Application of energy storage units in an interconnected hydro power system

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ABSTRACT

The main objective of Automatic Generation Control (AGC) is to balance the total system generation against system load and losses so that the desired frequency and power interchange with neighbouring systems are maintained. Any mismatch between generation and demand causes the system frequency to deviate from its nominal value. Thus the high frequency deviation may lead to system collapse. Therefore, it is necessary to include the active controller as Superconducting Magnetic Energy Storage Units (SMES) to maintain the nominal system frequency. This paper presents the application of energy storage units in an interconnected two area hydropower system. The proposed work consist of two area interconnected hydro power system with Superconducting Magnetic Energy Storage units has been designed to improve the dynamic performance of the system and also Integral Square Error (ISE) technique is used to obtain the optimal integral gain settings. The simulation result shows that the Load Frequency Control in an interconnected hydro power system with SMES units is considerably improved the system dynamics such as peak overshoot, settling time and frequency oscillation as compared to that of the system without SMES units. The system simulation realized by using MATLAB software.

Key words: *Automatic Generation Control, Load Frequency Control, Energy Storage Units, SMES unit, System dynamics, Hydro Power System.*
DOI: http://dx.doi.org/10.4314/ejst.v8i1.5

INTRODUCTION

Automatic Generation Control (AGC) or Load Frequency Control (LFC) is a very important factor in power system operation and control for supplying sufficient and reliable electrical power to consumer with good quality. Controlling the frequency has always been a major subject in electrical power system operation and is becoming much more significant recently with increasing size, changing structure and complexity in interconnected power systems. Each control area of interconnected power system must meet its own demand and its scheduled power interchange to maintain the power balance between the generation and the demand. If the power balance does not exist, then it will leads to frequency deviation which will cause unnecessary disturbances in the power system. A lot of research works has been made in this area and some of them are as follows.

A fuzzy logic controller for AGC in an interconnected thermal power system including SMES units has been studied (Demiroren and Yesil, 2004). Real time simulation of AGC for interconnected power system is presented and a new control strategy for digital controller is developed (Naimul Hasan *et al*., 2012). PI controller design using Maximum Peak Resonance Specification (MPRS) has been implemented to maintain frequency and the power interchange and also proved that effective and efficient method to control the overshoot, settling time and maintain the stability of the system (Prajod and Carolin, 2013). Effect of SMES unit in a restructured power system considering GDB non-linearity is examined (Rajaguru *et al*., 2015). A simulation model for load frequency control in an interconnected hydro power systems using fuzzy PID controller is presented and proved

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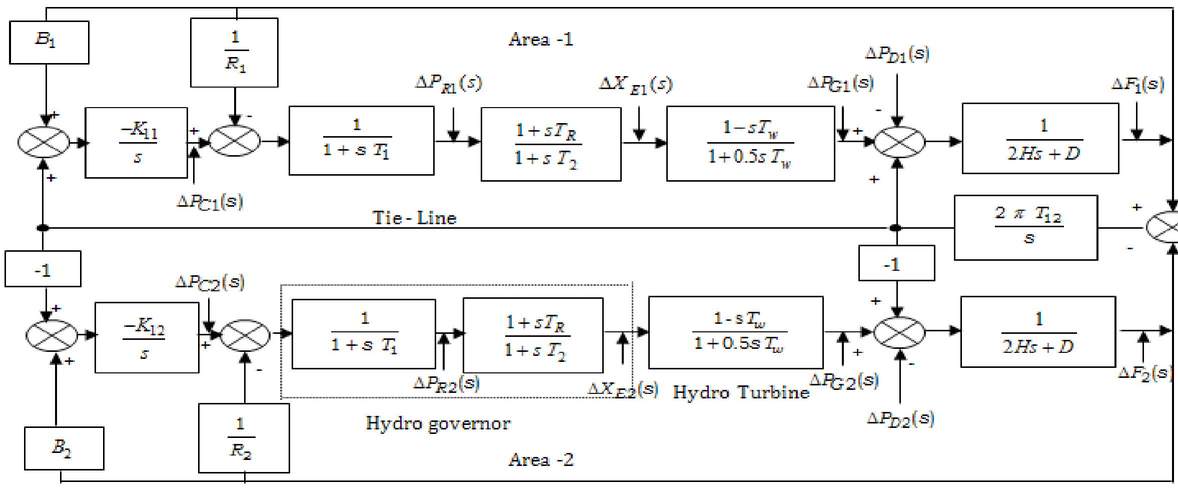

