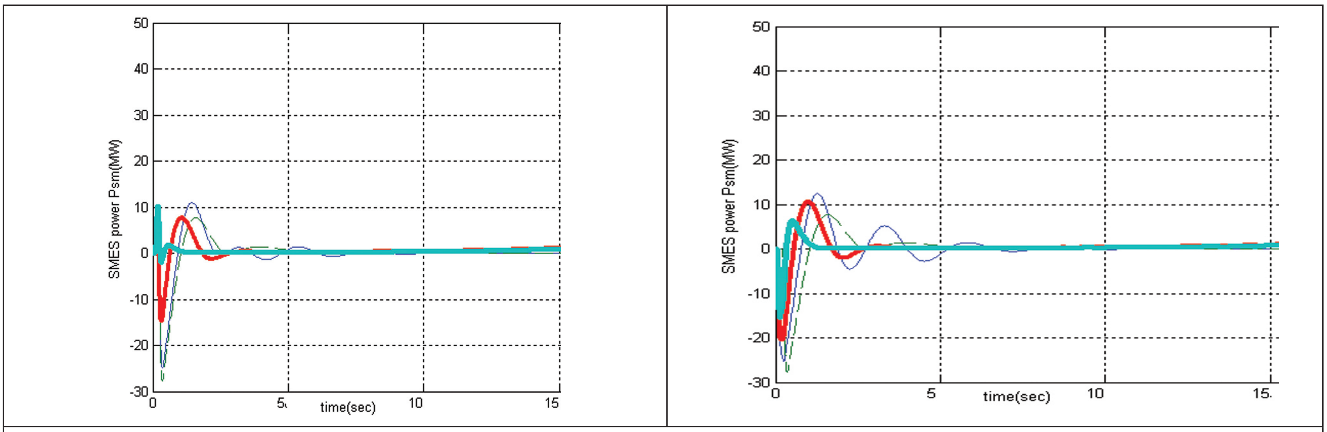


FIG. 9 SYSTEM PERFORMANCES FOR A STEP LOAD INCREASE ΔP_{L1}= 0.1 p.u MW IN AREA 1 (CASE I) WITH SMES UNIT

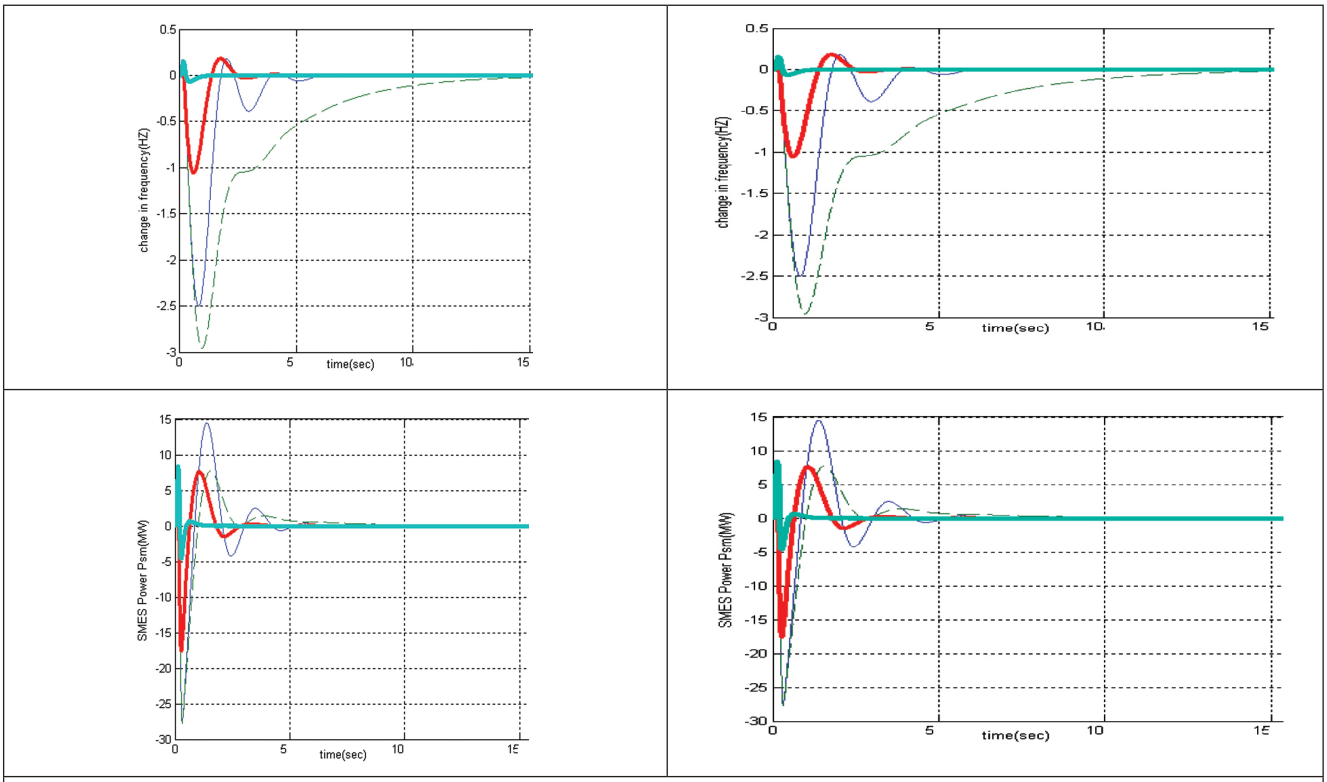


FIG. 10 SYSTEM PERFORMANCES FOR A STEP LOAD INCREASE ΔP_{L1}=ΔP_{L2}=0.1 p.u MW IN BOTH AREAS (CASE 2) WITH SMES UNIT

Table 1 shows the comparison of performances between the ANN controller, Conventional Integral Controller, PI controller and Fuzzy Proportional Integral Controller with SMES unit.

Results obtained in Table 1 shows that the use of ANN controller helps to reduce the settling time to 1.9s and the Area Control Error reduces to –0.0000272 MW.

TABLE 1

COMPARISON OF PERFORMANCES

Controllers	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

9.0 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. Results show that the ANN Controller has quite satisfactory generalization, capability, feasibility, reliability, accuracy and it is very powerful in reducing the frequency deviations and Area Control Error under a variety of load perturbations. Using ANN controller, the on-line 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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