Improvement of Performance of Load Following controller in a Deregulated Multi Area Hydro Thermal Gas System Employing Superconducting Magnetic Energy Storage

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Abstract—*This paper aims at investigating the enhancement of performance of load following based Hydro Thermal Gas system under deregulated market applying Superconducting Magnetic Energy Storage (SMES) against uncertainties. SMES device has been modeled and an attempt has been made to incorporate this device in the two area system thus improving the dynamic response of the system. The effect of this device on the system is demonstrated with the help of computer simulations. A systematic method has also been demonstrated for the modeling of this component in the system. Computer simulations reveal that due to the presence of SMES, the dynamic performance of the system in terms of settling time, overshoot and peak time is greatly improved than that of system without SMES.*

Keywords-- Load Following, SMES, Open market system, hydro thermal gas system.

I. INTRODUCTION

Large scale power systems are normally composed of control areas representing coherent groups of generators. In a practical interconnected power system, the generation normally comprises of a mix of thermal, hydro, nuclear and gas power generation. However, owing to their high efficiency, nuclear plants are usually kept at base load close to their maximum output with no participation in the system AGC. Gas power generation is ideal for meeting the varying load demand. Gas plants are used to meet peak demands only. Thus the natural choice for AGC falls on either thermal or hydro units. Literature survey shows that most of earlier works in the area of AGC pertain to interconnected thermal systems and relatively lesser attention has been devoted to the AGC of interconnected hydro-thermal system involving thermal and hydro subsystem of widely different characteristics. Concordia and Kirchmayer [1] have studied the AGC of a hydro-thermal system considering non-reheat type thermal system neglecting generation rate constraints. Kothari, Kaul, Nanda [2] have investigated the AGC problem of a hydro-thermal system provided with integral type supplementary controllers. The model uses continuous mode strategy, where both system and controllers are assumed to work in the continuous mode.

On the other hand, the concept of utilizing power electronic devices for power system control has been widely accepted in the form of Flexible AC Transmission Systems (FACTS) which provide more flexibility in power system operation and control [3]. The reported works [4-6] further shows that, with the use of SMES in both the areas, frequency deviations in each area are effectively suppressed. In view of this the main objectives of the present work are:

1. To develop the two area Simulink model of hydrothermal system under load following
2. To develop the model of SMES
3. To compare the improvement of dynamic performance of the system with SMES and without SMES

The remainder of the paper is organized as follows: Section (2) focuses on dynamic mathematical model considered in this work. Section (3) emphasizes on the development of mathematical model of SMES to be incorporated into the system. Section (4) demonstrates the results and discussions and some conclusions are presented in Section (5).

II. MARHEMATICAL MODELLING

Electric power systems are complex, nonlinear dynamic system. The Load Frequency controller controls the control valves associated with High Pressure (HP) turbine at very small load variations . The system under investigation has tandem-compound single reheat type thermal system. Each element (Governor, turbine and power system) of the system is represented by first order transfer function at small load variations in according to the IEEE committee report [11]. Figure 1 shows the transfer function block diagram of a two area interconnected network under deregulated scenario .The parameters of two area model are defined in Appendix.

