

# Load Frequency Control of an Isolated Power System in Presence of Controllable Energy Storage Devices

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Received: July 2017

Revised: October 2017

Accepted: November 2017

## ABSTRACT:

The usage of energy storage units in power system will reduce frequency oscillations immediately subjected to random load changes. In this project, investigations are carried out for an isolated power system with ALFC unit and isolated power system with mutual coupling effects. In each case the effect of different storage units is studied for random load changes. Here particle swarm optimization algorithm (PSO) and improved particle swarm optimization technique (IPSO) are used to tune the parameters of storage units to provide proper control strategy for the system. Instead of using two flexible storage devices, here one flexible storage unit is considered with constant storage system. Results are carried out in MATLAB/SIMULINK software.

**KEYWORDS:** Automatic Load Frequency Control, Secondary Controller, Energy Storage Systems, BESS, SMES, PSO, Improved PSO, Change in Frequency, Steady State Error, Power Compensation.

## 1. INTRODUCTION

There is an enormous need of energy from the electrical power system due to increase in demand. Since power system is a very complex network, maintaining system frequency and voltage within scheduled limits plays a pivot role. The generation should meet the load demand and the losses for the balanced supply and control of the power system. With the variation of active power, the frequency gets varied and the variation in reactive power affects the voltage level. With any fluctuation in these control parameters, it leads to the disturbance in the system thereby leading all the generators out of synchronism and to the outage. For the reliable and controlled operation of the power system, the system frequency and the voltage are to be controlled. This explains the necessity of insertion of automatic load frequency control loop and automatic voltage regulator in the feedback [1-3].

Various techniques like artificial Intelligence [3], hybrid-neuro-fuzzy [4], genetic fuzzy logic [5] and neural networks [6] are proposed by the researchers for interconnected systems. The energy storage technique is quite effective in damping oscillations due to frequency deviations and also economical. Battery energy storage system (BESS) and superconducting magnetic energy storage system (SMES) are incorporated in electrical system from many years with

wide range of benefits such as leveling of load, peak shaving, spinning reserve, capability to black-start, uninterruptible power supply (UPS), flicker compensation, voltage sag correction, area regulation and etc. with their fast acting nature and their static nature provides fast dynamic response unlike other generators [8-11]. The parameters of these storage devices are tuned for the more efficient operation of energy storage systems.

In [12] combination of bacterial foraging algorithm (BFA) and particle swarm optimization (PSO) called as hybrid-PSO (H-PSO) for multi area system is proposed. In [13], linear quadratic technique is used in designing the PID controller and genetic algorithm is applied. Teaching learning based optimization (TLBO) is applied to ALFC with multi source in [14]. Parameters of PID controller of ALFC are tuned with imperialist competitive algorithm in [15]. A fuzzy-logic controlled super-capacitor bank (SCB) for LFC of an interconnected system is proposed in [16].

In this study, ALFC with single area is taken with and without secondary regulation [1]. PI controller is used in control technique of LFC. The system block diagram consists of governor, turbine, generator and load with ALFC loop with any controller in its feedback. ALFC alone cannot serve the purpose hence BESS and SMES are both added for the system for the

better dynamic response. Well-known computing techniques PSO and improved PSO are applied to SMES unit and its parameters  $K_{smes}$  and  $T_{smes}$  are tuned for optimal solution. With the tuned parameters, the system can be operated more effectively in controlling frequency and other subsequent problems.

## 2. AUTOMATIC LOAD FREQUENCY CONTROL

ALFC of single area system consists of governor, turbine and generator with load. Steam valve regulates the inflow of the input according to the error signal generated by the sensor in the feedback. PI controller is used for secondary regulation which decreases the steady state error by increasing the system type by 1.

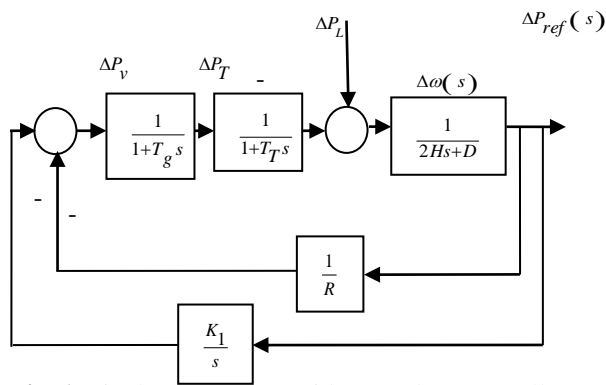


Fig. 1. Single area system with secondary controller.

Where  $\Delta P_L$  is the disturbance in load and  $\Delta P_{ref}(s)$  is the reference of change in speed. The primary loop in ALFC balances the output of the turbine according to the change in load. But there is also change in frequency which is regulated by the secondary loop having controller. With introducing the secondary controller, ALFC is named as AGC (Automatic Generation Control) in general. With the controller action, the steady state value of  $\Delta\omega(s)=0$  which in turn adjusts  $\Delta P_{ref}(s)$  accordingly so that the frequency change is nullified.

