

# **An Effect of Biogeography Based Optimization based frequency stabilizer on Load Frequency Control of an Interconnected Hydro-Thermal Power System**

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**ABSTRACT:** This paper made an attempt for the effective application of biogeography based optimization (BBO), a bio-inspired optimization method, to optimize gains of classical controller and frequency stabilizer in load frequency problem (LFC) of an interconnected two-area hydro-thermal power system. Thermal unit is equipped with single-stage reheat turbine and hydro unit is studied with electrical governor. Speed governor of both the control areas are studied with dead band (DB) type of non-linearity. Describing function approach is used to find linear model of DB non-linearity. BBO based integral squared error (ISE) criterion is used to minimize area control error (ACE), which is considered as an objective function for the study. 1% step load perturbation (SLP) in area-1 and MATLAB/SIMULINK environment is considered for investigating dynamic responses of concerned power system unit.

**KEYWORDS:** Automatic generation control, superconducting magnetic energy storage, Dead Band, ISE, Biogeography based optimization

## **I. INTRODUCTION**

An interconnected electrical power system generates transports and distributes electrical energy with nominal system frequency and terminal voltage. The main objective of power system operation and control is to balance between power generation and total load demands plus losses in system. Any mismatch between generation and load demand causes deviation of system frequency and tie-line power, which leads to instability of the system operation. In this aspect LFC plays very important role in power system operation and control. It is defined as sudden load perturbation that may continuously disturbed nominal operation of system frequency and tie-line power. Therefore, for stable operation of power system both frequency and tie-line power are made to be constant.

When the literature is studied, it's observed that first attempt in LFC has been made to control frequency and tie-line power via flywheel governor of synchronous machine. But, this method does not give satisfactory improvement of dynamic performances and hence secondary controller was included with governor control for further improvement of LFC. A number of secondary control scheme have been applied in the design of LFC over past few decades. Chon [1] was initiated work on LFC; however, concept of optimal controller for LFC design of interconnected power system was developed by Elgerd and Fosha [2]. Literature survey shows that most of the earlier works are carried out on single or multi area thermal systems [3-10]. Less attention is paid on the study of hydro-thermal system [11, 12]. Kothari et. al. [13] proposed sampled data LFC for two-area interconnected reheat thermal system without consideration of physical constraints.

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Several researchers proposed different controller scheme such as Artificial Neural Network [14, 15], Fuzzy logic [16], GA based [8, 17] etc. [3] to investigate two-area thermal system with classical type PI-controller, where parameters are optimized by PSO algorithm. State feedback based controller was designed to get better dynamic performance of LFC, but this require availability of all state variables of the system which are not readily available. The advent of intelligent controller has solved LFC problem to some extent but the design and implementation of these controllers are quite complex. That is why most of the power station employed classical controllers in the field of LFC because implementation of this controller is easy.

The internal characteristic of power system network is highly non-linear; therefore optimum values of classical controller parameters are insufficient to give better performance of the system. Sudden small load variation may change the operating point which causes deviation of tie-line power and power frequency from their nominal values. To damp out oscillations within short possible time, Super Magnetic Energy Storage unit is attached with LFC.

In this paper classical controllers are designed through BBO algorithm to study the dynamic responses of hydro-thermal system with governor non-linearity. To further improve controller performance, small size magnetic storage unit is attached with LFC and comparison between different dynamic performances is tabulated in this paper.

## II. SYSTEM DESCRIPTION

The LFC system investigated for present study is composed of an interconnection of two unequal system of area-1: 1600MW and area-2: 1800MW capacity. Area-1 is considered with single-stage reheats type thermal system and Area-2 is a hydro system with Electrical type governor. Both thermal and hydro governors are studied with Dead Band type non-linearity. Overall block diagram of test system is shown in Fig. 1. 1% step load perturbation (SLP) in area-1 is considered for study. Nominal values of all parameters are given in Appendix-1. MATLAB version 2009 is used to study the dynamics of an interconnected power system. Integral (I), Proportional plus Integral (PI), Proportional plus Integral plus Derivative (PID) type of controllers are used for this study. Optimum values of controller parameters are determined by Integral Square Error (ISE) criterion through BBO algorithm.

