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Application of Energy Storage Units in Power System for Improving the System Dynamics

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Abstract: Load – Frequency Control (LFC) is one of the important topics in power system operation and control. Frequency should be constant for providing a reliable and quality power supply. This paper presents the application of energy storage units in power system. The proposed work consist of two area interconnected power system with Superconducting Magnetic Energy Storage (SMES) unit and Super Capacitor Energy Storage (SCES) unit has been designed to improve the dynamic performance of the system and 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 power system with SCES units are considerably improved in terms of peak overshoot, settling time and frequency oscillation as compared to that of the system without SCES units and SMES units.

Keywords: Energy Storage Units, SMES, SCES, Load Frequency Control, System Dynamics.

I. INTRODUCTION

Load – Frequency Control (LFC) plays a vital role in power system because its duty to maintain frequency and tie-line power flow within the specified limits. LFC has three main objectives are as follows,

1. Maintain a system frequency in its nominal value
2. Maintaining the tie-line power flow
3. Maintaining the generation in each unit within an economically suitable value.

A lot of studies have been performed in this area are as follows, The Dual Mode two layered fuzzy logic controller is not only effective in damping out the frequency oscillations, but also capable of alleviating the transient frequency swing caused by large load disturbance and moreover the proposed Dual Mode two layered fuzzy load frequency controller provides very good transient and steady state response when compared to the Dual Mode PI controllers [1]. The load frequency control for interconnected power system using different controllers has been proposed and the PID controller is reasonably good over the conventional controller [2]. The PSO controller is having improved dynamic response and at the same time faster than conventional PI controller [3].

The Design of Load Frequency Controllers for Interconnected Power Systems with Superconducting Magnetic Energy Storage Units using Bat Algorithm has been proposed and the performance of the Bat algorithm is analyzed [4]. An approach of fuzzy logic controller has been investigated for two area frequency control of power system and the proposed result shows the intelligent controller is having more improved dynamic response [5]. The real time simulation to analyze the behavior of discrete controller for interconnected power system is presented [6]. Automatic generation and energy storage using super conducting magnetism has been proposed. The incorporation of SMES and TCPS units with PI controller in reheat thermal system reduces settling time greatly as compared to TCPS unit, use of SMES unit reduces overshoot further with almost the same settling time [7].

The qualitative and quantitative comparison has been carried out for Integral, PID and ANN- PID controllers. The superiority of the performance of ANN over integral and PID controller is highlighted [8]. A literature study is carried out to have an over view of the advantages and drawbacks for these new energy storage systems (SMES and SCES) compared to the existing systems and to study their potential use in the distribution grid [9]. The responses of a two-area interconnected thermal power system with reheat and non reheat units have been studied considering generation rate constraints and integral gain settings have been optimized by Integral Squared Error (ISE) technique. It concluded that CES units are efficient and effective for improving the dynamic performance of AGC of interconnected power systems [10].

II. MATHEMATICAL MODEL OF TWO-AREA INTERCONNECTED POWER SYSTEM

A two area system consists of two single area systems, Connected through a power line called tie-line, is shown in the Figure 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. Therefore, the tie-line power is sensed, and the resulting tie-line power is fed back into both areas. It is conveniently assumed that each control area can be represented by and equivalent turbine, generator and governor system.

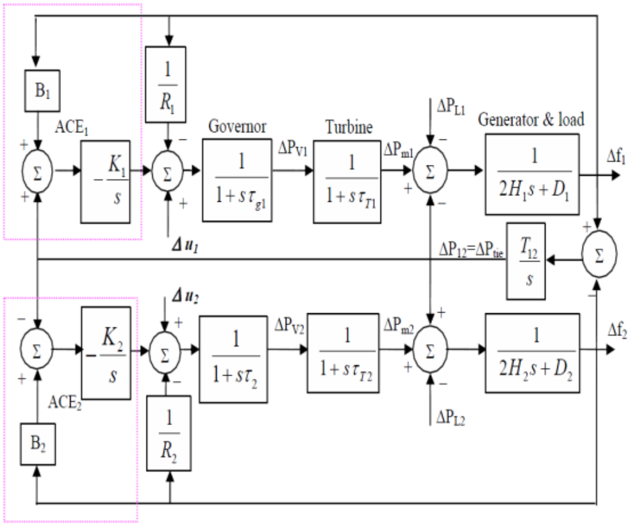


Fig1.Transfer Function Model of LFC in an inter-connected power system.