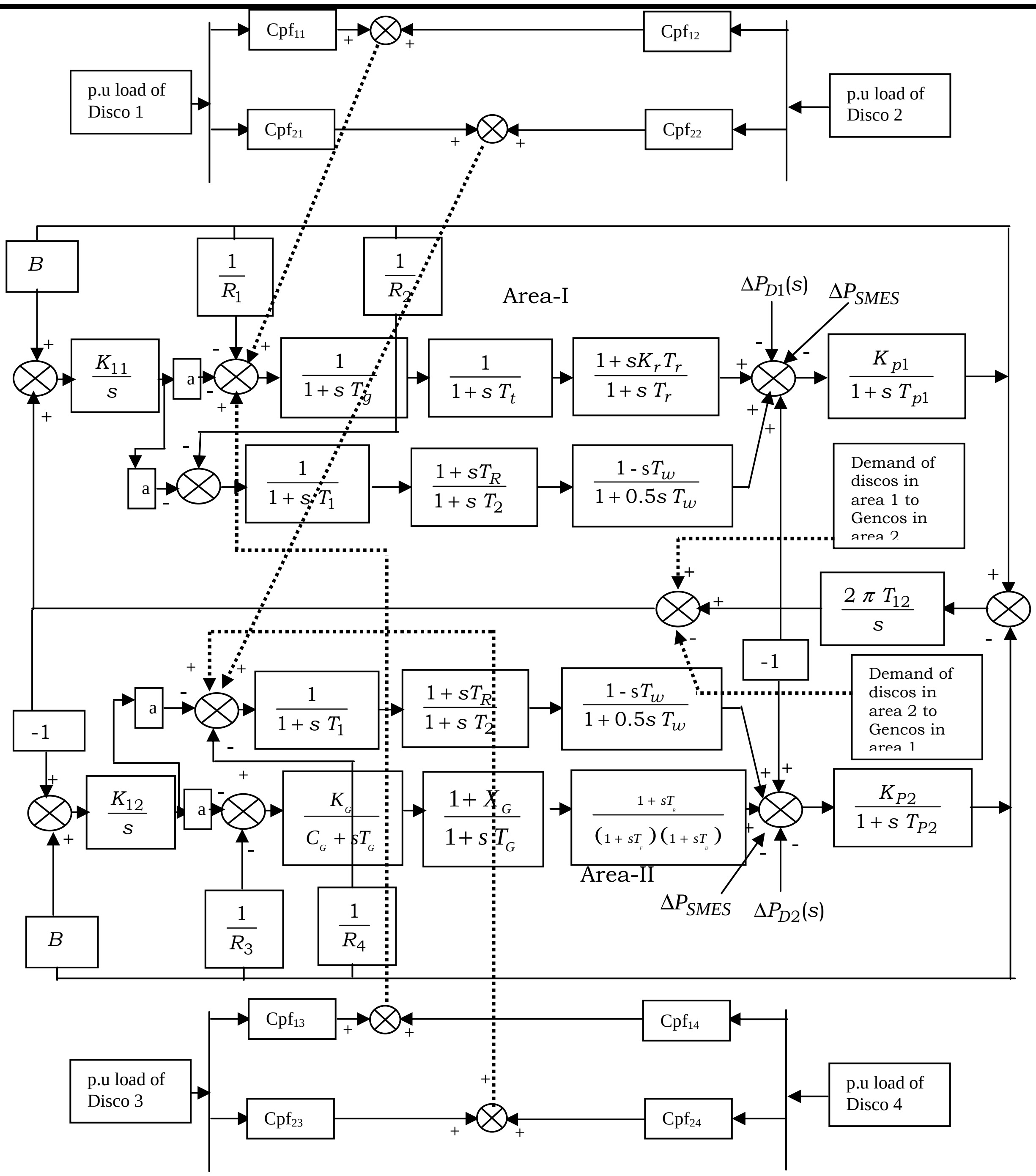


Fig.1: Two Area load following Hydro thermal gas system under deregulated scenario

III. DESIGN OF SMES

In the SMES unit, a dc magnetic coil is connected to the ac grid through a Power Conversion System (PCS) which includes an inverter/rectifier. The superconducting coil is contained in a helium vessel. Heat generated is removed by means of a low-temperature refrigerator. Helium is used as the working fluid in the refrigerator as it is the only substance that can exist as either a liquid or a gas at the operating temperature which is near absolute zero. The current in the superconducting coil will be tens of thousands or hundreds of thousands of amperes.

