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AGC OF THREE AREA INTERCONNECTED POWER SYSTEM INCORPORATING SMES

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Abstract - This paper presents the Automatic Generation Control (AGC) of three area interconnected power system incorporating Super Magnetic Energy Storage System (SMES) for two different case studies. A computational intelligent technique Particle Swarm Optimization (PSO) is processed to optimize the gain parameters of an Integral controller (IC) for three areas by considering the objective function as integral square error (ISE). Effectiveness of investigated power system is done by analysing the dynamic performances under 1% step increase of load. The dynamic performances of two different case studies are analysed and compared for AGC of interconnected power system without SMES and with SMES. The examinations of studies reveal that the implementation of AGC with SMES offers better dynamic performances under 1% step increase of load. An attempt has also been made to explore the impact of renewable hydro power system when considered as one of the area in power system model.

Keywords - Thermal Hydro Thermal Power System, Automatic Generation Control, Super Magnetic Energy Storage System, Particle Swarm Optimization, Area Control Error.

I. INTRODUCTION

Modern power system requires good quality, sufficient and reliable electric power. In an interconnected power system, AGC is a very significant and one of the important controls to be implemented during abnormal operation of [1,2]. Supervision of these parameters at the rated value is essential for acquiring high efficiency and minimum wear and tear of the consumer equipment. Therefore, the main parameters to be controlled are the frequency of system and voltage which determine the stability and quality of supply. Matching of total generation with load demand and associated system losses is the key for effective operation of interconnected power systems which are further weighted together as area control error (ACE).

Over the past decades, many research and different approaches have been proposed regarding AGC regulator designs incorporating different intelligent controllers like ant colony, neural networks, bacterial forging, fuzzy logic particle swarm optimization techniques, bat algorithm, Genetic algorithms, cuckoo algorithm, etc. The conventional integral controller with intelligent controller is the effective and commonly used controller because of its property of minimizing steady state error. Implementing different performance indices conventional integral gains are tuned [3, 4]. Integral square error (ISE) measures deeply on the large fluctuations as compared to small fluctuations which results in diminishing the primary swings of transient response.

Even though with these designed controllers at small load disturbances still the frequency and tie line power deviation persist for long duration [5]. This is due to its slow response and governor system is unable to absorb more frequency oscillations. This problem can be easily eliminated by the use SMES which can successfully reduce electromechanical oscillations [6]. Energy storage system provides additional energy to the kinetic energy and shares unexpected load disturbances in the moving mass of generator rotor. This results in more secure power system operation with fast acting active and reactive power compensation. For meeting varying load demand in interconnected power systems, there is a need to combine conventional and renewable power system [9].

The objective of this study is to analyze AGC of three areas interconnected power system with SMES for two case studies. Next section deals with explanation and identification of case studies for interconnected power system. Section 3 describes of PSO algorithm and its application to find IC gain parameters for interconnected power system model. Section 4 explains the block diagram and dynamic equation for SMES. Simulation of case studies is gathered in Section 5. Whereas, conclusion is offered in section 6.

II. REPRESENTATION OF MODEL

This study presents AGC of three area interconnected power system for 1% step increase of load in each area. The block diagram for AGC of three area interconnected power system is present in Fig.2. The parameters used in AGC of interconnected power system are given in Annexure A.

The control signal is

$$\Delta Pc_i\,(t) = -\, K_{Ii} \int (ACE_i)\, dt \qquad (1)$$

Where, K_{Ii} is Integral Gain Constant, ΔF_i is System frequency deviation, b_i is bias constant for *i= 1, 2 and 3* as area 1, area2 and area 3.

$ACE_i = b_i \Delta F_i(t) + \sum \Delta P_{tie\,ij}(t)$
(2)

Where j =1 to 3 and j ≠ i

$\Delta P_{tie\,ij}(t) = T_{ij} [\Delta F_i(t) - \Delta F_j(t)]$
(3)

We have considered the objective function as a summation of integral square of ACE for all areas. Scalar integral performance indices were justified with a proof to be the most valuable and suitable measures of dynamic performances. In this section and next section, parameters of IC of three areas AGC of interconnected multi source power system are considered and tuned using the integral square errors (ISE) criterion of different control area as an objective function.