Fig.1 shows the block diagram representing the two area power system. This model includes the conventional integral controller gains (K_1 , K_2) and the two auxiliary (stabilizing) signals(Δu_1, Δu_2). Each power area has a number of generators which are closely coupled together so as to form a coherent group, i.e. all the generators respond in unison to changes in the load. Such a coherent area is called a control area in which the frequency is assumed to be the same throughout in static as well as dynamic situation there exists a maximum on the rate of change of power that can be generated by steam plants. The constraints of the nonlinear characteristics of the turbine control should be considered in the load frequency controller design. If these constraints are not considered in the controller design, the power area is likely to chase large monetary disturbance. Since a tie line transports power in or out of an area, this fact must be accounted for in the incremental power balance equation of each area.

III. 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 the 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 ΔPc and is given by

$$\Delta P_C = -K_I \Delta FDT \qquad (1)$$
$$= -K_i\, ACE\, dt$$

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

$$J_1 = \int_0^t (\Delta F_1^2 + \Delta Ptie_1^2)dt. \qquad (2)$$

Where, ΔF_1 → change in frequency in area 1.

ΔP_{tie} → change in tie line power.

IV. 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.

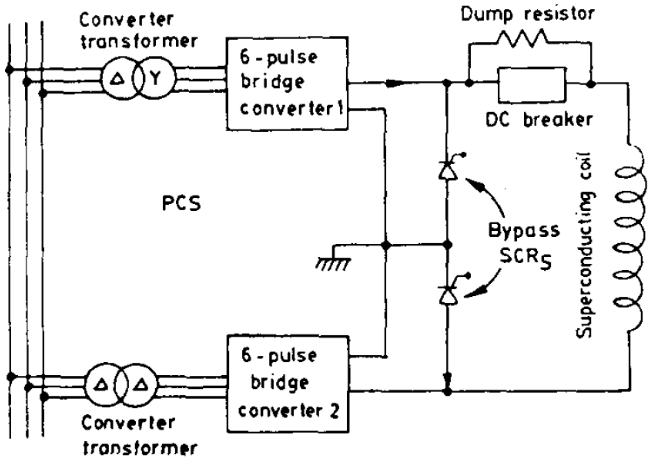


Fig.2 Configuration of SMES in the power system

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

$$\mathbf{E_D = 2V_{DO}COSA - 2I_DR_C} \qquad \textbf{(3)}$$

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 (KV) of each six pulse convertor at α=0 degree

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,

$$\mathbf{W_L = \quad (LI_d^2), MJ} \qquad \textbf{(4)}$$

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:

$$\Delta E_{di}(S) = \frac{K_{SMES}}{1+ST_{dci}} U_{SMESi}(S) - \frac{K_{id}}{1+ST_{dci}} \Delta I_{di}(S) \qquad \textbf{(5)}$$

$$\Delta I_{di}(S) = \frac{1}{sL_i} \Delta E_{di}(S) \qquad \textbf{(6)}$$

Where, ΔE_{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
ΔI_{di} (s) = inductor current deviation in SMES unit.

In this study, as in recent literature, the input signal to the SMES control logic is considered the ACE_i of the same area in power system [1]. The ACE_i is defined as follows:

$$\mathbf{ACE_i = B_i\Delta F_i + \Delta P_{tie,i}} \qquad \textbf{(7)}$$

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:

$$\mathbf{\Delta P_{SMES\ i} = \Delta E_{di}I_{doi} + \Delta I_{di}\Delta E_{di}} \qquad \textbf{(8)}$$

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. 3 shows the block diagram of SMES unit.

