BSA/WDO based optimization of two-area multi-sources automatic generation control

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***Abstract*—This paper presents comparative performance analysis of Automatic generation control with two recently developed meta-heuristic nature inspired algorithms called Backtracking search algorithm/Wind driven optimization algorithm. An attempt has been made to show the superiority of Wind driven optimization algorithm over Backtracking search algorithm to improve the transient performance of automatic generation control of an interconnected two-area multi-source power system with physical constraints governor dead band, generation rate constraints, reheat system. Comparative studies of BSA and WDO with PI/PID controller reveals that WDO based PID controller in both the areas improve the transient performance to a greater extent following small load perturbation(s).**

Keywords*— *Automatic genearation control, Backtracking search algorithm, Boiler dynamics, Generation rate constraints, governor dead band, wind driven optimization.

I. INTRODUCTION

The main aim of Automatic Generation Control (AGC) is to maintain the Area Control Error to zero so that there is stabilization in the system frequency and tie-line error. An electrical grid is an interconnected network for delivering electricity from suppliers to consumers. There are numbers of control areas or regions in the interconnected power systems and each control area is obliged to generate power such that there is a balance between powers generated and power demand. There are two basic control mechanism used to achieve power balance; reactive power balance (acceptable voltage range) and active power balance (acceptable frequency range). The former one is called AVR (Automatic Voltage Regulator) and latter is called the Automatic Generation Control (AGC) or Automatic Load Frequency Control (ALFC) [1]. In multi area system which is normally an interconnected system, there AGC is of an important aspect and it is installed on each generator. The main function of an AGC is to keep the Area Control Error to zero; such the system frequency deviation following a step load change is zero [2]. Complexity and growth of the utility grid system along with the increase in power demand it became necessitate using the intelligent system that combine knowledge, technique and methodology from various sources for the real time control of power system.

The researchers in this area have studied the LFC problem of thermal, Hydro-thermal, wind, diesel and many more using PID controller [3], fuzzy controller [4], fuzzy based PID controller [4], FOPID controller, 2-degree FOPID controller [5], decentralized controller and optimal MISO PID controller based on different algorithm. Many of the control strategy mentioned in the literature are optimal control, variable control structure, adaptive and self tuning control [3]. Some researchers investigated fuzzy logic based control and ANN approaches for AGC tuning. But, the problems identified with these are computational time required for rule base is considerable for fuzzy logic based control and more time is required for the data base for training the neural network controller in case of artificial neural network (ANN) [8]. In recent years, several attempt have been made to solve AGC problem by several intelligence based method like Genetic Algorithm (GA), Particle swarm optimization technique, Gravitational search algorithm [6], Differential Evolution algorithm [7], Improved particle swarm optimization, bacterial foraging optimization (BFO) [8], artificial bee colony (ABC), firefly algorithm (FA) [9], hybrid BFOA-PSO, hybrid PS-PSO [10] because of individual strength and weakness of the algorithm.

Section II of the paper gives a brief description and mathematical formulation of Automatic generation control (AGC). Section III describes the basics of Backtracking Search Algorithm and Wind Driven Optimization technique. Simulation studies are presented and discussed in section IV and conclusion is drawn in section V.

II. DESCRIPTION OF THE SYSTEM MODEL

Two area four units which have thermal and hydro plants in each area have been considered for investigation with physical constraints like governor dead band, generation rate constraints, reheat turbine and boiler dynamics. Each area has a rating of 2000MW with a nominal loading of 1000 MW. Each area has three inputs and two outputs. The inputs are controller input ΔP_{ref}, load disturbance ΔP_D and tie line power error ΔP_{tie}.

The outputs of the AGC are frequency deviation Δf and Area control error (ACE) which is given in eq (1). The parameter of PI/PID controller are tuned with Backtracking search algorithm and wind driven optimization technique. The system parmaters are taken from [11] and are given in appendix.

