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# Automatic Generation Control of Two Area Interconnected Hydro – Nuclear Power System with Superconducting Magnetic Energy Storage Units

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**Abstract:** This paper presents an Automatic Generation Control (AGC) of two area interconnected hydro – nuclear power system with Superconducting Magnetic Energy Storage (SMES) units. SMES unit is integrated to the AGC system to improve the dynamic performance of the system. Integral Square Error (ISE) technique is used to obtain the optimal integral gain settings. The proposed system is simulated by MATLAB / SIMULINK software. The simulation result shows that the hydro – nuclear power system with SMES units yields a better dynamic performance in terms of system oscillations, peak overshoot and settling time.

**Key words:** Automatic Generation Control · Hydro – Nuclear Power System · Integral Square Error Technique · Superconducting Magnetic Energy Storage unit

## INTRODUCTION

Automatic Generation Control or Load Frequency Control (LFC) has been used for several years to meet the objective of maintaining the system frequency at nominal value and the net tie – line power interchange from different areas at their scheduled values. Generation in large interconnected power systems comprises of thermal, hydro, nuclear and gas power generation. The configuration of today's integrated power system becomes more complex due to these power plants with widely varying dynamic characteristics. Nuclear units owing to their maximum efficiency and controllability problem are usually kept at base load close to their maximum output with no participation in system's AGC. Gas power plants are ideal for AGC, but these plants form a very small percentage of total system generation. Thus, the natural choice of AGC falls either on thermal or on hydro units. But with integration of nuclear power plant in the power system, it is also required to study the behavior of AGC for the interconnected power system considering nuclear power plant. A lot of research work has been made in this area are as follows.

Automatic Generation Control (AGC) of an interconnected four area hydro-thermal system using Superconducting Magnetic Energy Storage (SMES) unit is examined [1]. A simulation model for load frequency control in an interconnected hydro power system using fuzzy PID controller is presented and proved that fuzzy logic controller yields better control performance [2]. Particle Swarm Optimization (PSO) based PI – controller is designed for load frequency control of a two area interconnected power system and proved that PSO based PI – controller yields better dynamic performance than that of fuzzy based PI – controller [3]. 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 [4]. Load frequency control of interconnected hydro power system is investigated by considering fuzzy PI – controller [5]. A robust distributed model predictive control scheme for load frequency control of interconnected power system is designed [6]. Implementation of load following in multi-area hydro thermal system under restructured environment is investigated [7]. Real time simulation of AGC for interconnected hydro - nuclear power system is presented [8]. 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 [9]. Coordinated control of SMES system in automatic generation control of an interconnected two area multi-source power generation system is presented [10].

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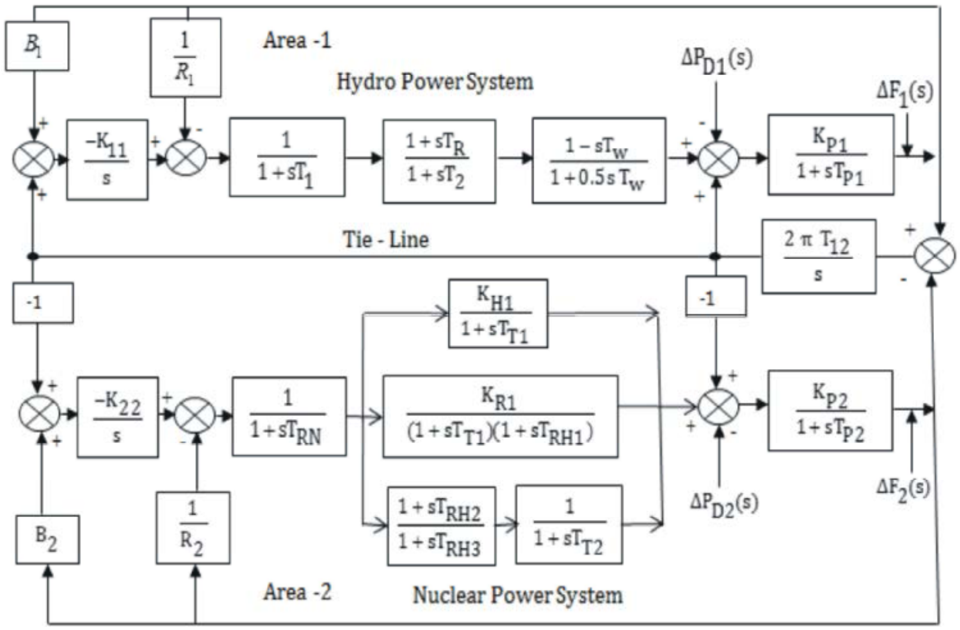


