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## Design of BAT Inspired Algorithm Based Dual Mode Gain Scheduling of PI Load Frequency Control Controllers for Interconnected Multi-Area Multi-Unit Power Systems

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### ABSTRACT

This paper presents the design and performance analysis of Bat inspired algorithm based dual mode gain scheduling of PI controllers load frequency control of an interconnected power systems. The bat inspired algorithm is based on the echolocation of bats. In this study, the bat inspired algorithm based dual mode PI controller is applied to the multi – area multi-units interconnected thermal power system in order to tune the PI controller parameter. The proposed controller is simple in structure and easy for implementation. The superiority of proposed controller is demonstrated by comparing the results of conventional PI controllers, Fuzzy gain scheduling of PI controllers and BAT PI controllers. The simulation results show the point that the proposed Bat inspired algorithm, based dual mode gain scheduling of PI controllers (BIDPI), provides better transient as well as steady state of response. It is also found that the proposed controller is less sensitive to the changes in system parameters.

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### List of Symbols:

- $f$  area frequency in Hz
- $i$  subscript referred to area  $i$  (1-2)
- $P_{ei}$  the total power exchange of area  $i$  in p.u. MW/Hz
- $P_{Di}$  area real power load in p.u. MW
- $P_{ci}$  area speed changer output in p.u. MW
- $X_e$  governor valve position in p.u. MW
- $K_p, K_i$  electric governor proportional and integral gains respectively
- $T_{Ps}$  area time constant in seconds
- $R$  steady state regulation of the governor in Hz/p.u. MW
- $T_g$  time constant of the governing mechanism in seconds
- $k_r$  reheat coefficient of the steam turbine
- $T_r$  reheat time constant of the steam turbine in seconds
- $T_t$  time constant of the steam turbine in seconds
- $\beta_i$  frequency bias constant in p.u. MW/Hz
- ACE Area Control error
- LFC Load Frequency Control
- AGC Automatic Generation Control
- BA BAT Algorithm
- $apf$  area participation factors
- $B$  Bias constant
- ISE Integral square error
- FGPI Fuzzy gain scheduling PI
- $N$  number of interconnected areas
- $\Delta$  Incremental change of a variable
- $T_p$  Power system time constant

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$\Delta P_{tie\ i-j}$  incremental change in tie line power connecting between area  $i$  and area  $j$  in p.u.

$N$  number of interconnected areas

$S$  Laplace frequency variable

$V_i$  Velocities of bat

$x_i$  Position of bat

$f_{\min}$  Minimum frequency of bats emits sound pulses.

$f_{\max}$  Maximum frequency of bats emits sound pulses.

$r_i$  Pulse emission rate of  $i^{\text{th}}$  bat.

$r_0$  Initial Pulse emission rate of bats.

$A_0$  Initial Loudness of sound produce by the bats.

$A_{\min}$  Minimum Loudness of sound produce by the bats.

$x_*$  Current global best solution

$\beta$  Random vector

$\lambda$  Wavelength of sound.

### Superscript

$T$  transpose of a matrix

### Subscripts

$i, j$  area indices ( $i, j = 1, 2, \dots, N$ )

## INTRODUCTION

Controlling large interconnected power systems is one of the most challenging problems for controller designers (Wood, A J *et al.*, 1996). One of the most important control objectives in power systems is to control the output power of generating units. Controlling the output power of generating units in such a way that the transient deviations of the frequency of each area and the interchanged power between areas remain within the specified limits and their steady state error equals zero (Kundur, P.,1994). The successful operation of interconnected power systems requires matching the total generation with the total load demand and with the associated system losses. With time, the operating point of a power system changes, and hence, systems may experience deviations in nominal system frequency and scheduled power exchanges to other areas, which may yield undesirable effects.

LFC or AGC is one of the most important issues in electric power system design and operation for supplying sufficient and reliable electric power with good quality. The main objectives of LFC for a power system are

- Ensuring zero steady-state error for frequency deviations
- Minimizing unscheduled tie line power flows between neighbouring control areas.
- Getting good tracking for load demands and disturbances.
- Maintaining acceptable overshoot and settling time on the frequency and tie line power deviations.

Based on the above objectives, the two variable frequencies and the tie line power exchanges are weighted together by a linear combination to form a single variable called ACE, which is used as the control signal in the LFC problem (Shayeghi, H *et al.*, 2009).

A number of control strategies for LFC have been proposed in the literature over past decades in the design of load-frequency controllers in order to achieve better dynamic performance (Lalit Chandra Saikia., *et al.*, 2012; Navin, R.K., 1971; Beverani, H., *et al.*, 2004; Ramar, K., Velusami, S., 1989; Jiang, L., *et al.*, 2012; Kumar, I.P., *et al.*, 2005; Velusami, S., *et al.*, 2006). Among the various types of load frequency controllers, the most widely employed is the simple conventional controllers. These conventional controllers for LFC are still popular with the industries because of their simplicity, easy realization, low cost, and robust nature. Generally, the conventional approach using the proportional plus integral controller results in relatively large overshoots in transient frequency deviations. Further, the settling time of the system frequency deviation is also relatively long (Velusami, S., *et al.*, 2006).

It is well known that if the control law employs an integral control, the system will have no steady – state error. However, it increases the type of the system by one. Therefore, the response with the integral control is slow during the transient period. In the absence of integral control, the gain of the closed loop system can be increased significantly to improve the transient response since the proportional plus integral control which does not eliminate the conflict between the static and dynamic accuracy. This conflict may be resolved by improving the principle of dual mode control (Mohamed Thameem Ansari, M., *et al.*, 2010; Velusami, S., *et al.*, 2006).

Usually, a linear model around a nominal operating point is used in the load frequency controller design. However, because of the inherent characteristics of the changing loads, the operating point of a power system changes very much during a daily cycle. As the operating point of the system gets changed, the controller performance in the system may not be optimal. Therefore, a fixed controller, which is optimal under one operating condition, may not be suitable in another status unless some precautions are considered. Hence, it is necessary to track the operating point of the system and accordingly update its parameter to achieve a better control scheme.