No ac power system normally operates at these current levels and hence a transformer is mounted on each side of the converter unit to convert the high voltage and low current of the ac system to the low voltage and high current required by the coil. The energy exchange between the superconducting coil and the electric power system is controlled by a line commutated converter. To reduce the harmonics produced on the ac bus and in the output voltage to the coil, a 12-pulse converter is preferred. Figure 2 shows the schematic representation of SMES unit. When there is a sudden rise in the load demand, the stored energy is almost released through the PCS 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. Similar action occurs during sudden release of loads. In this case, 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 α provides the dc voltage appearing across the inductor to be continuously varying within a certain range of positive and negative values. The inductor is initially charged to its rated current I_{do} by applying a small positive voltage. Once the current reaches its rated value, it is maintained constant by reducing the voltage across the inductor to zero since the coil is superconducting.

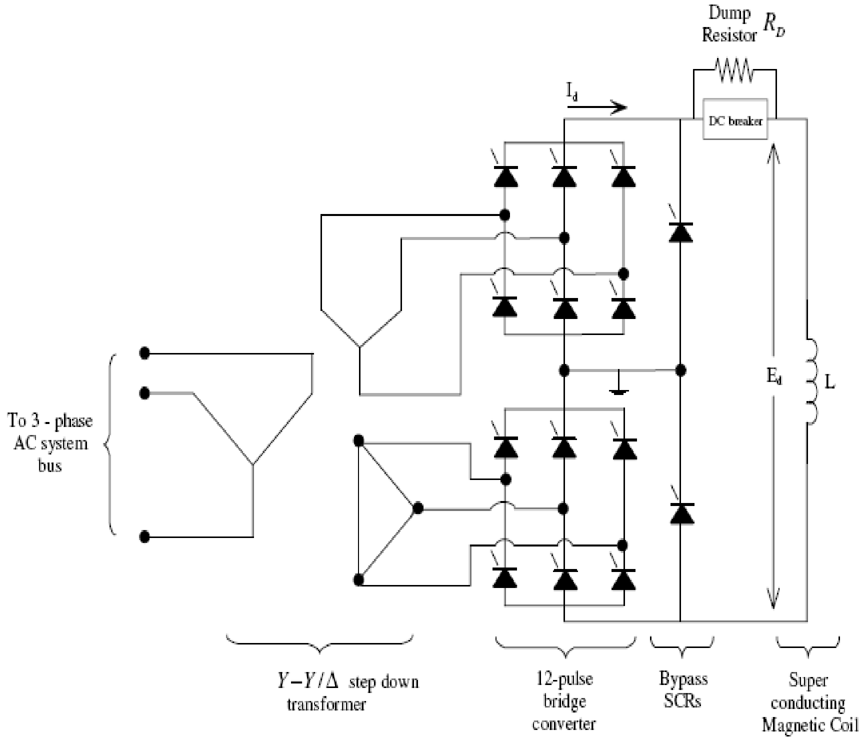


Fig.2: Schematic diagram of SMES

3.1 Control of SMES Unit

Either frequency deviation or Area Control Error (ACE) can be used as the control signal to the SMES unit The block diagram for the SMES unit can be represented as shown in Figure 3.

In this work the frequency deviation of area 1 is employed as input to the SMES device. It can be seen from Figure 3 that the structure of SMES consists of gain block K_{SMES} , time constant T_{SMES} and two stage phase compensation blocks having time constants T_1, T_2, T_3, T_4 respectively. A performance index considered in this work to compare the performance of proposed method is given by $J = \int_0^t \left(\alpha \cdot \Delta f_1^2 + \beta \cdot \Delta f_2^2 + \Delta P_{tie12}^2\right)$.

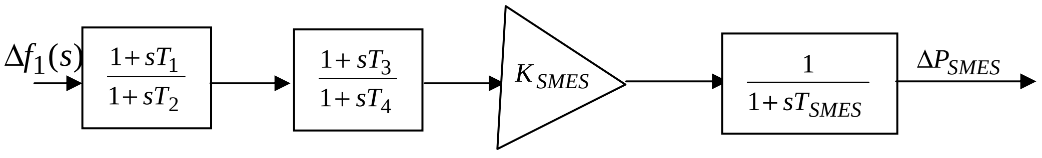


Fig. 3: Schematic diagram of SMES applied to system

IV. RESULTS AND ANALYSIS

Simulation studies are performed to investigate the performance of the two-area hydrothermal system under deregulated Environment. Here in the two-area hydrothermal system three Gencos and two Discos are considered in each area. It is assumed in this work that one Genco in each area is under AGC only and the remaining Gencos participate in the bilateral contracts. It is assumed that there is 0.2% step load disturbance of each Disco, as a result of which the total step load disturbance in each area and accounts to 0.4% and each Genco participates in AGC as defined by following area participation factors (apfs):

