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*Research Article*

# Load Frequency Control in an Interconnected Hydro–Hydro Power System with Superconducting Magnetic Energy Storage Units

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***Abstract***

*In the power system, any sudden change in the load leads to deviation in frequency and tie-line power flow. So, Load Frequency Control (LFC) is an important issue in power system operation and control. This paper deals with the Load Frequency Control in an interconnected two area hydro-power system with Superconducting Magnetic Energy Storage (SMES) units, to stabilize the system frequency oscillations. Assumed that all the areas in a system are operate at same frequency because the traditional approach for interconnection of hydro systems turned out to be unsuccessful. The proposed work consist of two area interconnected hydro-hydro power system with SMES 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 hydro power system with SMES units yields a better dynamic performance in terms of system oscillations, peak overshoot and settling time.*

***Keywords:*** *Load Frequency Control; Hydro power system; Interconnected Power System; Integral Square Error Technique; Superconducting Magnetic Energy Storage (SMES) unit; Energy Storage Units.*

## 1. Introduction

The power system composed of several interconnected control areas, any sudden changes in the load causes frequency deviations. So load frequency control plays an important role in the interconnected power system for supplying reliable and good quality of power supply. In a hydro power system, the frequency regulation can also be affected due to water flow fluctuation. This leads to imbalance between power generation and power demand. As a result, frequency will deviate from its nominal value. Maintaining frequency and power interchanges with interconnected control areas at the scheduled values are the main task of a load frequency control.A lot of research work has been made in this area are as follows.

A simulation model for load frequency control in an interconnected hydro power systems using fuzzy PID controller is presented and proved that fuzzy logic controller yields better control performance (Ramanand, 2014). Automatic Generation Control (AGC) of an interconnected four area hydro-thermal system using Superconducting Magnetic Energy Storage (SMES) unit is examined (A. Ruby meena, 2014). 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.V.S, 2013). Load frequency control in an interconnected two area hydro-hydro system has been studied (Ramanand, 2013).

Real time simulation of AGC for interconnected power system is presented and a new control strategy for digital controller is developed (Naimul Hasan, 2012). Implementation of load following in multi-area hydro thermal system under restructured environment is investigated (A. Suresh Babu, 2012). A fuzzy logic controller for AGC in an interconnected thermal power system including SMES units has been studied (Demiroren A, 2004). 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 SC, 1992). 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 (Banerjee S, 1990).

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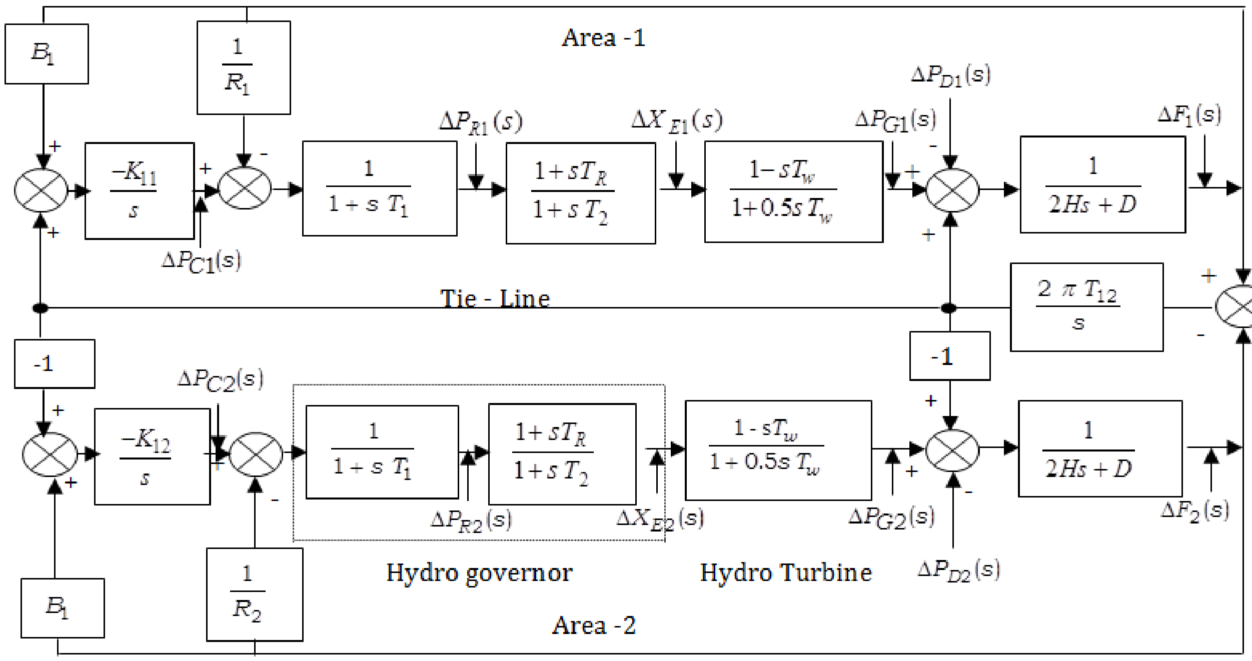


