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TRANSIENT PERFORMANCE ANALYSIS OF CPSS BASED POWER SYSTEM WITH THE PRESENCE ENERGY STORAGE DEVICES

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ABSTRACT

This paper analyzed a comparative transient performance of different types of single machine power system connected to infinite bus under the presence of energy storage devices like Superconducting Magnetic Energy Storage (SMES) and Capacitive Energy Storage (CES). For Automatic Generation Control (AGC) loop, thermal unit is considered. The thermal unit is either single or double reheat turbine. PI controller is provided in the AGC loop. The power system AVR loop is provided with Conventional Power System Stabilizer (CPSS), the performances are compared under the presence of SMES and CES units. It is shown that CES based PI controlled AGC loop along with CPSS assists best transient performance of the power system in all cases under different operating conditions. The transient performances are carried out with different load variations.

KEYWORDS: Automatic Generation Control (AGC), Automatic Voltage Regulator (AVR), Capacitive Energy Storage (CES), Conventional Power System Stabilizer (CPSS), Superconducting Magnetic Energy Storage (SMES)

I. INTRODUCTION

In any power system, oscillations may arise due to line Faults, bus bar faults or load changes.so it is desirable feature to achieve better frequency constancy. However, both active and reactive power demands are never steady and they continually change with the rising or falling trend. The Steam input to turbo-generators (or water input to hydro-generator) must, therefore, be continuously regulated to match the active power demand, failing which the machine speed will vary with consequent change in frequency which may be highly undesirable (maximum permissible change in power frequency is ±0.1%). Also the excitation of generators must be continuously regulated to match the reactive power demand with reactive generation, otherwise the voltages at various system buses may go beyond the prescribed limits. In modern large interconnected systems, manual regulation is not feasible and therefore automatic generation and voltage regulation equipment is installed on each generator. To ensure the quality of the power supply, we need to design a load frequency management system that deals with the management loading of the generator with the frequency. There has been continuing interest in designing strategy for load frequency controls has been proposed since 1970 [1-3]. Concordia and Kirchmayer [4] have studied the AGC of a hydro-thermal system considering non-reheat type thermal system neglecting generation rate constraints. Kothari, Kaul, Nanda [5] have investigated the AGC problem of a hydro-thermal system provided with integral type supplementary controllers. The model uses continuous mode strategy, where both system and controllers are assumed to work in the continuous mode. It is to be appreciated that in a realistic situation, the system works in the continuous mode whereas the controllers work in the discrete mode. Perhaps Nanda, Kothari and Satsangi [6] are the first to present comprehensive analysis of AGC of an interconnected hydrothermal system in continuous-discrete mode with classical controllers. In the interconnected hydro-thermal system used by them, the thermal system uses reheat turbine. and the hydro system uses a mechanical governor. In modern hydro thermal system, reheat type turbine and electric governor [6] are used.

Generator excitation controls have been installed and made faster to improve stability. Power system stabilizers have been added to the excitation systems to improve oscillatory instability it is used to provide a supplementary signal to the excitation system. The basic function of the power system stabilizer is to extend the stability limit by modulating generator excitation to provide positive damping torque to power swing modes. A. Chatterjee, S.P.

Ghosal, and V. Mukherjee have described a comparative transient performance of single-input conventional power system stabilizer (CPSS) and dual-input power system stabilizer (PSS), namely PSS4B. Radman and Smaili have proposed the PID based power system stabilizer and Wu and Hsu [18] have proposed the self-tuning PID power system stabilizer for a multi machine power system. A typical power system stabilizer consists of a phase compensation stage, a signal washout stage and a gain block. To provide damping, a PSS must provide a component of electrical torque on the rotor in phase with the speed deviations. Power system stabilizer input signals includes generator speed, frequency and power. For any input signal, the transfer function of the PSS must compensate for the gain and phase characteristics of the excitation system, the generator and the power system. These collectively determine the transfer function from the stabilizer output to the component of electrical torque, which can be modulated via excitation control. The PSS, while damping the rotor oscillations, can cause instability of the turbine generator shaft torsional modes. Selection of shaft speed pick-up location and torsional notch filters are used to attenuate the torsional mode frequency signals. The PSS gain and torsional filter however, adversely affects the exciter mode damping ratio. The use of accelerating power as input signal for the PSS attenuates the shaft torsional modes inherently, and mitigates the requirements of the filtering in the main stabilizing path. One of the solutions to increase system damping is the use of an electrical storage unit such as Battery Energy Storage Systems (BESS), Compressed Air Energy Storage (CAES), Flywheel Energy Storage (FES), Superconducting Magnetic Energy Storage (SMES), and Capacitive Energy Storage (CES).As compared to other devices the efficiency of SMES and CES is better [16]. Although superconductivity was discovered in 1911, SMES has been under study for electric utility energy storage application since the early 1970s .Since the successful commissioning test of the BPA 30-MJ unit [7], SMES systems have received much attention in power system applications, such as, diurnal load demand leveling, frequency control, automatic generation control, uninterruptible power supplies, etc. The real power can be absorbed or released from the low loss superconducting magnetic inductor according to system power requirements. The uses of SMES and battery energy storage for load levelling application and for improvement of the dynamic performance of power system have been described [8-11]. The importance of control system using SMES has been presented as one of the powerful stabilizers for undamped oscillations that tend to occur in a long distance bulk power transmission system has been viewed and analyzed in the literature [8]. In [9] the improvement in AGC with the addition of a small capacity SMES unit is studied, and time domain simulations are used to study the performance of the power system dynamics are analyzed. Their applications in real power have invited problems form the viewpoints of operation, maintenance, cost but the only advantages of SMES is very much useful for high power applications. However, SMES is an expensive device. However, capacitive energy storage (CES) may be a better alternative to damp out the power frequency oscillation, following any perturbation in power system. A small rating capacitive energy storage (CES) can effectively damp out the power frequency and tie line power oscillations caused by small perturbations to the load. The use of superconducting magnetic energy storage (SMES) units for LFC application has been suggested [9,16]. The losses in CES units would be considerably less when compared with SMES units of same storage capacity. The CES units are practically maintenance free. Furthermore, they do not impose any environmental problem, unlike magnetic energy storage units [16]. The operation is quite simple and less expensive compared with SMES, which requires a continuously operating liquid helium system. In CES systems, there is no need to ensure a continuous flow of current, as required in magnetic storage systems .By suitable control of CES unit to the system significantly improves this situation and the oscillations are practically damped out.