apf_1 =0.25, apf_2 =0.25, apf_3 =0.5, apf_4 =0.25, apf_5 =0.25, apf_6 =0.5 and the Discos contract with the Gencos as per the following Disco Participation Matrix

$$\text{DPM} = \begin{bmatrix} 0.25 & 0.3 & 0.1 & 0.3 \\ 0.25 & 0.1 & 0.4 & 0.4 \\ 0 & 0 & 0 & 0 \\ 0.25 & 0.4 & 0.3 & 0.1 \\ 0.25 & 0.2 & 0.2 & 0.2 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

A nominal value of 0.5 is considered for the gain setting of integral controller in both the areas. Table 1 shows the comparison between the dynamic performance of the system with and without SMES. It can be observed that the system with SMES has better dynamic performance than the system without SMES. Contract violation case has also been considered in this work. In this case it is considered that Disco_1 demands additional load of 0.3% after 30 sec and Disco_4 in area 2 demands additional load of 0.3% after 60 sec. It can be seen that the uncontracted power is supplied by the Gencos in the same area as that of the Disco which has demanded for additional power.

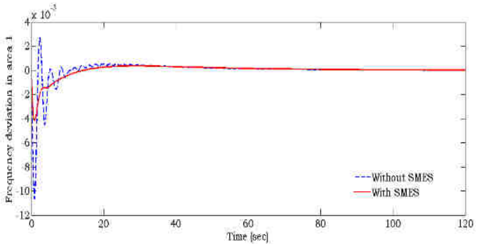
TABLE.1:COMPARISON OF SYSTEM PERFORMANCE WITH AND WITHOUT SMES

	Area-I			Area-II		
	Peak time (sec)	Overshoot	Settling Time (sec)	Peak time (sec)	Overshoot	Settling Time (sec)
With SMES	**0.804**	**0.00416939**	**2.305**	**0.729**	**0.00464404**	**2.225**
Without SMES	0.835	0.0106458	4.39	0.79	0.0112863	4.5

TABLE .2: COMPARISON OF PERFORMANCE INDEX VALUES

	Performance Index Value (Base case)	Performance Index Value (contract violation)
With SMES	$\mathbf{5.201}\times10^{-6}$	$\mathbf{2.363}\times10^{-5}$
Without SMES	1.748×10^{-5}	5.006×10^{-5}

Figure 4 shows the comparison between the frequency deviations and tie line power error deviations for both the cases. Figures 5 and 6 shows the generation of gencos of both areas. Figure 7 shows the comparison of frequency deviations and tie line power error deviations during the contract violation. Figures 8 and 9 depict the various generation of gencos during contract violation. The comparison of both the system in terms of performance index has been carried out in Figures 10 and 11. It can be observed from the figures that the system with SMES has less performance index than the system without SMES which indicates that the system has less error in the presence of SMES.



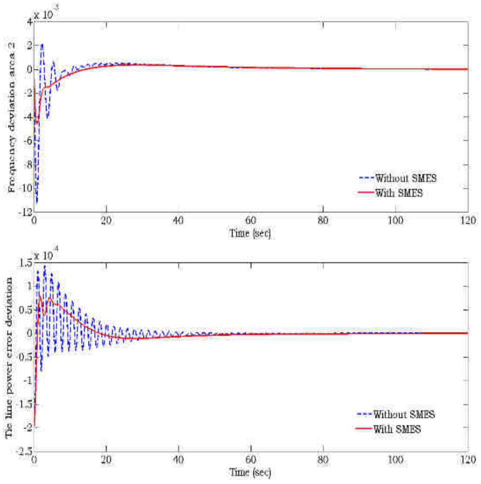
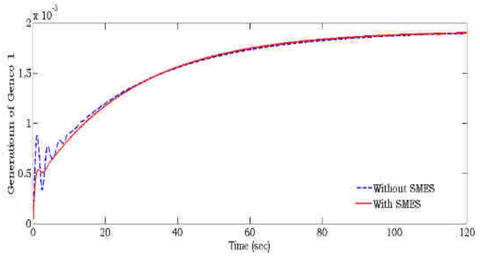