Fig. 1: Transfer function model of two area interconnected hydro – nuclear power system

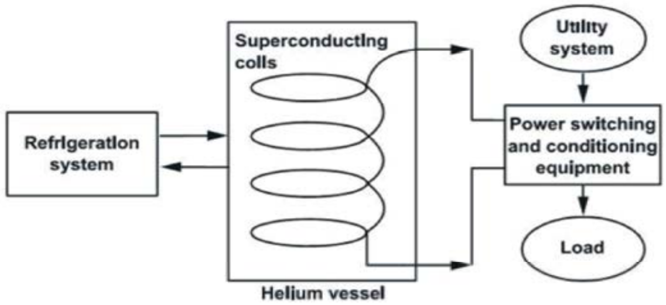


Fig. 2: Block diagram of SMES unit

**Transfer Function Model of Two Area Interconnected Hydro - Nuclear Power System:** A two area system consists of two single area systems, connected through a power line called tie-line, is shown in the Fig. 1. Each area feeds its user pool and the tie line allows electric power to flow between the areas. It is conveniently assumed that each control area can be represented by an equivalent turbine, generator and governor system. Fig.1 shows the transfer function model of two area interconnected hydro – nuclear power system with conventional integral controller. 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:** An SMES unit consists of a large superconducting coil at the cryogenic temperature. Fig. 2 represents the block diagram of the SMES unit. The superconducting coil is maintained at cryogenic temperature. This temperature is maintained by a cryostat or dewar that contains helium or nitrogen liquid vessels. A power conversion/conditioning system connects the SMES unit to an AC power system and it is used to charge/discharge the coil.

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;

$$E_d = 2V_{do}Cos_\alpha - 21_d R_c \quad (1)$$

where,
$E_d$ = DC voltage applied to the inductor (KV)
$\alpha$ = firing angle (degree)
$I_d$ = current through the inductor (KA)
$R_c$ = equivalent commutating resistance ($\Omega$)
$V_{do}$ = maximum open circuit bridge voltage of each six-pulse convertor at $\alpha$=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,

$$W_L = \frac{1}{2}(LI_d^2), MJ \quad (2)$$

where,
L = inductance of SMES, in Henry
$I_d$ = current through the inductor (KA).

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:

$$\text{X}E_{di}(S) = \frac{K_{SMES}}{1+ST_{dci}}U_{SMESi}(S) - \frac{K_{id}}{1+ST_{dci}}\Delta I_{di}(S) \quad (3)$$

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

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

The $ACE_i$ is defined as follows:

$$ACE_i = B_i\, \Delta F_i + \Delta p_{tie}, i \quad (5)$$

where,
$B_i$ = Frequency bias in area i
$\Delta F_i$ = 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:

$$\Delta P_{SMESi} = \Delta e_{di}\, I_{doi} + \Delta i_{di}\, \Delta E_{di} \quad (6)$$

where,
$\Delta P_{SMESi}$ = 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. 3 shows the mathematical model of SMES unit.

**Integral Controller:** The integral control composed of a frequency sensor and an integrator. The frequency sensor measures the frequency error $\Delta$f 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 integrator produces a real-power command signal $\Delta$Pc and is given by

$$\Delta p_c = -K_i\, \Delta f dt \quad (7)$$

$$= -K_i\, ACEdt \quad (8)$$

where,
$\Delta$Pc = 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.