II. MATERIALS AND METHODS

A single machine connected to infinite bus system (SMIB) is considered [2]. The MATLAB-SIMULINK representation of SMIB system with AVR, exciter, Synchronous generator, CPSS loop, AGC loop and subsystem loop is shown in fig 2, AGC loop subsystem in fig 3,subsystem SMES and CES is shown in fig 4 and fig 5. A two axis fourth order model represents the synchronous generator with AVR, IEEE STIA thyristor excitation system along with generator and equivalent transmission line reactance.

A. *Combining LFC And AVR*

Due to weak coupling relationship between the AVR and AGC, the voltage and frequency are regulated separately. The study of coupling effects of the AVR and AGC can be found in Kundur [2], where it is mentioned that a small change in the electrical power ΔP_e is the product of the synchronizing power coefficient PS and the change in the power angle $\Delta\delta$. Taking in to account that the voltage is proportional to the main field winding flux E_d, the following linearized equation is obtained (2).

$$\Delta P_e = K_2\Delta\delta + K_1 E' \tag{2}$$

Where K_1 is the change in the electrical power for a change in the direct axis flux linkage with constant rotor angle and K_2=PS. By modifying the generator field transfer function and taking in to account the effect of rotor angle. The equation for the stator EMF can expressed as (3).

$$E' = \frac{K_G}{(1+ST_G)}(V_f - K_3\Delta\delta) \tag{3}$$

Where K_3 is the demagnetizing effect of a change in the rotor angle (at steady state). The small effect of this rotor angle $\Delta\delta$ upon the generator terminal voltage can be expressed as equation (4)

$$\Delta V_t = K_4\Delta\delta + K_5 E' \tag{4}$$

Where K_4=change in terminal voltage with the change in rotor angle for E_d, K_5 is the change in terminal voltage with the change in E_d for a constant rotor angle. Therefore, the simulation model for a fourth order machine time constant is generated figure 2. [17]

III. SINGLE INPUT CONENTIONAL POWER SYSTEM STABILIZER

The basic function of a PSS is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal. To provide damping, the stabilizer must produce a component of electrical torque in phase with the rotor speed deviation. For the simplicity, a conventional PSS is modeled by two stage (identical), lead/lag network, which is represented by a gain Kpss and four time constants T_{d1} to T_{d4}. This network is connected with a washout circuit of a time constant Tww as shown in Figure 4.

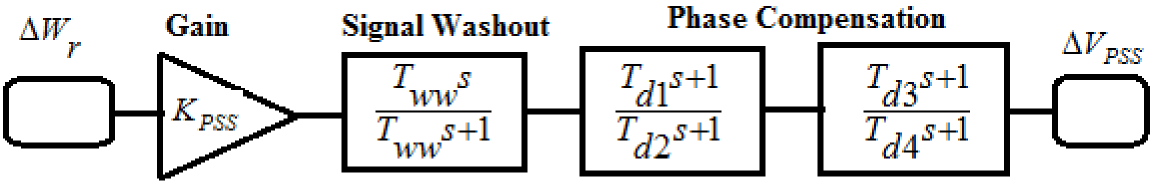

Figure 1. Block Diagram of PSS

In Figure 1 the phase compensation block provides the appropriate phase lead characteristics to compensate for the phase lag between exciter input and generator electrical torque. The phase compensation may be a single first order block as shown in Figure 1 or having two or more first order blocks or second order blocks with complex roots. The signal washout block serves as high pass filter, with time constant Tw high enough to allow signals associated with oscillations in Wr to pass unchanged, which removes d.c. signals. Without it, steady changes in speed would modify the terminal voltage. It allows PSS to respond only to changes in speed.

The stabilizer gain K_{pss} determines the amount of damping introduced by PSS. Ideally, the gain should be set at a value corresponding to maximum damping; however, it is limited by other consideration.