**Fig.1** Transfer Function Model of two area interconnected hydro-hydro power system

## 2. Mathematical Model of Two Area Interconnected 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 Fig.1. Each area feeds its user 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. Fig.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.

## 3. SMES Model

The Fig.2 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 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.

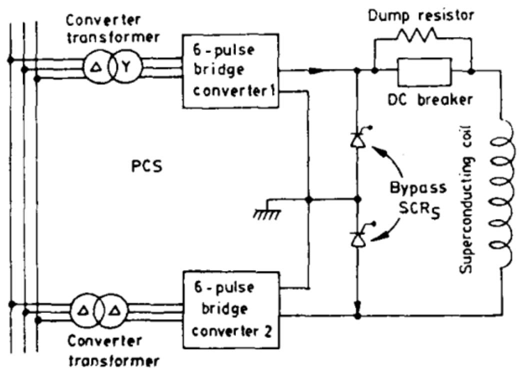


**Fig.2** Configuration of SMES unit

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

$$E_d = 2V_{do}\text{Cos}\alpha - 2I_d R_c \quad (1)$$

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 (Ω)
$V_{do}$= 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,

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

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:

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

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

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

The $ACE_i$ is defined as follows:

$$ACE_i = B_i \Delta F_i + \Delta P_{tie,i} \tag{5}$$

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.

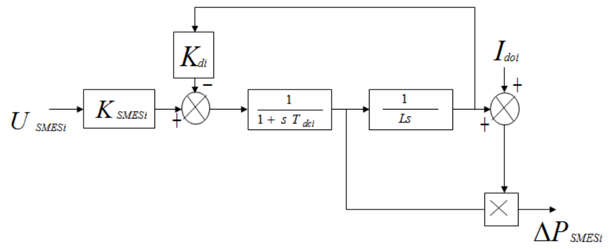


**Fig.3** Block diagram of SMES unit

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

$$\Delta P_{SMES,i} = \Delta E_{di} I_{doi} + \Delta I_{di} \Delta E_{di} \tag{6}$$

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 block diagram of SMES unit.

## 4. 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 integrator produces a real-power command signal $\Delta P_c$ and is given by

$$\Delta P_c = -K_i \Delta f\, dt \tag{7}$$
$$= -K_i ACE\, dt \tag{8}$$

Where,

$\Delta P_c$ = 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. 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

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

Where,

$\Delta f_1$= change in frequency in area 1
$\Delta P_{tie}$ = change in tie-line power

The optimum values of KI are given in appendix.