Fig.4: Comparison of Frequency deviations and tie line power error deviations



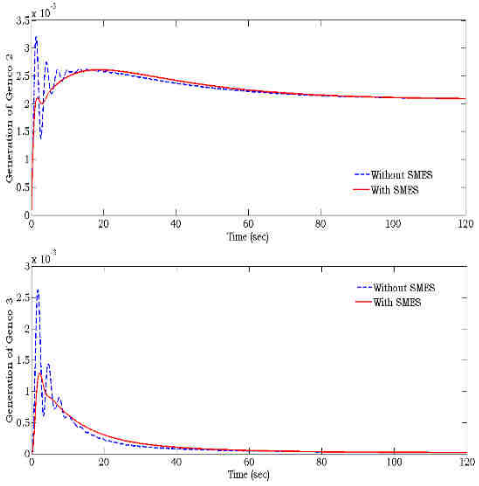


Fig.5: Generation of Gencos of Area I

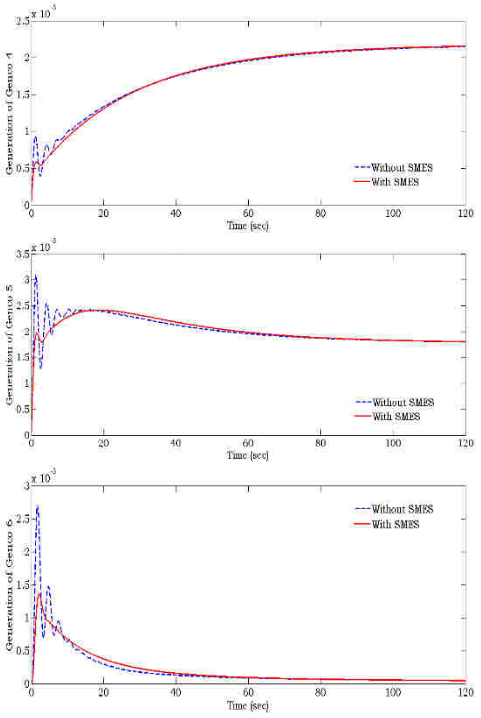
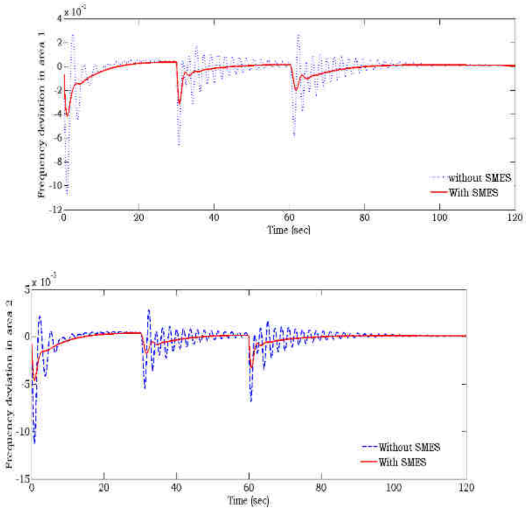


Fig. 6: Generation of Gencos of Area II



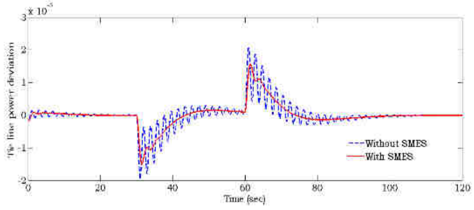


Fig.7: Comparison of Frequency deviations and tie line power error deviations during contract violation