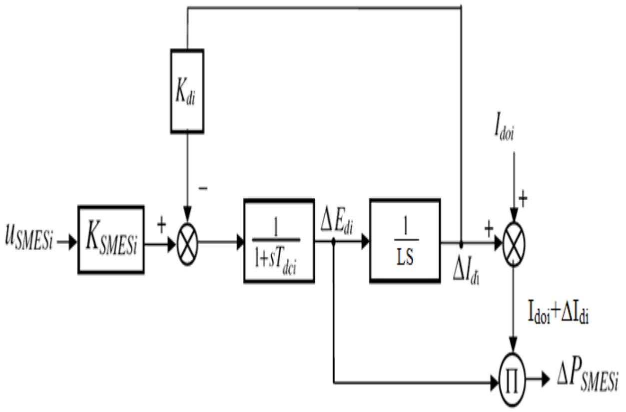


Fig.3. The block diagram of SMES unit

V. MODELLING OF SUPER CAPACITOR ENERGY STORAGE (SCES) UNIT

The block diagram of Super Capacitor Energy Storage (SCES) Unit is shown in Fig.4. Either frequency deviation or Area Control Error (ACE) can be used as the control signal to the SCES unit ($\Delta error_i = \Delta f_i$ or ACE_i). E_{di} is then continuously controlled in accordance with this control signal. For the ith area, if the frequency deviation Δf_i (i.e., $\Delta error_i = \Delta f_i$). Of the power system is used as the control signal to SCES, then the deviation in the current, ΔI_{di} is given by

$$\mathbf{\Delta I_{di} = \frac{1}{1+STDCi}[K_{SCES,i.}.\Delta f_i - K_{vdi.}\ .\Delta E_{di}]} \qquad \textbf{(9)}$$

If the tie-line power flow deviations can be sensed, then the Area Control Error (ACE) can be fed to the SCES as the control signal (i.e., $\Delta error_i = ACE_i$). Being a function of tie-line power deviations, ACE as the control signal to SCES, may further improve the tie-power oscillations.

Thus, ACE of the two areas are given by

$$\mathbf{ACE_i = B_i\Delta f_i + \Delta P_{tie\ ij}\ \ ; i, j = 1, 2} \qquad \textbf{(10)}$$

Where, $\Delta P_{tie\ ij}$ is the change in tie-line power flow out of area i to j.

Thus, if ACE_i is the control signal to the SCES, then the deviation in the current ΔI_{di} would be

$$\mathbf{\Delta Id_i = \frac{1}{1+STDCi}[K_{SCES,i.}.\Delta ACE_i - K_{vdi.}.\Delta E_{di}]; i, j = 1, 2} \qquad \textbf{(11)}$$

The control actions of Super Capacitor Energy Storage units are found to be superior to the action of the governor system in terms of the response speed against, the frequency fluctuations.

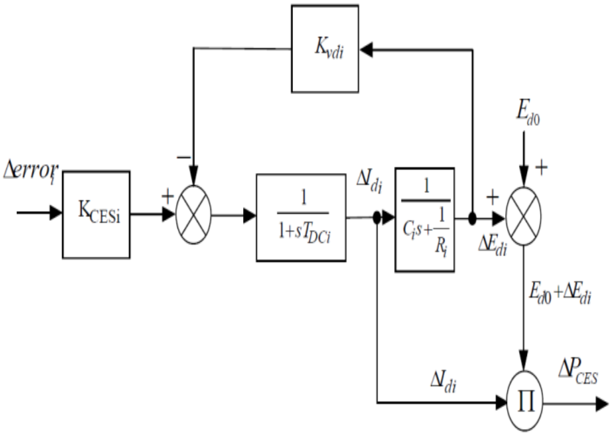
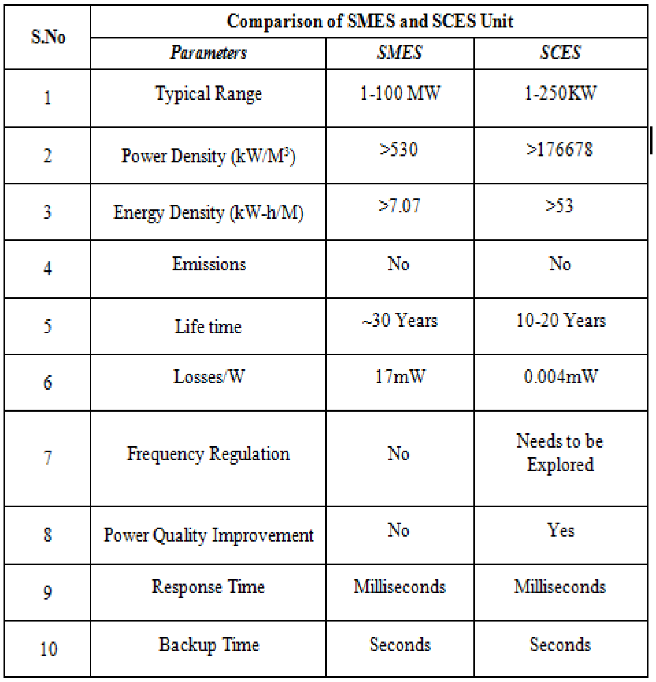