The transfer function of ALFC in fig.1 is given as,

$$\frac{\Delta\omega(s)}{-\Delta P_L(s)} = \frac{(1+T_g s)(1+T_T s)}{(2Hs+D)(1+T_g s)(1+T_T s)+\frac{1}{R}} \quad (1)$$

The energy storage systems (ESS) i.e., BESS and SMES are added to the single area system which improve the performance of the ALFC while load changing. The fast responding storage system can damp electromechanical oscillations in the power system since it provides the storage capacity in addition to the

generator rotor's kinetic energy to share the sudden change in load.

### 2.1. Modeling of BESS

BESS is economical now-a-days since the capital cost is reduced to an economic level. It absorbs power when the system frequency is high and injects power when the frequency is under the lower limit. Thus it is balancing the frequency within the limits [8].

The lag transfer function of BESS in first order is given as [17]:

$$\frac{\Delta f}{\Delta P_{BESS}} = \frac{k_{BESS}}{1+T_{BESS}s} \quad (2)$$

The block diagram representation is as follows:

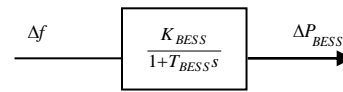


Fig. 2. Battery energy storage system.

### 2.2. Modeling of SMES

SMES is advantageous because of its static nature resulting in less losses and significantly high efficiency about 98.8% [10]. It is eco-friendly since it has no chemical reactions involved in it and no toxins are released into atmosphere.

Electrical energy is converted into magnetic energy and it is stored by SMES. Whenever there is load fluctuations i.e., raise or dip, the semiconductor coil inside the SMES will absorb or release the energy respectively. It allows the DC current to flow in the coil without any mechanical linkages but magnetically. To release the power, the reverse process takes place [18]. The two specifications of SMES device are rated power ( $P_{rs}$ ) and energy stored in the device ( $E_s$ ). The equations are represented as follows:

$$E_s = \frac{1}{2} L_{coil} I_{coil}^2 \quad (3)$$

$$P_{rs} = \frac{dE_s}{dt} = L_{coil} I_{coil} \frac{dI_{coil}}{dt} \quad (4)$$

The first order transfer function of SMES is given as:

$$\frac{\Delta f}{\Delta P_{SMES}} = \frac{K_{SMES}}{1+T_{SMES}s} \quad (5)$$

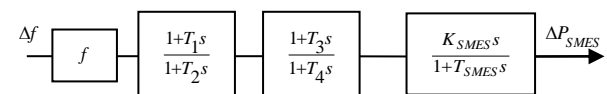


Fig. 3. Super conducting magnetic energy storage system as frequency controller.

The transfer function of Fig.3 is as follows:

$$\frac{\Delta f}{\Delta P_{SMES}} = \frac{f(1+T_1s)(1+T_3s)}{(1+T_2s)(1+T_4s)} \quad (6)$$

Where f is the proposed system frequency.

### 2.3. Proposed Model of ALFC with ESS

With the introduction of energy storage systems, the reliability and the system security gets improved. In this paper, BESS and SMES are two storage units added to a conventional single area model on load side. Some of the load demand is shared by them.

The input to the ESS is change in frequency and their output is their respective power compensation for the change in load. PSO and IPSO are the two techniques applied to tune the parameters of SMES whereas the parameters of BESS are tuned with PSO in MATLAB/SIMULINK. The tuning algorithms work on the objective of minimization of change in system frequency.

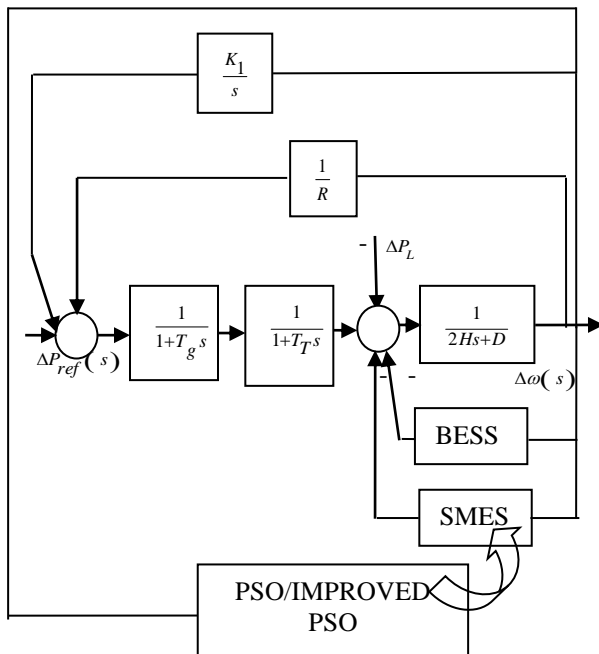


Fig. 4. Single area system with ESS.

### 3. OPTIMIZATION TECHNIQUES

Particle swarm optimization (PSO) and improved particle swarm optimization (IPSO) are the two techniques proposed in this paper.

