Effect of SMES Unit in a Restructured Power System Considering GDB Non - Linearity

V. Rajaguru
Lecturer / ECE,
Debre Berhan University
Debre Berhan,,
Ethiopia.

R. Sathya,
Assistant Professor / EEE,
Krishnasamy College of Engg & Tech,
Cuddalore, India.

V. Shanmugam,
Assistant Professor / EEE,
Krishnasamy College of Engg & Tech,
Cuddalore, India.

***Abstract* — In power system, any sudden change in load leads to the deviation in frequency and the tie-line power flow. Therefore, Load Frequency Control (LFC) is an important issue in power system operation and control for supplying reliable electric power with good quality. This paper presents the effect of Super conducting Magnetic Energy Storage (SMES) unit in a restructured power system considering Governor Dead Band (GDB) non-linearity. The proposed work consist of two area interconnected power system in a restructured environment with SMES unit considering GDB non-linearity has been designed to improve the dynamic performance of the system and Integral Square Error (ISE) technique is used to obtain the optimal Proportional - Integral gain settings. The simulation result shows the load frequency control in a restructured power system with and without SMES unit considering GDB non-linearity for different contracted scenarios.**

Keywords—Load Frequency Control; Restructured power system; Super conducting Magnetic Energy Storage (SMES) unit; Governor Dead Band (GDB) non-linearity.

I. INTRODUCTION

The power system composed of several interconnected control areas, any sudden changes in the load causes frequency deviations. So Load Frequency Control (LFC) plays a vital role in an interconnected power system for supplying reliable and good quality of power supply. The main objective of the LFC is to maintain zero steady state errors for frequency deviation and good tracking load demands in a multi-area restructured power system.

A lot of studies have been made in this area are as follows. A study of two area Load Frequency Control in deregulated power system is presented and any mismatch between actual and contracted demands will result in a frequency deviation [1]. Automatic Generation Control (AGC) of two area interconnected power system has been studied and the concept of Distribution Company (DISCO) Participation Matrix (DPM) is presented [2]. Usually the Governor Dead Band (GDB) effects are neglected in the load frequency control studies for simplicity. But for realistic analysis of system performance, this should be incorporated. This results in considerable effects on the amplitude and settling time of oscillations [3]. A new optimal controller for the automatic generation control problem in deregulated power system is proposed and the performance of a two area power system considering different contracted scenarios has been proposed [4]. A multi stage fuzzy Proportional – Integral – Derivative (PID) type controller is proposed to solve the LFC problem in a restructured power system and the results of the proposed controller are compared with the classical fuzzy PID type controller and mixed H_2 / H_∞ controller through some performance indices to illustrate its robust performance [5]. A new approach for the design of decentralized biased controllers for LFC of interconnected power systems is presented and the simulation results proved that the biased controllers provide better transient as well as steady state response [6]. A fuzzy logic controller for AGC in a interconnected power system including SMES units has been studied [7]. A comprehensive digital computer model of a two area interconnected power system including the GDB non-linearity, steam reheat constraints and the boiler dynamics is developed. The improvement in AGC with the addition of a small capacity SMES unit is studied [8]. Fast – acting energy storage devices can effectively damp electromechanical oscillations in a power system. A power system with a SMES unit of 4 – 6 MJ capacity would reduce the maximum deviation of frequency and tie-line power flow by about 40% in power areas of 1000 – 2000MW capacity is analyzed [9].

II. SMES MODEL

The Fig.1 shows the basic configuration of a SMES unit in the power system. The superconducting coil can be charged to a set value (which is less than the full charge) from the utility grid during normal operation of the grid. The DC magnetic coil is connected to the AC grid through a Power Conversion System (PCS) which includes an inverter/rectifier. Once charged, the superconducting coil conducts current, which supports an electromagnetic field, with virtually no losses. The coil is maintained at extremely low temperature (below the critical temperature) by immersion in a bath of liquid helium.

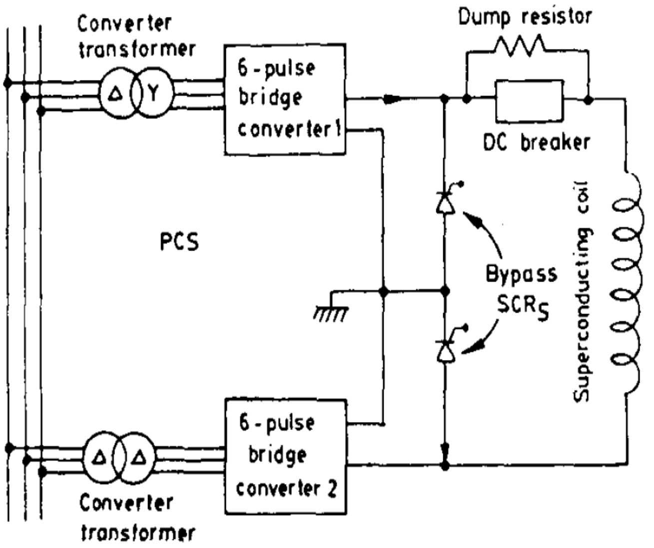


Fig.1. Configuration of SMES in the power system

When there is a sudden rise in the demand of load, the stored energy is almost immediately released through the PCS to the grid as line quality AC. As the governor and other control mechanisms start working to set the power system to the new equilibrium condition, the coil charges back to its initial value of current. Similar is the action 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 operation of SMES units, that is, charging, discharging, the steady state mode and the power modulation during dynamic oscillatory period are controlled by the application of the proper positive or negative voltage to the inductor. This can be achieved by controlling the firing angle of the converter bridges.

Neglecting the transformer and the converter losses, the DC voltage is given by

$$E_d = 2V_{do}\cos\alpha - 2I_dR_c \qquad (1)$$

Where, E_d = DC voltage applied to the inductor (KV)

α = firing angle (degree)

I_d = current through the inductor (KA)

R_c = equivalent commutating resistance (Ω)

V_{do}= maximum open circuit bridge voltage of each six pulse convertor at α=0 degree (KV)

The inductor is initially charged to its rated current, I_{do} by applying a small positive voltage. Once the current has attained the rated value, it is held constant by reducing voltage ideally to zero since the coil is superconducting. A very small voltage may be required to overcome the commutating resistance.

The energy stored at any instant,

$$W_L = (½)(LI_d^2), \text{ MJ} \qquad (2)$$

Where, L = inductance of SMES, in Henry.