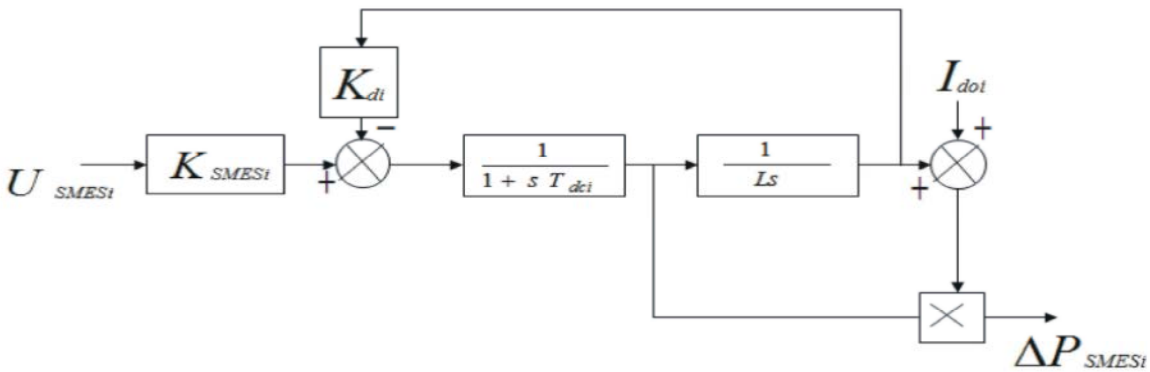


Fig. 3: Mathematical Model of SMES unit

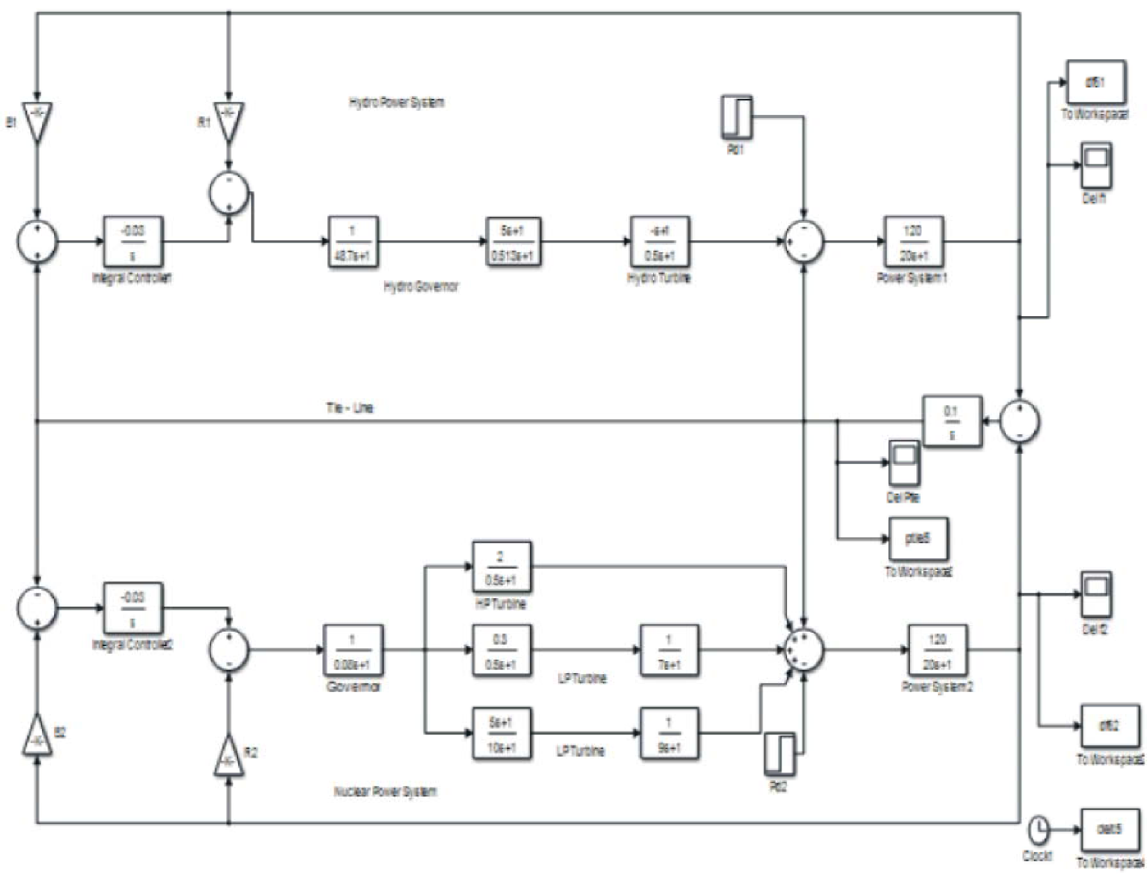


Fig. 4(a): Automatic Generation Control of Two Area Interconnected Hydro – Nuclear Power System without SMES Units