IV. SUPERCONDUCTING MAGNETIC ENERGY STORAGE

An SMES unit consists of a large superconducting coil at the cryogenic temperature. This temperature is maintained by a cryostat or dewar that contains helium or nitrogen liquid vessels. The transfer function model SMES unit contained DC Superconducting coil and converter which are connected by Star-Delta/Delta-Star transformer is shown in fig 1. The converter impresses positive or negative voltage on the superconducting coil. Charge and discharge are easily controlled by simply changing the delay angle α that controls the sequential firing of the thyristors . If α is less than 90˚, the converter operates in the rectifier mode (charging). If α is greater than 90˚ , the converter operates in the inverter mode (discharging). As a result, power can be absorbed from or released to the power system according to requirement. At the steady state, SMES should not consume any real or reactive power [21]. The control of the converter firing angle provides the DC voltage Ed appearing across the inductor to be continuously varying within a certain range of positive and negative values. The inductor is initially charged to its rated value I_{do} by applying a small positive voltage. Once the current reaches the rated value, it is maintained

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constant by reducing the voltage across the inductor to zero since the coil is [24-25] superconducting. Neglecting the transformer and the converter losses. The DC voltage is given by [24].

$$E_d = 2V_{do}\ COS\alpha - 2I_d\ R_c \tag{7}$$

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 (ohm), V_{do} = maximum open circuit bridge voltage of each 6-pulse converter at α = 0 deg (KV). The inductor is first charged to its rated current, I_{do} by applying a little 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 require to overcoming the commutating resistance. The energy stored at any instant [7], $w_L = \frac{L*I_d^2}{2}$ MJ Where, L=Inductance of SMES (H).

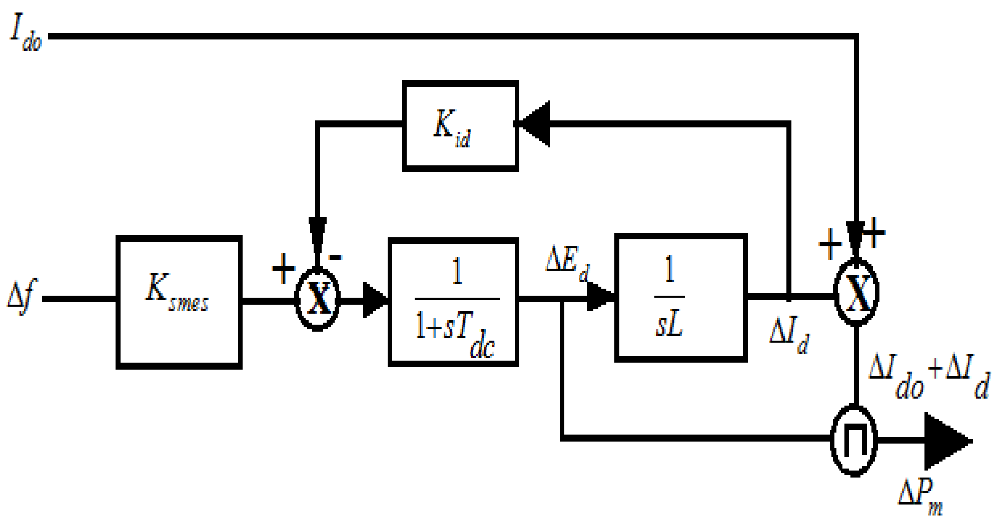

Figure 2. Block Diagram of SMES

Frequency deviation as a control signal:

In the present SMIB system, area controlled error (ACE) is only Δf .The frequency deviation Δf of the power system is sensed and used to control the SMES voltage, E_d. When power is to be pumped back in to the grid in the case of fall in the frequency due to sudden loading in the armature, the control voltage E_d is to be negative since the current through the inductor and thyristor cannot change its direction. The incremental change in the voltage applied to the inductor is expressed as:

$$\Delta E_d = [\frac{K_F}{(1+ST_{dc})}]\Delta f \tag{6}$$

Where ΔE_d is the incremental change in converter voltage; T_{dc} is the converter time delay, K_f is the gain of the control loop and S is the Laplace operator d/dt.

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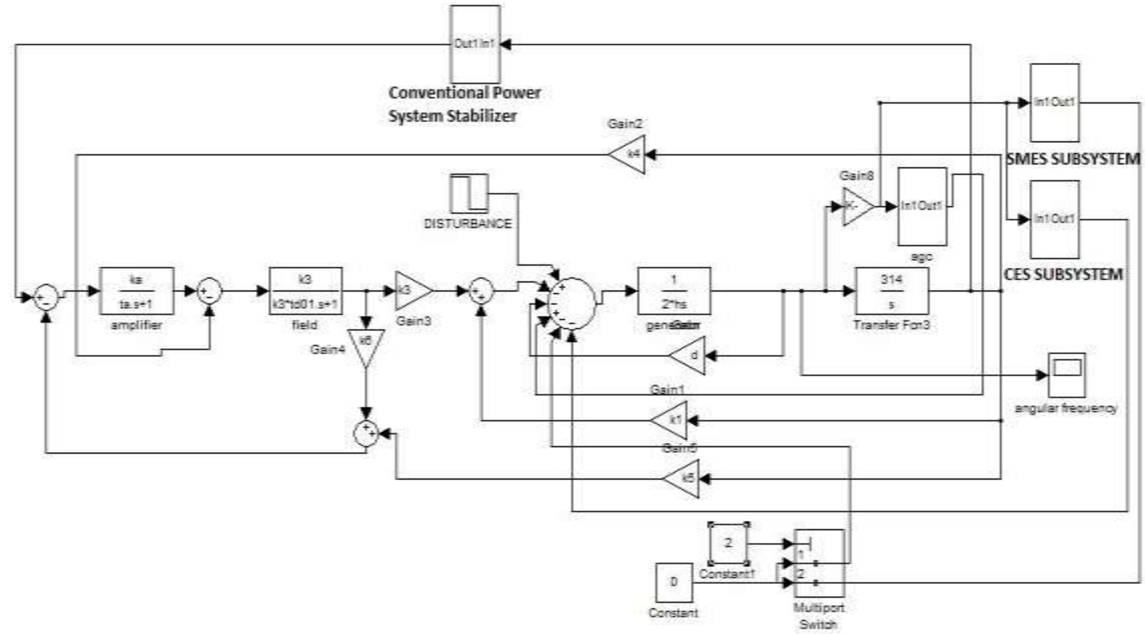