In LFC operation, the E_d is continuously controlled by the input signal to the SMES control logic. 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. Thus, in order to improve the current restoration to its steady state value the inductor current deviation is used as a negative feedback signal in the SMES control loop. Based on the above discussion, the converter voltage deviations applied to the inductor and inductor current deviations are described as follows:

$$\Delta E_{di}(S) = \frac{K_{SMES}}{1+ST_{dci}} U_{SMES\,i}(S) - \frac{K_{id}}{1+ST_{dci}} \Delta I_{di}(S) \qquad (3)$$

$$\Delta I_{di}(S) = \frac{1}{SL_i} \Delta E_{di}(S) \qquad (4)$$

Where

$\Delta E_{di}(s)$ = Converter voltage deviation applied to inductor in SMES unit

K_{SMES} = gain of control loop SMES

T_{dci} = convertor time constant in SMES unit

U_{SMES} = control signal of SMES unit

K_{id} = gain for feedback ΔI_d in SMES unit

$\Delta I_{di}(s)$ = inductor current deviation in SMES unit.

The ACE_i is defined as follows:

$$ACE_i = B_i\Delta F_i + \Delta P_{tie,I} \qquad (5)$$

Where

B_i = Frequency bias in area *i*.

ΔF_i = Frequency deviation in area *i*.

$\Delta P_{tie,i}$ = Net tie line power flow deviation in area *i*.

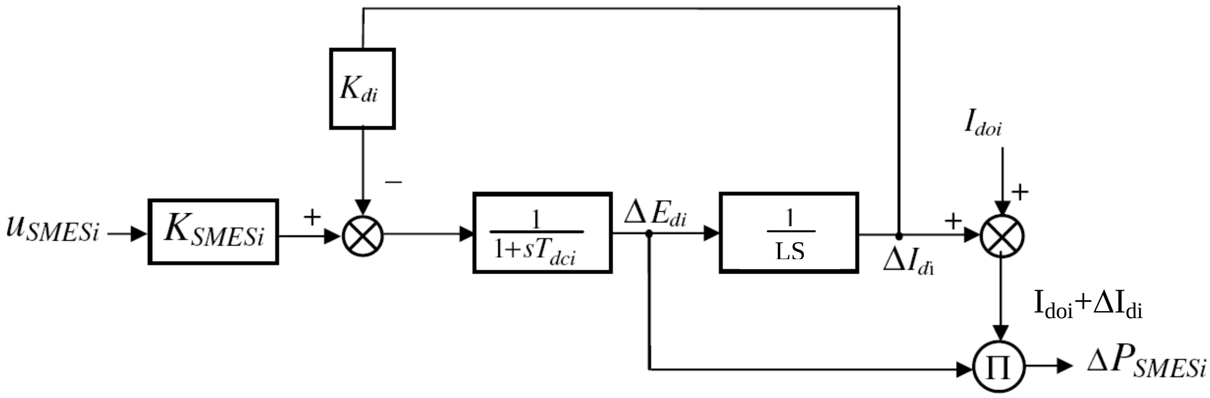


Fig. 2. The block diagram of SMES unit

The deviation in the inductor real power of SMES unit is expressed in time domain as follows:

$$\Delta P_{SMES\ i} = \Delta E_{di} I_{doi} + \Delta I_{di} \Delta E_{di} \qquad (6)$$

Where, ΔP_{SMESi} = Deviation in the inductor real power of SMES unit in area i.

This value is assumed to be positive for transfer from AC grid to DC. Fig. 2 shows the block diagram of SMES unit.

III. RESTRUCTURED POWER SYSTEM

A. Traditional V_S Restructured Scenario

The traditional power system industry has a "vertically integrated utility" (VIU) structure. In the restructured or deregulated environment, vertically integrated utilities no longer exist. The utilities no longer own generation, transmission, and distribution; instead, there are different entities, viz, GENCO's (Generation Companies), TRANSCOs (Transmission Companies) and DISCO'S (Distribution Companies).

As there are several GENCO's and DISCO's in the restructured structure, a DISCO has the freedom to have a contract with any GENCO for transaction of power. A DISCO may have a contract with GENCO in another control area. Such transactions are called "Bilateral Transactions". All the transactions have to be cleared through an impartial entity called an Independent System Operator (ISO). The ISO has to control a number of ancillary services, one of which is Load-Frequency Control.

B. DISCO Participation Matrix

In the restructured environment, GENCO's sell power to various DISCO'S at competitive prices. Thus, DISCO'S have the liberty to choose the GENCO's for contracts. They may or may not have contracts with the GENCO's in their own area. This makes various combinations of GENCO-DISCO contracts possible in practice. We introduce the concept of a "DISCO participation matrix" (DPM) to make the visualization of contracts easier. DPM is a matrix with the number of rows equal to the number of GENCO's and the number of columns equal to the number of DISCO'S in the system. Each entry in this matrix can be thought of as a fraction of a total load contracted by a DISCO (column) toward a GENCO (row). Thus, the ij^{th} entry corresponds to the fraction of the total load power contracted by DISCO from a GENCO. The sum of all the entries in a column in this matrix is unity. DPM shows the participation of a DISCO in a contract with a GENCO; hence the name "DISCO participation matrix."

Consider a two-area system in which each area has two GENCO's and two DISCO'S in it. Let $GENCO_1$, $GENCO_2$, $DISCO_1$, and $DISCO_2$ be in area I and $GENCO_3$, $GENCO_4$, $DISCO_3$, and $DISCO_4$ be in area II as shown in Fig.3.

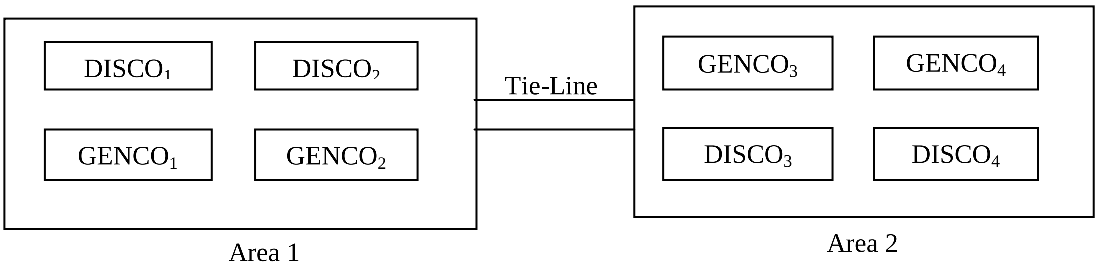


Fig. 3. Schematic diagram of a two – area system in restructured environment

The corresponding DPM will become

$$\mathrm{DPM}=\begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix} \quad (7)$$

Where cpf refers to "contract participation factor." Suppose that $DISCO_3$ demands 0.1 pu MW power, out of which 0.025 pu MW is demanded from $GENCO_2$, 0.03 pu MW from $GENCO_2$, 0.035 pu MW from $GENCO_4$ and 0.01 pu MW from $GENCO_4$.