Gain scheduling is a technique commonly used in designing controller for non-linear systems. Its main advantage is that the controller parameter can be changed very quickly in response to changes in the system dynamics because no parameter estimation is required. Besides being an effective method to compensate for non-linear and other predictable variations in the system dynamics, it is simpler to implement than automatic tuning or adaptation. However, the conventional gain scheduling also has its drawbacks. One drawback is that the system parameter may be rather abrupt across the regional boundaries, which may result in unsatisfactory or even unstable performance across the transition regions. In order to solve the above mentioned problems of conventional gain scheduling, the fuzzy gain scheduling of PI/PID controllers is reported in the literature (Banerjee, A., *et al.*, 2014; Zhao Zhen-Yu., *et al.*, 1993; Chang., *et al.*, 1997; Cam Ertugrul., *et al.*, 2005; Precup, R.E., *et al.*, 2013; Chang c s., *et al.*, 1998; Bevrani, H., *et al.*, 2012) But Fuzzy gain scheduling a sophisticated technique is easy to design and implement. Nevertheless, the determination of membership function and control rules is an essential part of the design. To achieve satisfactory membership functions and control rule the designer's experience is necessary. Generally, it is difficult for a human expert to search for a number of proper rules for the fuzzy system. The application of artificial intelligence techniques have been successfully employed to many complex nonlinear optimization problems in a number of engineering fields in general and in the area of power systems in particular (Chan, KY., *et al.*, 2013; Yazdani, D., *et al.*, 2013). Xin-She Yang (Yang Xin-She., *et al.*, 2012; Yang, X.S., 2010) proposed the bat algorithm. BA is inspired by the research on the social behaviour of Bats. The BA is based on the echolocation behavior of Bats.

Keeping the above point in view, the load frequency control using bat inspired algorithm based dual mode gain scheduling of PI controllers is proposed for interconnected power systems. Simple BAT algorithm is used an optimization tool to obtain the optimal gains for dual mode gain scheduling of PI controllers. The proposed controller is practically as simple as that of the conventional controller and can be implemented with very little additional cost. Application of this controller to a multi area-multi unit power system demonstrates the effectiveness of the proposed controller. Moreover, it has also been observed that the proposed controller is less sensitive to system parameter variations.

#### Statement of the problem:

The large power system consists of a number of control areas and units that are interconnected through tie-lines as shown in Fig.1. Due to the large scale of the most power systems, design and implementation of the decentralized controllers are preferable. Therefore, each control area has its own load frequency controller. The controller compensates every changes in the local loads or imbalances in the tie-line power interchanges and maintains the system frequency in its nominal value.

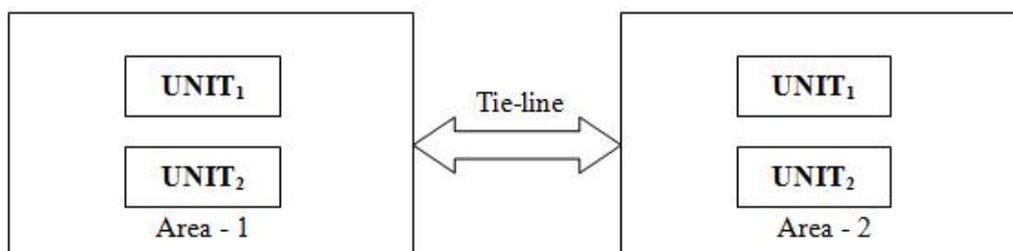


Fig. 1: Schematic diagram of two-area multi unit reheat power systems.

Control theory. The state variable equation of the minimum realization model of the 'N' area interconnected power system is expressed as

$$\begin{aligned}\dot{X} &= Ax + Bu + \Gamma d \\ v &= Cx \\ y &= Hx\end{aligned}\tag{1}$$

Where  $x = [x_1^T, \Delta P_{ei}, \dots, x_{(N-1)}^T, \Delta P_{e(N-1)}, \dots, x_N^T]^T$

$$n = \sum_{i=1}^N n_i + (N-1) \quad n\text{-state vector}$$

$$u = [u_1, \dots, u_N]^T = [\Delta P_{C1}, \dots, \Delta P_{CN}]^T \quad N\text{-control input vector}$$

$$d = [d_1, \dots, d_N]^T = [\Delta P_{D1}, \dots, \Delta P_{DN}]^T \quad N\text{-disturbance input vector}$$

$$v = [v_1, \dots, v_N]^T \quad N\text{-control output vector}$$

$$y = [y_1, \dots, y_N]^T \quad 2N\text{-measurable output vector}$$

Where  $A$  is system matrix,  $B$  is the input distribution matrix,  $\Gamma$  is the disturbance distribution matrix,  $C$  is the control output matrix distribution matrix,  $H$  is the measurable output distribution matrix,  $x$  is the state vector,  $u$  is the control vector, and  $d$  is the disturbance vector of load changes.

#### Output feedback control scheme:

It is a known fact that by incorporating an integral controller, the steady-state requirements can be achieved. In order to introduce an integral function to the controller, the system, Eq.(1) is augmented with new state variables defined of as a intergral of  $ACE_i$  ( $\int v_i dt$ ),  $i = 1, 2, \dots, N$ . The augmented system of order  $(N + n)$  can

$$\text{be described as} \quad \dot{\bar{X}} = \bar{A}x + \bar{B}u + \bar{\Gamma}d\tag{2}$$

$$\text{Where } \bar{x} = \begin{bmatrix} \int v dt \\ x \end{bmatrix} \begin{matrix} \}N \\ \}n \end{matrix}, \quad \bar{A} = \begin{bmatrix} 0 & C \\ 0 & A \end{bmatrix}, \quad \bar{B} = \begin{bmatrix} 0 \\ B \end{bmatrix} \quad \text{and} \quad \bar{\Gamma} = \begin{bmatrix} 0 \\ \Gamma \end{bmatrix}$$

As the newly added state variables ( $\int v_i dt$ ),  $i = 1, 2, \dots, N$  will also be available for feedback in each area,

the new measurable output 'y' can be written  $\bar{y} = \bar{H}\bar{x}$

$$\text{Where } \bar{y} = [\bar{y}_1^T, \dots, \bar{y}_N^T]^T \quad \bar{H} = [\bar{H}_1^T, \dots, \bar{H}_N^T]^T \quad \text{and}$$

$$\bar{H}_i = \begin{bmatrix} 0 \dots 1 \dots 0 & 0 \\ 0 & -H_i \end{bmatrix} \begin{matrix} \vdots \\ \text{-----} \end{matrix}$$