#### 3.1. Particle Swarm Optimization

It is a computational technique to optimize the complex nonlinear functions by iterations. It is based on

population of the particles and is a metaheuristic process. It is one of the swarm intelligence techniques and is evolved from the behavior of swarm particles such as flock of birds or school of fish for their search of food. PSO is first proposed by James Kennedy and Russell Eberhart in 1995.

PSO is an easy computational technique with fast convergence and less than 100 iterations are sufficient even for very large complex functions. The position of every individual organism is  $p^i_k$  and the velocity is  $v^i_k$ . The best position of each organism is  $p_{best}$  and the overall optimized position is  $g_{best}$ . The velocity is updated by comparing previous and the new fitness values and then the position of the swarm is updated [19].

The velocity of each organism in the swarm is updated by the following equation,

$$V_i^{k+1} = \omega V_i^k + c_1 r_1 p_{best_i} + c_2 r_2 g_{best} \quad (7)$$

The variable  $g_{best}$  is the best position of the entire swarm. Using the updated velocity, the new position should be updated using the following equation,

$$P_i^{k+1} = P_i^k + V_i^{k+1} \quad (8)$$

If the new position satisfies the constraints, then this is the optimized position of the swarm.

$$P_{best_i} = P_i^k \quad (9)$$

Where,  $c_1, c_2$  = acceleration constant

$r_1, r_2$  = random numbers between 0 to 1

$\omega$  = inertia weight factor

The inertia weight factor is set by

$$\omega = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{k_{max}} * k \quad (10)$$

Where, k is the iteration value.

PSO uses few parameters and hence it is simple and very easy to realize. The convergence is also very fast when compared to traditional optimization techniques. Since it does not use the gradient of the problem, it can be applicable to irregular or noisy systems.

#### 3.2. Improved Particle Swarm Optimization

Standard PSO is an evolutionary algorithm which has its limitation of falling into local optimum very easily when operating with a complex objective function. To overcome this feature, genetic algorithm (GA) is combined with standard PSO which is IPSO.

GA is the search algorithm evaluated with the inspiration of genetics or natural selection. IPSO includes genetic parameters like cross over rate, mutation which are analogous to the gene mutation and crossover in reproduction. IPSO also holds fast convergence nature of PSO [20-22]. The genetic selection is included to avoid the problem of trapping in the local optimum position. In the process of searching, particles experience is not only best positions but also worst positions. The worst positions either by the individual particle or by the entire population are noted and avoided by the next generation population which increases the probability of attaining global optimum by the selection operation. Two parent particles are selected and two offspring particles are generated by crossover operation so that cornering in local optimum is diverted. After grouping the particles on the base of their fitness values, the first half i.e. best particles replace the second half category i.e. worst particles to maintain the size of the swarm.

The position and velocity of the particles are updated by the following equations in IPSO. The velocity of each particle is updated by including the diminution of worst positions.

$$V_i^{k+1} = \omega V_k^i + c_1 r_1 (P_{best_i} - P_w) + c_2 r_2 (g_{best} - g_w) \quad (11)$$

Where  $P_w$  and  $g_w$  are the worst positions of individual and entire swarm particles and the position of the swarm particle is reformed by Eq.(8) and weight of inertia factor is given as follows:

$$\omega(k) = \omega_{max} - (\omega_{max} - \omega_{min}) \left( \frac{k}{k_{max}} \right)^C \quad (12)$$

Where C is the nonlinearity constant

After every evolution, some particles are randomly selected and cross over operation is carried.

$$P_m^1 = P_m [1 + \zeta] \quad (13)$$

Where  $P^1$  and  $P$  are the new and mutated positions of  $m^{th}$  particle respectively.  $\zeta$  is the random number selected which follows the standard normal distribution. The mutated parameter are accepted by annealing algorithm in which annealing temperature is the variable (T).