Figure 3. MATLAB-SIMULINK representation of SMIB with AVR Synchronous Generator, CPSS Loop, AGC Loop, SMES Loop, CES Loop

V. Capacitive Energy Storage

A Capacitive Energy Storage (CES) unit consists of, from circuit point of view, a super-capacitor or a cryogenic hyper-capacitor (CHC), a power conversion system (PCS) which includes a inverter/rectifier . The storage capacitor may consist of many discrete capacitors connected in parallel, having lumped capacitance C .The capacitor can be charged to a set value of voltage (which is less than the full charge) from the utility grid during normal operation of the grid [22]. Charging in the steady state mode and the power modulation during dynamic oscillatory period is controlled by the application of the proper voltage to the capacitor so that the desired current flows into or out of the CES. This can be achieved by controlling the firing angle of the convertor bridges.

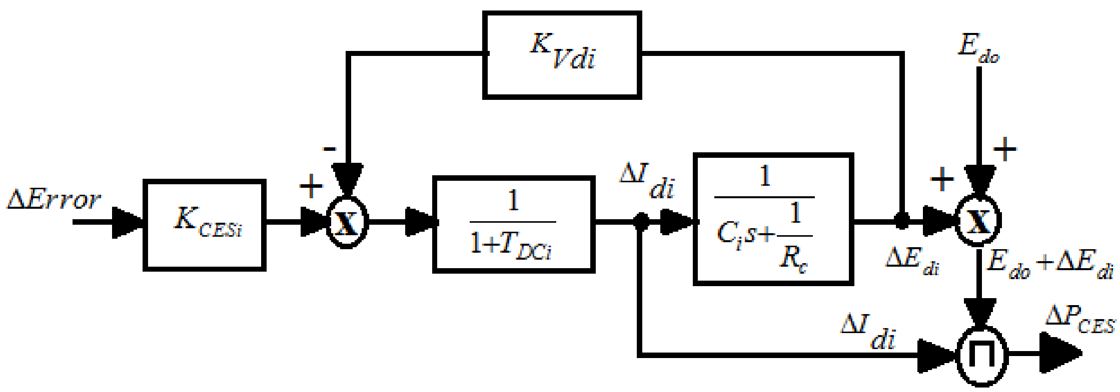

Figure 4. Block Diagram of CES

Neglecting the transformer and the convertor losses, the DC voltage is given by [17]

$$E_d = 2\,E_{do}\cos\alpha - 2\,I_d\,R_D \qquad (7)$$

Where; E_d = DC voltage applied to the capacitor (kV), α = firing angle (degree), I_d = current through the capacitor (kA), R_c=equivalent commutating resistance (ohm), V_{do}= maximum open circuit bridge voltage.

The capacitor is initially charged to its normal voltage, E_{do} by the PCS. Once the voltage of the capacitor has reached, E_{do} it is kept floating at this voltage by continuing Supply from the PCS to compensate for Dielectric and other leakage losses of the capacitor. The energy stored at any instant, $W_c = \frac{CE_d^{\,2}}{2}$ MJ (8)

Where C = capacitance of CES (farad)

A. Frequency deviation as control signal

In CES unit also combine with SMIB system, so area controlled error (ACE) is only Δf .The frequency deviation Δf of the power system is sensed and used to control the CES current I_d. The incremental change in CES current is expressed as [17]

$$\Delta I_{di} = [\frac{K_{CFi}}{1+ST_{DCi}}]\,\Delta f_i \quad (9)$$

Where i=1, 2, ΔI_{di} is the incremental change in current of CES unit (kA), T_{DC} is the convertor time delay (second),K_{CFi} is the gain of the control loop (kA/Hz), S is the Laplace operator (d/dt).