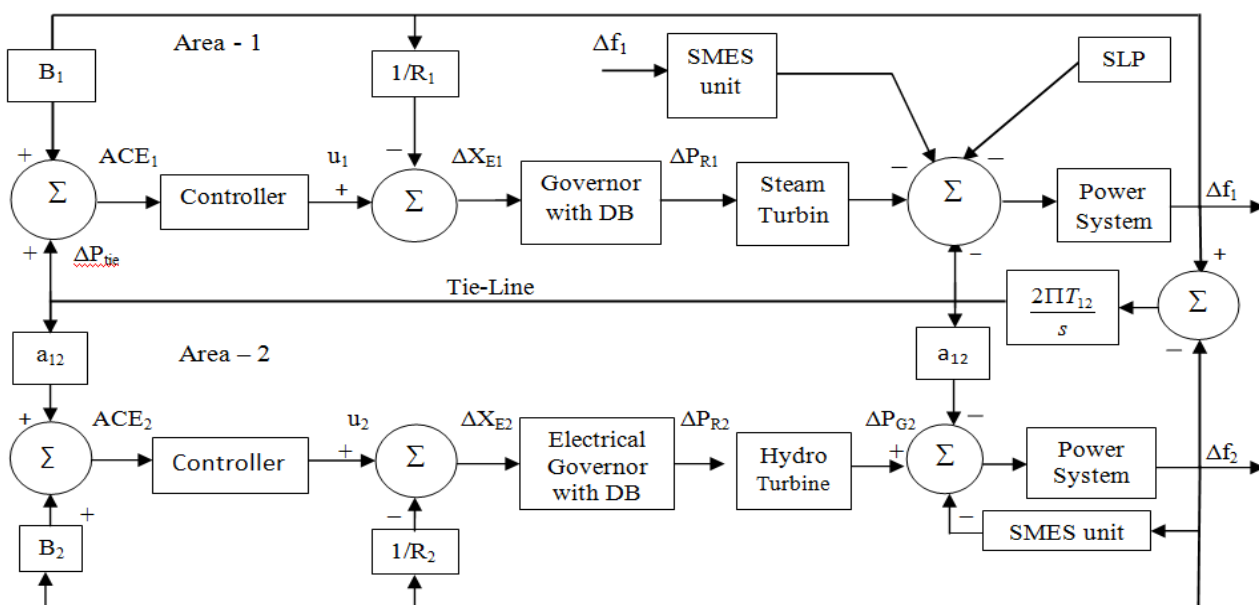


Fig. 1 Block Diagram of a Two-area hydro-Thermal Interconnected Power System

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### III. GOVERNOR DEAD BAND (GDB)

GDB is defined as the total magnitude of sustained speed change within which there is no resulting changes in valve position. The limiting value of DB is 0.06% [18].

The hysteresis type of non-linearity is expressed as,

$$y = f(x, \dot{x}) \tag{1}$$

Where,  $x = A \sin(\omega_0 t)$  (2)

$\omega_0 = 2\pi f_0$  and  $f_0$  is the fundamental frequency of oscillation in Hz. Since, non-linearity always possess continuous oscillations with constant frequency and amplitude, hence it is realistic to consider input as defined in (2). Expanding (1) in Fourier series form [4],

$$y = y_0 + N_1 x + \frac{N_2}{\omega_0} \frac{dx}{dt} + \dots \tag{3}$$

Since, non-linearity is symmetric about the real axis, hence,  $y_0 = 0$ . Therefore, equation (3) can be re-written as,

$$y = N_1 x + \frac{N_2}{\omega_0} \frac{dx}{dt} + \dots \tag{4}$$

Taking Laplace Transform of equation (4), we have

$$Y(s) = N_1 X(s) + s \frac{N_2}{\omega_0} X(s)$$

$$\Rightarrow \frac{Y(s)}{X(s)} = N_1 + s \frac{N_2}{\omega_0} \tag{5}$$

Equation (5) defines the linear model of GDB non-linearity. According to [4], the values of  $N_1$  and  $N_2$  are considered as 0.8 and (-0.2), respectively.