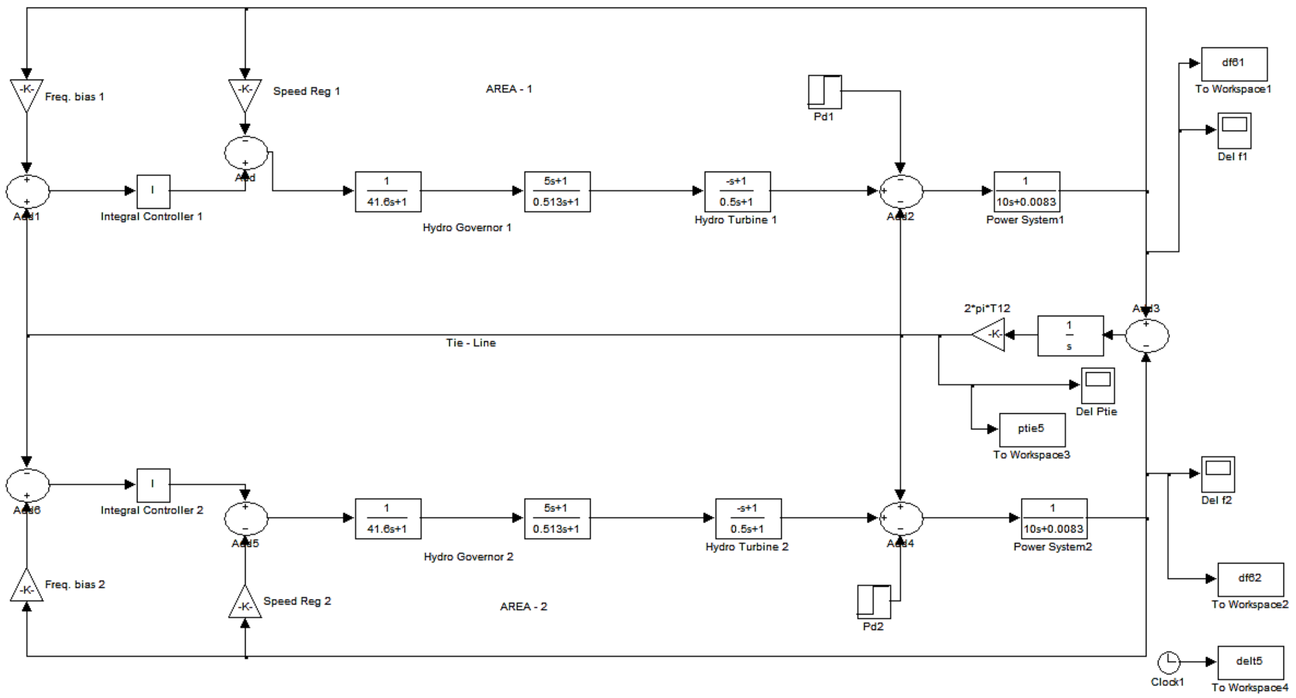


**Fig.4** (a) Load frequency control in an interconnected hydro – hydro power system without SMES units

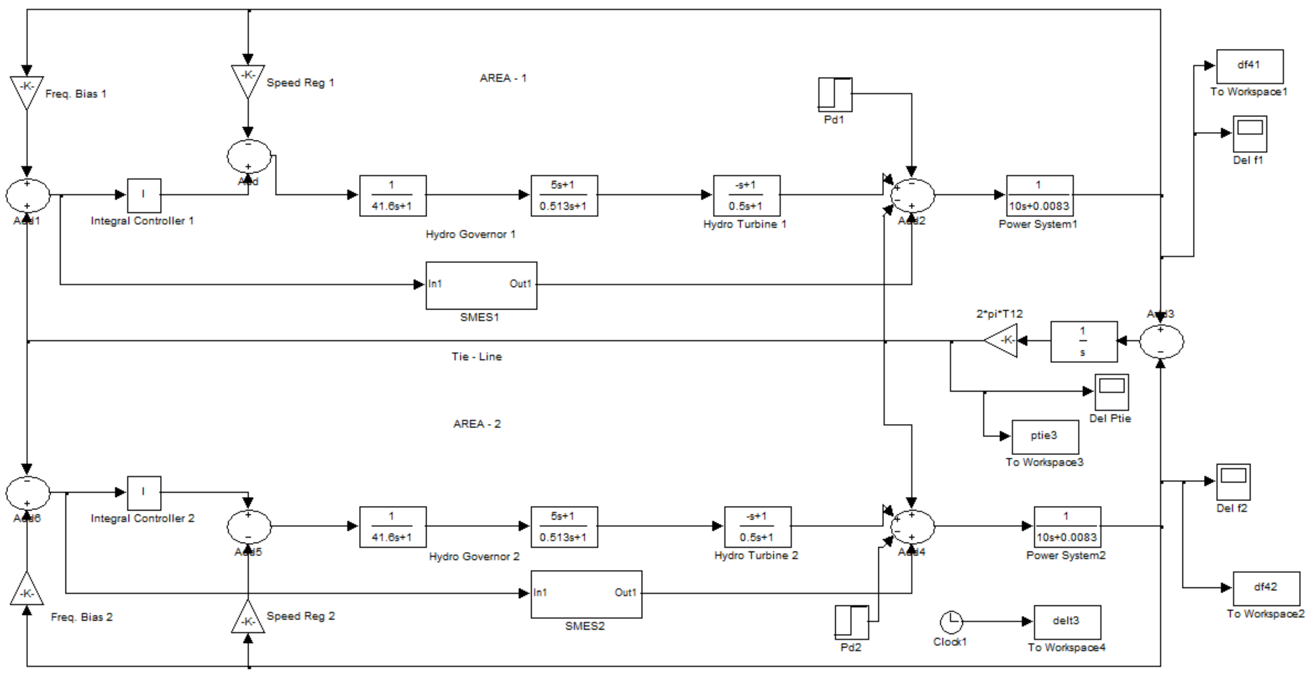


**Fig.4 (b)** Load frequency control in an interconnected hydro – hydro power system with SMES units

## 5. Simulation Model and Results

The fig.4 (a & b) shows the simulation diagram of Load Frequency Control in an interconnected hydro – hydro power system with & without SMES unit.