Then column 3 entries in (12) are easily defined as

$$cpf_{13}=\frac{0.025}{0.1}=0.25, \quad cpf_{23}=\frac{0.03}{0.1}=0.3, \quad cpf_{33}=\frac{0.035}{0.1}=0.35, \quad cpf_{43}=\frac{0.01}{0.1}=0.1 \quad (8)$$

Other *cpf*s are defined similarly to obtain the entire DPM. It should be noted that $\sum_i cpf_{ij}=1$. The diagonal elements of DPM correspond to local demands. Off diagonal elements correspond to the demands of the DISCO'S in one area to the GENCO's in another area.

IV. GOVERNOR DEAD BAND

Governor Dead Band (GDB) is defined as the total magnitude of a sustained speed change with in which there is no resulting change in valve position. The Governors in all areas in a power system have dead bands, which are important for speed control under small disturbances. The dead band affects the stability of the system. One way to improve the stability of the system is to optimize the bias factor 'B' associated with change of frequency (as opposed to tie-line power) in Area Control Error (ACE). In addition, the total ACE can be used to improve stability by proper selection of its integrating factor K_I in the determination of supplementary control.

The limiting value of dead band is specified as 0.06%. One of the effects of Governor Dead Band is to increase the apparent steady-state speed regulation 'R'. This can be seen from the fig.4. by joining points 1 and 2 and multiplying the slope of this line with 1/R. The slope of the line 'K' without dead band is 1.The GDB of the form shown in fig.4.exists in real system.

The hysteresis type of non-linearity is expressed as,

$$Y=F(x,\dot{x}) \text{ rather than as } Y=F(x) \quad (9)$$

To solve the non-linear problem, it is necessary to make the basic assumption that the variable 'x', appearing in the above equation is sufficiently close to a sinusoidal equation, that is

$$x \cong A \sin \omega_0 t \quad (10)$$

Where, $x \rightarrow$ is a variable

$A \rightarrow$ is the amplitude of the oscillation

$\omega_0 \rightarrow$ is the frequency of the oscillations

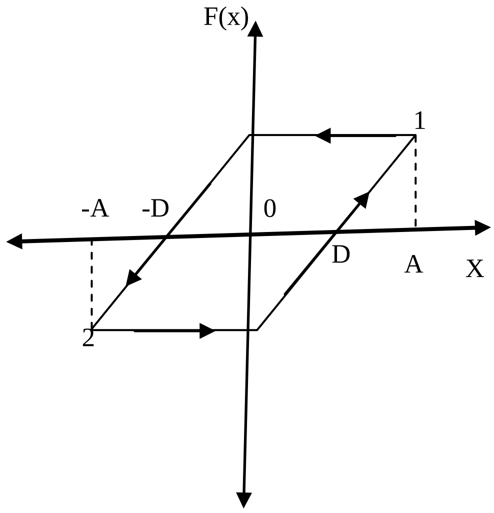


Fig. 4. Governor Dead Band non-linearity

As the variable function is complex and periodic function of time, it can be developed in a Fourier series as follows,

$$F(x,\dot{x}) = F^\circ + N_1 x + \frac{N_2}{\varpi_0}\dot{x} + \ldots \quad (11)$$

As the backlash non-linearity is symmetrical about the origin, F° is zero. From the above equation, for simplification, neglect higher order terms. The Fourier co-efficients are derived as N_1=0.8 and N_2=-0.2. By substituting the values in the above equation, we get the transfer function for GDB as follows,