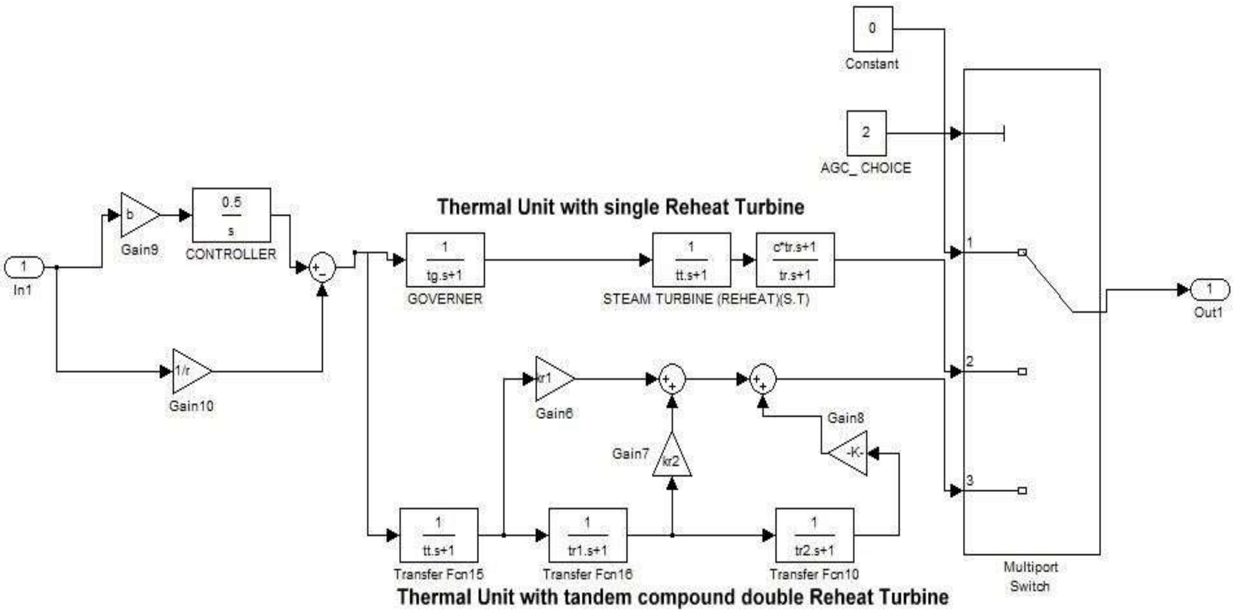

Figure 5. AGC loop Sub System

VI. SIMULATION RESULT

Simulation results is shown from figure 6 to figure 15.the SMES and CES is located at the generator terminal, the optimal transient performance of the power system corresponding to an operating condition of P=0.9, Q=0.1, R= 0.003, X_e =0.997, E_t =1.0 (all are in p.u.) for thermal unit with single stage reheat turbine in the AGC loop. From below given figure it is noticed that the fluctuation is suppressed and the damping of power oscillations are hardly improved. The damping is improved when the active power control is used. In contrast with these, the fluctuation is also suppressed and damping is improved as well when the simultaneous control of active and reactive power is applied. Due to the application of SMES and CES action the system transient performance is considerably improved and peak overshoot (M_p),settling time (T_s), Rise Time (T_p) is also improved under different loading condition. The value of Settling time t_s, M_p, Rise Time T_r are reduced with the application of CES and

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SMES as shown in table 1. From figure 6 to figure 15, the dynamic performance has been compared with CES and SMES with CPSS system. The main task of both CES and SMES may be attributed from the action of a sudden rise in the demand of load. Under this contingency condition, the stored energy in CES and SMES is almost immediately released through the PCS to the grid as line quality AC. As the governor and different control mechanisms start working to set the power system to the new equilibrium condition. Thus, improved transient performance is gained with the application of CES and SMES in the interactive with AVR and AGC with CPSS system.

Table 1. Performance Single Machine Power System with CPSS under the influence of SMES and CES for different load variations

% Load	SMES			CES		
	M_p (10^{-5})	t_r (sec)	t_s (sec)	M_p (10^{-5})	t_r (sec)	t_s (sec)
+1	6.98	0.1	3.6	6.05	0.1	1.8
+5	7.33	0.1	3.8	6.35	0.1	1.9
+10	7.68	0.1	3.9	6.65	0.1	2.0
+15	8.03	0.1	3.9	6.96	0.1	1.6
+20	8.38	0.1	3.9	7.26	0.1	1.6
+25	8.73	0.1	3.7	7.50	0.1	1.5
-5	6.63	0.1	4	5.85	0.1	1.8
-15	5.90	0.1	3.8	5.75	0.1	1.6
-20	5.58	0.1	3.9	4.84	0.1	1.7
-25	5.24	0.1	3.9	4.38	0.1	1.5

VII. CONCLUSION

This paper concludes that Inclusion of CES and SMES unit in the coordinated AVR, CPSS and AGC loop with either single stage or double stage reheat turbine improves the transient performance considerably. In this work initially the effectiveness of power system stabilizer in damping power system oscillation is reviewed. CPSS with CES unit shows the better control performance than CPSS with SMES unit in terms of settling time (Ts), Peak overshoot (Mp) and damping effect. Therefore, it can be concluded that the performance of CPSS with CES unit is better than CPSS with SMES unit. Hence Capacitive Energy Storage Unit and Superconducting magnetic energy storage units with CPSS are successfully practically implemented for improving small signal dynamic performance of the power system.