Figure1. Transfer Function Model of two area interconnected hydro-hydro power system

that fuzzy logic controller yields better control performance (Ramanand and Sankeswari, 2014). Load frequency control in an interconnected two area hydro-hydro system has been studied (Ramanand *et al*., 2013). Automatic Generation Control (AGC) of an interconnected four area hydro-thermal system using Superconducting Magnetic Energy Storage (SMES) unit is examined (Ruby meena and Senthilkuma, 2014). Implementation of load following in multi-area hydro thermal system under restructured environment is investigated (Suresh *et al*., 2012). 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 (Tripathy *et al*., 1992).

Even in the existence of controllers (such as Integral controller, Proportional Integral controller and Proportional Integral Derivative controller), the governor not able to correct the frequency variations quickly. Therefore, now a day's along with this conventional controller we incorporate active controllers like SMES units for better control.Wecan use optimization tools (such as Fuzzy Logic, Genetic Algorithm, Particle Swarm Optimization, etc.,) for further improvement in the dynamic performance of the system.

MODEL OF TWO AREA INTER-CONNECTED HYDRO–HYDRO POWER SYSTEM

A two area system consists of two single area systems, Connected through a power line called tie-line, is shown in the Figure1. Each area feeds itsuser pool, and the tie line allows electric power to flow between the areas. Information about the local area is found in the tie line power fluctuations. It is conveniently assumed that each control area can be represented by and equivalent turbine, generator and governor system. Figure 1, shows the block diagram representing the two area interconnected hydro power system. This model includes the conventional integral controller gains (K_{11}, K_{12}). Each power area has a number of generators which are closely coupled together so as to form a coherent group. Such a coherent area is called a control area in which the frequency is assumed to be same.

SMES UNIT

The Figure2, 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.

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 modula-

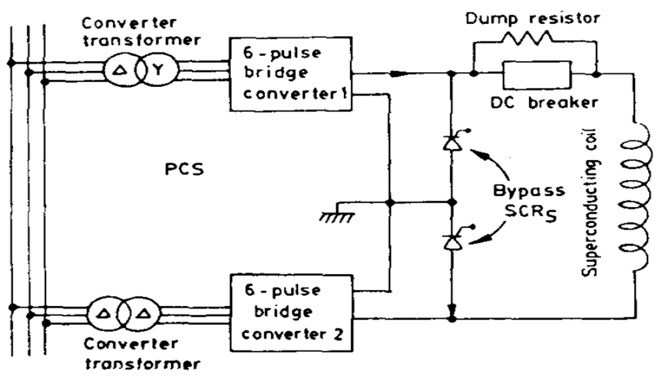

Figure 2. Configuration of SMES unit

tion 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

$$Ed = 2Vdo\cos\alpha - 2I_dR_c \qquad (1)$$

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,

$W_L = (½)(LI_d^2)$, MJ (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 deviationsapplied to the inductor and inductor current deviations are described as follows:

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

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

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 inSMES unit.

This value is assumed to be positive for transfer from AC grid to DC. Figure 3,shows the blockdiagram of SMES unit.

INTEGRAL CONTROLLER

The integral control composed of a frequency sensor and an integrator. The frequency sensor measures the frequency error (Δf) and this error signal is fed into the integrator. The input to the integrator is called Area Control Error (ACE). The ACE is the change in area frequency, which when used in an Integral-control loop, forces the steady-state frequency error to zero.