The constant matrix  $\bar{H}_i$  ( $i = 1, 2, \dots, N$ ) is of dimension  $2 \times (N + n)$ . Hence, the matrix  $H$  is of dimension  $2N \times (N + n)$ . For the design of a decentralized output, the augmented system should be controllable and should not have unstable fixed modes. It can be easily shown that the augmented system will be controllable only if the

system is controllable and the matrix  $\begin{bmatrix} 0 & C \\ B & A \end{bmatrix}$  is of rank  $(N + n)$

$$\text{The decentralized feedback control law } u_i = -k_i^T y_i \quad i = 1, 2, \dots, N\tag{3}$$

To meet the objectives stated in the previous section. The control law Eq. (3) can be written in-terms of  $v_i$  as  $u_i = -k_{i1} \int v_i dt - k_{p1} v_i \quad i = 1, 2, \dots, N$

Where  $k_i^T = [k_{i1} | k_{p1}]$  is a 2-dimensional integral and proportional feedback gain vector,  $v_i$  the scalar control output of area  $i$ . The constant gain output feedback controller and fuzzy gain scheduling of PI controller with output feedback are used in this study as the benchmark for comparison with the proposed controller

**Design of bat inspired algorithm based dual mode gain scheduling of pi controllers:**

A new design procedure(Sathya .,etl al., 2015) to obtain the gains of PI controllers using the output feedback is discussed in this section.

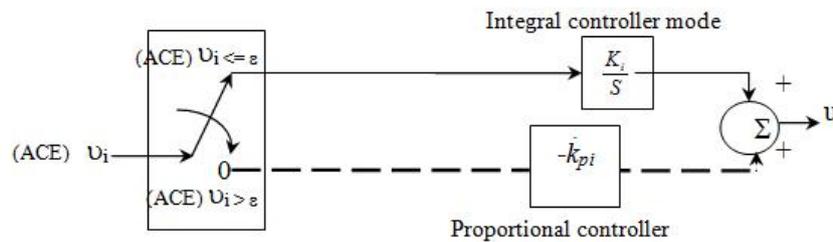
**Output feedback dual mode control scheme:**

The block diagram of the dual mode controller of area  $i$  is shown in Fig.2. The Dual mode controller operates the switching between proportional controller mode or integral controller mode depending upon the magnitude of the output signal  $v_i$ .  $\varepsilon > 0$  is found constant indicating the specified limit of the output error signal where  $K_{i1}$  is the gain of the integral controller and  $K_{pi}$  is the gain of the proportional controller.

$$u_i = -k_{i1} \int v_i dt \quad \text{for } |v_i| \leq \varepsilon \tag{5}$$

and

$$v_i = -k_{p1} v_i \quad \text{for } |v_i| > \varepsilon \tag{6}$$



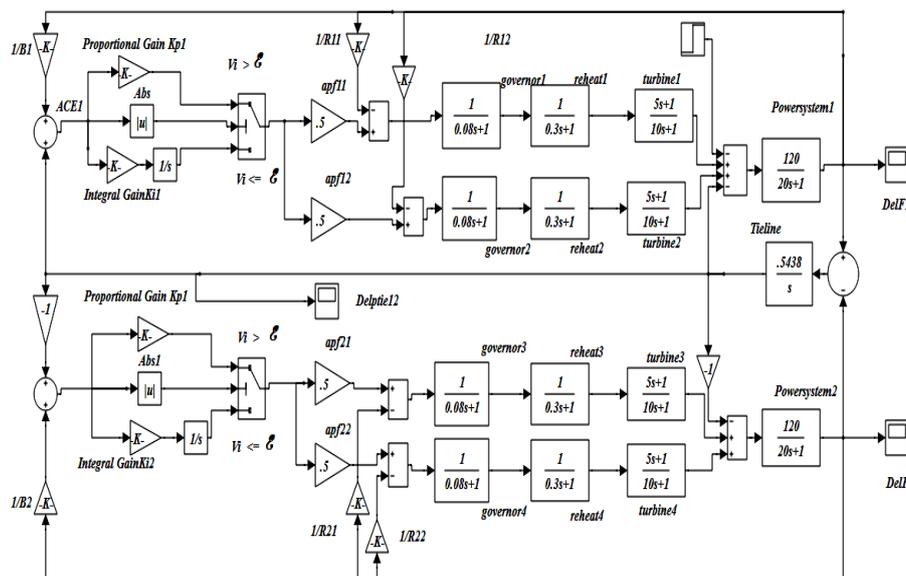
**Fig. 2:** Block diagram of a dual mode gain scheduling PI controller of area  $i$ .

If the frequency and tie-line power deviations to be zero at steady state, the  $ACE_i$  should be zero. To meet the above design requirement, the  $ACE$  is defined as:  $ACE_i = \beta_i \Delta f_i + \Delta P_{tiei-j}$

where ‘ $i$ ’ represents the control area and ‘ $\beta_i$ ’ the frequency bias constant. The objective is to obtain the optimum value of the controller parameters which minimize the performance index  $J$  which is given by

$$J = \int_0^t \left\{ (\Delta f_i)^2 + (\Delta P_{tiei-j})^2 \right\} dt \tag{7}$$

A new nature inspired metaheuristic search algorithm called as Bat Search Optimization algorithm is used for the optimal designing of PI controller for LFC in two area interconnected power system to damp the power system oscillations. To simplify the analysis, the two interconnected areas are considered identical. The optimal parameter values are  $K_{p1} = K_{p2} = K_p$  and  $K_{i1} = K_{i2} = K_i$ . In the next section a new procedure for designing dual mode namely; controller feedback gain  $K_{i1}$  and proportional controller feedback gain  $K_{p1}$  is developed.