### IV. SUPERCONDUCTING MAGNETIC ENERGY STORAGE (SMES)

Small load perturbation in any area of an interconnected system causes deviation of frequency and tie-line power, even though the controller parameters are optimized. For this reason, SMES unit installed with interconnected system. As mentioned in [19], best suitable location of placing of SMES unit is at the terminal bus of an area Under normal operating condition, SMES coil is charged to a pre-defined minimum value (less than rated value) from AC power through power converting system. Once the coil is charged, current starts to flow through coil. The coil is continuously immersed in a bath of liquid Helium for cooling. Tripathy et. al. [4] describe that very small size SMES unit (order of 18 MJ or less) is required to improve dynamic response of LFC system.

Fig. 2(a) shows the power circuit diagram of SMES unit. When there is a sudden rise in load, the energy stored into the magnetic field released to power unit. When primary and secondary control loop starts working to restore the frequency and power to nominal value, SMES coil again come back to its initial state. Similar action takes place during sudden release of load.

The proper operation of SMES unit is achieved by applying appropriate voltage across the coil; this can be made by controlling firing angle of Power Conversion System (PCS). The charge stored in the coil at any instant of time is,  $W_L = 0.5LI_d^2$ , where  $L$  and  $I_d$  are the inductance in Henry and current through coil in KA, respectively.

As described in [19], SMES is considered as active power flow controller, as shown in Fig. 2(b). This stabilizer is expressed as cascaded lag-lead controller.

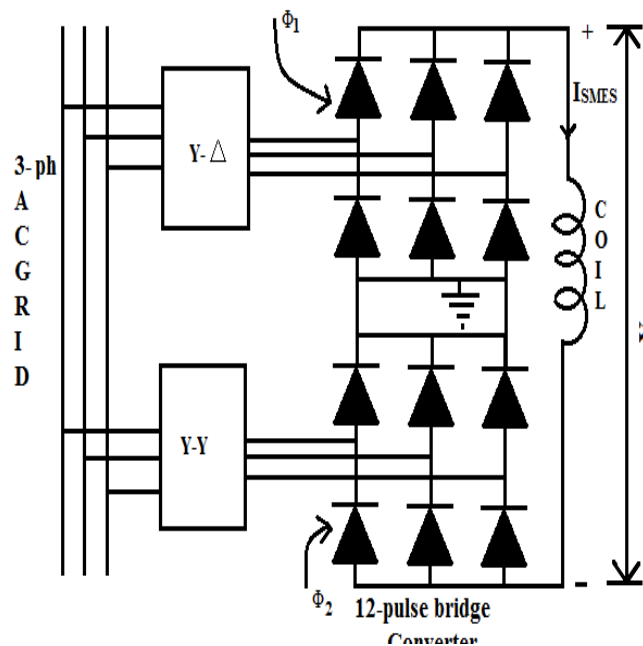


Fig. 2 (a): Power Circuit Diagram of SMES unit

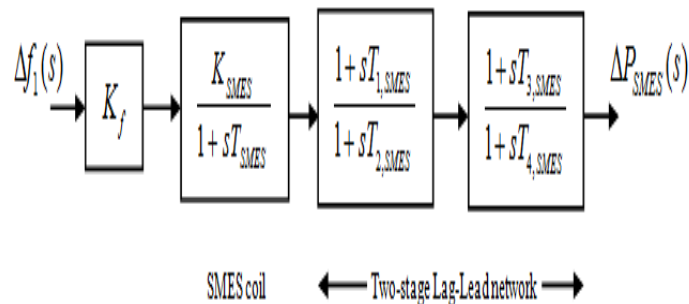


Fig. 2(b): Transfer Function model of SMES unit

### V. BIOGEOGRAPHY BASED OPTIMIZATION

Biogeography based optimization (BBO) is a new kind optimization algorithm based on bio-population. It simply mimics the migration process of biological animals to find optimum values of the given problem. Bio-geography is the study of distribution of species in nature and each possible solution is an island [20]. Each possible features of island is called habitat suitability index (HSI). Features are like rain fall, diversity of vegetables, land area, temperature etc. maximum availability of features in island leads to high HSI value and minimum availability gives poor HSI value. To maintain balance in nature, always poor HSI share own features with high HSI. In BBO, a habitat (H) is a vector of size N defined randomly. Before optimization, each population is evaluated and then follows migration and immigration process to reach global minima or maxima.