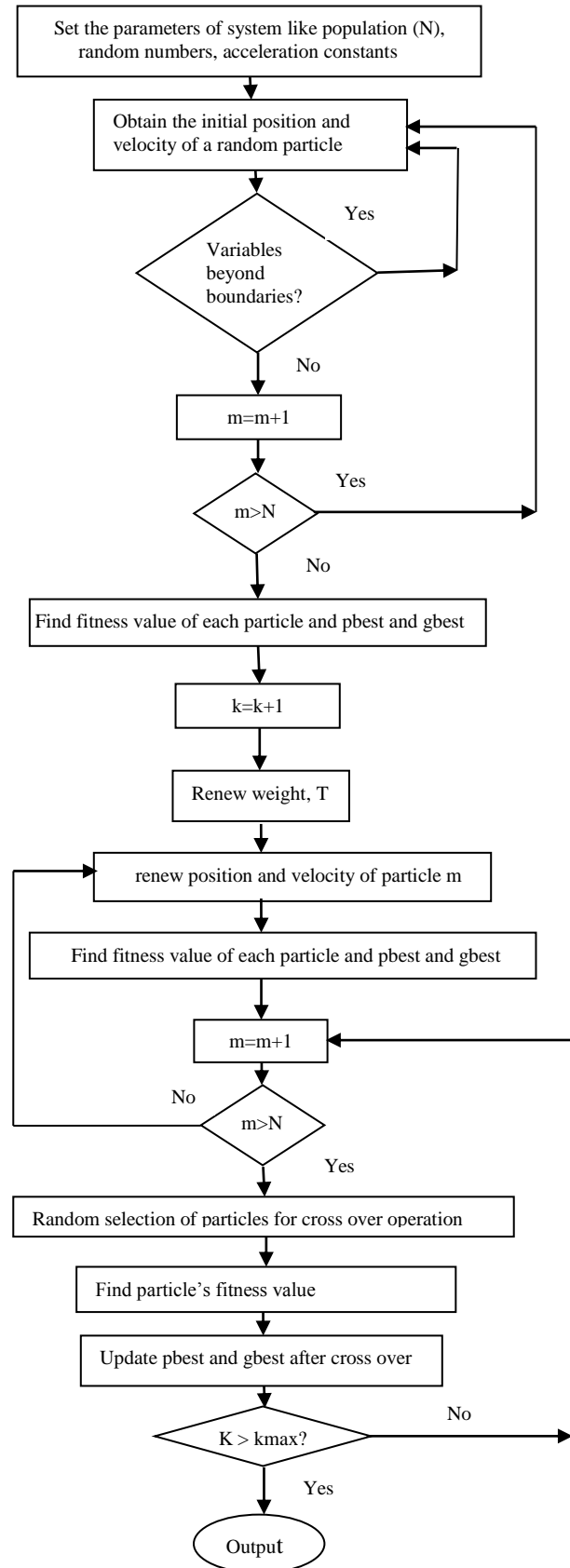


Fig. 5. Flowchart of IPSO algorithm.

4. SIMULATION RESULTS

The model of single area with ESS is simulated in MATLAB/SIMULINK environment. The proposed techniques PSO and IPSO are programmed in MATLAB (.m file). The PI controller in secondary loop has K=6 as its integral gain. The parameters of BESS are fixed and parameters of SMES are tuned with both PSO and IPSO. To analyze the system nature, it is simulated at different load levels and the comparison between with and without secondary loop, with and without ESS and also between two applied algorithms is carried out.

It is observed that with the inclusion of ESS, the peak value of change in frequency ( $\Delta f_{peak}$ ) gets reduced and also the steady state error ( $e_{ss}$ ) is minimized. The power compensation by the generator is reduced because of the power shared by ESS. The results are observed with BESS alone, with SMES alone and with both BESS and SMES. The proposed model is simulated for four different load conditions.

Single area system with and without secondary loop is simulated and plots between change in frequency and time with different ESS by applying PSO and IPSO are plotted in preceding figures. BESS parameters are tuned with PSO and kept fixed while SMES parameters are tuned with both PSO and IPSO for comparison purpose.

4.1. With 1% Load Increase

With introducing BESS, the peak value of change in frequency with PSO is  $0.6201 \times 10^{-3}$  Hz and with IPSO even though the settling time increases the peak of  $\Delta f$  decreases to  $0.1772 \times 10^{-3}$  Hz along with steady state error improvement from  $0.41 \times 10^{-3}$  to  $0.1238 \times 10^{-3}$ . This is illustrated in Fig. 6.

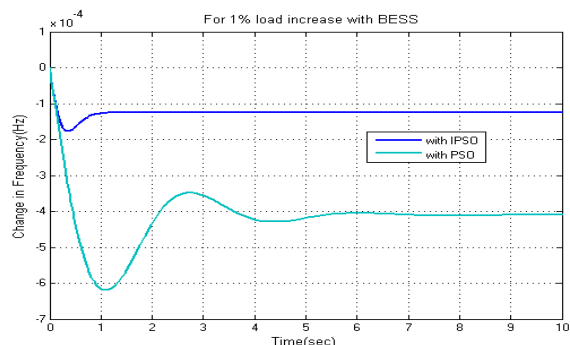


Fig. 6. Comparison of IPSO and PSO results of single area system without secondary controller with BESS for 1% load increase.

In Fig. 7 instead of BESS, SMES is added to single area system which further reduces the peak of variation in frequency to  $0.324 \times 10^{-3}$  Hz and steady state error as

$0.2607 \times 10^{-3}$  when tuned with PSO and  $0.2015 \times 10^{-3}$  Hz is peak of  $\Delta f$  and error is  $0.1278 \times 10^{-3}$  when tuned with Improved PSO which states that SMES gives better results than BESS.