$$F(x,\dot{x}) = N_1 x + \frac{N_2}{\varpi_0}\dot{x} + \ldots \quad (12)$$

V. CONVENTIONAL PI - CONTROLLER

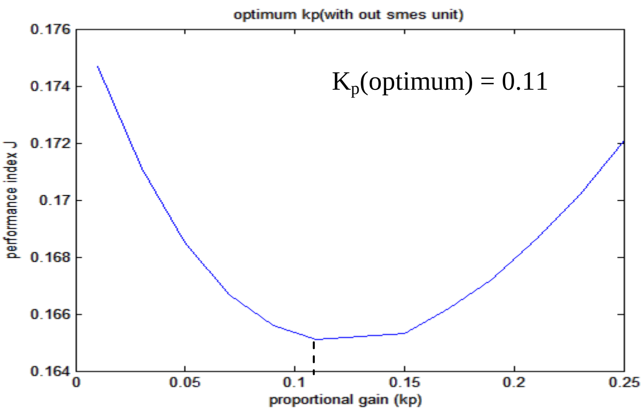


Fig.5. Performance index curve for optimal K_P

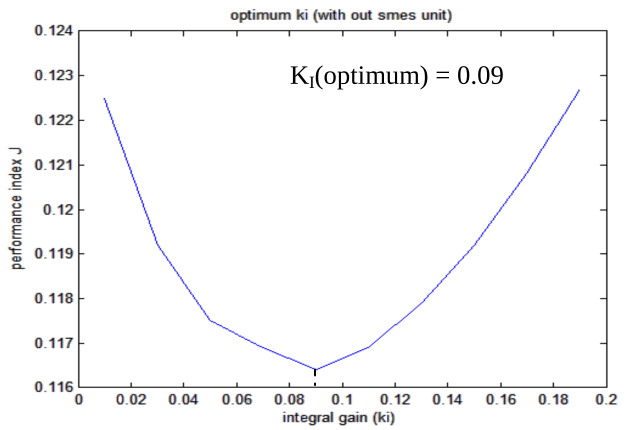


Fig.6. Performance index curve for optimal K_I

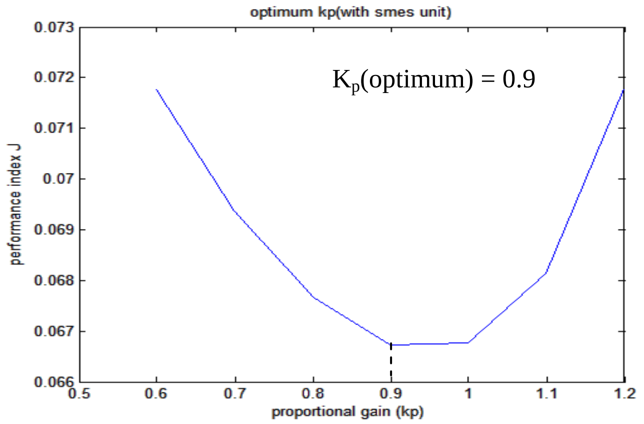


Fig.7. Performance index curve for optimal K_P

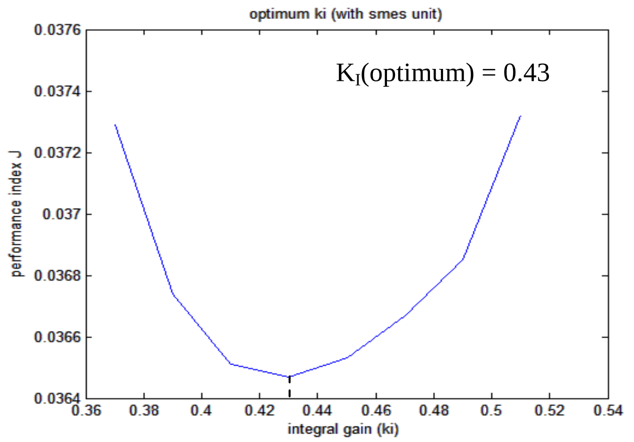


Fig.8. Performance index curve for optimal K_I

P-I controller (proportional – Integral controller) is a feedback controller which drives the plant to be controlled with a weighted sum of the errors (difference between the output and desired set-point) and the integral of that value.

The controller output is given by $\Delta K_P + K_I \int \Delta dt$. (13)

Where $\Delta \rightarrow$ is the set point error
$K_P \rightarrow$ proportional gain
$K_I \rightarrow$ Integral gain

The integral term in a PI controller causes the steady – state error to be zero for a step input.

For conventional PI - controller the gains K_P and K_I have to be determined by using Integral Square Error (ISE) criterion.

The objective function used for this technique is

$$J = \int_0^t (\Delta F_1^2 + \Delta Ptie_1^2) dt. \quad (14)$$

Where, $\Delta F_1 \rightarrow$ change in frequency in area 1.
$\Delta P_{tie} \rightarrow$ change in tie line power.

On the basis of performance index (J) curve (J V_S K_P & J Vs K_I) the feedback gains are determined to achieve the optimality of system performance. Figs. 5, 6, 7& 8 show optimum values of K_P and K_I, for with and without SMES unit.

VI. SIMULATION MODEL AND RESULTS

A two area interconnected restructured power system with SMES unit considering GDB non-linearity is used to illustrate the behavior of the proposed LFC scheme. The data used for simulation is given in the appendix. Both the areas are assumed to be identical. The governor-turbine units in each area are assumed to be identical.

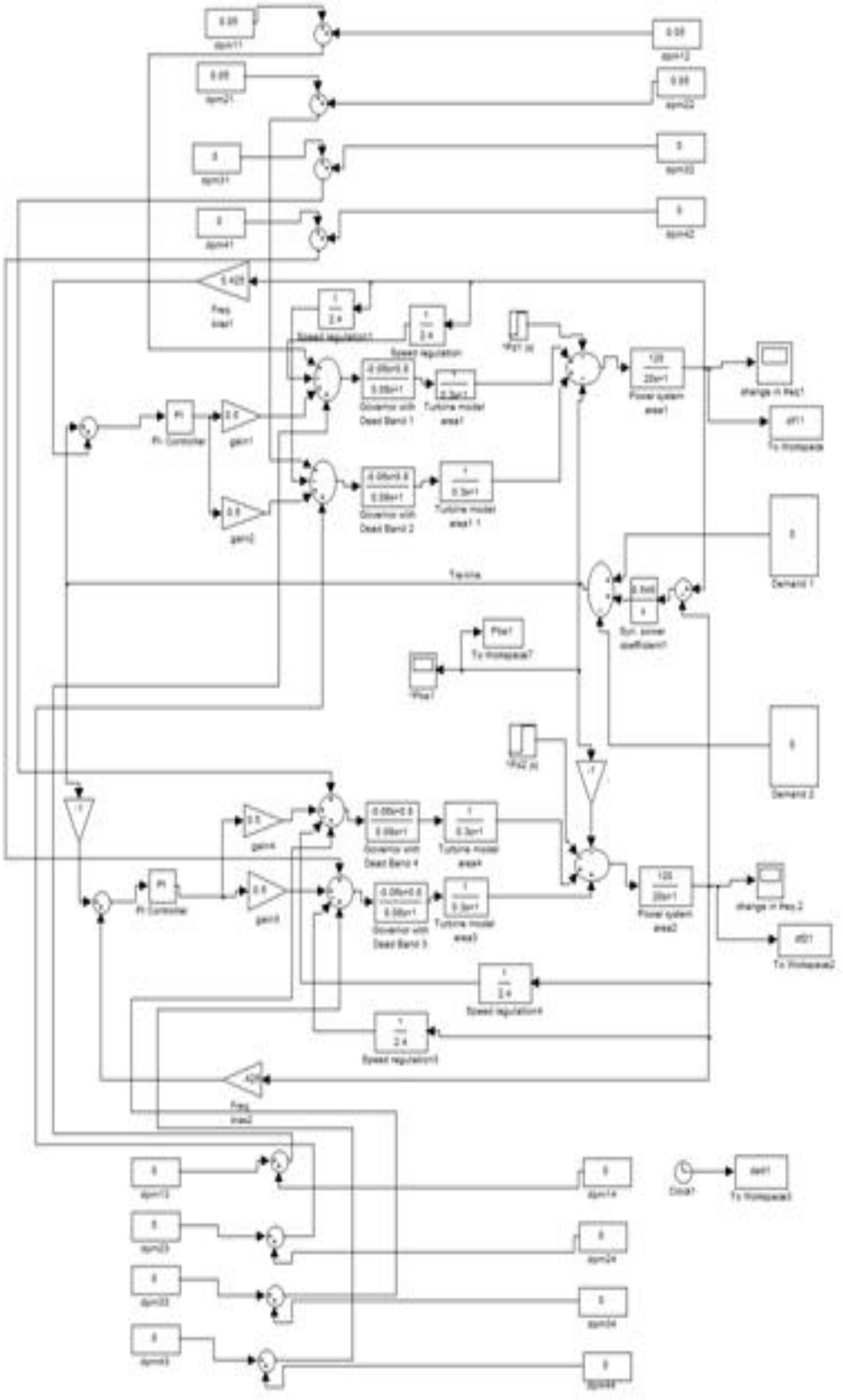


Fig.9 (a). Simulation model of load frequency control in a restructured power system without SMES unit considering GDB non-linearity for case-1