As both areas are considered to be an identical, therefore the controller parameter in both the areas are assumed to be an identical so that $K_{P1} = K_{P2} = K_P, K_{I1} = K_{I2} = K_I, K_{D1} = K_{D2} = K_D$. The error inputs to the controllers are the respective Area Control Error (ACE) given by,

$$e_1(t) = ACE_1 = B_1 \Delta f_1 + \Delta P_{tie} \quad (1)$$

$$e_2(t) = ACE_2 = B_2 \Delta f_2 - \Delta P_{tie} \quad (2)$$

The control inputs of the power system u_1 *and* u_2 are the outputs of the controllers. With PI structure ($K_{D1} = K_{D2} = 0$) the control inputs are obtained as :

$$u_1 = K_{P1} ACE_1 + K_{I1} \int ACE_1 \quad (3)$$

$$u_2 = K_{P2} ACE_2 + K_{I2} \int ACE_2 \quad (4)$$

The control inputs of the power system $u_1$and u_2 with PID structure are obtained as:

$$u_1 = K_{P1} ACE_1 + K_{I1} \int ACE_1 + K_{D1} \frac{dACE_1}{dt} \quad (5)$$

$$u_2 = K_{P2} ACE_2 + K_{I2} \int ACE_2 + K_{D2} \frac{dACE_2}{dt} \quad (6)$$

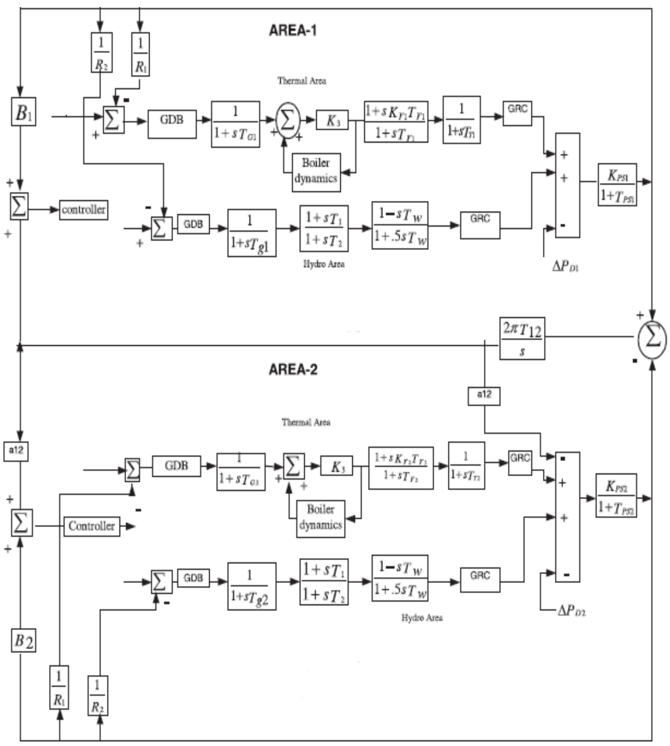

Fig. 1. Block diagram of 2 area multi source AGC

A. Governor Dead Band

The joint American institute of electrical engineer – American society of mechanical engineers (AIEE-ASME) standards for steam and hydraulic turbines define dead band as “the total magnitude of a sustained speed change within which there is no resulting measurable change in the position of the governor control valves or gates”. It is expressed as percentage of rated speed. The standards limit dead band with 0.06% (0.036 Hz) [4]. It is caused by mechanical friction and backlash and by valves overlap in by hydraulic relays [4].

B. Generation Rate Constraints

In a power system with thermal units and hydro units generation can only change at a specific maximum rate. For thermal power plants generally it is taken in the range of 3-10% per minute. In the present work of this paper GRC is chosen to be 3%/min. While in hydro units it is chosen to be 270%/min and 360%/min for raising and falling level respectively.