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Vol. 5, Special Issue 13, October 2016

Migration algorithm is defined as [20]

Select  $H_i$  randomly with probability  $\alpha\lambda_i$

```

if  $H_i$  is selected
  for  $j = 1$  to  $p$ 
    select  $H_j$  with probability  $\alpha\mu_i$ 
      if  $H_j$  is selected
        randomly select SIV from  $H_j$ 
        replace a random SIV in  $H_i$  with  $H_j$ 
      end
    end
  end
end
end
  
```

In BBO, the mutation is used to increase diversity of population so that good solution can be achieved. The mutation rate ( $m$ ) can be defined as:

$$m = p_{mutate} * \left( 1 - \frac{P_i}{P_{max}} \right) \tag{6}$$

where,  $p_{mutate}$  is a user defined parameter and  $p_{max} = \text{argmax}(p_i)$ ,  $i = 0, 1, 2, \dots, p$ .

Habitat mutation is described as follows [20]

```

for  $j = 1 : N$ 
  use  $\lambda_i$  and  $\mu_i$  to compute the probability  $P_i$ 
  select SIV  $H_i(j)$  with probability  $\alpha P_i$ 
  if  $H_i(j)$  is selected
    repeat  $H_i(j)$  with a randomly generated SIV
  end
end
end
  
```

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Vol. 5, Special Issue 13, October 2016

## VI. PARAMETER OPTIMIZATION

A control system is optimum when selected objective function is minimized. Optimum values of controller parameters and SMES units are directly depend on optimality which is computed for proper coordination between the areas and to extract maximum benefits from the system [4]. The controller parameters are to be set to optimal values for maintaining system stability. Integral square error (ISE) criterion is used here for optimization through Bio-Geography Based Optimization (BBO) algorithm. The objective function is to be minimized:

$$J = \sum_{i=1}^{N_{\max}} [B_i \Delta f_i + \Delta P_{tie}]^2 \Delta T \quad (7)$$

Where,  $J$  = fitness function,  $B_i = D_i + \frac{1}{R_i}$  = Biasing factor,  $\Delta P_{tie}$  = error in tie-line power,  $N_{\max}$  = maximum number of iteration.

## VII. RESULTS AND DISCUSSION

The main objective to perform this simulation is to test effectiveness and superiority of BBO based classical controllers on two-area hydro-thermal system with governor non-linearity. The model of test system under study has been developed in Matlab/Simulink environment and proposed BBO algorithm has been written in (.m file). The objective function (ACE) is evaluated in (.m file) using ISE criterion and used to optimized gains of controller parameters. Simulations were performed on a personal computer having 2.4 GHz core i3 processor with 2 GB RAM in Matlab R2009 environment. The nominal values of system parameters are illustrated in Table 1 and 0.01 p.uMW load variation in area-1 is considered to investigate frequency, tie-line power deviation.

For successful implementation of BBO, optimum gains of different parameters are required to be determined. Owing to the uncertain behavior of BBO, fifty trials have been made to select optimum values of input parameters of same for better optimization of controller parameters and following are found to be best for LFC problem: population size = 40, mutation probability = 0.05, total number of iteration = 100, elitism parameter = 4, maximum immigration and emigration rate = 1.

Fig. 3 shows convergence behavior of proposed BBO algorithm under different mode of operation. Dynamic performances of test system under different operating conditions are shown in Fig. 4 to12. The optimum values of all parameters at the end of optimization are tabulated in Table 2 and 3. Transient specifications in terms of settling time, overshoot, undershoot of frequency and tie-line power are given in Table 4 and 5.

Table 1: Nominal values of system parameters

Parameter	values	Parameter	values	Parameter	values
f	60 Hz	B	0.425	T <sub>ps</sub>	20 sec
T <sub>12</sub>	0.0866	R <sub>i</sub>	2.4Hz/pu MW	K <sub>ps</sub>	120
T <sub>g</sub>	0.08 sec	T <sub>i</sub>	0.3 sec	T <sub>w</sub>	1 sec
K <sub>r</sub>	0.5	T <sub>r</sub>	10 sec	K <sub>p</sub>	1
K <sub>D</sub>	4	K <sub>I</sub>	5		

Table 2: Optimized values of controller parameters using BBO

Controller	K <sub>i1</sub>	K <sub>i2</sub>	K <sub>p1</sub>	K <sub>p2</sub>	K <sub>d1</sub>	K <sub>d2</sub>	J
I	1.9993	0.0003	-	-	-	-	14.1181
PI	1.9986	0.0001	0.7394	0.2482	-	-	8.9427
PID	1.9942	0.0066	1.9974	0.0004	1.9899	0.1938	5.0591