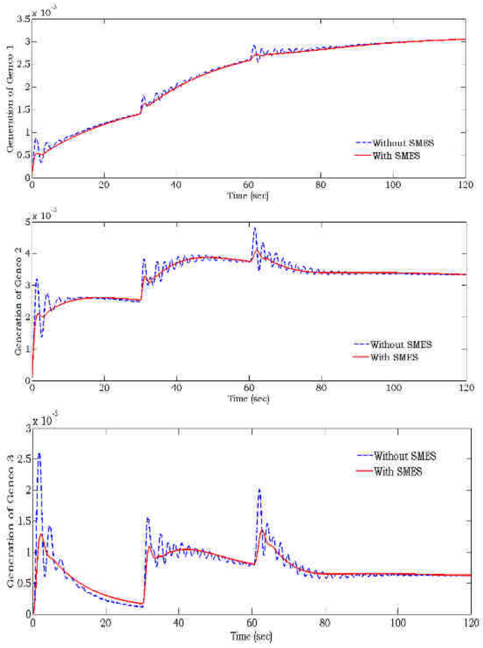


Fig.8: Generation of Gencos of Area I during contract violation

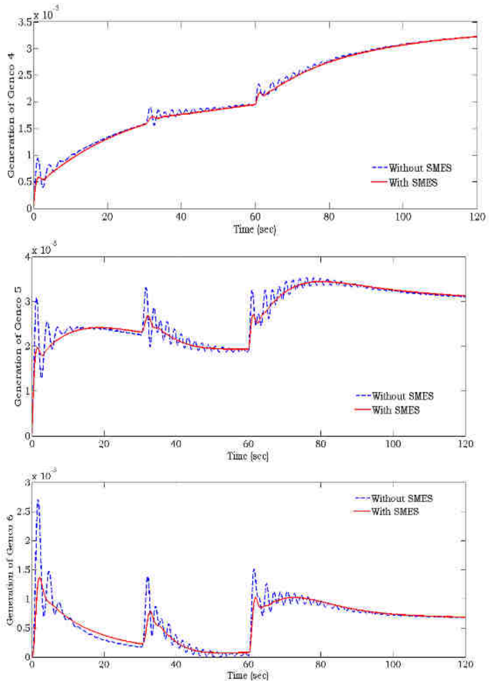


Fig.9: Generation of Gencos of Area II during contract violation

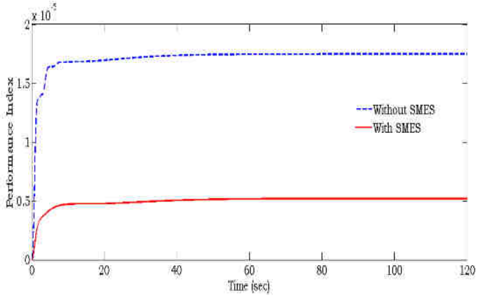


Fig.10: Comparison of performance index values during normal case

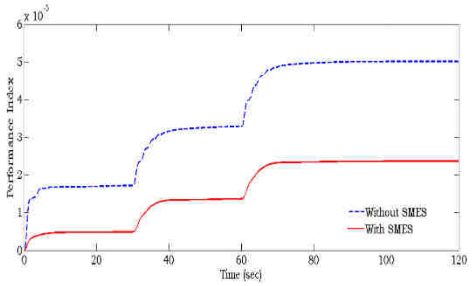


Fig.11: Comparison of performance index values during contract violation

V. CONCLUSIONS

A systematic method has been suggested for the design of a Superconducting Magnetic Energy Storage for a multi area system under deregulated scenario. This paper has also investigated the performance of the system with SMES with respect to reduction of frequency deviations and tie line power deviations during a load change on a multi area system. The simulation results indeed show that the proposed method indeed successfully mitigates the frequency and tie line power deviations during a load change and also it can be seen that the performance index of the system with SMES is less than the system without SMES which indicates the superiority of the proposed method.