**Fig. 3:** Simulink model of Two-area multi unit thermal re-heat interconnected power systems

**System Investigated:**

BAT inspired algorithm based dual mode gain scheduling of PI controllers concept is employed to provide a robust design methodology for the power system LFC. The test system under study, which is shown in Fig. 3, contains two areas which are connected through tie-lines. For the purpose of this study, the system base frequency is 60 Hz and each area consists of two generating units.

Investigations have been carried out in the two equal area interconnected thermal power system and each area consists of two reheat units as shown in Fig 3. The interconnected power system nominal data are given in APPENDIX A1 and BAT Algorithm parameters are given in APPENDIX A2 . apf11 and apf12 are the ACE participation factors in area 1 and apf21 and apf22 are the ACE participation factor in area2. Note that apf11+apf12 = 1.0 and apf21+apf22 = 1.0.

**Gain scheduling of PI controllers by Bat Algorithm:****Bat Algorithm:**

As the bat algorithm is based on the echolocation behaviour of Microbats (Yangn. X. S., 2010). In echolocation, each pulse generated by a microbat may last only for 8–10 ms with a frequency ranging 25 kHz to 150 kHz, which corresponds to the wavelengths of 2 mm to 14 mm. In BA, the echolocation characteristics of Microbats can be idealized with the following assumptions. Bat-inspired algorithms or bat algorithms can be developed by idealizing some of the echolocation characteristics of microbats. The following assumptions are made to approximate bat's echolocation properties to solve an optimization problem (Yang Xin-She., et al 2012; Yang, X.S., 2010):

1. It is assumed that the bats are able to detect distance of prey, background obstacles and difference in the available prey/food in the search path in some magical way using echolocation property.
2. An  $i^{th}$  Bat may randomly fly with location as  $\underline{x}_i$ , velocity as  $\underline{v}_i$ , frequency as  $\underline{f}_{min}$  but with varying wavelength as  $\underline{k}_i$  and loudness of echo as  $\underline{A}_0$  to search food/prey. The Microbats have an ability to adjust frequency (wavelength) of the emitted pulses of echo and rate of pulse emission out of  $\underline{r} \in [0, 1]$  according to the distance of their prey/food.
3. The loudness of the echo pulse should be varied as reducing with decreased distance of the food, i.e. from large  $\underline{A}_0$  to a minimum value  $\underline{A}_{min}$  (at target/prey location).

**BA procedural steps:**

Let in an optimization problem; the objective function is represented by Minimization of  $F(x)$  which is subjected to  $\underline{x}_i \in \underline{X}_i$ ,  $i = 1, 2, 3 \dots N$ .

**Step-1: Initialization**

- As an initial step, the bat population is initiated as position  $\underline{x}_i$  and velocity as  $\underline{v}_i$  with  $i = 1, 2, 3, \dots N$ .
- Initial pulse frequency is defined as  $\underline{f}_i \in [\underline{f}_{min}, \underline{f}_{max}]$ .
- The pulse rates  $\underline{r}_i$  and the loudness  $\underline{A}_i$  are also set as above.
- Check number of iterations or  $t < \underline{T}_{max}$ .

**Step-2: Generation of new solutions**

- New solutions may be generated by adjusting the pulse frequency and keeping wavelength as constant.
- For each bat ( $i$ ), its position  $\underline{x}_i$  and velocity  $\underline{v}_i$  in a d-dimensional search space should be defined.  $\underline{x}_i$  and  $\underline{v}_i$  should be subsequently updated during the iterations. The new solutions  $\underline{x}_i^t$  and velocities  $\underline{v}_i^t$  at time step 't'

can be calculated by:

$$\underline{f}_i = \underline{f}_{min} + (\underline{f}_{max} - \underline{f}_{min}) \underline{\beta} \quad (8)$$

$$\underline{v}_i^t = \underline{v}_i^{t-1} + (\underline{x}_i^{t-1} - \underline{x}_*) \underline{f}_i \quad (9)$$

$$\underline{x}_i^t = \underline{x}_i^{t-1} + \underline{v}_i^t \quad (10)$$

where the  $\underline{\beta}$  is defined for uniform distribution as a vector and selected as  $\underline{\beta} \in [0, 1]$ . The  $\underline{x}_0$  stands as the best location in search space after comparing solutions of all the n bats. The product of  $\underline{f}_i$  and  $\underline{v}_i$  represents the velocity increment. The velocity increment can be adjusted by changing one and keeping fixed another according to a problem. The generally used range of frequency is  $0 \leq f \leq 100$  and each bat at initialization step is selected from  $f = [\underline{f}_{min}, \underline{f}_{max}]$ .

**Step-3: Local search**

Once the best current solution is selected among the available solutions, then a new solution is generated by using local random walk and assigned to each bat as in Eq. (11). If  $\epsilon \in [1, 1]$  represents a random number range and  $\underline{A}_t = \langle \underline{A}_i^t \rangle$  stands for average value of loudness of all initiated n bats at time t.

$$x_{new} = x_{old} + \varepsilon \underline{A}_i \max(\text{var}) \quad (11)$$

Step-4: Bat flying and generation of a new solutions

As the number of iteration increases, the loudness  $\underline{A}_i$  and the rate  $\underline{r}_i$  of pulse emission have to be updated. As a microbat reaches to its target/prey the rate of pulse emission increases while the loudness decreases. The loudness is generally selected from  $[\underline{A}_0, \underline{A}_{min}] = [1, 0]$ . The  $\underline{A}_0 = 1$ , represents the maximum loudness of emitted pulse by microbat in search of prey, while  $\underline{A}_{min} = 0$  indicates that the microbat got the target/prey and not emitting any loudness. Thus, the loudness and the rate of pulse emission is updated as

$$\underline{A}_i^{t+1} = \underline{\alpha} \underline{A}_i^t, \quad \underline{r}_i^{t+1} = \underline{r}_i^0 [1 - e^{-\gamma t}] \quad (12)$$

where  $\underline{\alpha}$  and  $\underline{\gamma}$  represent the constant values. Here,  $\alpha$  is similar to the cooling factor of a cooling schedule in the simulated annealing [45] and the range of these constants is as  $0 < \alpha < 1$  and  $0 < \gamma$ .

$$\underline{A}_i^t \rightarrow 0, \quad \underline{r}_i^t \rightarrow \underline{r}_i^0 \text{ as } t \rightarrow \infty \quad (13)$$

To make optimization simpler, the value of  $\alpha$  and  $\gamma$  should be selected as same, therefore, in this study  $\underline{\alpha} = \underline{\gamma} = 0.9$ . As in Eq. (13), the initial loudness and emission rate may be represented by  $\underline{A}_i^0$  and  $\underline{r}_i^0$ , respectively.