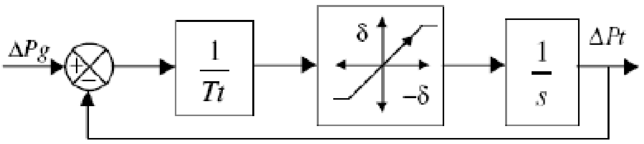

Fig. 2. Non-linear turbine model with GRC

C. Boiler Dynamics

Inclusion of boiler dynamics in thermal unit has been considered and detailed configuration shown in below fig. 3 [4]. Modelling of boiler dynamics includes the long-term dynamics of fuel and steam flow on boiler drum pressure as well as combustion controls.

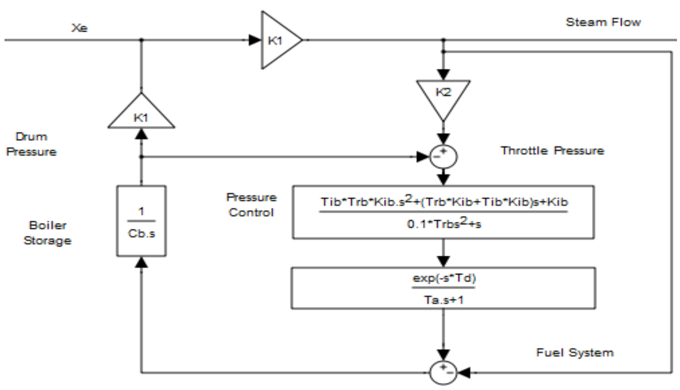

Fig. 3. Boiler dynamics of thermal units system

III. BACKTRACKING SEARCH ALGORITHM (BSA) AND WIND DRIVEN OPTIMIZATION (WDO)

WDO: Motivation for WDO appears from the earth’s atmosphere, where wind blows in an attempt to equalize horizontal imbalance in the air pressure. WDO is a modern nature inspired global optimization method based on atmospheric motion. It is revealed that WDO is easy to execute and highly effective in solving multi-dimensional numerical optimization problems [6]. Basically this technique is working on the population based iterative heuristic global optimization algorithm for multi-dimensional and multi modal problems with the ability to implement constraints on the search domain. As compared to similar particle based procedures, WDO exploits additional terms in the velocity update equation such as gravitation and coriolis forces, which is used to provide robustness and extra degrees of freedom to fine tune.

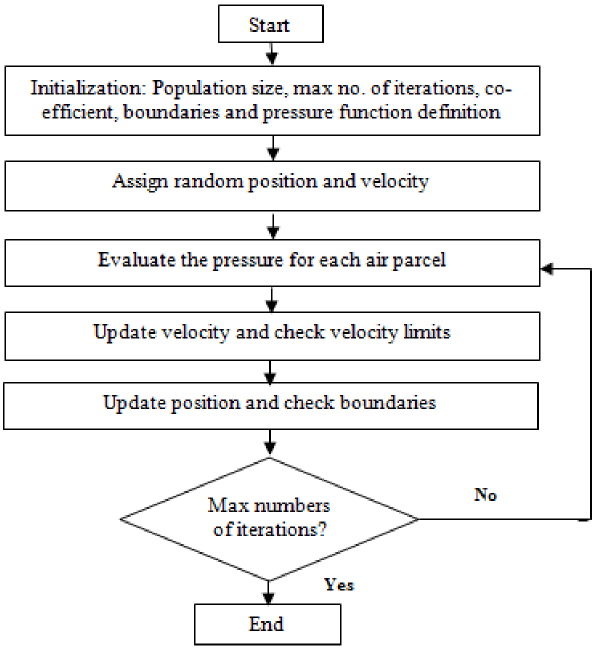

Fig. 4. Flowchart of WDO technique

BSA: BSA is a new evolutionary algorithm for solving real valued numerical optimization algorithm. BSA uses three genetic operators- selection, mutation and crossover- to generate trial individuals [5]. BSA has a random mutation strategy that uses only one direction individual for each target individuals, in contrast with many genetic algorithms such as DE and its derivative JDE, JADE and SADE. BSA randomly chooses the direction individual from individuals of a randomly chosen previous generation. BSA uses a non-uniform crossover strategy that is more complex than the crossover strategies used in many genetic algorithms. BSA is divided into five processes as in other EA's.