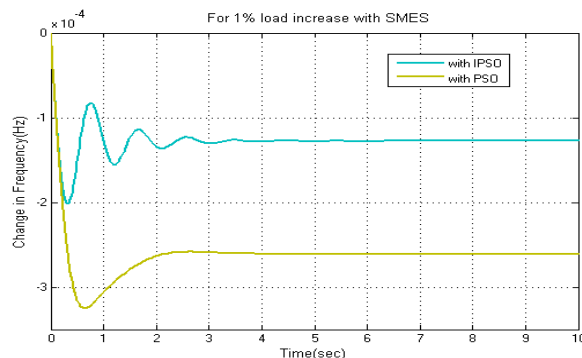


Fig. 7. Comparison of IPSO and PSO results of single area system without secondary controller with SMES for 1% load increase.

When both the units are added, the peak of  $\Delta f$  is further reduced to  $0.7690 \times 10^{-3}$  Hz with PSO and  $0.1281 \times 10^{-3}$  Hz with IPSO technique. The error also depletes to  $0.039 \times 10^{-3}$  and  $0.0722 \times 10^{-3}$  when tuned with PSO and IPSO respectively.

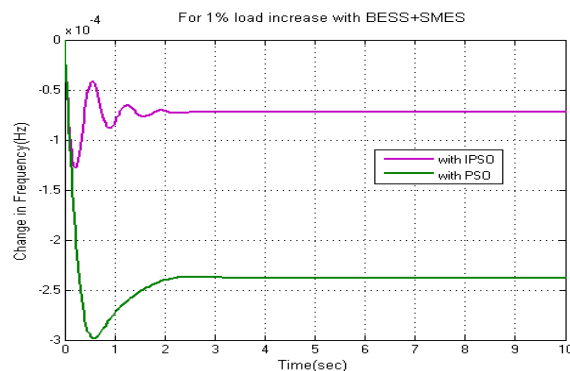
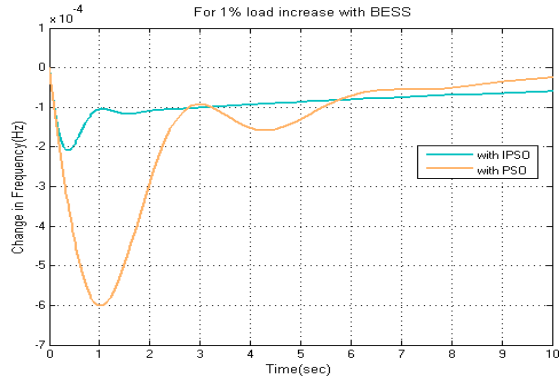


Fig.8. Comparison of IPSO and PSO results of single area system without secondary controller with both BESS and SMES for 1% load increase

Secondary controller is introduced and peak of  $\Delta f$  is  $0.7126 \times 10^{-3}$  Hz and  $e_{ss}$  is  $0.6605 \times 10^{-6}$  which are far less than system without secondary controller. The settling time is increased with secondary controller when compared with the case of without secondary controller.

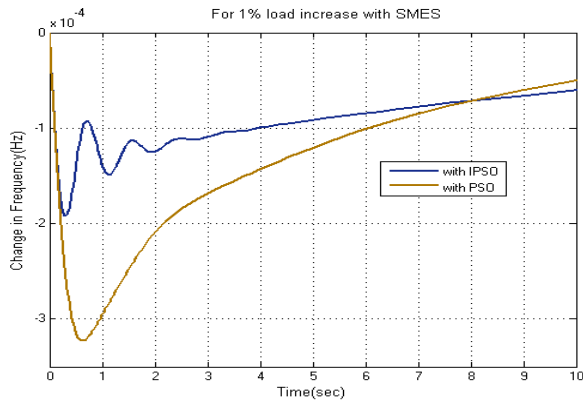
In Fig. 9 BESS is added and the results are plotted. It is evident from the plot that the error is almost tending to zero with secondary control action.  $\Delta f_{peak}$  and  $e_{ss}$  both are improved with secondary controlling action.  $\Delta f_{peak}$  is improved from  $0.6853 \times 10^{-3}$  Hz with

PSO to  $0.1771 \times 10^{-3}$  Hz with IPSO. Settling time with PSO is 30.5 and with IPSO it is 78.3.



**Fig. 9.** Comparison of IPSO and PSO results of single area system with secondary controller with BESS for 1% load increase.

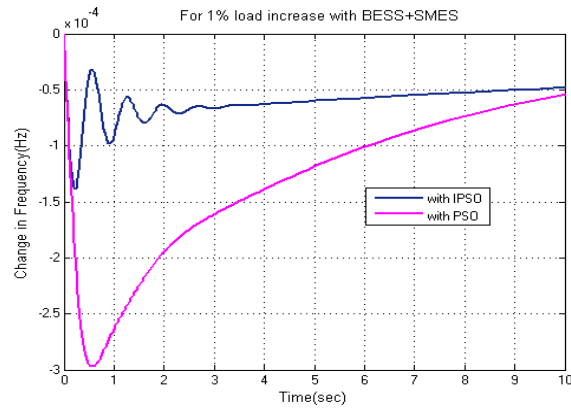
With addition of SMES to secondary controlling action, the control is more effective since the steady state error and change in frequency are improved as  $0.3224 \times 10^{-3}$  Hz with PSO incorporation and  $0.1917 \times 10^{-3}$  Hz with IPSO tuning.  $e_{ss}$  is 0 with IPSO and with PSO this is about  $0.0183 \times 10^{-6}$  which is near to 0.