The value of emission rate at time  $t$  can be selected from  $\underline{r}_i^0 \in [0, 1]$ .

Step 5: Checking the stopping criterion

If the maximum count of iterations is reached as a stopping criterion is satisfied, then the process of computation is terminated. Otherwise, go to steps 3 and 4 to repeat the process.

Based on the above approximations and idealization, the pseudo-code of the Bat Algorithm (BA) for dual mode gain scheduling of PI controller can be summarized are given in Table 1.

**Table 1:** Pseudo-code of BAT algorithm for dual mode gain scheduling PI controller gain scheduling design..

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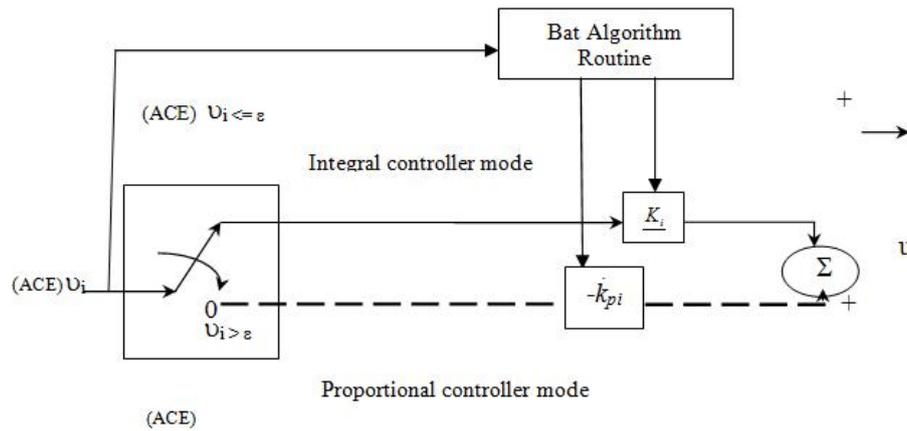
Define objective function  $f(\underline{x})$ ,  $\underline{X} = (\underline{x}_1, \underline{x}_2, \dots, \underline{x}_d)^T$  i.e.  $K = \underline{X}(1)$ ;  $T_i = \underline{X}(2)$ ;
 $\underline{T}_2 = \underline{X}(3)$ ;
Set initial population loudness and velocities of the microbats  $\underline{x}_i$  ( $i = 1, 2, \dots, n$ ) and  $\underline{v}_i$  [ $n = 25$ ] for the  $K_p$  &  $K_i$ 
based on  $\varepsilon$ 
Set the pulse frequency  $f_i$  at  $\underline{x}_i$  [ $f_{min} = 0$ ;  $f_{max} = 2$ ]
Define lower & upper parameter bound as  $\underline{L}_b = [00.2 \ 0.02]$  and
 $\underline{U}_b = [501.5 \ 0.15]$ 
begin
while ( $t < t_{max}$ )%  $t_{max}$  is the maximum number of iterations
generate new solutions by adjusting frequency and
updating velocities & loudness as in Eqs. (9)–(11)
if ( $rand > r_i$ )
decide & select a best solution among the generated solutions &
randomly generate a local solution around the selected best solution by a
local random walk as in Eqs. (12) and (13):  $\underline{F}_{new} = f(\underline{x})$ 
end if
if ( $rand < A_i$  &  $f(\underline{x}_i) < f(\underline{x}_g)$ )
select the new solutions and increase  $r_i$  but reduce  $A_i$ 
end if
rank the bats at each iteration and find their current  $\underline{x}_g$  (best) and minimum
objective function value  $f_{min}$  corresponding to  $\underline{x}_g$ 
show last iteration based  $f_{min}$  (minimum ISE value) & best (optimized  $K_p$  &  $K_i$ 
parameter value)

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Bat-inspired algorithm is applied for optimizing the gains of a proportional plus integral controller for a two area interconnected reheat thermal power system. The objective is to obtain the optimum values of the controller parameters which will minimize the performance index  $J$  i.e. objective function,  $J$  given in Eq.(7). In this simulation the objective function of Bat inspired algorithm to minimize the performance index is given in Eq.(7).

*Application of proposed BAT inspired algorithm based dual mode gain scheduling of PI controllers for interconnected power systems:*

The proposed Bat inspired algorithm based dual mode gain scheduling of PI controller is applied to an interconnected two-area thermal power system with reheat turbines. The block diagram of dual mode gain scheduling of PI controller using Bat algorithm routine is shown in Fig.4 and the simulink diagram of the above system is shown in Fig.4. The Data for the system is taken from and is given in the appendix.