A. Initialization

BSA initializes the population P with eq. (7)

$P_{i,j}=(up_j-low_j)$*rand+low_j (7)

For $i=1, 2, 3,.., N$ *and* $j=1, 2, 3,.., D;$ where N and D are population size and dimension of the problem respectively. UP and LOW are upper and lower limits of each population.

B. Selection-I

Selection-I in BSA decide the historical population *oldP* used for calculating the search direction.

$oldP_{i,j}$~U(low_j,up_j) (8)

Provision of redefining *old P* at the beginning of each iteration through if-then rule is,

If a<b then old P := P|a,b ~U(0,1), (9)

where := is the update operation, eq(8) ensure that BSA designates a population belonging to a randomly selected previous generation as the historical population and remembers this historical population until it is changed. Thus, BSA has a memory after old P is determined.

C. Mutation

Mutation is generated from the initial trial population using eq.(10) .

Mutant=P+F·(old P-P). (10)

F decides the amplitude of the search domain-direction matrix (*old P-P*) because; historical population is used in calculating the search direction matrix.

D. Crossover

BSA's crossover process generate the final form of the trial population T. BSA's crossover has two steps. The first step calculate a binary integer valued matrix map of size N·D that indicates the individuals of T to be manipulated by using the relevant individuals of P. If map(n,m)=1 T is updated with T(n,m)=P(n,m); where n=1, 2, .., N and m=1, 2, .., D.

```
Input: Mutant, mixrate, N and D
Output: T: Trial-Population
map(1:N, 1:D)=1   //   Initial-map is an N-by-D matrix of ones.
if a<b | a,b ~ U(0,1) then
    for i from 1 to N do
        map_{i,u(1:⌈mixrate·rand·D⌉)}=0 | u=permuting (1, 2, 3,…, D)
    end
else
    for i from 1 to N do, map_{i,randi(D)}=0, end
end
T := Mutant  // Initial T
for  i from 1 to N do
        for j from 1 to D do
         |   if map_{i,j} =1 then T_{i,j} := P_{i,j}
        end
 end
```

Algorithm 1. Crossover Strategy of BSA

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Input: T, search space limits  (i.e., low_j, up_j )
Output:  T
for i from 1 to N do
   for j from 1 to D do
        if (T_{i,j}< low_j) or (T_{i,j}< up_j) then
        |   T_{i,j}= rand·(up_j − low_j) +low_j
        end
   end
end
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Algorithm 2. Boundary condition mechanism of BSA

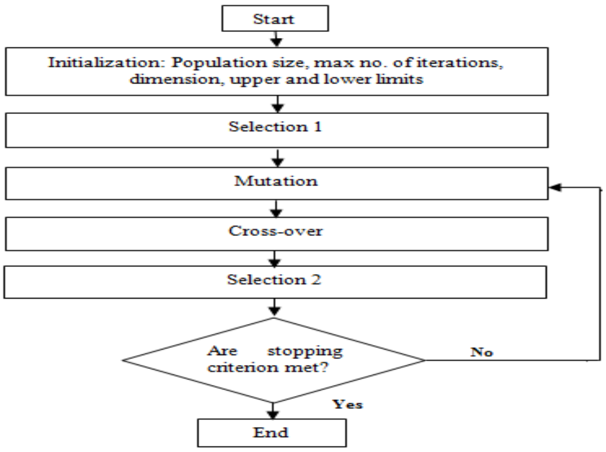

Fig. 5. Flowchart of BSA technique

IV. Simulation results

Investigation have been carried out on a two area multi source thermal-hydro system with constraints like GDB, GRC, Boiler dynamics and reheat thermal units. SLP of 1% in area1 at tie t=0 sec is considered. If the system is hit with a disturbance at t=0.5 sec or t=1 sec, the same waveform is observed as the waveform observed at t=0 sec but only after the respective hit time. The system frequency deviation before time t=0.5 sec should be zero. The objective function used in this study is ISE (Integral Square Error). ISE tends to minimize the large error quickly and settles the steady state frequency and tie-line deviation quickly.