Fig4. Block diagram of SCES unit

VI. COMPARISON OF SMES AND SCES UNIT

The following table shows the comparison of various parameter of SMES & SCES unit.

TableI. Comparison of SMES and SCES unit



S.No	Comparison of SMES and SCES Unit		
	Parameters	*SMES*	*SCES*
1	Typical Range	1-100 MW	1-250KW
2	Power Density (kW/M^3)	>530	>176678
3	Energy Density (kW-h/M)	>7.07	>53
4	Emissions	No	No
5	Life time	~30 Years	10-20 Years
6	Losses/W	17mW	0.004mW
7	Frequency Regulation	No	Needs to be Explored
8	Power Quality Improvement	No	Yes
9	Response Time	Milliseconds	Milliseconds
10	Backup Time	Seconds	Seconds

VII. SIMULATION MODEL AND RESULTS

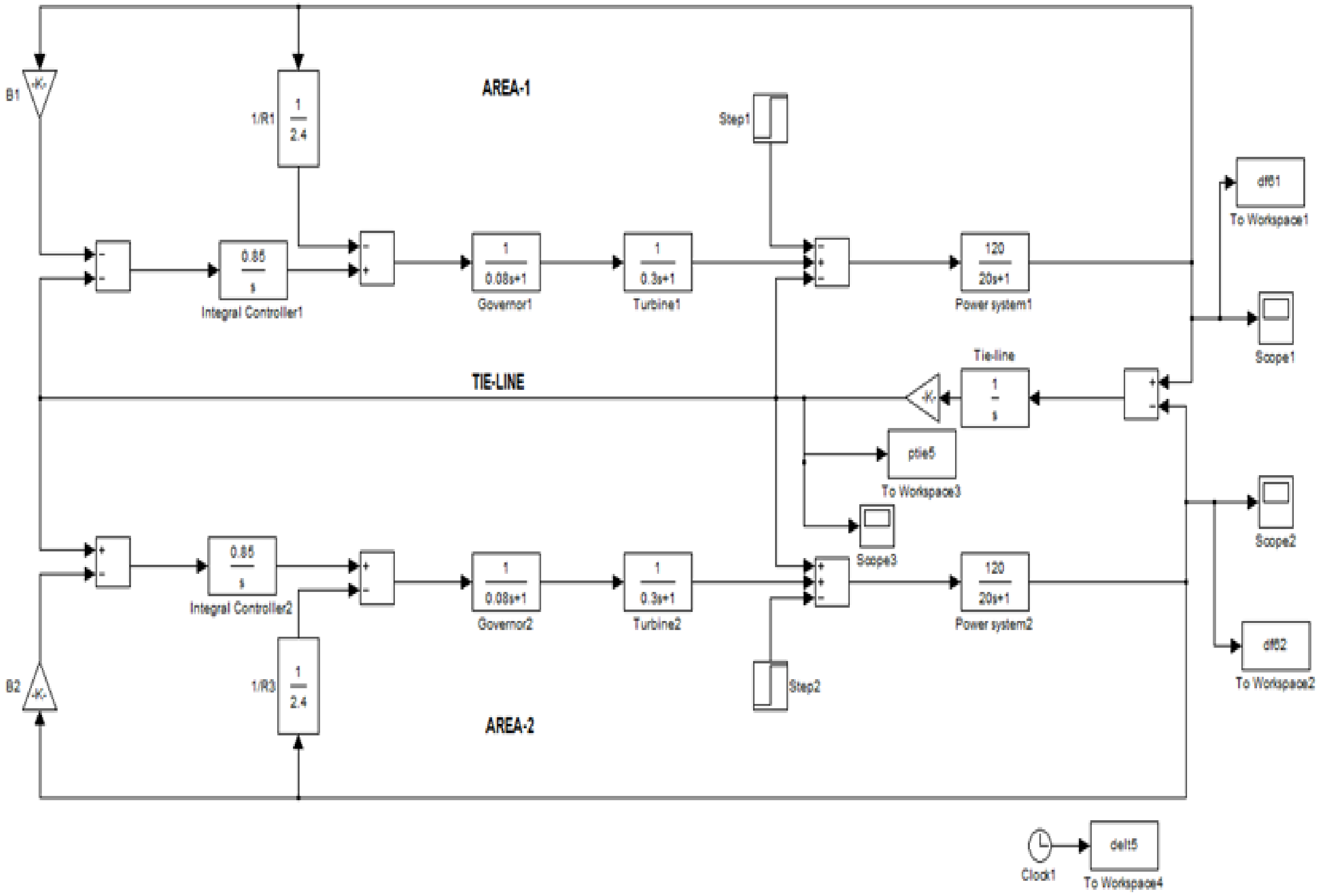


Fig5. (a) Load frequency control in an interconnected power system without SMES & SCES units.

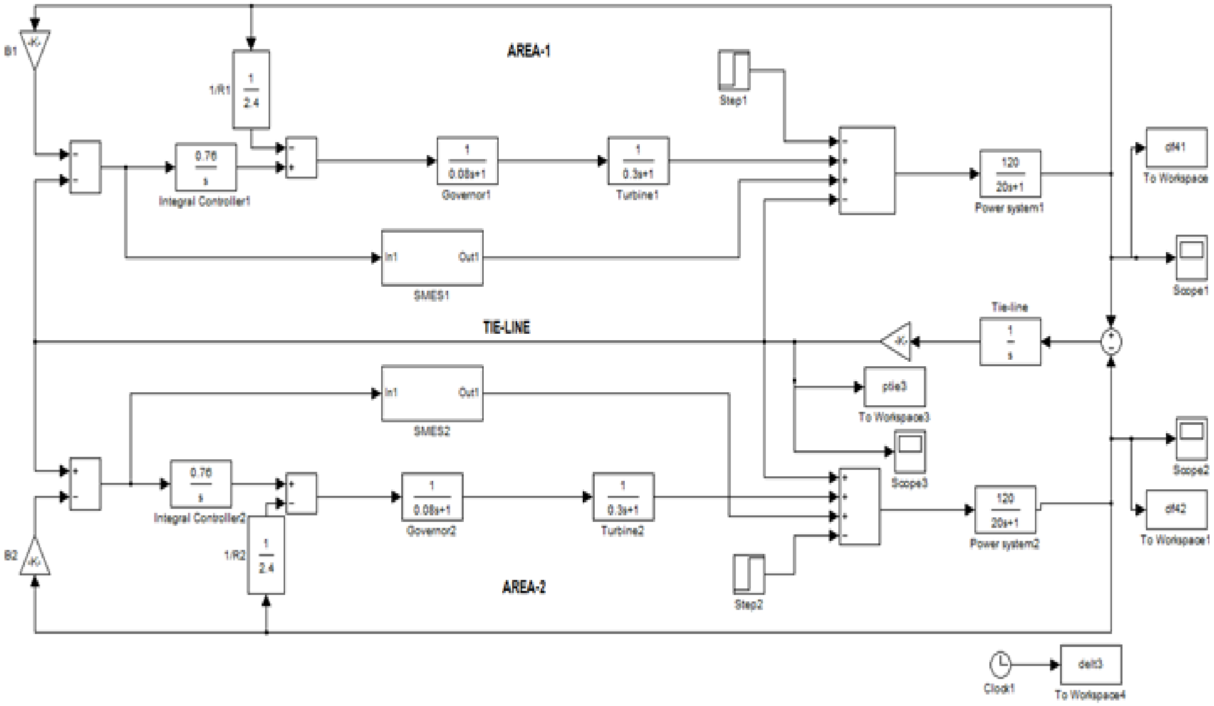


Fig.5 (b) Load frequency control in an interconnected power system with SMES units