**Fig. 4:** Block diagram of a dual mode gain scheduling PI controllers using Bat algorithm routine of area i.

**Design of conventional PI controllers and fuzzy gain scheduling of PI controllers with output feedback:**

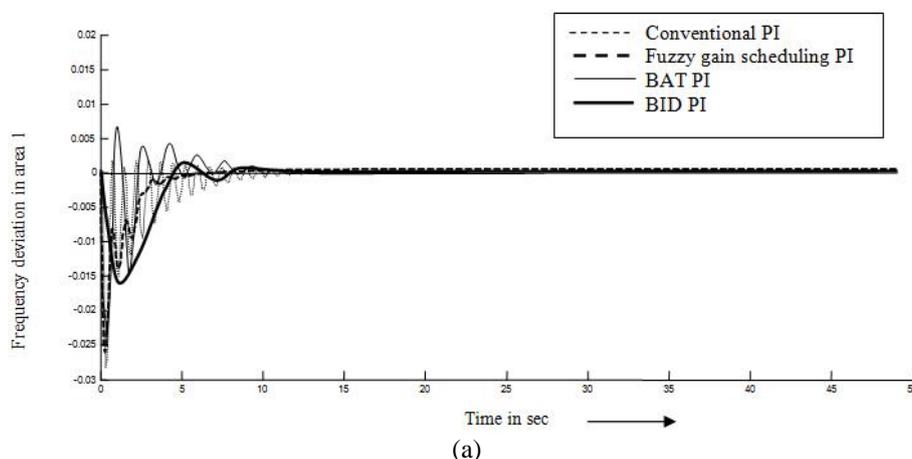
The conventional proportional and integral (PI) controllers with output feedback are designed using integral square error (ISE) criterion and the feedback gain are  $K_p=1.16$  and  $K_i= 0.27$ . Gain scheduling is an effective way of controlling systems whose dynamics change nonlinearly with the operating conditions. It is normally used when the relationship between the systems dynamic and operating conditions are known, and for which a single linear time-invariant model is insufficient. In this paper, we use this technique to schedule the parameter of the PI controller according to change of the area control error  $ACE_i$  and  $\Delta ACE_i$ . In the proposed scheme, the PI parameters,  $K_p, K_i$  are adjusted according to the current  $ACE_i$  and its first difference  $\Delta ACE_i$ . The fuzzy gain scheduling of PI controllers with output feedback is also designed using the method given in. This conventional PI controllers and fuzzy scheduling of PI controllers with output feedback are used as the benchmark for comparison with the proposed controllers.

**Design of proposed Bat inspired algorithm based dual mode gain scheduling of PI controllers with output feedback:**

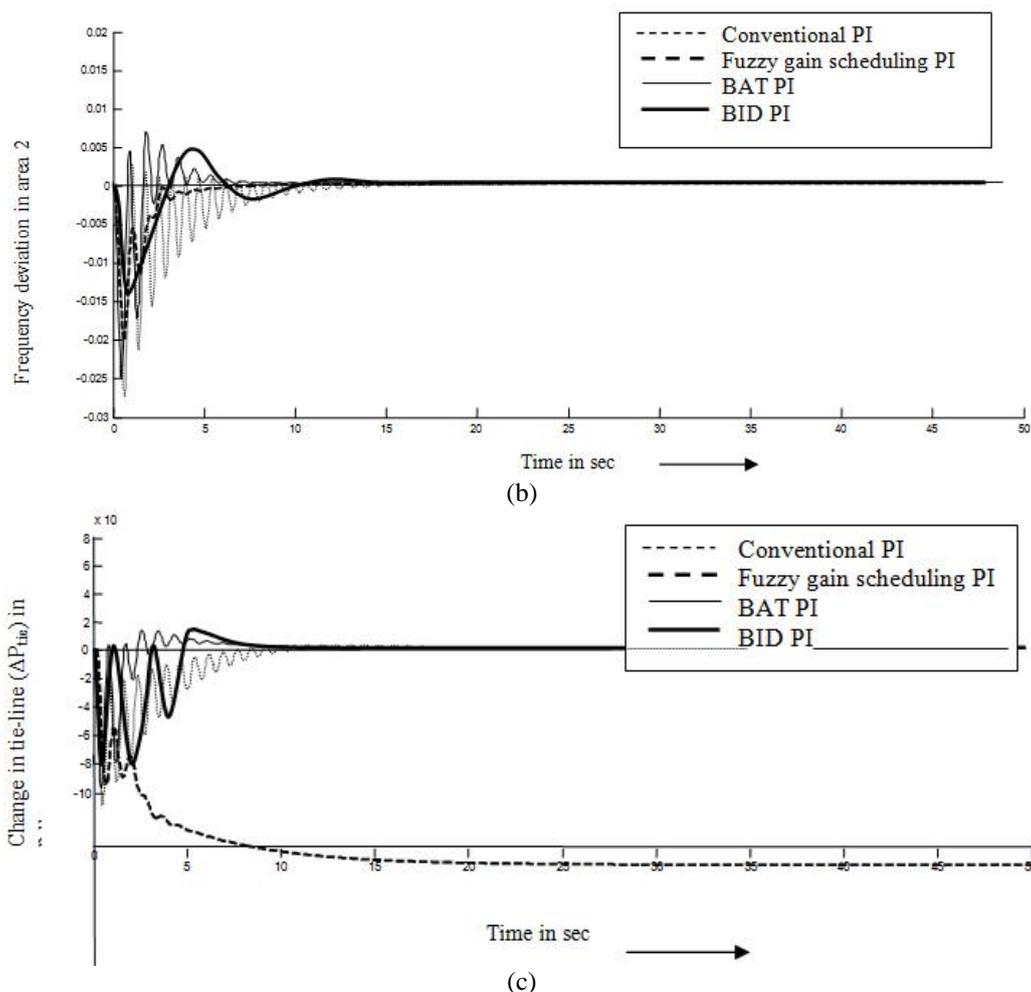
Design of proposed Bat inspired algorithm based dual mode gain scheduling of PI controllers with output feedback scheme is carried out for interconnected two-area thermal power systems with reheat turbines. The simulink block diagram of the system is shown in Fig.4. Since the switching limit value  $\epsilon$  should be greater than the steady state error of the system output  $\Delta f_i$ , with only proportional controllers it is chosen as 0.003. The following parameters are used for BIDPI controller in this study: Total population = 30; Number of iterations = 20; Loudness  $\underline{A} = 0.9$ ; Wavelength  $\underline{r} = 0.1$ ; Frequency  $f_{\min} = -0.2, f_{\max} 0.9$ . In BIDPI controller optimum the gain values are selected by varying the above mention parameters.

**Simulation results and observations:**

The Bat inspired algorithm based dual mode gain scheduling of PI controllers, in section 5.2, is implemented in two area multi unit reheat thermal power system. The performance of this controller is simulated for 0.01 p.u K.W step load change and the corresponding thermal generator frequency deviation  $\Delta f_1$  and  $\Delta f_2$  and tie line power  $\Delta p_{tie12}$  are plotted and show in Fig.5.