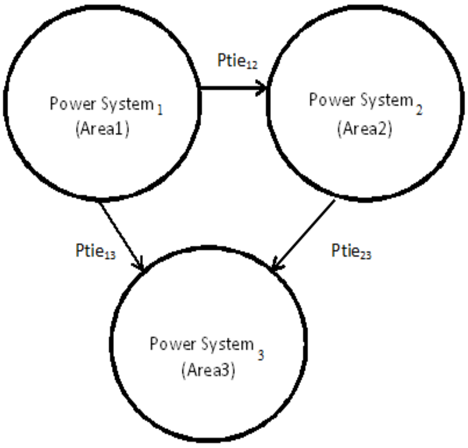


Fig1. Representation of three area interconnected power system

This objective function basically happens to judge the large errors broadly and low errors narrowly.

$J_0 = \int ACE_1^2(t)dt + \int ACE_2^2(t)dt + \int ACE_3^2(t)\,dt$
(4)

Further analysis of the system in terms of dynamic performances has been done by identifying different case studies given in Table I. These case studies are recognized on the combinations of different sources of interconnected power system. For the both case studies, tuning of IC parameters are accomplished by considering the above explained objective function with PSO technique.

Case Study	Types of Power Plants
1.	Thermal power plant only
2.	Thermal and hydro power plant

Table 1. Different case studies under consideration

III. PSO TUNED IC FOR AGC OF INTERCONNECTED POWER SYSTEM WITHOUT SMES

PSO algorithm is proved to be a help while solving numerous optimization problems for AGC. Kennedy defined this technique as a population (swarm) based stochastic optimization algorithm which considered aggregation and goal [8,9]. The quality attributes, principle of diverse response, principle of stability and principle of adaptability of PSO algorithm make it a worthy choice for optimizing gains of AGC of power system.

PSO is one of its kind and the utmost modern algorithms to calculate nonlinear and non-continuous optimization problems [11]. It is not more susceptible of being trapped on local optima unlike various different artificial intelligences that her set till date and their based optimization techniques. PSO is a population based concept which works with each individual's decision based on its own experience and other individual's experience. The process is inspired by the societal and collaborative nature represented by flying birds [13]. Particles using randomized show an inclination to flow in the solution region indeed. In correspondence with these particles, every particle resource its respective coordinates within the workspace which is further followed with the best fitness received till now. This value is taken as the best value X_{pbest} which is analyzed by the particle till the moment by any particle in the group of particles and it is considered as X_{gbest}. Every individual within the PSO takes off to the search space having a velocity with regards to the individual personal information followed by the companion's experience as well.

The modification of the particles velocity can be mathematically modeled as per the following equation.

$V_l^{m+1} = w_v * V_l^m + c_1 * rand_1 * (X_{pbest\,l} - X_l^m) + c_2 * rand_2 * (X_{gbest\,l} - X_l^m)$ (5)

Where V is particle velocity, $rand_l$ is uniform distributed random numbers between 0 and 1, X_{pbest} is current best position, X_{gbest} is global best position, m is iteration number, w_v is an inertia weight factor, c_1 and c_2 are coefficient constant, n is swarm population size, l =1… n and l is practically analyzed as the state of swarm defining in the n dimensional space.

$w_v = w_{max} - [(w_{max} - w_{min}) * l] / maxiter$
(6)

If the value of w is large then it facilitates the global search, whereas if the value is small then it facilitates a local search.

Now the position of particle is modified as

$$X_l^{m+1} = X_l^m + V_l^{m+1} \quad (7)$$

At the end of iterations by minimizing the performance index ISE, the optimized gain parameters of IC of each area by considering 1% load disturbances will be given by the best position of swarm.

In the present study, we obtained the minimum performance index of 0.00035 and 0.0048 after 50 iterations of PSO tuned IC parameters for both the case studies in AGC of interconnected power system without SMES as shown in Table II, by considering 1% step increase of load in each area.
After exploring, we analyze that when we add hydro renewable source as one of the interconnected power system, the system takes some noticeable time to settle. To further improve the dynamic responses of both case studies, we employ SMES in each area.