Appendix:

AGC loop data : R=2.4Hz/per unit MW, b=0.275,

Single stage-reheat turbine data: Tg=0.08s,Tt=0.3s, c=0.35, Tr=4.2s

Double stage-reheat turbine data: Tr1=10s , Tr2=10s, Tt=0.3s, alpha=Kr1=0.2,beta=Kr2=0.2

SMIBdata: Xd=0.973, Xd'=0.19, D=0.0, Xq=0.55, Tdo'=7.765s H=4.63,Re=0.003,Xe=0.997

AVR loop data: Ka=50,Ta=0.05s

CPSS data : Tww=10s **,**Td2=0.05s **,** Td4=0.05s

SMES data: T_{dc}=0.03 s, K_f=35 KV/unit MW, K_{id} = 0.20 KV/KA , I_{ido} = 4.5 KA, L = 2.42H.

CES data: C=1 F, R=100 Ohm, tdc=0.05s ,kvd=0.1kA/kV kace=40 kA/unit MW ed0=20v

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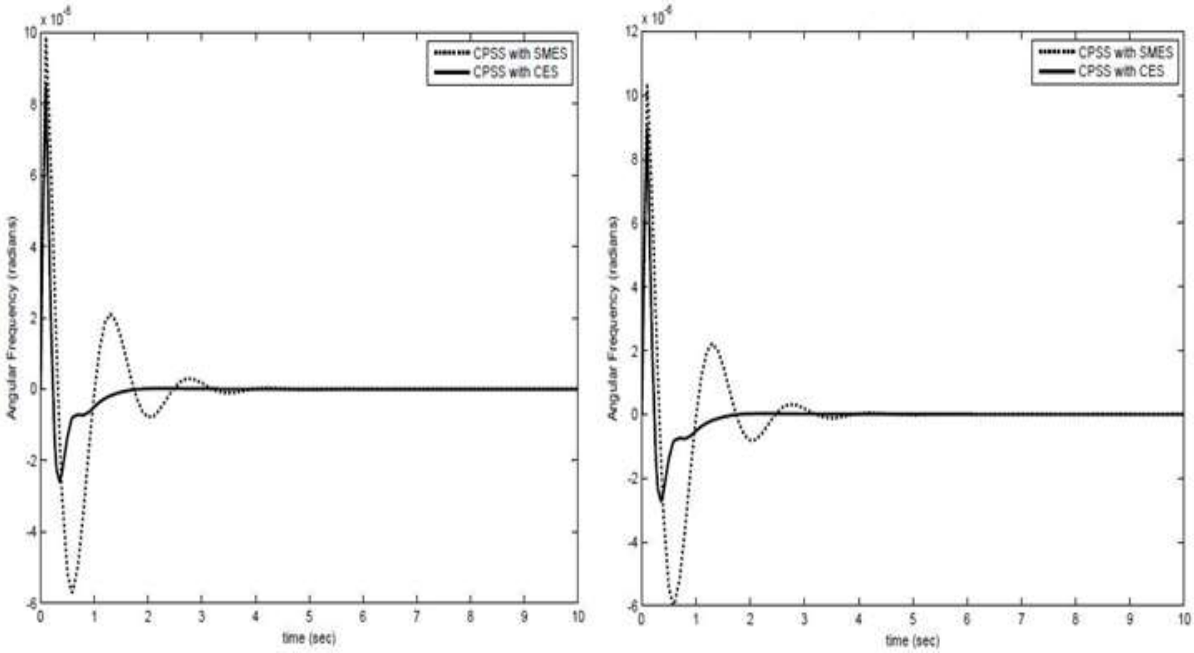

Fig. 6 and 7. ***Comparative performance of AGC with CPSS under +1% and 5% load variations with the presence of SMES and CES***