Appendix

(a) System data

R =2.4 Hz/p.u.MW; $D = 8.33 \times 10^{-3}$ p.u. MW/Hz; K_g =1; T_g =0.08 sec; K_t =1; T_t =0.3 sec; K_r =0.5; T_r =10 sec; T_1, T_2, T_R =41.6, 0.513, 5 sec; T_w =1 sec; K_p =120 Hz/p.u. MW; T_p =:20 sec; B =0.425 p.u. MW/Hz; c_g=1; b_g=0.05; X_G=0.6; Y_G=1;

$K_{SMES} = 0.3; T_{SMES} = 0.0352$

REFERENCES

[1] C. Concordia and L.K.Kirchmayer, "Tie-Line Power and Frequency Control of Electric Power System - Part II**",** AIEE Transaction, vol. 73, Part- 111-A, pp. 133-146, April 1954.

[2] M.L.Kothari, B.L.Kaul and J.Nanda, "Automatic Generation Control of Hydro-Thermal system", journal of Institute of Engineers(India), vo1.61, pt EL2, , pp85-91, Oct 1980.

[3] Chun-Feng Lu, Chun-Chang Liu and Chi-Jui Wu. "Effect of battery energy storage system on load frequency control considering governor dead band and generation rate constraints" IEEE transactions on energy conversions Vol. *10* September 1995,pp.555- 561.

[4] Banerjee S, Chatterjee JK, Tripathy SC. Application of magnetic energy storage unit as continuous var controller. IEEE Trans Energy Conver 1990;5 (1):39–45.

[5] Tripathy SC, Kalantar M, Balasubramanian R. Dynamics and stability of wind and diesel turbine generators with superconducting magnetic energy storage unit on an isolated power system. IEEE Trans Energy Conver 1991;6 (4):579–85.

[6] Banerjee S, Chatterjee JK, Tripathy SC. Application of magnetic energy storage unit as load frequency stabiliser. IEEE Trans Energy Conver 1990*;5 (1):*46–51.

[7] Jayant Kumar, Kah-Koeng and Gerald Sheble, "AGC simulator for price based operation Part1", IEEE *Transactions on Power Systems, vol.12,no.2,* May 1997,pp. 527-532.

[8] Jayant Kumar, Kah-Hoeng and Gerald Sheble, "AGC simulator for price based operation part- 2", *IEEE Transactions on Power Systems, Vol.12, no. 2,* May1997, pp 533-538.

[9] Bjorn H.Bakken and OvesGrande, "Automatic generation control in a deregulated environment", *IEEE Transactions on Power Systems, vol.13, no.4,* Nov1998,pp. 1401-1406.

[10] V. Donde, M. A. Pai and I. A. Hiskens, "Simulation and optimization in an AGC system after deregulation", IEEE Trans. on Power systems, Vol. 16, No 3, Aug 2001, pp 481-489.

[11] "Dynamic Models for steam and Hydro Turbines in Power system studies,"IEEE committee report. *Transactions in Power Apparatus &Systems Vol.92,No.6,Nov./Dec.1973,pp.1904-915*.

[12] J. Nanda, Lalit Chandra Saikia, "Comparison of Performances of Several Types of Classical Controller in Automatic Generation Control for an Interconnected Multi-Area Thermal System", Proceedings of 2008 Australasian Universities Power Engineering Conference, Paper No 22.

[13] S. C. Tripathy, R. Balasubramanian & P. S. Chandramohanan Nair, "Small rating Capacitive Energy Storage for dynamic performance improvement of Automatic Generation Control," Proc. IEE, vol. 138, no. 1, pp. 103-111, Jan. 1991.

[14] Dhanalakshmi, S. Kannan, S. Mahadevan, " Market modes for deregulated environment - A review", Proceedings of 2011 International conference on Emerging Trends in Electrical and Computer Technology (ICETECT), 23-24 March 2011