$$ISE=\int_0^{t_{sim}}(\Delta F_1)^2+(\Delta P_{tie})^2+(\Delta F_2)^2$$

The results are obtained by MATLAB (R2010a) on a 2.40 GHz Intel (R) Core (TM) i3 processor personal computer with 4-GB RAM. Optimized parameter of the PI/PID controller by BSA and WDO technique are listed in the table below. Transient response of the frequency deviation in area1, area2 and tie line power deviation for PI and PID controller are shown respectively in below figure (6-11),

Table 1 Optimized parameter of PI controller using BSA

Generating units	Optimized controller parameter with Backtracking search algorithm	
	K_P	K_I
Area 1		
Thermal	0.0413	-0.0783
Hydro	0.1676	0.0055
Area 2		
Thermal	0.0343	-0.086
Hydro	0.4087	0.1924

Table 2 Optimized parameter of PI controller using WDO

Generating units	Optimized controller parameter with wind driven optimization technique	
	K_P	K_I
Area 1		
Thermal	-0.0043	-0.0745
Hydro	-0.3305	-0.0820
Area 2		
Thermal	0.3545	-0.0387
Hydro	-0.2616	-0.1072

Table 3 Optimized parameter of PID controller using BSA

Generating units	Optimized controller parameter with Backtracking search algorithm		
	K_P	K_I	K_D
Area 1			
Thermal	0.0918	-0.0856	-0.1076
Hydro	-1	-0.0765	-0.2265
Area 2			
Thermal	-0.2324	-0.0689	0.0637
Hydro	-0.6367	0.4771	-0.7157

Table 4 Optimized parameter of PID controller using WDO

Generating units	Optimized controller parameter with wind driven optimization technique		
	K_P	K_I	K_D
Area 1			
Thermal	0.0269	-0.1180	-0.3272
Hydro	0.2243	-0.0306	-0.0991
Area 2			
Thermal	0.1971	0.0420	0.1527
Hydro	-0.4912	-0.0218	-0.1149

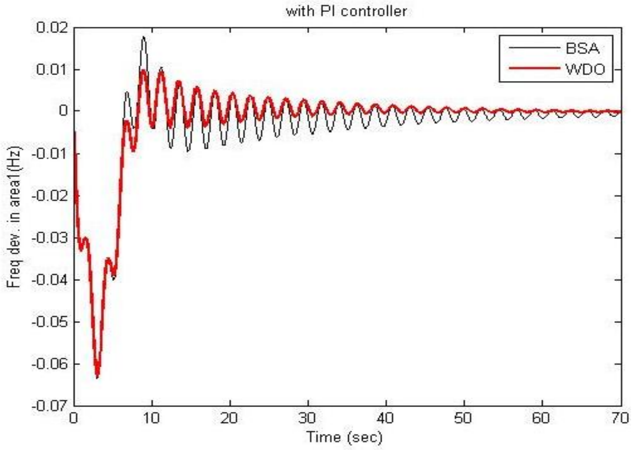

Fig. 6. Frequency deviation in area1 (Hz)

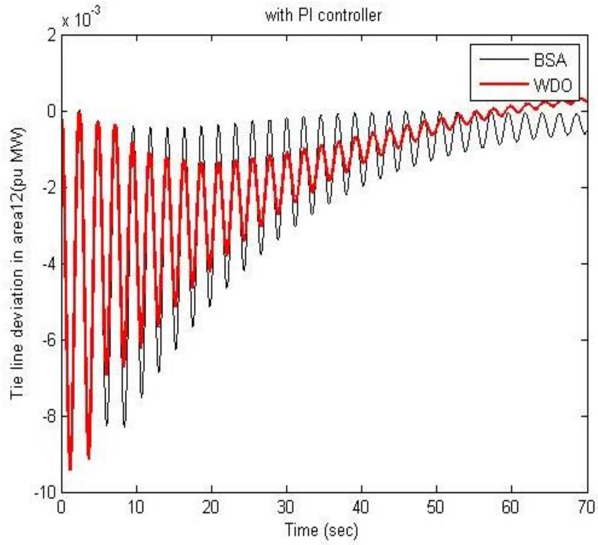

Fig. 7. Tie line power deviation (P.U. MW)