**Fig. 10.** Comparison of IPSO and PSO results of single area system with secondary controller with SMES for 1% load increase.

Fig. 11 illustrates the data with both BESS and SMES insertion into the system.  $\Delta f_{peak}$  is  $0.2971 \times 10^{-3}$  Hz and error is  $0.0038 \times 10^{-6}$  when tuned with PSO and  $0.1249 \times 10^{-3}$  Hz and 0 respectively when tuned with IPSO.

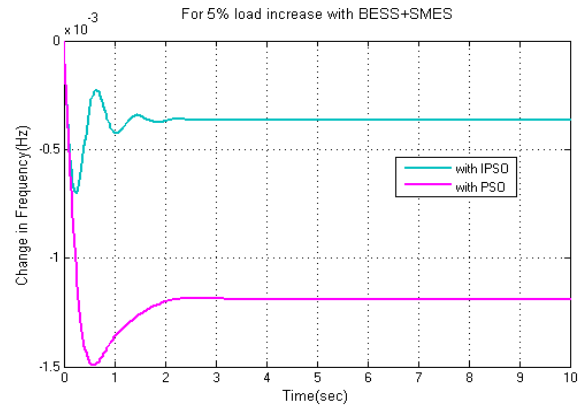
In both the cases with and without secondary controlling action, IPSO gives better results when compared to PSO due to the insertion of cross over operator in IPSO. This explains the advantage of Genetic Algorithm techniques when compared to Evolutionary techniques.



**Fig. 11.** Comparison of IPSO and PSO results of single area system with secondary controller with both BESS and SMES for 1% load increase.

**4.2. With 5% Load Increase**

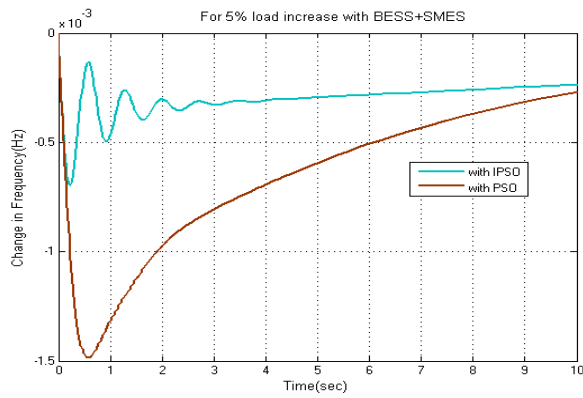
Same analysis is carried out for  $\Delta PL=0.05$  and the system is tuned with both PSO and IPSO.  $\Delta f_{peak}$  is  $1.4922 \times 10^{-3}$  Hz and  $e_{ss}$  is  $1.2000 \times 10^{-3}$  for the system without secondary controlling action when tuned with PSO which includes both the ESS.



**Fig. 12.** Comparison of IPSO and PSO results of single area system without secondary controller with both BESS and SMES for 5% load increase.

With IPSO the peak is still deprived to  $0.7005 \times 10^{-3}$  Hz and the error is  $0.3633 \times 10^{-3}$ .

In Fig. 13, the plot indicates the system with secondary control in which  $\Delta f_{peak}$  improved from  $1.4859 \times 10^{-3}$  Hz with PSO to  $0.6976 \times 10^{-3}$  Hz with IPSO. The error dwindled to 0 with IPSO whereas with PSO it is  $0.0192 \times 10^{-6}$  which is also a very small value.

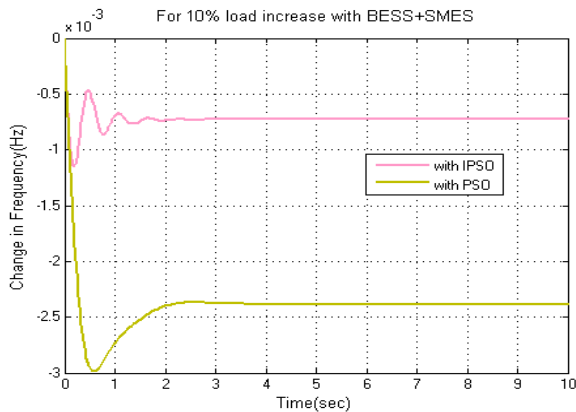


**Fig. 13.** Comparison of IPSO and PSO results of single area system with secondary controller with both BESS and SMES for 5% load increase

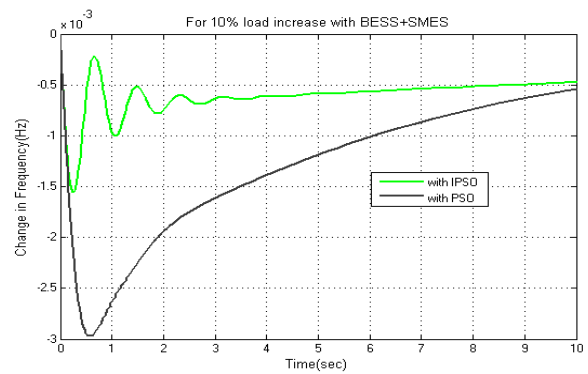
**4.3. With 10% Load Increase**

The system parameters are maintained as it is and  $\Delta PL$  changed to 0.1 i.e. 10% increment in load.