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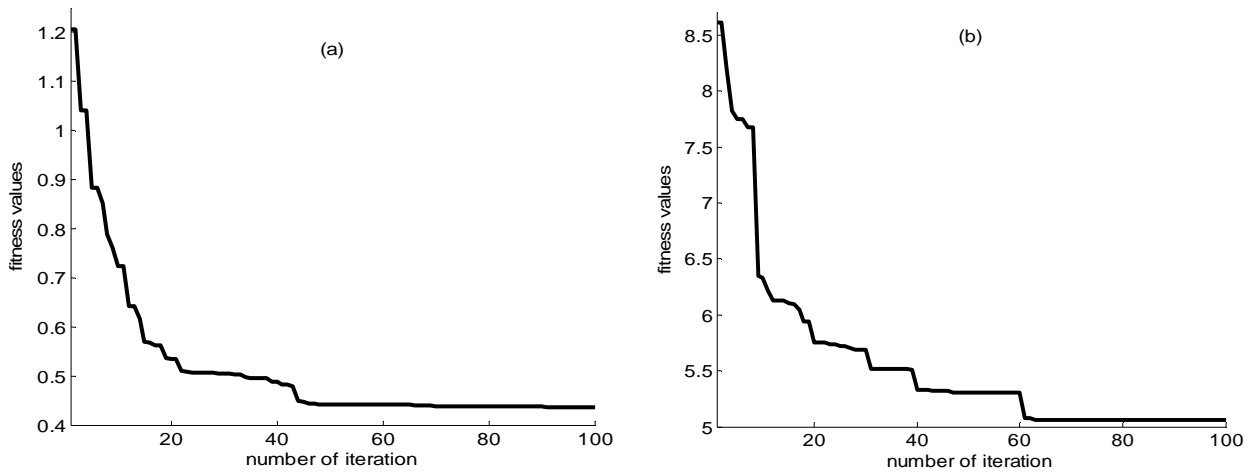


Fig. 3: Convergence curve of BBO algorithm (a) PID controller only, (b) PID-controller and SMES

Table 3: Optimized values of controller and SMES parameters

Controller	$K_{i1}$	$K_{i2}$	$K_{p1}$	$K_{p2}$	$K_{d1}$	$K_{d2}$	$K_{SMES}$	$T_{SMES}$	$T_1$	$T_2$	$T_3$	$T_4$	J
I	1.9994	0.0257	-	-	-	-	0.997	0.483	0.997	0.069	0.2447	0.5126	0.5353
PI	1.995	0.051	1.99	0.461	-	-	0.99	0.639	0.999	0.096	0.998	0.6430	0.5002
PID	1.99	0.086	1.998	0.519	1.998	0.000	0.999	0.0112	0.999	0.3656	0.1916	0.3503	0.4365