The ACE_i is defined as follows:

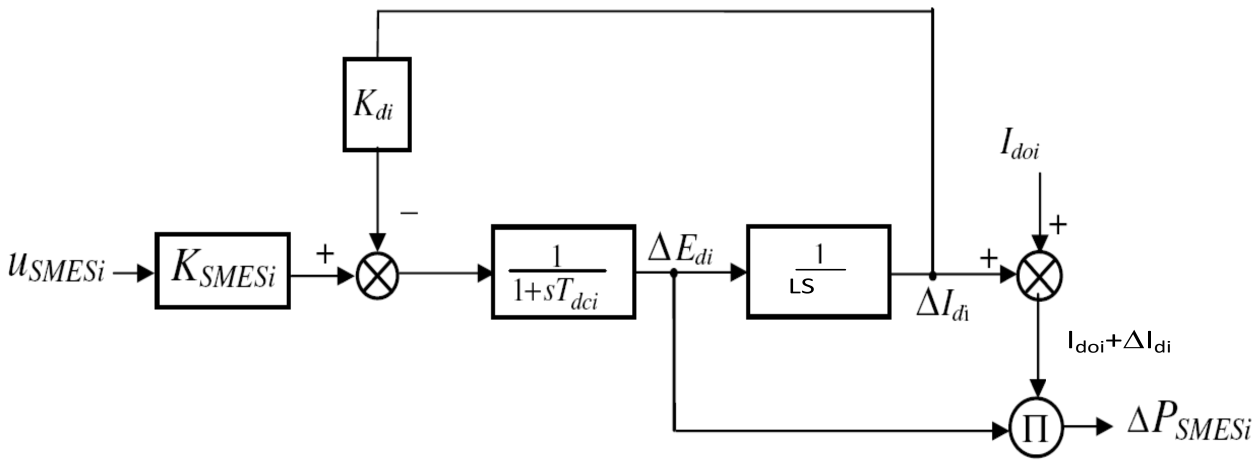

Figure 3. The block diagram of SMES unit

$ACE_i = B_i \Delta F_i + \Delta P_{tie,i}$ (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.

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

$\Delta PSMES_i = \Delta E_{di} I_{doi} + \Delta I_{di} \Delta E_{di}$ (6)

Where,

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

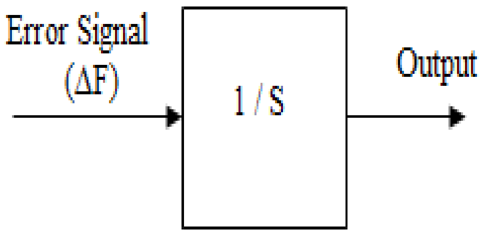

Figure 4. Mathematical model of Integral Controller

Figure 4,shows the mathematical model of integral controller.Here,' 1' can be called as integral gain (K_I). Thisgain can be optimized by several techniques suchas integral square error technique, singularfrequency technique, etc.,The integrator produces a real-power command signal ΔPc and is given by

$$\Delta P_c = -K_i \int \Delta f \, dt \qquad (7)$$

$$= -K_i \int ACE \, dt \qquad (8)$$

Where,

ΔPc = input of speed –changer

K_i = integral gain constant.

The value of K_i is so selected that the response will be damped and non-oscillator. Here, the integral controller gains K_I is determined by using Integral Square Error (ISE) criterion. The objective function used for this technique is

$$J = \int_0^t (\Delta F_1^2 + \Delta Ptie_1^2) dt \qquad (9)$$

Where,

ΔF_1 = change in frequency in area 1

ΔP_{tie} = change in tie-line power.

The optimum values of K_I are given in appendix.