Fig. 14 and Fig. 15 explain the system performance without and with secondary controller. Peak of frequency distortion in system without secondary controller is  $2.9843 \times 10^{-3}$  Hz and error is  $2.4000 \times 10^{-3}$  when PSO is incorporated and with IPSO those values are  $1.4965 \times 10^{-3}$  Hz and  $0.7286 \times 10^{-3}$  respectively. With secondary controller,  $\Delta f_{peak}$  is  $2.9715 \times 10^{-3}$  Hz and  $e_{ss}$  is  $0.0385 \times 10^{-6}$  when PSO technique is used and  $1.3818 \times 10^{-3}$  Hz and 0 error when IPSO technique is used.



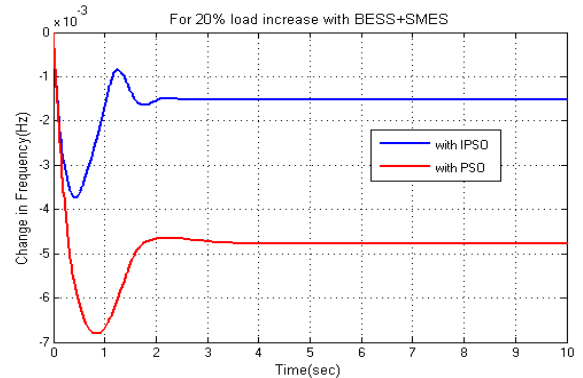
**Fig. 14.** Comparison of IPSO and PSO results of single area system without secondary controller with both BESS and SMES for 10% load increase.



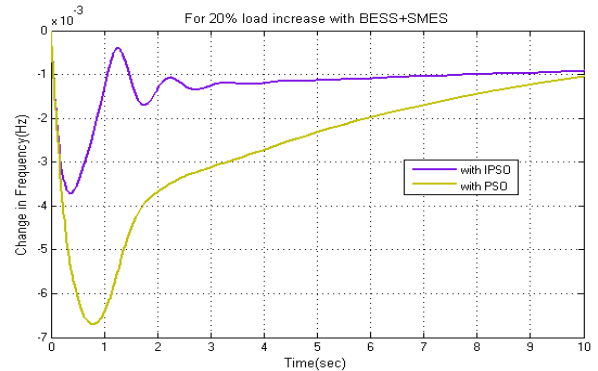
**Fig. 15.** Comparison of IPSO and PSO results of single area system with secondary controller with both BESS and SMES for 10% load increase.

**4.4. With 20% Load Increase**

The system is simulated with  $\Delta PL=0.2$  and performance plots are obtained in Fig. 16 and Fig. 17.



**Fig. 16.** Comparison of IPSO and PSO results of single area system without secondary controller with both BESS and SMES for 20% load increase.



**Fig. 17.** Comparison of IPSO and PSO results of single area system with secondary controller with both BESS and SMES for 20% load increase

With PSO  $6.6972 \times 10^{-3}$  Hz is peak of frequency change and error is  $0.0750 \times 10^{-6}$  which are improved to  $3.7233 \times 10^{-3}$  Hz and 0 respectively in the system with secondary controlling with both ESS added.

## 5. RESULTS ASSESSMENT

For the proposed system, different load variations are applied and corresponding peak value of change in frequency, steady state error, settling time and compensation of power by system and ESS are enlisted in the tables below. Table 1 to Table 3 represents single area without secondary control. Table 4 to Table 6 represents single area with secondary control.

**Table 1.** Performance analysis of ALFC without secondary controller.

$\Delta PL$	$T_s$	$\Delta f_{peak}$ ( $10^{-3}$ )	ess ( $10^{-3}$ )	$\Delta p_{mech}$ ( $10^{-3}$ )
0.01	10.9	0.74	0.48	09.6153
0.05	12.5	3.72	2.40	48.0769
0.10	12.8	7.44	4.80	96.1538
0.20	13.0	14.9	9.61	192.3076

In Table 1, for all the load changes, the system without secondary control can supply 96.15% of the demand.