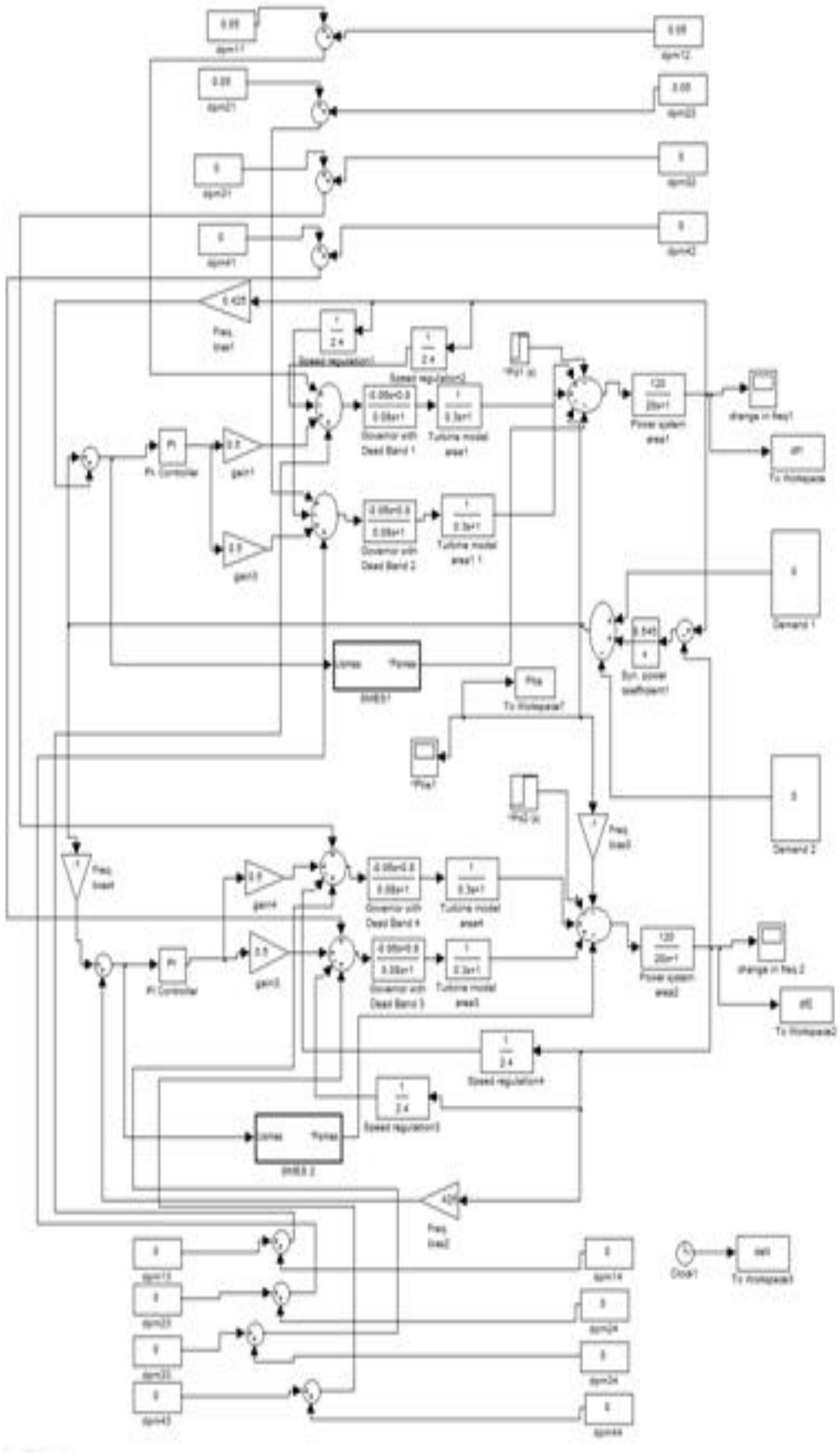


Fig.9 (b). Simulation model of load frequency control in a restructured power system with SMES unit considering GDB non-linearity for case-1