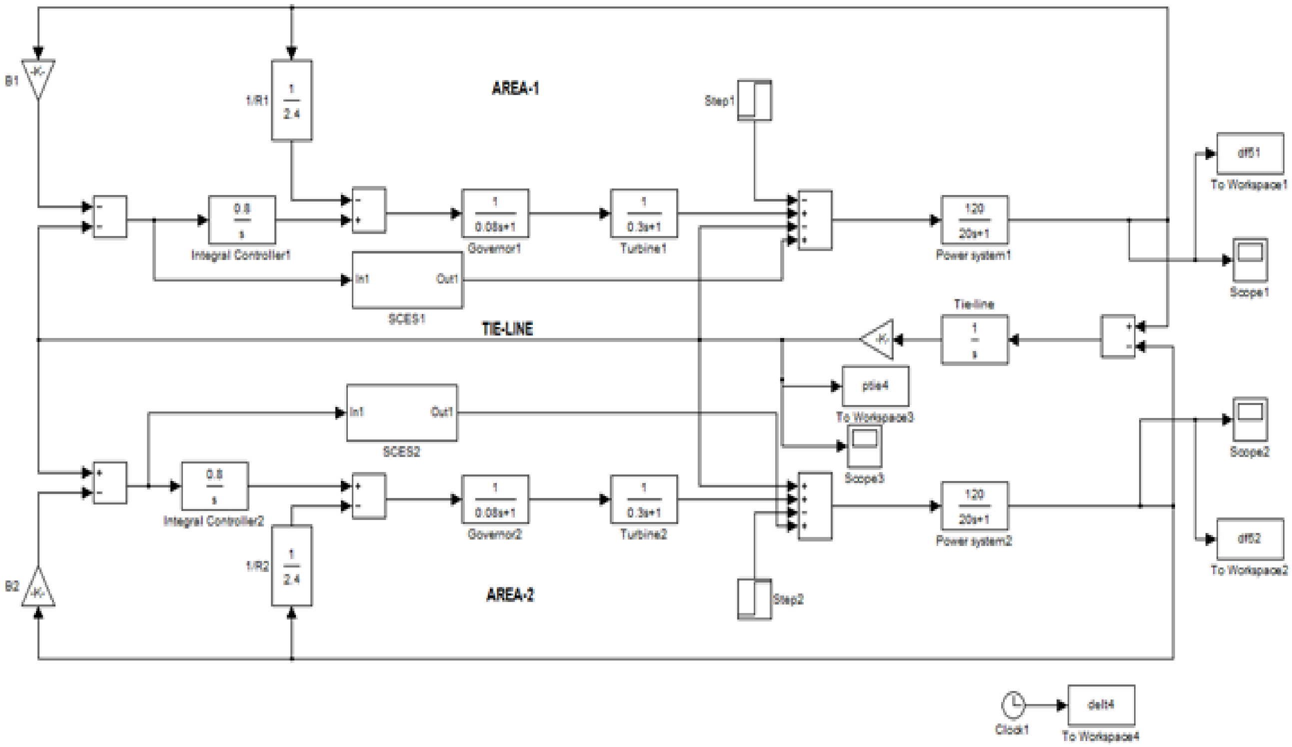


Fig.5 (c) Load frequency control in an interconnected power system with SCES units

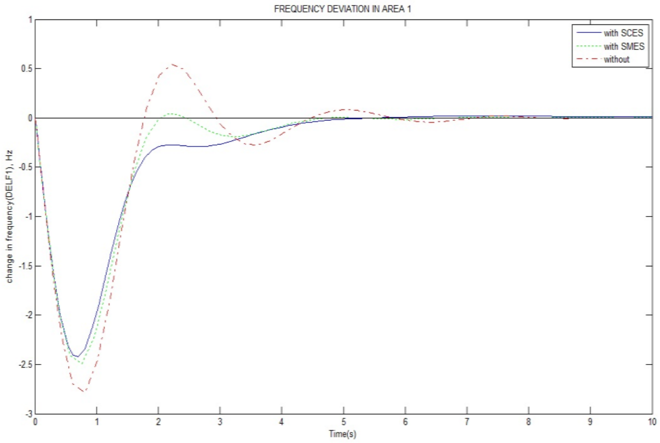


Fig .6 (a) Frequency Response of Area-1 (Δf_1)