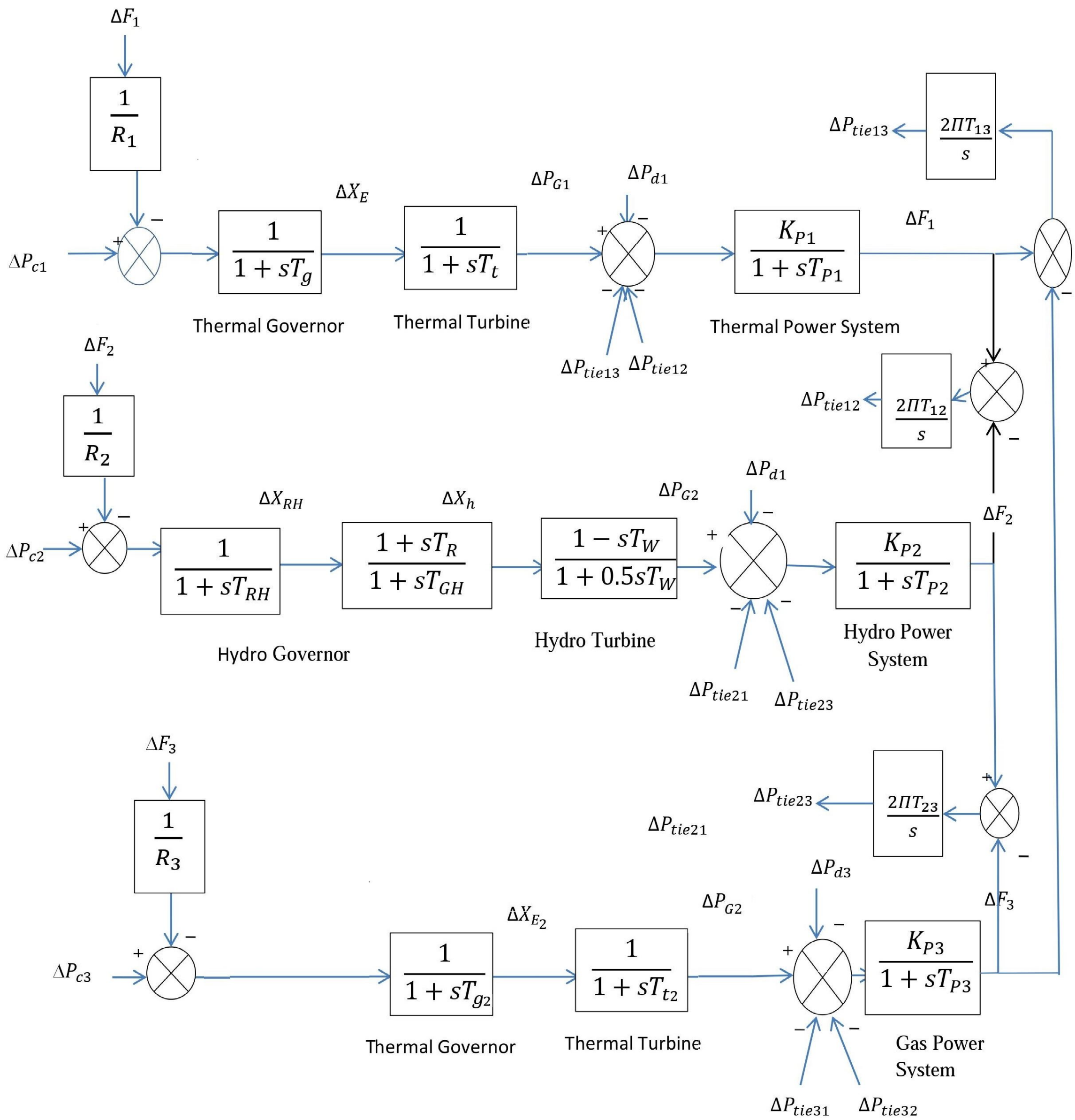


Fig 2. Transfer function model of power system under exploration

Case Study	IC Gain parameters			Settling Time (s)				PSO parameters
	K_{I1}	K_{I2}	K_{I3}	ΔF_1 (Hz)	ΔF_2 (Hz)	ΔF_3 (Hz)	ISE	
1	0.95	0.95	0.9	10	10	10	0.00035	n=301, m=50, c_1= 0.12, c_2=1.2, d=3
2	0.41	0.4	0.61	65	53	65	0.0048	

Table II. Characteristics of PSO tuned IC for AGC without SMES

The basic flow chart of PSO is given as:

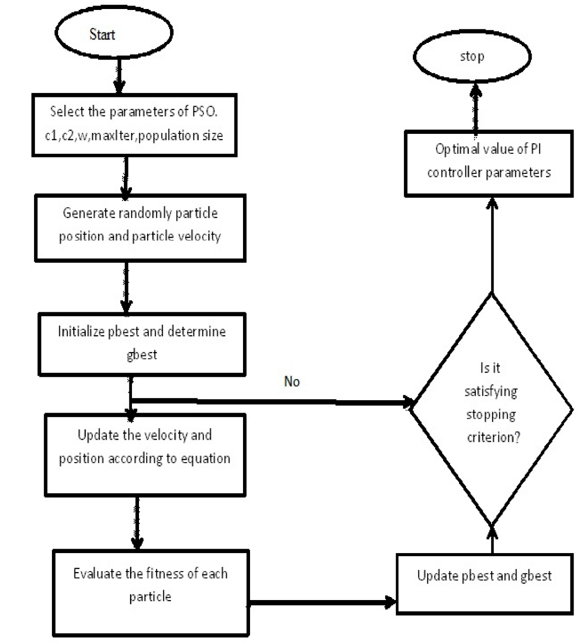


Fig 3. Particle swarm optimization flowchart

III. MODELLING FOR AGC OF INTERCONNECTED POWER SYSTEM WITH SMES

In modern power system, advances in SMES units did the researchers to explore it fully in power system. It can generate and absorb active and reactive power which aids in the rapid requirement of power system and various applications [10]. The block diagram of SMES as given in Fig.4, shows the deviation of inductor current which is considered as signal of negative feedback in the control loop [11]. Therefore, when there is a sudden demand in load, the feedback provides the current which can restore. SMES rebuilds the inductor current quickly to a nominal value after distributing to load. Dynamic equation for SMES can be given as:-

$$\Delta E_d(s) = (1/(1+sT_{DC}))(K_{SMES}\, ACE_i(s) - K_{id}\, \Delta I_d(s)) \quad (8)$$

$$\Delta I_d(s) = \Delta E_d(s)/ sL \quad (9)$$

Where ΔE_d is converter voltage incremental change, T_{DC} is converter time delay, K_{SMES} is the gain of the control loop, I_d is inductor current, K_{id} is the gain corresponding to current feedback. Parameter values for SMES unit applied to AGC of interconnected power systems are given in Appendix B. Study of PSO tuned IC for AGC of interconnected power system with SMES for both the case studies are discussed in next section, by considering 1% step increase of load.

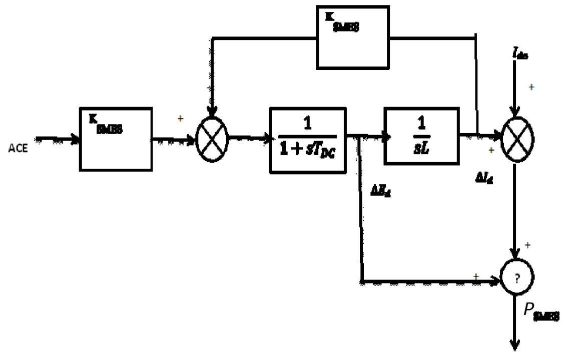


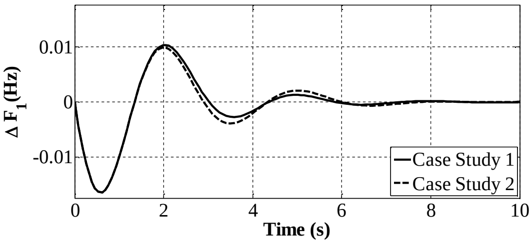
Fig 4. Block diagram of SMES

IV. SIMULATION RESULTS

The performance for AGC of three area interconnected power system using IC is realized with SMES and without SMES units by considering both case studies under 1% load disturbances. The rating of power system model for both case studies is given in Appendix B. Capacity of power system for the consider models is same for all the investigations. PSO technique is applied to optimize the IC gain parameters for each area of considered power models. Table II shows the characteristics of PSO tuned IC for AGC of interconnected power system without SMES in terms of settling time for both the case studies. It was established that AGC of interconnected power system with SMES under 1 % load disturbances gives better dynamic performances for both the case studies under 1% step increase of load. Fig.5 shows the dynamic responses for both case studies, AGC of three area interconnected power system with SMES, under 1% step increase of load in area 1. The performance index gets improved to 0.0000018 for both the case studies with the application of SMES in power system model. Fig.6 shows the dynamic responses for both case studies, AGC of three area interconnected power system with SMES, under 1% step increase of load in area 2. Fig.7 shows the dynamic responses for both case studies, AGC of three area interconnected power system with SMES, under 1% step increase of load in area 3. Fig.8 shows the dynamic responses for both case studies, AGC of three areas interconnected power system with SMES, under 1% step increase of load in each area. For the above said case, System response characteristics as shown in Table III are considerably improved when compared to AGC without SMES in Table II.