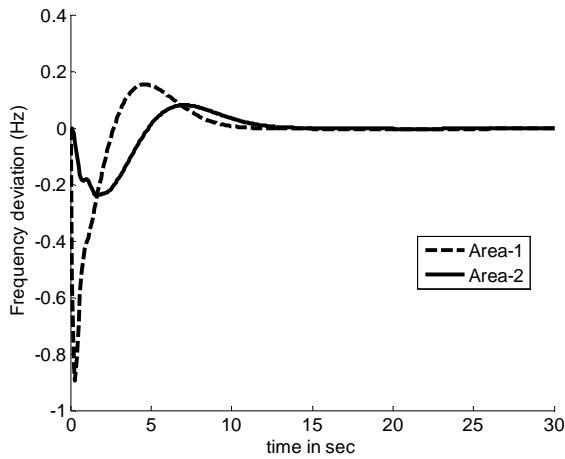


Fig. 4: Frequency error with SMES using I-Controller

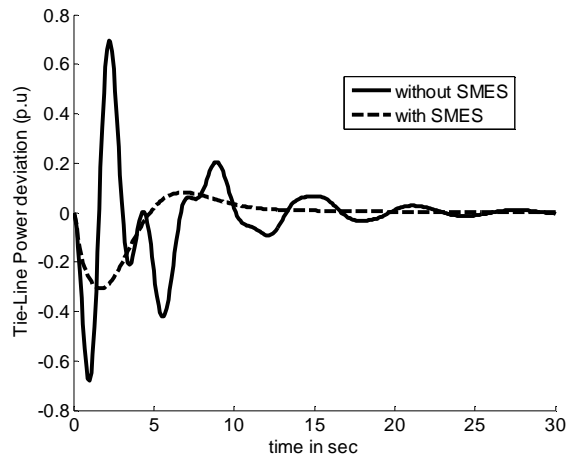


Fig.5: Tie-Line power error using I-Controller

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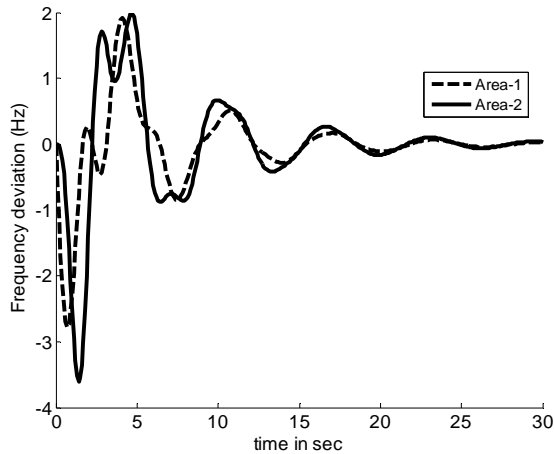


Fig. 6: Frequency error without SMES using I-Controller

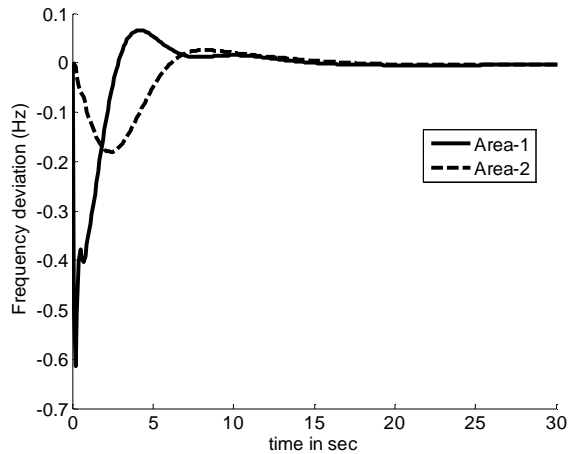


Fig. 7: Frequency error with SMES using PI-Controller

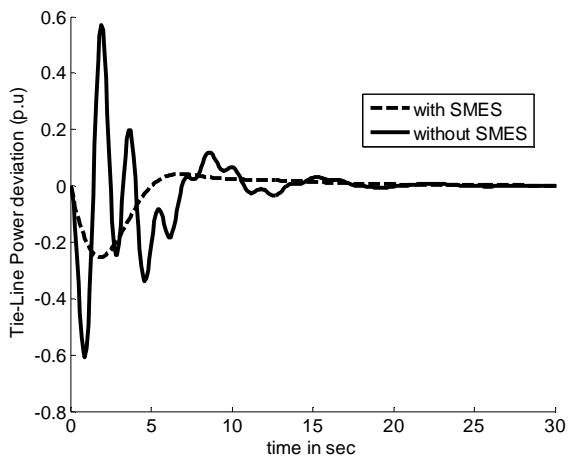


Fig. 8: Tie-Line Power error using PI-Controller

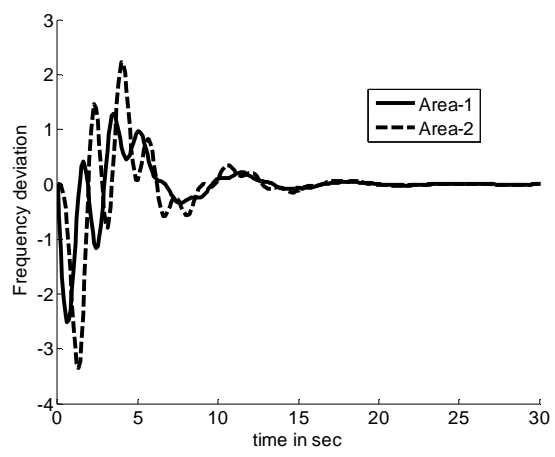


Fig. 9: Frequency error without SMES using PI-Controller

Table 4: Transient response specifications without SMES

Controller	Area-1			Area-2			Tie-line power		
	OS	US	ST	OS	US	ST	OS	US	ST
I	1.912	2.777	23.9	1.978	3.700	23.9	0.695	0.681	24.7
PI	1.284	2.521	15.9	2.232	3.349	17.5	0.608	0.608	17.2
PID	0.561	1.178	15.8	0.598	1.041	15.7	0.192	0.192	21.2