For conventional Integral controller, the gains $K_I$ have to be determined by using Integral Square Error (ISE) criterion. The objective function used for this technique is;

$$J = \int_0^t (\Delta_{F1}{}^2 + \Delta Ptie_1^2)dt \qquad (9)$$

where,

$\Delta f_1$= change in frequency in area 1

$\Delta P_{tie}$ = change in tie-line power.

The optimum values of $K_I$ are given in appendix

**Simulation Model and Results:** The Fig. 4(a&b) shows the simulation diagram of Automatic Generation Control of two area interconnected hydro – nuclear power system with & without SMES unit.

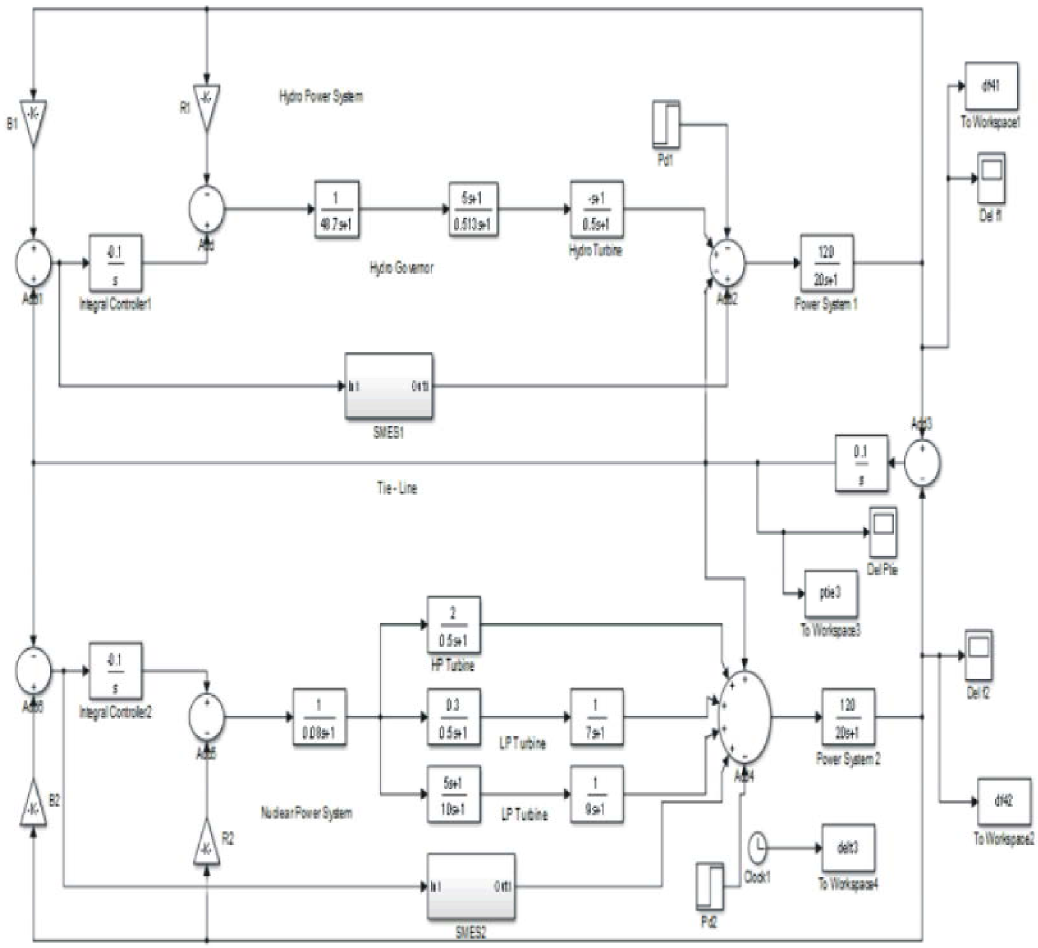


Fig. 4(b): Automatic Generation Control of Two Area Interconnected Hydro – Nuclear Power System with SMES Units