System variables	Settling Time in Case Study1(s) (1% step increase of load)				Settling Time in Case Study2 (1% step increase of load)			
	Area 1	Area 2	Area 3	Area all	Area 1	Area 2	Area 3	Area all
ΔF_1 (Hz)	5	4	4	5	4	50	7	40
ΔF_2 (Hz)	4	4	4	4	3.5	50	6	40
ΔF_3 (Hz)	4	4	3	3	4	50	6	40
ISE	0.0000018	0.0000019	0.0000018	0.0000019	0.0000018	0.000033	0.0000029	0.000038

Table III. System response characteristics of AGC with SMES



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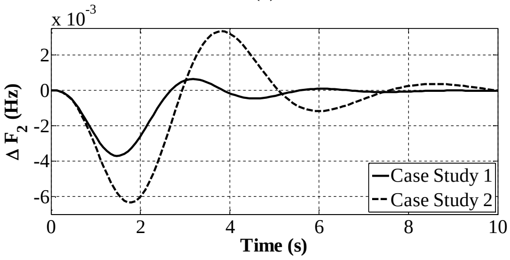

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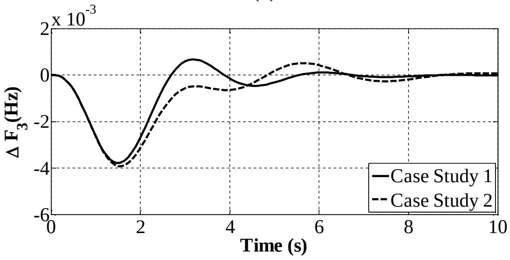
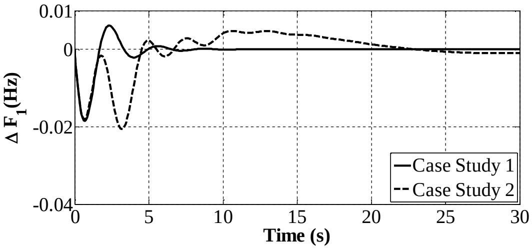


(c)

Fig 5. Transient responses of AGC with SMES by increasing 1% step load in area 1 (a) Frequency deviation of area1 (b) Frequency deviation of area2 (c) Frequency deviation of area3



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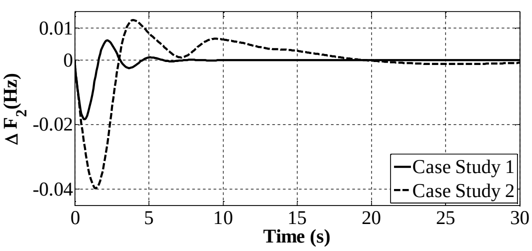

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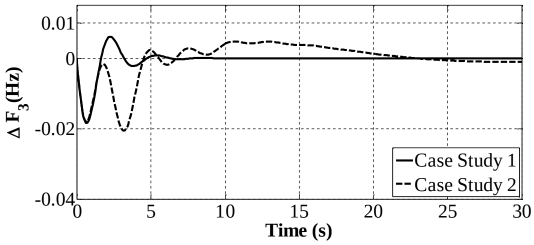
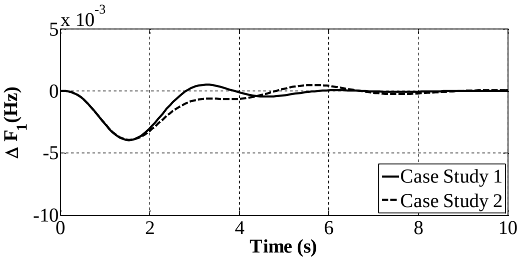


(c)

Fig 6. Transient responses of AGC with SMES by increasing 1% step load in area 2 (a) Frequency deviation of area1 (b) Frequency deviation of area2 (c) Frequency deviation of area3



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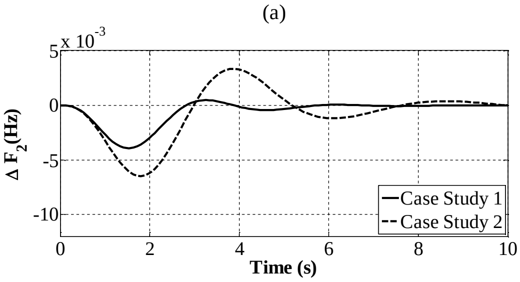