Table 5: Transient Response Specification with SMES unit

Controller	Area-1			Area-2			Tie-line power		
	OS	US	ST	OS	US	ST	OS	US	ST
I	0.1534	0.8936	9.38	0.0801	0.2401	13.4	0.0815	0.3074	13.7
PI	0.0663	0.6141	12.3	0.0260	0.1801	16.6	0.0416	0.2530	19.6
PID	0.0446	0.4653	11.4	0.0278	0.1733	21.8	0.0465	0.2249	20.4



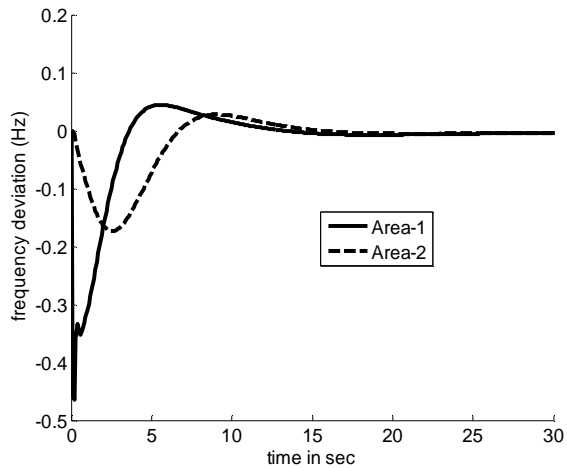


Fig. 10: Frequency error with SMES using PID-Controller

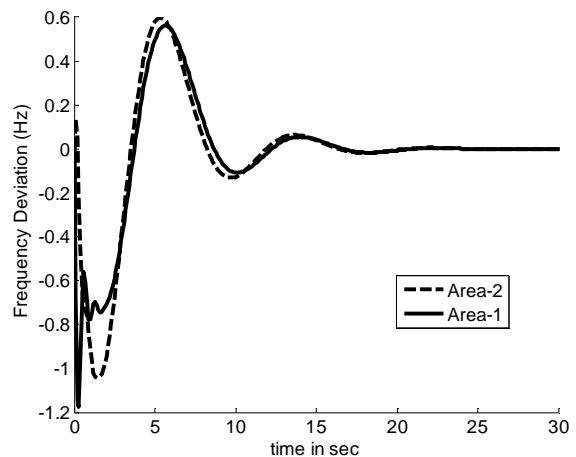


Fig. 11: Frequency error without SMES using PID controller

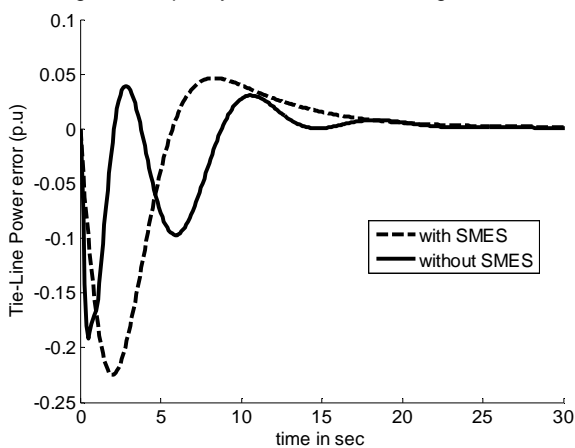


Fig. 12: Tie-Line Power error using PID-Controller

## VIII. CONCLUSION

In this article, new gain scheduling of classical controller parameters is proposed for LFC in power system. It has been demonstrated from the dynamic responses that governor dead band has destabilizing effect on power system dynamics. A bio-inspired population based optimization, BBO algorithm is used to optimize controller and frequency stabilizer gains. It has been also concluded that small size SMES unit can effectively die-out transient oscillations. The simulation results shows that performance of PID controller with coordination of SMES unit gives better performance compare to others

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