Fig .5(a, b, & c) shows the simulation results of two area interconnected hydro 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 the SMES units. Thus, from the Simulation Results, We say 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.

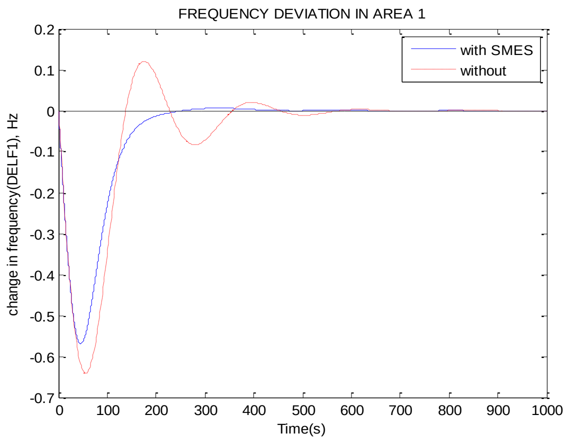


**Fig .5 (a)** Frequency Response of Area-1 ($\Delta f_1$)

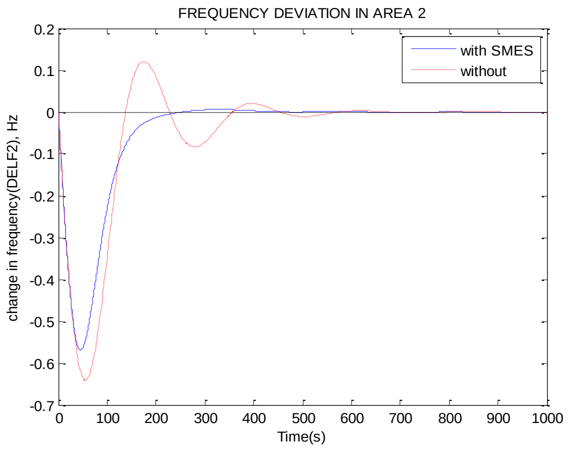


**Fig. 5 (b)** Frequency Response of Area-2 ($\Delta f_2$)

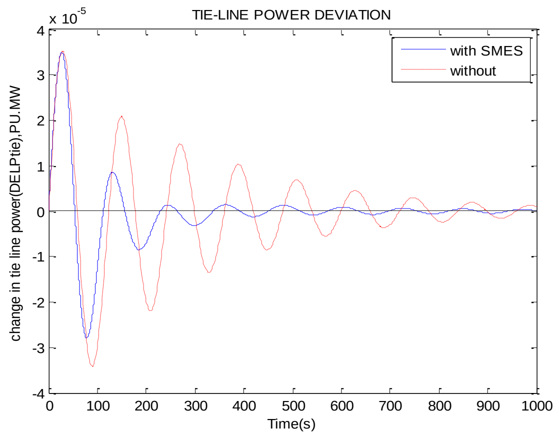


**Fig.5 (c)** Tie line power deviation of area-1 & area-2 ($\Delta p_{tie\ 1,2}$)

## Conclusions

In this paper, Load Frequency Control in an interconnected two area hydro-hydro power system with SMES unit is proposed. The power system model consists of identical hydro units with 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 – hydro power system.

## Appendix

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

$P_{r1} = P_{r2}$ = 2000MW, T1 = 41.6 sec, $T_2$ = 0.513 sec,
$T_R$ = 5 sec, $T_W$ = 1 sec, H = 5 sec, D = 8.33*$10^{-3}$ Pu. MW/Hz,
B = 0.425 Pu.MW/Hz, R = 2.4 Hz/Pu.MW, $K_I$=0.009.

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

$P_{r1} = P_{r2}$ = 2000MW, T1 = 41.6 sec, $T_2$ = 0.513 sec,
$T_R$ = 5 sec, $T_W$ = 1 sec, H = 5 sec, D = 8.33*$10^{-3}$ Pu. MW/Hz,
B = 0.425 Pu.MW/Hz, R = 2.4 Hz/Pu.MW, $K_I$=0.01.

A.3 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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