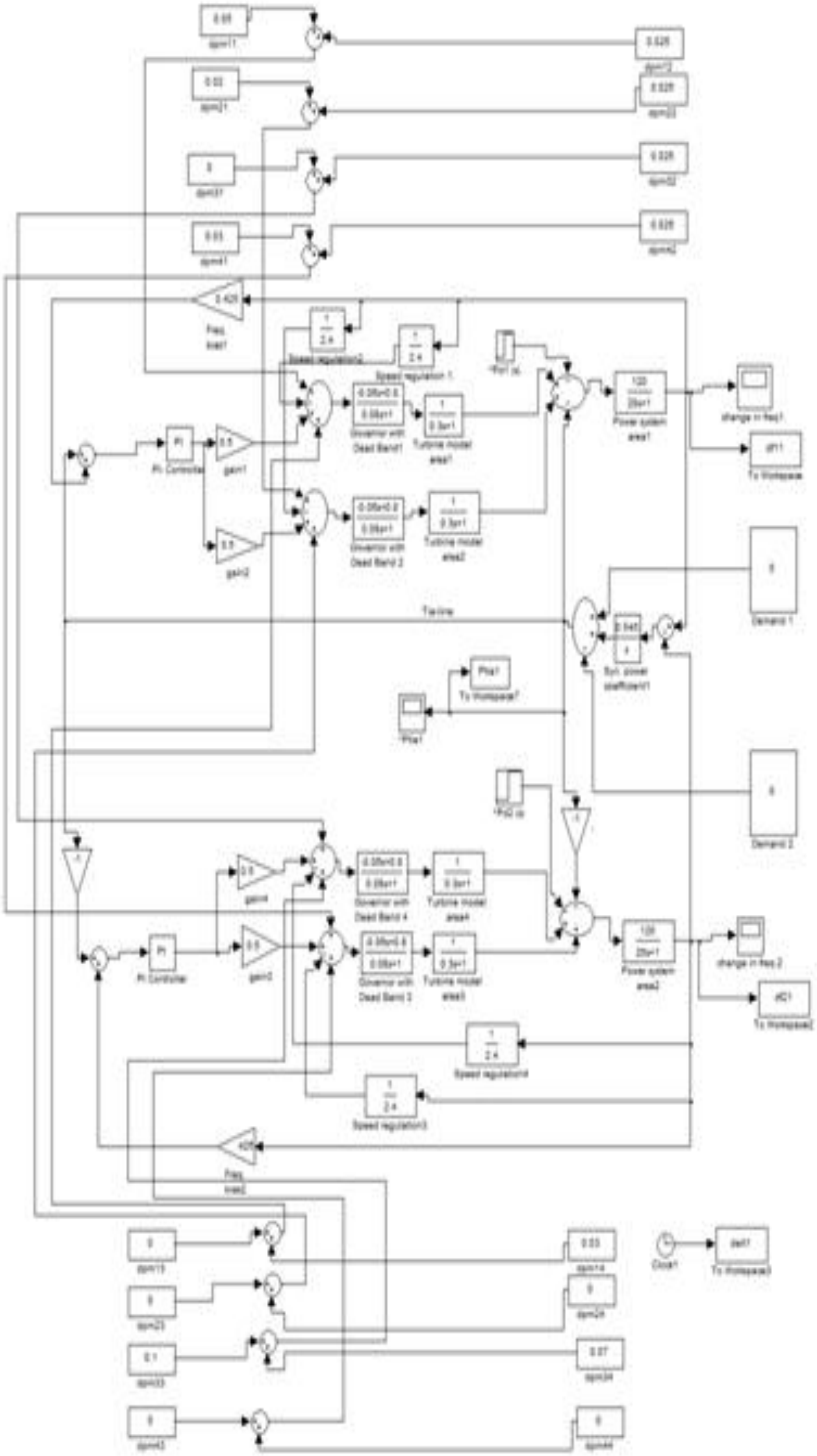


Fig.10 (a). Simulation model of load frequency control in a restructured power system without SMES unit considering GDB non-linearity for case-2

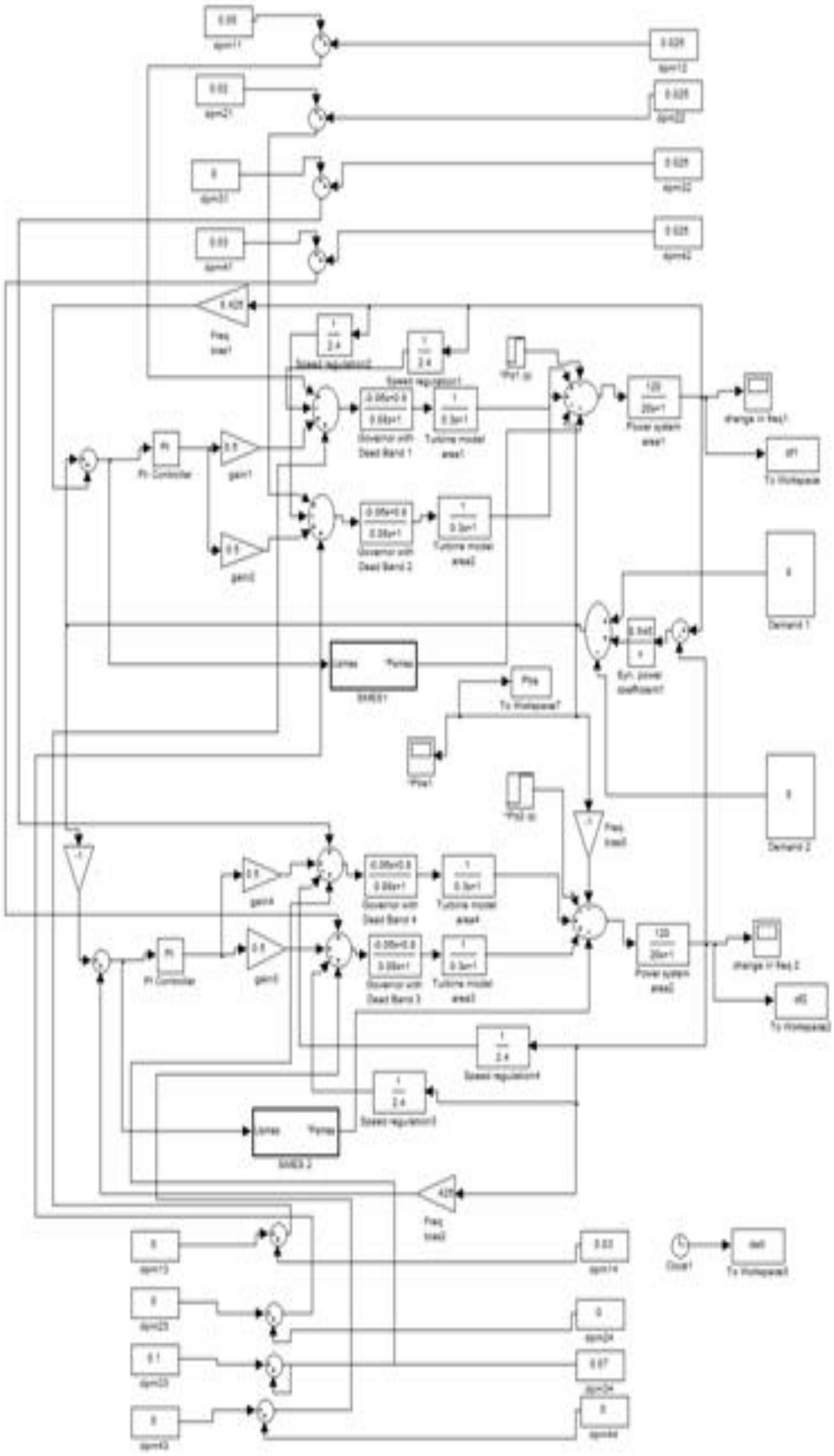
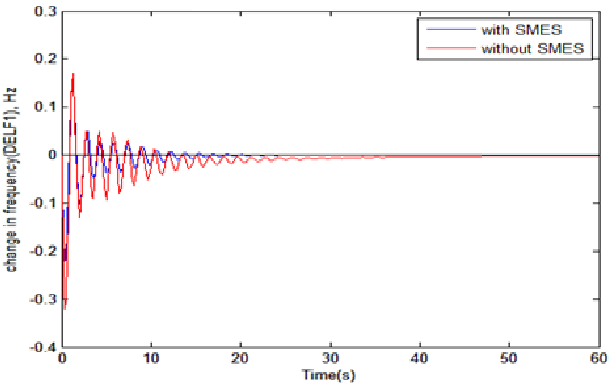
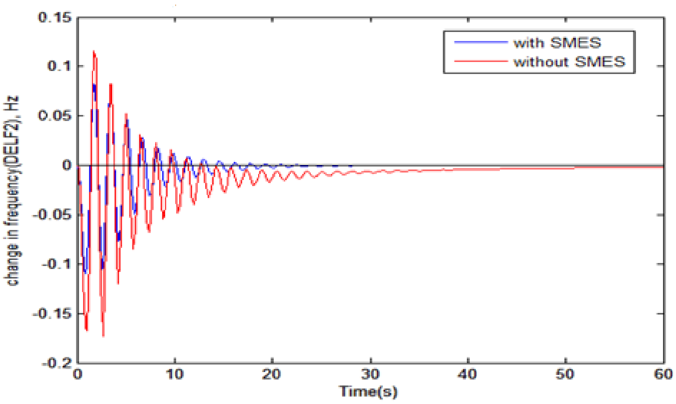