(a)



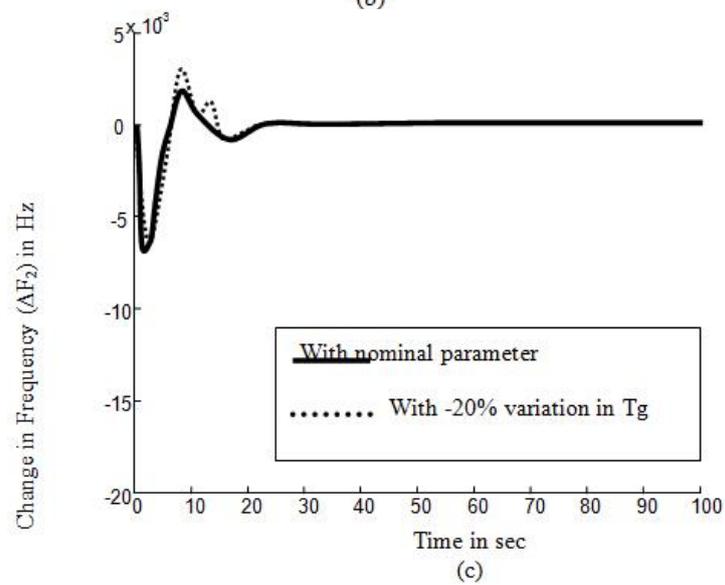
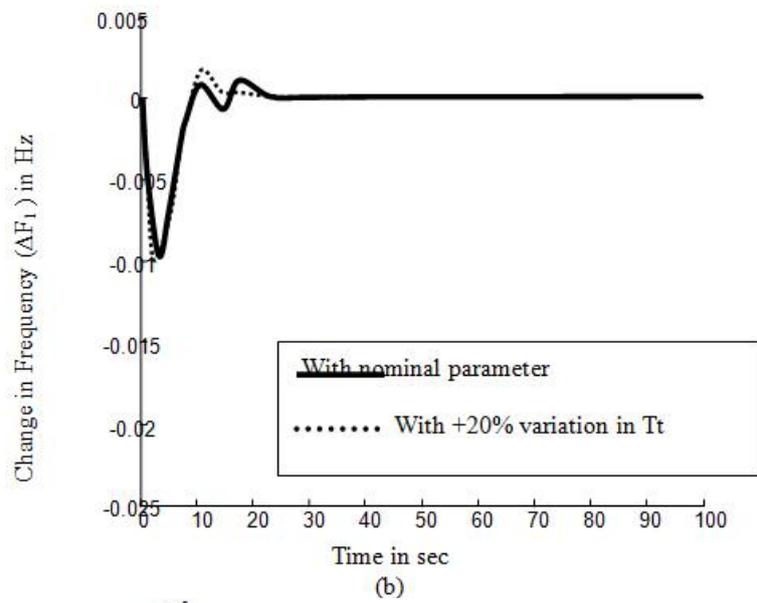
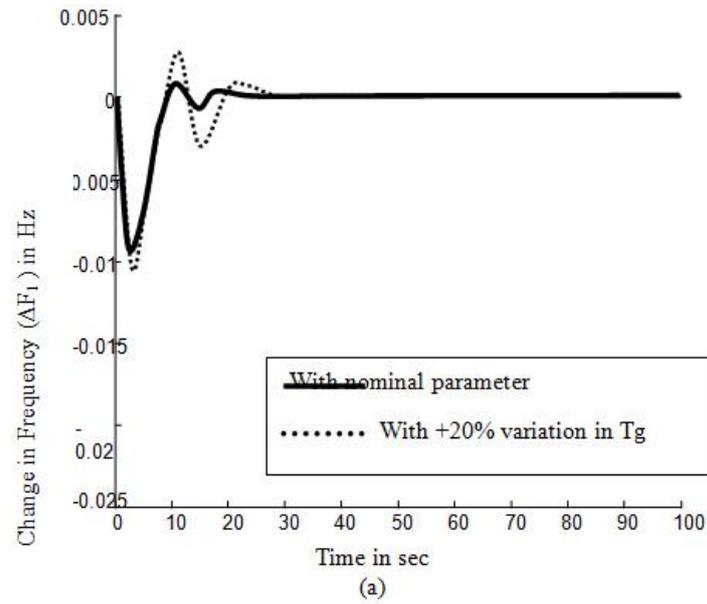
**Fig. 5:** Comparison Frequency Deviation and tie-line power deviation for 0.01 p.u.M.W step load change in area1 with Conventional, Fuzzy gain scheduling PI controller, BAT PI, BID PI controller: (a) Frequency deviation of area 1, (b) Frequency deviation of area 2, and (c) tie-line power deviation of area 1