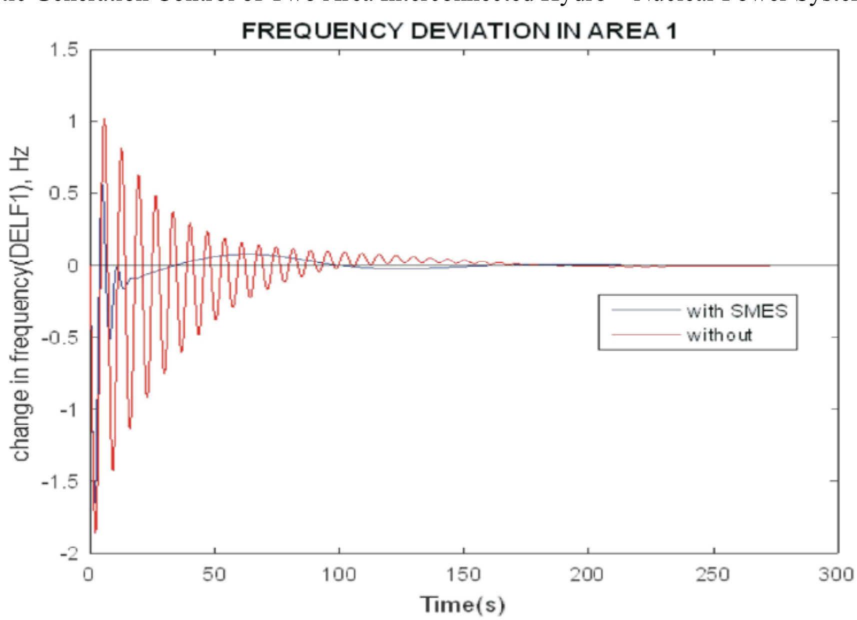


Fig. 5(a): Frequency Response of Area-1 ($\Delta f_1$)

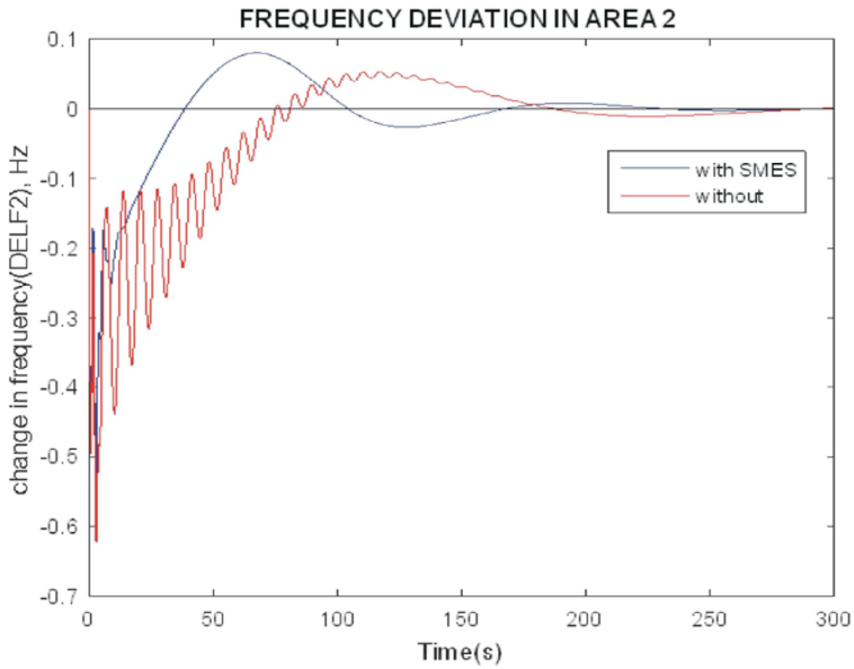


Fig. 5(b): Frequency Response of Area-2 ($\Delta f_2$)