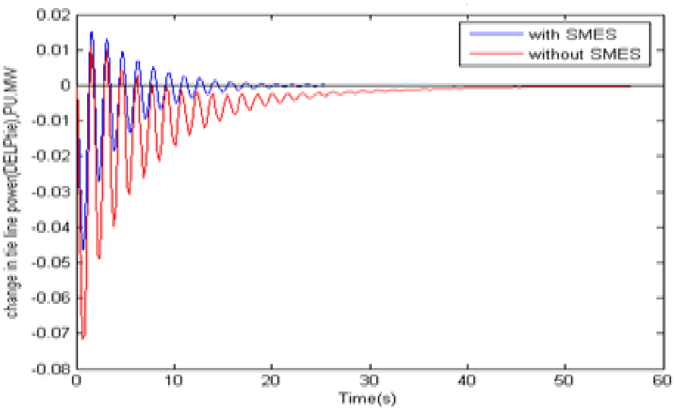
Fig.10 (b). Simulation model of load frequency control in a restructured power system with SMES unit considering GDB non-linearity for case-2



(a) - Frequency deviation in area - 1

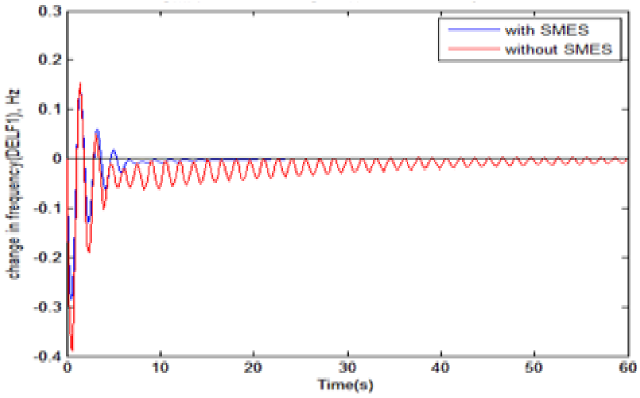


(b) - Frequency deviation in area - 2

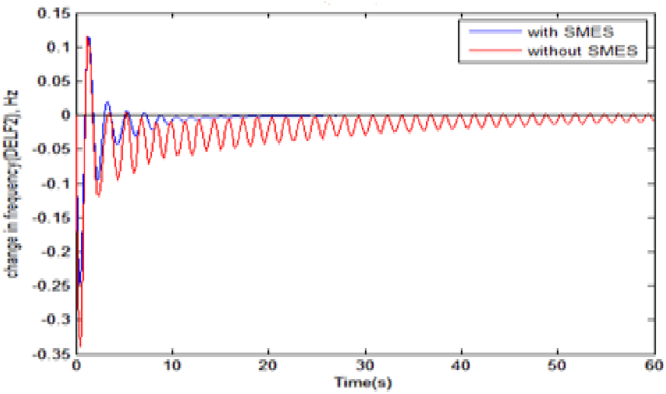


(c) - Tie-Line power deviation

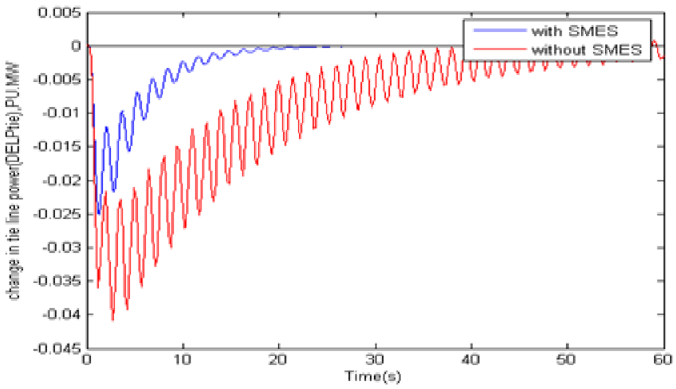
Fig.11. Frequency response of a two area interconnected restructured power system considering GDB non-linearity for case-1



(a) - Frequency deviation in area - 1



(b) - Frequency deviation in area - 2



(c) - Tie-Line power deviation

Fig.12. Frequency response of a two area interconnected restructured power system considering GDB non-linearity for case-2

Case – 1 : Base Case

The GENCO's in each area participate equally in LFC (i.e., ACE participation factors are apf 1=0.5, afp2=1 apf1=0.5; apf3=1-apf2=0.5; apf4=1-apf3=0.5). The load change occurs only in area 1. Thus, the load is demanded only by DISCO1 and DISCO2. Let the value of this load perturbation be 0.1 pu MW for each of them.

$$DPM = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

The DISCO3 and DISCO4 do not demand power from any GENCO's, and hence corresponding participation factors (columns 3 and 4) are zero. DISCO1 and DISCO2 demand identically from their local GENCO's viz. GENCO1 and GENCO2.