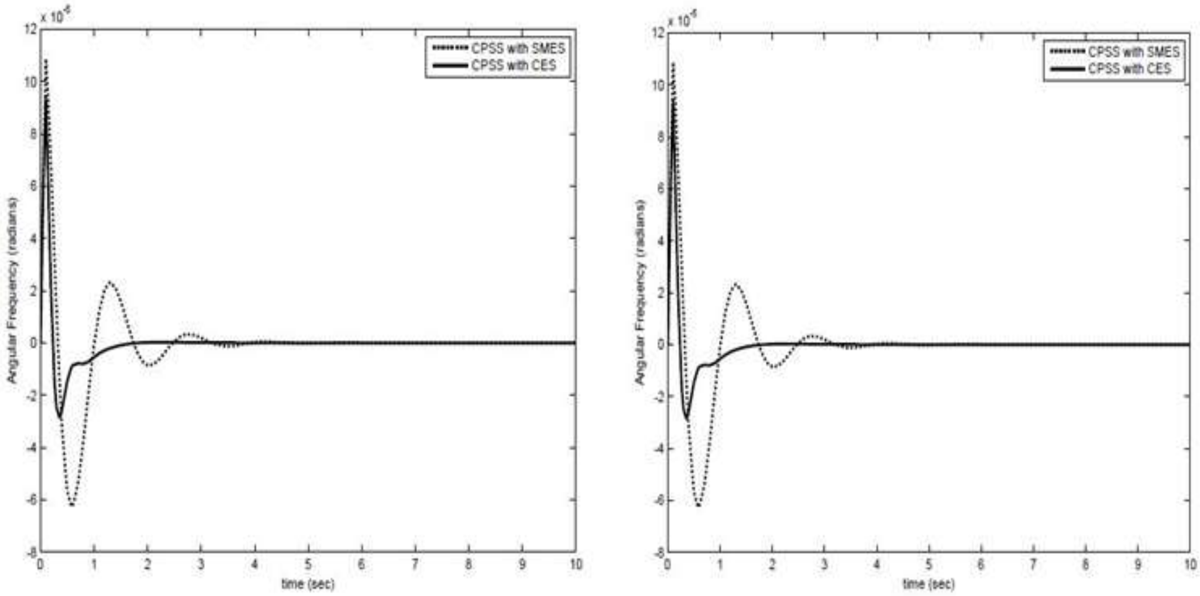

Figure 8 & 9. ***Comparative performance of AGC with CPSS under +10% and +15%load variations with the presence of SMES and CES***

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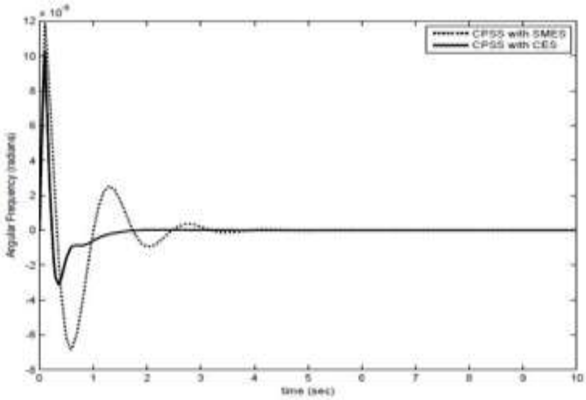


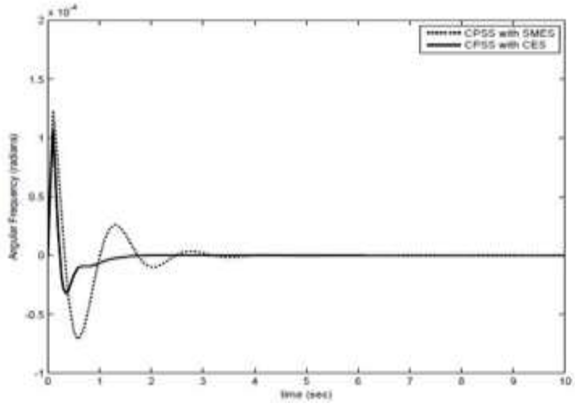
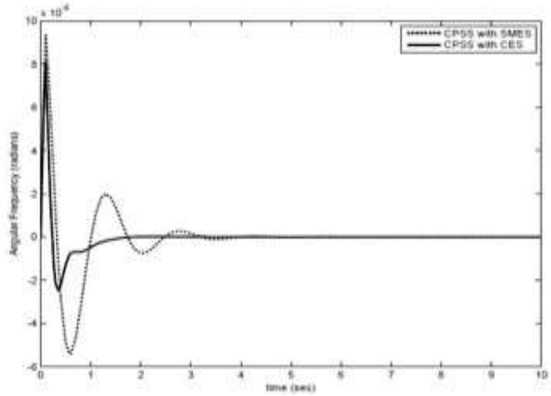


Figure 10 & 11. ***Comparative performance of AGC with CPSS under +20% and +25%load variations with the presence of SMES and CES***



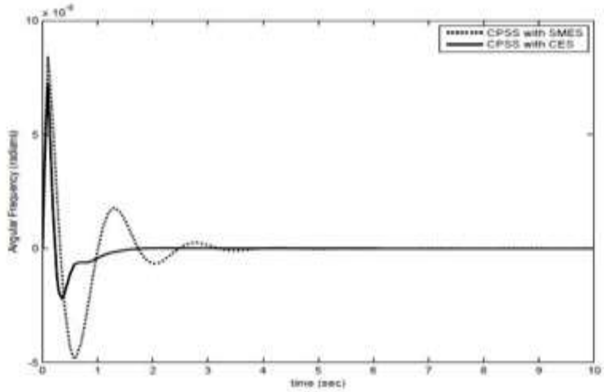
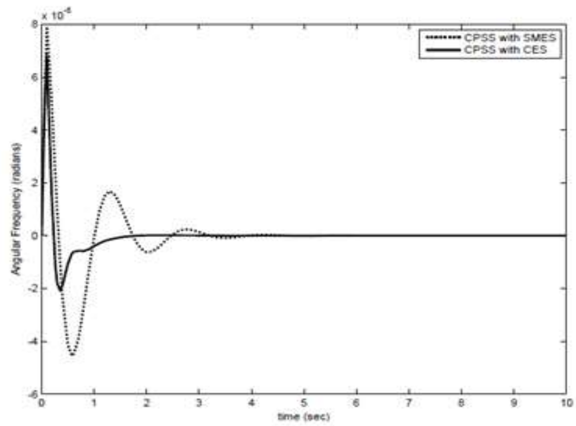


Figure 12 &13 ***Comparative performance of AGC with CPSS under -5% & -15% load variations with the presence of SMES and CES***