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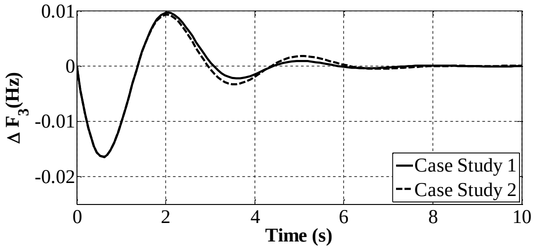
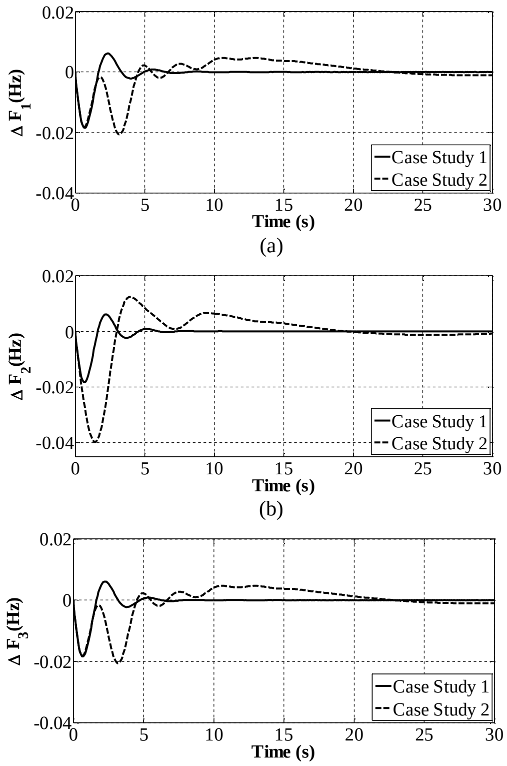


(c)

Fig 7. Transient responses of AGC with SMES by increasing 1% step load in area 3 (a) Frequency deviation of area1 (b) Frequency deviation of area2 (c) Frequency deviation of area3

Critical investigation for design AGC of three area interconnected power system with SMES shows that the system response characteristics in terms of settling time and performance index is comparatively less when compared to the data given in Table II , for 1% step increase of load in each area. It is examined that when we considered renewable hydro source in case study 2, the transient responses require large time to settle, as compared to case study 1 with conventional thermal source under 1% step increase of load. This can be significantly improved using the design of AGC with SMES.



(a) (b) (c)

Fig 8. Transient responses of AGC with SMES by increasing 1% step load in each area (a) Frequency deviation of area1 (b) Frequency deviation of area2 (c) Frequency deviation of area3

CONCLUSION

The effect of SMES unit on the performance for AGC of three area interconnected power system has been carried out for two different case studies under load changes. It has been observed that SMES respond quickly, for the improvement in dynamic responses of frequency oscillations when ACE is used as the input to SMES unit. The results show that PSO tuned IC helps in diminishing the frequency deviation for AGC of interconnected power system incorporating SMES under a variety of load perturbation in an area. In addition, it has been analyzed that when we consider one of the power system as hydro renewable source in three area interconnected power system then the model gives sluggish response as compared to the thermal conventional source. Above said the effect of hydro power system has been significantly improved by incorporating SMES unit.

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APPENDIX A

Nomenclature

R	Speed regulation of the generator
P_r	Rated power system capacity
T_g	Time constant of speed governor
T_t	Time constant of thermal turbine
T_P	Power system Time constant
T_W	Water starting turbine for hydraulic turbine
K_P	Power system gain
ΔP_G	Change in generated power
ΔP_D	Change in load demand
ΔP_C	Change in speed governor
ΔX_{RH}	Incremental change in mechanical governor
ΔP_{tie}	Tie-line power deviation
ΔX_E	Governor valve position Incremental change
ΔX_h	Hydraulic governor Incremental change

APPENDIX B

Nominal Parameters of Power System

General Power System	Therm al	Hydro	SMES
Pr=2000MW,f=60Hz, R = 2.4Hz/p.u. MW , b=0.425p.u.Mw/Hz, Kp=120,T_p=20s,P_{tie}=200 MW	T_t=0.3s T_g=0.0 8s	T_{RH}=41.6s , T_R=5s, T_{GH}=0.51 3s, T_W=1s	L = 2.6H, T_{DC} = 0.03s, K_{SMES}=100K V/ Unit ACE, I_{do} = 4.5KA

★★★