Fig.9(a & b) shows the simulation model of two area interconnected restructured power system with and without SMES unit considering GDB non-linearity for this base case.

Case – 2 : Bilateral Transactions

In this case where all the DISCO'S contract with the GENCO'S for power as per the following Disco Participation Matrix (DPM):

$$DPM = \begin{bmatrix} 0.5 & 0.25 & 0 & 0.3 \\ 0.2 & 0.25 & 0 & 0 \\ 0 & 0.25 & 1 & 0.7 \\ 0.3 & 0.25 & 0 & 0 \end{bmatrix}$$

It is assumed that each DISCO demands 0.1 pu MW power from GENCO'S as defined by cpfs in DPM matrix. The off diagonal blocks of the DPM correspond to the contract of a DISCO in one area with a GENCO in another area.

Fig.10(a & b) shows the simulation model of two area interconnected restructured power system with and without SMES unit considering GDB non-linearity for this bilateral transaction case.

The above two different contracted scenarios (i.e., case-1 & 2) are simulated by using MATLAB and the simulation results are shown in Fig.11 & 12.

The fig.11(a,b&c) & fig.12(a,b&c) show the simulation results of Frequency deviation of area 1 (Δf_1), Frequency deviation of area 2 (Δf_2), and Tie-Line power deviation (ΔP_{tie}) in a restructured power system with and without SMES unit considering GDB non-linearity for different contracted scenarios.

VII. CONCLUSION

In this paper, Load-Frequency Control for an interconnected power system with SMES unit considering GDB non-linearity is proposed for the solution of LFC problem in a Restructured Environment. LFC provides a relatively simple, yet effective method of adjusting generation to minimize frequency deviations and regulate Tie-line power flow. In addition to this the Integral Square Error (ISE) technique is used to obtain conventional P-I controller gains. Thus, the simulation results show that the dynamical performance of the system (such as frequency oscillation, peak over shoot and settling time) is significantly improved when an SMES unit is included in a two-area interconnected restructured power system with GDB non-linearity.

APPENDIX

A.1 Data for the two area interconnected restructured power system without SMES unit considering GDB non-linearity
T_G = 0.08 sec , T_T = 0.3 sec , K_P = 120 Hz/pu , T_p = 20 sec , T_{12} = 0.545 pu/Hz ,K_p = 0.11 , K_I = 0.09, B = 0.425 Pu/Hz , R = 2.4 Hz/pu, N_1=0.8, N_2 = -0.06.

A.2 Data for the two area interconnected restructured power system with SMES unit considering GDB non-linearity
T_G = 0.08 sec , T_T = 0.3 sec , K_P = 120 Hz/pu, T_p = 20 sec , T_{12} = 0.545 pu/Hz , K_P= 0.9, K_I = 0.43, B = 0.425 Pu/Hz, R = 2.4 Hz/pu, N_1=0.8, N_2 = -0.06.

A.3 Data for SMES unit

L = 2.65 H
T_{dc} = 0.03 sec
K_{SMES} = 50 KV/unit MW
K_{di} = 0.2 KV/kA
I_{do} = 4.5 kA

REFERENCES

[1]. Isha Garg, Mohd. Ilyas, "Study of two area Load Frequency Control in deregulated power system", International Journal of Innovative Technology and Exploring Engineering, Vol.1, No.2, pp. 42-45, 2012.
[2]. Vijay Rohilla, K.P Singh Parmar, Sanju Saini, "Optimization of AGC parameters in the restructured power system environment using GA", International Journal of Engineering Sciences & Emerging Technologies, Vol.3, No.2, pp.30 - 40, 2012.
[3]. B.Anand and A.Ebenezer Jeyakumar, "Load Frequency Control with Fuzzy Logic Controller Considering Non-Linearities and Boiler Dynamics", ICGST-ACSE Journal, Vol.8, No.3, pp.1539-1545, 2009.
[4]. E. Rakhshani, J.Sadeh, "Load Frequency Control of multi-area restructured power system", IEEE POWER INDIA CONFERENCE & POWERCON, 2008.
[5]. Hossein Shayeghi Heidar Ali Shayanfar, Aref Jalili, "Multi stage fuzzy PID Load Frequency Controller in a restructured power system", Journal of Electrical Engineering, Vol.58, No.2, pp. 61-70, 2007.
[6]. I.A.Chidambaram and S.Velusami, "Decentralized Biased Controllers for Load-Frequency control of Interconnected Power Systems Considering Governor Dead Band Non-Linearity", IEEE INDICON Conference, pp.521-525, 2005.
[7]. Demiroren A, Yesil E, "Automatic Generation Control with Fuzzy Logic Controllers in the Power System including SMES units", Electrical Power and Energy Systems, Vol.26, No.1, pp. 291–305, 2004.
[8]. Tripathy SC, Balasubramanian R, Chanramohanan Nair PS, "Effect of Superconducting Magnetic Energy Storage on Automatic Generation Control considering governor dead band and boiler dynamics", IEEE Transaction on Power Systems, Vol.7, No.3, pp.1266–73, 1992.
[9]. Banerjee S, Chatterjee JK, Tripathy SC, "Application of Magnetic Energy Storage unit as Load-Frequency stabilizer", IEEE Transaction on Energy Conversion, Vol.5, No.1, pp. 46–51, 1990.

BIOGRAPHIES

V. Rajaguru received B. E. degree in Electrical and Electronics Engineering in 2006 from Annamalai University, India, and M.E degree in Power Systems Engineering in 2009 from Annamalai University, India. He is currently working as a Lecturer in Electrical and Computer Science Engineering Department at Debre Berhan University, Debre Berhan, Ethiopia.

R. Sathya received B. E. degree in Electrical and Electronics Engineering in 2006 from Annamalai University, India, and M.E degree in Power Systems Engineering in 2009 from Annamalai University, India. She is currently working as a Assistant Professor in Krishnasamy College of Engg & Tech., Cuddalore,TamilNadu, India.

V. Shanmugam received B. E. degree in Electrical and Electronics Engineering in 2001 from Annamalai University, India, and M.E degree in Power Systems Engineering in 2009 from Annamalai University, India. He is currently working as a Assistant Professor in Krishnasamy College of Engg & Tech., Cuddalore,TamilNadu, India.