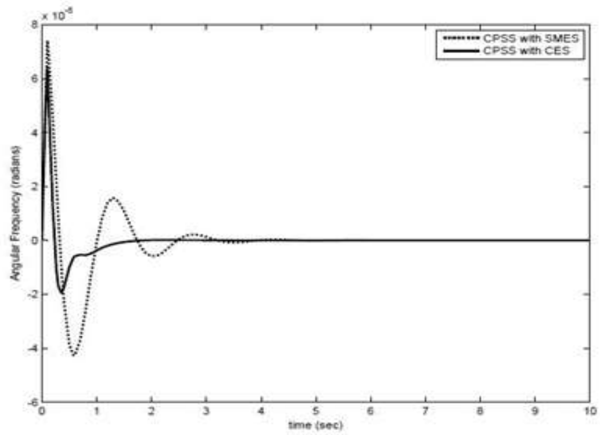


Figure 14 & 15. ***Comparative performance of AGC with CPSS under -20% & -25% load variations with the presence of SMES and CES***

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Impact Factor: 4.116
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REFRENCES

[1] ANSI/IEEE std 122-1985, "IEEE recommended practice for functional and performance characteristics of control system for steam turbine generator units", The institute of EEE USA,1985.
[2] P.Kundur,"Power System Stability and Control", McGraw-Hill Inc, 1994.
[3] P.M.Anderson and A.A.Faurd, "Power System Control & Stability", IEEE, Press, Revised printing, 1994C.
[4] Concordia and L.K.Kirchmayer, "Tie-Line Power and Frequency Control of Electric Power Systcm - Part It", AIEE Transaction, vol. 73, Part- 111-A, April 1954, pp. 133-146.
[5] M.L.Kothari, B.L.Kaul and J.Nanda, "Automatic Generation Control of Hydro-Thermal system", journal of Institute of Engineers(India), vo1.6 I.
[6] J.Nanda, M.L.Kothari, P.S.Satsangi, "Automatic Generation Control of an Interconnected hydrothermal system in Continuous and Discrete modes considcring Generation Rate Constraints", IEE Proc., vol. 130, pt D, No. I , Jan. 1983, pp 455-460.
[7] H. J. Boenig and J. F. Hauer, "Commissioning tests of the Bonneville power administration 30 MJ superconducting magnetic energy storage unit," IEEE Trans. Power App. Syst., vol. PAS-104, no. 2, pp. 302–309, Feb. 1985.
[8] S.C. Tripathy, R.Balasubramaniam, P.S. Chandramohan Nair," Effect of Superconducting Magnetic Energy Storage on Automatic Generation Control Considering Governer Dead band and Boiler dynamics. "IEEE tran. On power system Vol 7,Aug 1992.
[9] S.C. Tripathy, R. Balasubramanian,P.S. Chandramohan Nair , "Small rating capacitive energy storage for dynamic performance improvement of automatic generation control", IEE proceedings, Vol 138,Jan 1991.
[10] H.A. Peterterson, N.Mohan and R.W.Boom, "Super Conductive energy storage Inductor-Converter Units for power system", IEE Trans. On Powerapparatus and systems, Vol. PAS-94,No.4,PP 1337-1348, July/August 1975.
[11] R.J. Loyd, J.D.Rogers et al., "A feasibility utility scale superconducting Magnetic Storage Plant", IEEE Trans. onEnergy conversion, Vol. EC-1, No.4, PP 63-64, December 1986.
[12] O.I Elgerd, "Electric Energy System Theory: An Introduction", (Book), McGraw Hill, 1982.
[13] Y.Mitani, K.Tsuji, Y.Murakami, "Application of Superconducting Magnetic Energy storage to improve power system dynamic performance"IEEE trans. On power system, Vol 3,No.4-1988.
[14] Rogers, J.D., Boenig, H.J., Bronson, J.C., Colyer, D.B., hassenzahl, W.V., Turner, R.D., and Schermer, R.I.: '30 MJ superconducting magnetic energy storage (SMES) unit for stabilizing an electric transmission system', IEEE Trans., 1979,
[15] Mohd. Hasan Ali, Bin Wu, and Roger A. Dougal, "An Overview of SMES Applications in Power and Energy Systems", IEEE Transactions on Sustainable Energy, Vol. 1, No. 1, April 2010.
[16] **S.** Dhundhara, Y.P Verma, "Evaluation of CES and DFIG Unit in AGC of Realistic Multisource Deregulated Power System", *International Transactions on Electrical Energy Systems*, vol. 27,issue 5, pp. 1-14, 2016.
[17] Rajesh.J, D. Das "Automatic Generation Control of an Interconnected Power System with Capacitive Energy Storage"IJEEE,2010
[18] Michael J. Basler and Richard C. Schaefer "Understanding Power System Stabilizer," Basler Electric Company IEEE Trans., pp. 46-67, August 2005.
[19] M.L. Kothari, J. Nanda, and K. Bhattacharya, "Design of Variable Structure Power System Stabilizers with Desired Eigen values in the Sliding Mode," IEE Proceedings, Part C, vol. 140, No.4, July 1993.
[20] Recommended Practice for Excitation System Models for Power System Stability Studies," IEEE Standard 421.5-1992, August 1992.

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