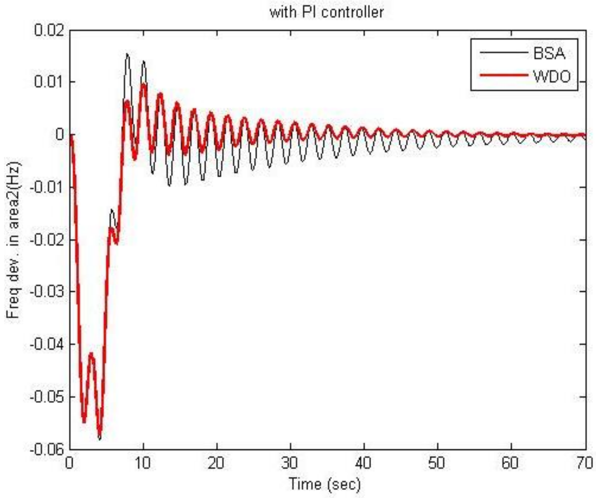

Fig. 8. Frequency deviation in area2 (Hz)

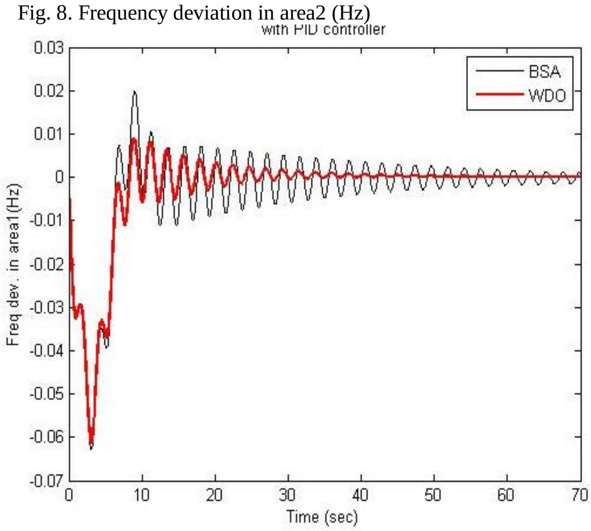

Fig. 9. Frequency deviation in area1 (Hz)

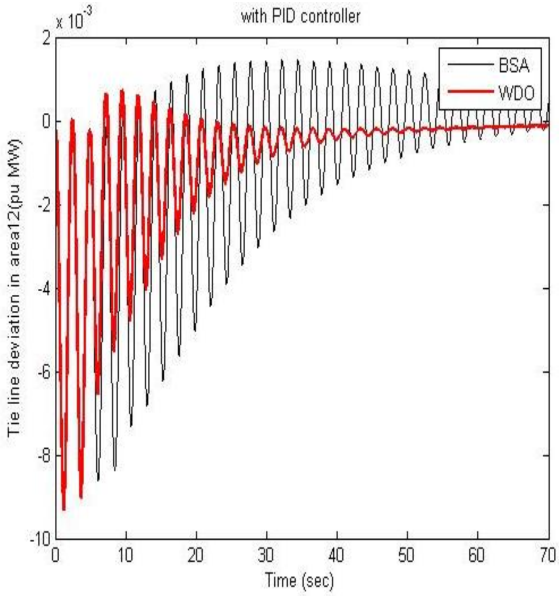

Fig. 10. Tie line power deviation (P.U. MW)