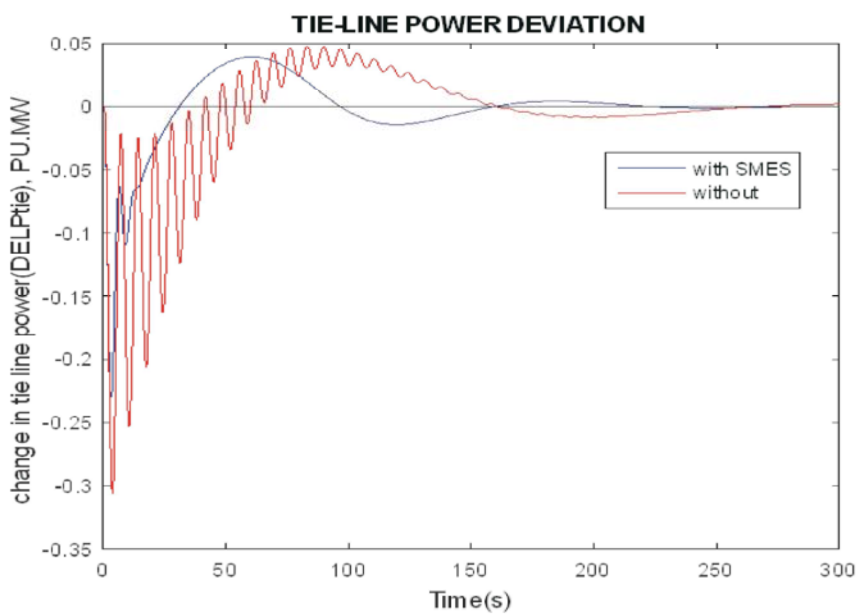


Fig. 5(c): Tie line power deviation of area-1 & area-2 ($\Delta p_{tie\ 1,\ 2}$)

Fig. 5(a, b, & c) shows the simulation results of two area interconnected hydro - nuclear power system with SMES unit and also for without SMES unit considering Integral controller. Fig. 5(a & b) shows the frequency response of area-1 (i.e. $\Delta f_1$) and area-2 (i.e. $\Delta f_2$) for the system with & without SMES unit. And the Fig. 5 (c) shows the tie line power deviation ($\Delta p_{tie}$) for the system with and without SMES units. Thus, from the Simulation Results, we say that the dynamic performance (such as frequency oscillations, peak overshoot and settling time) of the hydro - nuclear power system is significantly improved when the SMES units are incorporated in a system.

## CONCLUSION

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, AGC of two area interconnected hydro - nuclear power system with SMES unit is investigated. The power system model consists of hydro - nuclear units with SMES units and without SMES units are considered for this study and the system performance are observed for 1% step load disturbance. In addition to this, Integral Square Error technique is used to obtain the conventional integral controller gains. The simulation results show that the dynamic performance of the system (such as frequency oscillations, peak overshoot and settling time) is significantly improved when the SMES units are incorporated in a two area interconnected hydro – nuclear power system.

## APPENDIX

*A.1 System Data*

$P_{r1} = P_{r2}$ = 2000MW
$T_1$ = 48.7 sec
$T_R$ = 5 sec
$T_2$ = 0.513 sec
$T_W$ = 1 sec
$K_{P1} = K_{P2}$ = 120 Hz/Pu.MW
$T_{P1} = T_{P2}$ = 20 sec
$B_1 = B_2$ = 0.425 Pu.MW/Hz
$R_1 = R_2$ = 2.4 Hz/Pu.MW, $K_I$=0.009
$T_{RN}$ = 0.08 sec
$K_{H1} = K_{R1}$ = 2; 0.3
$T_{T1} = T_{T2}$ = 0.5 sec; 9 sec
$T_{RH1} = T_{RH2} = T_{RH3}$ = 7 sec; 5 sec; 10 sec
$K_I$ (With and without SMES unit) = 0.1; 0.03

*A.2 Data for SMES block*

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.

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