RESULTS AND DISCUSSION

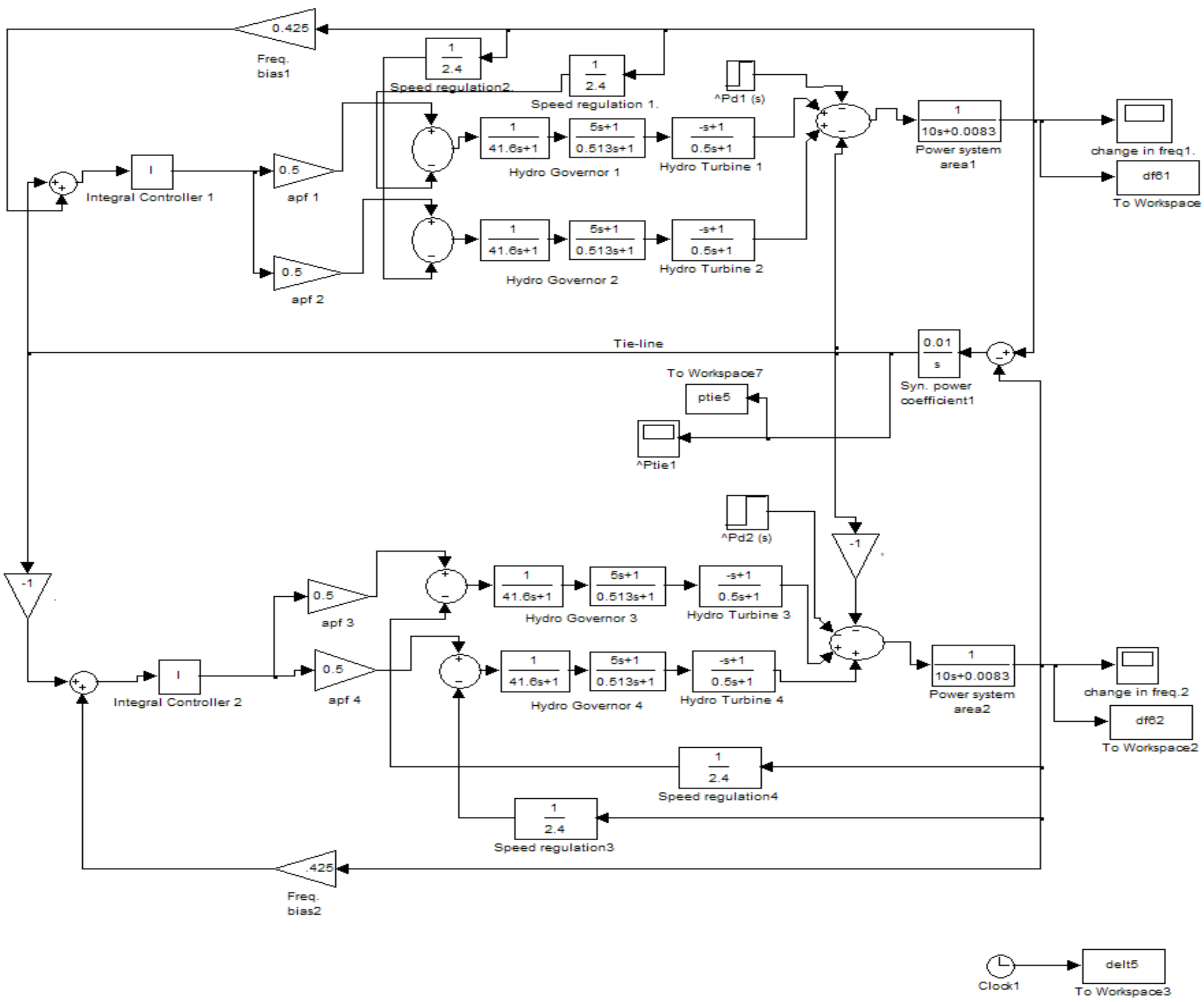

Figure5 (a). Load frequency control in an interconnected hydro – hydro power system without SMES units