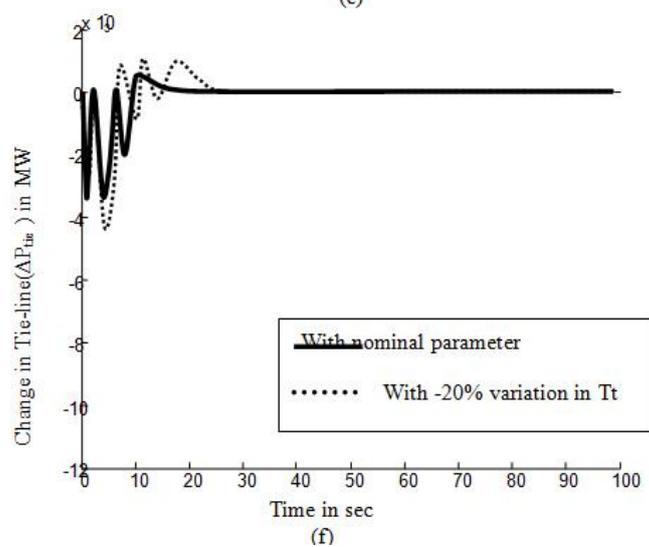
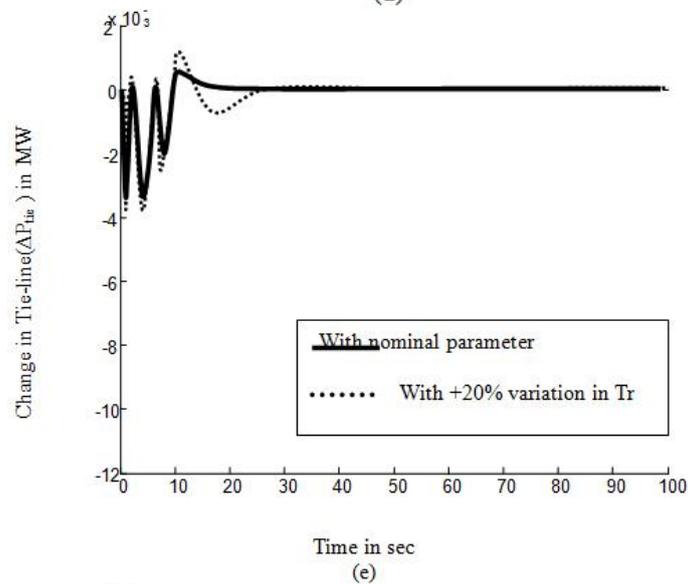
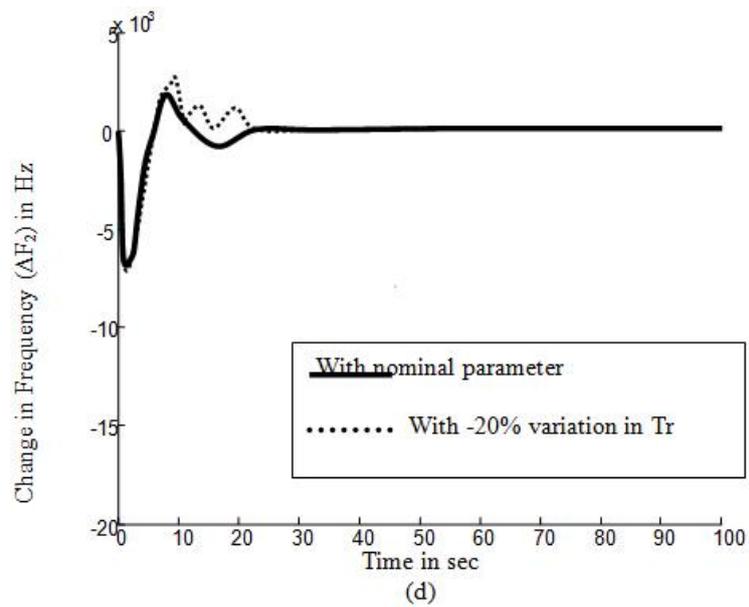
For easy comparisons, the response of  $\Delta f_1$  and  $\Delta f_2$  and  $\Delta P_{tie12}$  of the system with optimum proportional plus integral controllers designed on the basis of ISE, fuzzy gain scheduling of PI controller and Bat PI controller are plotted in the same Fig.5. From the result, fuzzy gain scheduling of PI controllers membership function of  $ACE$ ,  $\Delta ACE$ ,  $K_p$ ,  $K_i$  and output surface viewer in matlab for  $K_p$ ,  $K_i$  are given in Fig.(6), it is observed that the proposed BIDPI controller has less overshoot and settling time. For convenience the performance of various control schemes are given in the table 2.

Controller	Overshoot/Undershoot			Settling Time		
	$\Delta f_1$	$\Delta f_2$	$\Delta P_{tie}$	$\Delta f_1$	$\Delta f_2$	$\Delta P_{tie}$
Conventional PI	+0.001 -0.018	+0.013 -0.015	+0.009 -0.045	40.96	40.57	46.71
Fuzzy gain scheduling PI	+0.000 -0.026	+0.00 -0.019	+0.00 -0.095	09.51	10.00	15.35
BAT PI	+0.008 -0.022	+0.007 -0.025	+0.010 -0.065	13.12	14.20	16.50
BIDPI	+0.002 -0.016	+0.005 -0.013	+0.015 -0.059	09.20	13.12	10.50

**Performance analysis of the proposed controller under parameter variation:**

The performance of the proposed controller has been analyzed under parameter variation. The parameter  $T_g$ ,  $T_p$ ,  $T_i$  are varied by  $\pm 20\%$ . From the nominal value one at a time the simulations are carried out and their results are shown in Fig.7. From the results, it is found that the proposed Bat inspired algorithm based dual mode gain scheduling of PI controllers is less sensitive to parameter variation.





**Fig. 7:** Comparisons of thermal frequency deviations and tie-line power deviations of area1 for 0.01 p.u K.W step load change with system parameter variation.

### Conclusions:

This paper presents a design of BIDPI to area thermal-thermal interconnected power system. This design takes advantage of the superior characteristics inherent PI controller and dual mode concept of the search ability of Bat inspired algorithm. Simulation study results of two area interconnected power system with reheat turbines reveal that the proposed controller provides a high quality transient and steady- state response. Further, it is observed that the controller is less sensitive to change in the parameters of the system.

### ACKNOWLEDGEMENT

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### Appendix A1:

**Data for the interconnected two-area thermal power system Zhao( Zhen-Yu.,et al.,1993) :**

Rating of each area = 2000 MW, base power = 2000 MVA,  $f = 60$  Hz,  $K_{r12} = K_{r22} = 0.5$ ,  $R_{11} = R_{12} = R_{21} = R_{22} = 2.4$  Hz/p.u. Hz,  $T_{g11} = T_{g12} = T_{g21} = T_{g22} = 0.08$  s,  $T_{r12} = T_{r22} = 10$  s,  $a_{12} = -1$ ,  $\Delta P_{D1} = 0.01$  p.u.MW,  $T_{111} = T_{112} = T_{121} = T_{122} = 0.3$  s,  $K_{ps1} = K_{ps2} = 120$  Hz/p.u. MW,  $T_{ps1} = T_{ps2} = 20$  s,  $b_1 = b_2 = 0.425$  p.u. MW/Hz,  $2\pi T_{12} = 0.545$  p.u. MW/Hz,  $apf_{11} = apf_{12} = apf_{21} = apf_{22} = 0.5$

### Appendix A2:

**Parameter of BAT Algorithm:**

Total population = 30; Number of iterations = 20; Loudness  $\underline{A} = 0.9$ ; Wavelength  $\underline{r} = 0.1$ ; Frequency  $\underline{f}_{\min} = 0$ ,  $\underline{f}_{\max} = 0.9$ .

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