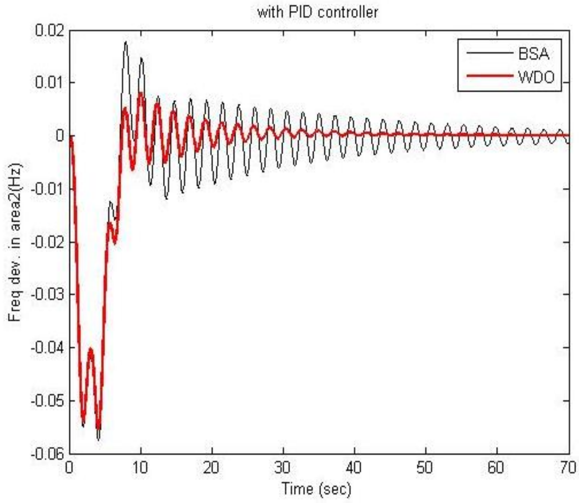

Fig. 11. Frequency deviation in area2 (Hz)

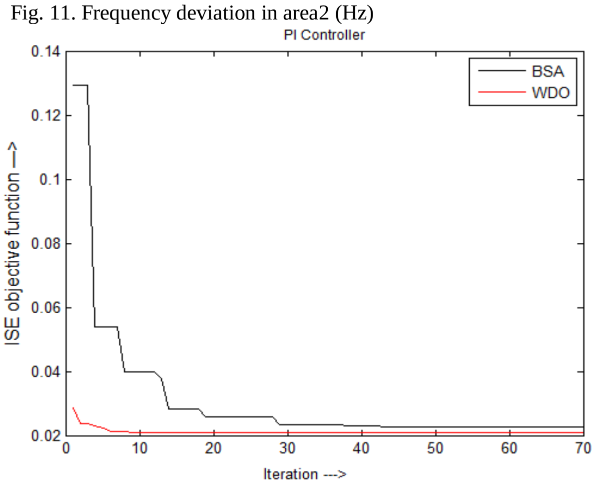

Fig. 12. Convergence characteristics with PI Controller

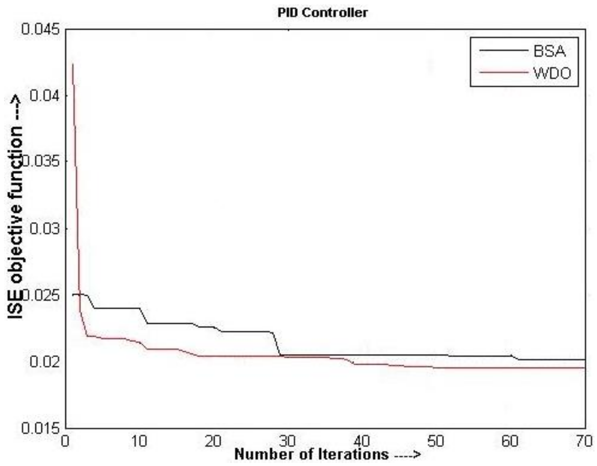

Fig. 13. Convergence characteristics with PID Controller

V. CONCLUSION

In this paper, an attempt has been made to tune the parameter of PI/PID controller in a two area multi sources unit including physical constraints with Backtracking and wind driven optimization technique and it is found that WDO is giving good results compared with BSA in terms of settling times, overshoot and undershoot as observed in the transient waveform of frequency deviation in area1, area2 and tie line power deviation.

Appendix: Nominal system parameters are,

B_1=0.425 p.u. MW/Hz (frequency bias factor); R_1=R_2=2.4 Hz/p.u. (governor speed regulation); T_{g1}=T_{g1}=0.08s (governor time constant); T_{t1}=T_{t1}=0.3s (turbine time constant); K_{P1}=K_{P2}=120 Hz/pu (power system gain); T_{ri}= 10s (turbine reheat time constant); K_{r1}=0.333 (turbine reheat gain); T_{P1}=T_{P2}=20s; a_1=-1; T_{12}=0.0707; T_{ri}= 10s; K_{r1}=0.5; f=60 Hz; P_R= 2000MW (rating); P_L=1000 MW (nominal loading); **parameters of boiler dynamics are**: T_{ib}=26; K_{ib}=0.03; T_{rb}=69; K_1=0.85; K_2=0.095; K_3=0.92; C_b=200; T_d=0; T_f=10.

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