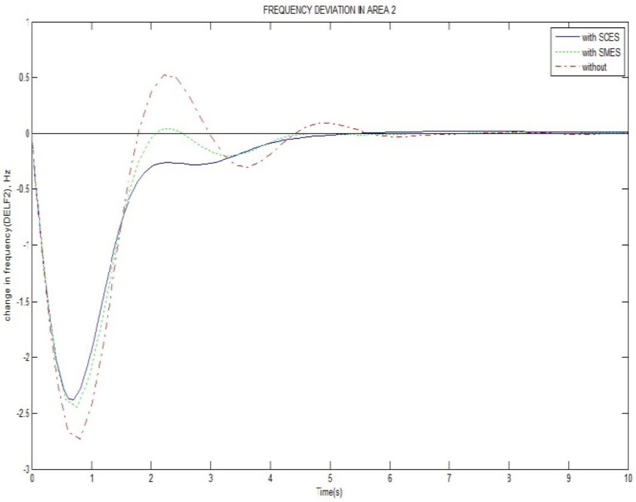


Fig. 6 (b) Frequency Response of Area-2 (Δf_2)

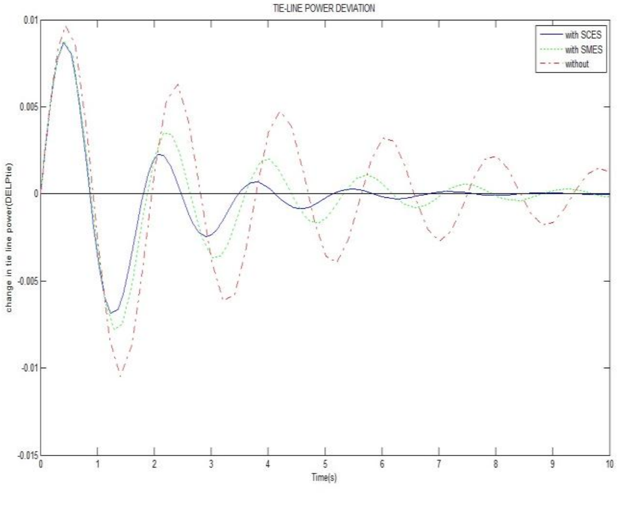


Fig6(c). Tie line power deviation of area1 & area2($\Delta p_{tie1,\,2}$)

The fig.5 ((a), (b), & (c)) shows the simulation diagram of Load-Frequency Control in an interconnected power system without & with SMES and SCES unit.

Fig .6((a), (b), & (c)) shows the simulation results of two area interconnected power system with SMES & SCES unit and also for without SMES & SCES unit considering Integral controller. Fig.7. ((a) & (b)) shows the frequency response of area-1 (i.e. Δf_1) and area-2 (i.e. Δf_2) for a system with SMES and SCES unit and also for a system without the energy storage unit. Whereas fig.6 (c) shows the tie line power deviation (Δp_{tie}) for a system with and without the energy storage units. Thus, from the Simulation Results, We say that the Performance of the SCES unit is better than the SMES unit and the conventional Integral controller of a system.

VIII. CONCLUSION

In practice, power system generally has more than two areas, and each area is different from others. But, in this study, the power systems of two thermal areas are considered. The Simulation Result shows that, the Performance of SMES and SCES units are close to each other in the context of transient analysis. But SCES is practically maintenance free, it does not impose any environmental problem and it is quite simple and less expensive. Load-Frequency Control of an Interconnected power system with SCES unit improves the dynamic response of a system (such as overshoot, settling time, and frequency oscillation) than the conventional controller and SMES unit of a two area Interconnected power system.

IX. APPENDIX

A1. Data for the two areas Interconnected power system

$T_G = 0.08$ sec, $T_T = 0.3$ sec, $K_P = 120$ Hz/pu ,

$T_p = 20$ sec, $T_{12} = 0.545$ pu/Hz, B = 0.425 Pu/Hz

A2. 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

A3. Data for SCES block

$K_{vd} = 0.1$ KV/KA

$K_0 = 70$ KV/Hz

C = 1 F

R = 100Ω

K_{SCES}=0.7 Hz/pu MW

T_{SCES} =0.01 sec

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