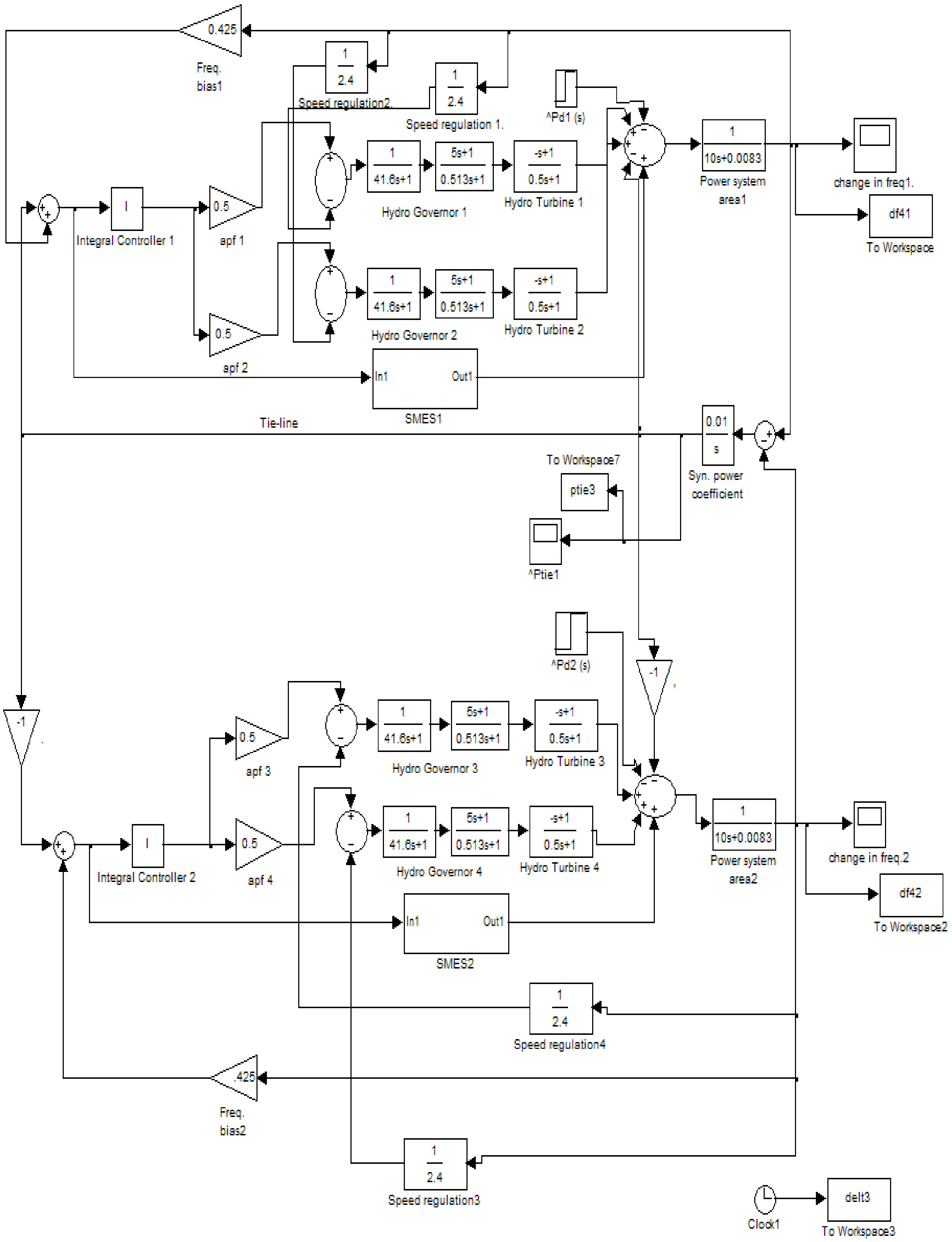

Figure 5 (b**).** Load frequency control in an interconnected hydro – hydro power system with SMES units