**Table 2.** Performance analysis of ALFC+ESS without secondary loop with PSO technique.

$\Delta PL$	$T_s$	$\Delta f_{peak}$ ( $10^{-3}$ )	ess ( $10^{-3}$ )	$\Delta p_{mech}$ ( $10^{-3}$ )	$\Delta p_{esd}$ ( $10^{-3}$ )
0.01	1.07	0.76	0.03	00.7864	9.1703
0.05	4.60	1.49	1.20	23.8344	25.2121
0.10	4.10	2.98	2.40	47.6689	50.4242
0.20	4.80	6.81	4.77	95.3379	100.8485

With the introduction of ESS, when tuned with PSO the system compensation is reduced to 47.66% and the remaining demand is supplied by ESS whose compensation is around 50.42% which implies the reduction of burden on the conventional system. This is illustrated in Table 2 in which PSO technique is incorporated.

**Table 3.** Performance analysis of ALFC+ESS without secondary loop with IPSO technique.

$\Delta PL$	$T_s$	$\Delta f_{peak}$ ( $10^{-3}$ )	ess ( $10^{-3}$ )	$\Delta p_{mech}$ ( $10^{-3}$ )	$\Delta p_{esd}$ ( $10^{-3}$ )
0.01	4.25	0.12	0.07	1.4452	8.4969
0.05	3.24	0.70	0.36	7.2755	42.4333
0.10	4.80	1.49	0.72	14.5670	84.8501
0.20	3.64	3.73	1.52	30.4321	168.3505

Also with ESS, the system settling time gets reduced from 10.9 sec to 1.07 sec for 1% load change condition when tuned with PSO. Similarly, when tuned with IPSO, the settling time diminished to 4.25 sec for 1% load increase and 4.8 sec for 10% load increase condition.

**Table 4.** Performance analysis of ALFC with secondary loop.

$\Delta PL$	$T_s$	$\Delta f_{peak}$ $*10^{-3}$	ess $*10^{-6}$	$\Delta p_{mech}$ $*10^{-3}$
0.01	20.8	0.71	0.66	10.0000
0.05	25.6	3.56	0.70	50.0000
0.10	26.2	7.12	0.92	100.0000
0.20	26.6	14.2	1.16	200.0000

For system without secondary control, when added with ESS which are tuned with IPSO the burden on the system still reduced to 14.55% and compensation by ESS is 84.85% which is shown in Table 3.

**Table 5.** Performance analysis of ALFC+ESS without secondary loop with PSO technique.

$\Delta PL$	$T_s$	$\Delta f_{peak}$ ( $10^{-3}$ )	ess ( $10^{-6}$ )	$\Delta p_{mech}$ ( $10^{-3}$ )	$\Delta p_{esd}$ ( $10^{-3}$ )
0.01	53.4	0.29	0.003	9.9980	0.0020
0.05	53.4	1.48	0.019	49.9903	0.0100
0.10	53.5	2.97	0.038	99.9806	0.0201
0.20	55.5	6.69	0.075	199.9622	0.0392

The parameters of system with secondary control are enlisted in Table 4 in which the settling time increased from 10.9 sec to 20.8 sec for 1% load change but the system supplies 100% demand effectively unlike in the system without controller in which only 96.15% is supplied. This proves that with secondary control the system performance is improved.

**Table 6.** Performance analysis of ALFC+ESS with secondary loop with IPSO technique

$\Delta PL$	$T_s$	$\Delta f_{peak}$ ( $10^{-3}$ )	ess	$\Delta p_{mech}$ ( $10^{-3}$ )	$\Delta p_{esd}$ ( $10^{-6}$ )
0.01	110	0.12	0	0.0999	0.0979
0.05	138	0.69	0	0.4994	0.5638
0.10	130	1.38	0	0.9989	1.0686
0.20	115	3.72	0	1.9984	1.5565

Table 5 is for system with ESS when tuned with PSO. The load compensation by the system is decreased from 100% to 99.98% and the remaining load is 0.02% which is shared by ESS. Settling time increased from 20.8sec to 53.4 sec. With IPSO, the load shared by system is 0.99% and the remaining load 0.001% is shared by ESS in Table 6. It is observed that with secondary controller, the change in power is much reduced when compared without secondary controller even though there is variation in load.



## 6. CONCLUSION

It is known that today's power system is very complex and connected with large number of loads. With variation of any one of the loads, the entire system frequency may vary enormously which may lead to black out of entire grid. Only secondary controller is not enough to maintain the frequency balance for such a wide and complex network. Hence this paper proposes the addition of BESS and SMES which are effective and efficient storage units. With their fast acting nature, they respond for the sudden change in load even before the actual system. Some of the power will be compensated by ESS which decreases the burden on the actual system.

Incorporation of IPSO and PSO techniques to tune the parameters of ESS still improves the system performance. It is evident from the results obtained. Whereas IPSO is more effective than PSO in reducing the frequency fluctuations, steady state error and power compensation by the system in both the cases with and without secondary controller. It can be noticed from all the figures and tables in results section. However, the settling time varies differently for different scenarios with change in system parameters.

## 7. APPENDIX

**Table.7** Parameters of ALFC

Parameters	Value
$T_g$	0.2
$T_t$	0.5
$H$	5
$D$	0.8
$R$	0.05
$K_1$	1

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