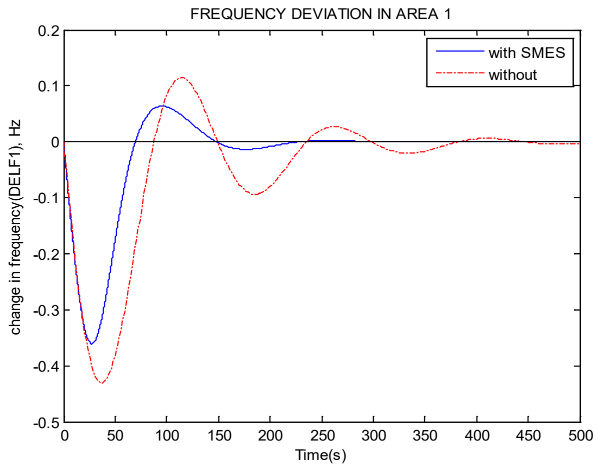

Figure 6(a). Frequency Response of Area-1

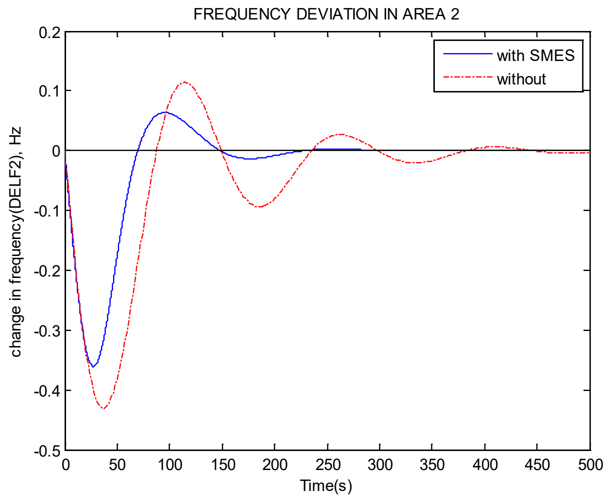

Figure 6(b). Frequency Response of Area-2

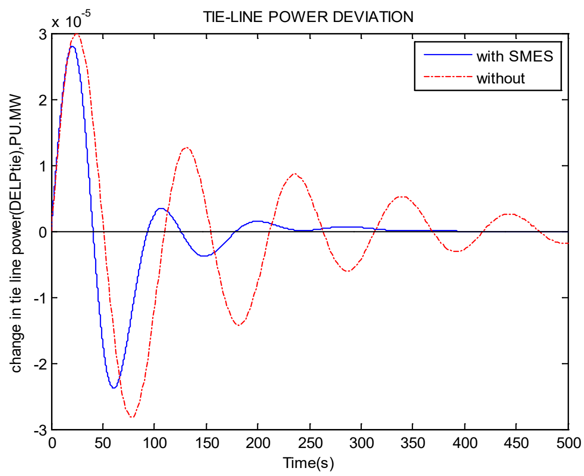

Figure 6 (c). Tie line power deviation of area-1 &2

The figure 5 (a & b), shows the simulation diagram of Automatic Generation Control or Load Frequency Control in an interconnected hydro – hydro power system with & without SMES unit.

Figure 6 (a, b, & c), shows the simulation results of two area inter-connected hydro - hydro power system with SMES unit and also for without SMES unit considering Integral controller. Figure 6 (a and b), shows the frequency response of area-1 (i.e. Δf_1) and area-2 (i.e. Δf_2) for the system with & without SMES unit. And the figure 6(c) shows the tie line power deviation (Δp_{tie}) for the system with and without the SMES units. Thus, from the Simulation Results, it is clear that the dynamic performance (such as frequency oscillation, peak overshoot and settling time) of the hydro power system is significantly improved than that of the system without SMES unit.

CONCLUSIONS

Automatic Generation Control provides a relatively simple, yet extremely effective method of adjusting generation to minimize frequency deviation and regulate the tie-line power flows. In this paper, application of energy storage units in an interconnected hydro power system is proposed. The power system model consists of identical hydro units (two units per area) with and without SMES units are considered for this study. In addition to this, Integral Square Error (ISE) technique is used to obtain the optimum conventional integral controller gains. The simulation results show that the dynamic performance of the system is significantly improved in terms of frequency oscillations, peak overshoot and settling time when the SMES units are included in a two area interconnected hydro – hydro power system.

ACKNOWLEDGEMENTS

The authors wish to thank the authorities of Debre Berhan University, Debre Berhan, Ethiopia for the facilities provided to prepare this paper and also we would like to thank all the faculty of Electrical and Computer Engineering department for his valuable suggestion and continuous support.

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APPENDIX

A.1 Data for the two-area interconnected hydro-hydro power system without SMES unit.

T1= 41.6 s, T_2 = 0.513 s, T_R = 5 s, T_W = 1 s, H = 5 sec, D = 8.33*10^{-3} Pu. MW/Hz, K_I=0.02, B = 0.425 Pu.MW/Hz, R = 2.4 Hz/Pu.MW.

A.2 Data for the two-area interconnected hydro-hydro power system with SMES unit.

T1= 41.6 s, T_2 = 0.513 s, T_R = 5 s, T_W = 1 s, H = 5 sec, D = 8.33*10^{-3} Pu. MW/Hz, K_I=0.04, B = 0.425 Pu.MW/Hz, R = 2.4 Hz/Pu.MW.

A.3 Data for SMES block

L =2.65 H, T_{dc}= 0.03 s, K_{SMES} = 70 KV/unit MW,

K_{di}= 0.2 KV/KA, I_{do} = 4.5KA.