Crow Search Optimized Fuzzy PI controller for AGC of an interconnected multi-area power system

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ABSTRACT: This paper introduces a fresh principal evolutionary algorithm called crow search algorithm (CSA) for solving load frequency control (LFC) problem in power system. In the proposed work fuzzy pi controller is used to improve the frequency and tie line power constancy of inter connected power system. In this research work the automatic generation control (AGC) of a three equal area and each area having one thermal unit with reheat type turbine and a Generation Rate Constraint (GRC) of 3% per min is taken for each area. The controller parameter is tuned by applying CSA algorithm and compared with DE-PSO algorithm. For this the required objective function ITAE .The variation step load by 1% is considered for area one only while other area doesn't have any load variation for this analysis. The deviation in system frequency and tie-line power signals of above said controllers are compared and it is seen that CSA technique based and fuzzy pi controller having excellent performance over other in regards for settling time, peak overshoot and undershoot with reduced oscillation.

Keywords-Load Frequency Control, Crow Search Algorithm, Fuzzy Logic Controller, Proportional-Integral-Derivative controller.

I.INTODUCTION

The principle of the load frequency control (LFC) is to support the scheduled frequency and scheduled tie-line power in a usual mode of operation, through the small deviation in operating situations. It maintains the generation demand of a region in a predefined limit by regulating the governor output. The vast interconnected areas describe a coherent group of generators. The various areas are interconnected all the way through tie-lines. The tie-lines are used for transferring the energy within the consecutive two-area and gives inter-area support in case of sudden load change situations of the power system. On the occurrence of a load change, the error in frequency and planned power interchange between areas takes place in the system. This error has to be corrected by load frequency control (LFC), which is established as the regulation of power output of generators within a tolerable limit [1,2].

The various number of the conventional controller like PI, PID is used in a control system, as this controller is easier to execute, easy to understand with low cost. Their control strategy is reliable and reported as robust for various operating situations. The response of the system with these controllers is slower and more inferior to the intelligent controller.

Numerous researchers have used the conventional controller and optimal PID controller for controlling frequency deviation and Tie-Line power. In this paper, a double area LFC is designed for frequency, and power deviation control and the parameters are optimized with CSA. The proposed Fuzzy logic gives the superior results than the conventional controller like PID; the intelligent controller results are equated with classical controller Using MATLAB software. The power deviation and frequency response found by the fuzzy logic controller in LFC are equated with LFC having PID controller regarding settling time, rise time and peak-overshoot. It is found that fuzzy provides a better result as contrast to the conventional controller.

From the Literature studies disclose that numerous control methodologies have been suggested by number of researchers over the past decades for LFC of power system. Out of numerous control strategies and various optimization methodologies like conventional [3], optimal control [4], Genetic Algorithm (GA) [5], Particle Swarm Optimization (PSO) [6], Bacteria Foraging Optimization Algorithm (BFOA)[7], Fuzzy Logic Controller(FLC) [8], and Artificial Neural Network (ANN) [9] have been suggested for LFC. In [10] the gains of the PI controller are optimized by using craziness based PSO algorithm. In [11] Fuzzy PID controller is optimized using DEPSO algorithm for the optimization PID controller. In [12] it has been suggested by many scholars that Fuzzy Logic Controller (FLC) progress the closed loop standards of PI controller and can hold any deviations in service. In [13] the dynamic performances are shown of load frequency control by the Ant Bee Colony (ABC) optimized PI-PD controller to be better than PSO. A pso-ps optimized fuzzy pi control is described In [14] . Bacteria foraging optimization algorithm based load frequency controller for interconnected power system is described in [15]. For solving constrained engineering optimization problems, Crow search algorithm is described in [16]. Fuzzy pss for single machine infinite bus power system is described in [17]. Optimal tuning of fuzzy logic power system stabilizer using harmony search algorithm is described in [18].

II.POWER SYSTEM MODELLING

The interconnected power system consists of three area thermal units of same capacity, characteristics and parameter is shown in fig.1. Three area models are designed with ara-1 and area-2 as thermal unit with reheat turbine and area-3 is taken with GRC to introduce nonlinearities. GRC is known as Generation Rate Constant which is non linear in nature. The three area LFC power system equations are:

$$\Delta P_{v1}(s) = \frac{1}{1+\tau_g}\Delta P_{g1}(s) \quad (1)$$

$$\Delta P_{v2}(s) = \frac{1}{1+\tau_g}\Delta P_{g2}(s) \quad (2)$$

$$\Delta P_{v2}(s) = \frac{1}{1+\tau_g}\Delta P_{g2}(s) \quad (3)$$

Where

$$\Delta P_{gi}(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta\boldsymbol{\omega}_i(s) \quad (4)$$

The change in prime mover power is given by

$$\Delta P_{mi}(s) = \Delta P_{vi}(s)\frac{1}{1+\tau_T s} \quad (5)$$

The frequency deviations of each control areas are

The change in prime mover power is given by

$$\Delta P_{mi}(s) = \Delta P_{vi}(s)\frac{1}{1+\tau_T s} \quad (6)$$

The frequency deviations of each control areas are

$$\Delta F_i = \left[\frac{K_{psi}}{1+s\tau_{psi}}\right]\Delta P_{gi}(s) - \Delta P_{Li}(s) - \Delta P_{tiei}(s) \quad (7)$$

$$\Delta P_{tie1}(s) = \frac{2\pi T_{12}}{s}[\Delta F_1(s) - \Delta F_2(s)] + \frac{2\pi T_{13}}{s}[\Delta F_1(s) - \Delta F_3(s)] \quad (8)$$

$$\Delta P_{tie2}(s) = \frac{2\pi T_{12}}{s}[\Delta F_2(s) - \Delta F_1(s)] + \frac{2\pi T_{23}}{s}[\Delta F_2(s) - \Delta F_3(s)] \quad (9)$$

$$\Delta P_{tie3}(s) = \frac{2\pi T_{31}}{s}[\Delta F_3(s) - \Delta F_1(s)] + \frac{2\pi T_{23}}{s}[\Delta F_3(s) - \Delta F_2(s)] \quad (10)$$

$$\Delta P_{tie3}(s) = \frac{2\pi T_{31}}{s}[\Delta F_3(s) - \Delta F_1(s)] + \frac{2\pi T_{23}}{s}[\Delta F_3(s) - \Delta F_2(s)] \quad (11)$$

The Area Control Error(ACE) is the input to the controller in all areas. The turbine power is set to be at its rated value by the output power.

$$ACE_i(s) = \Delta P_{tiei}(s) + B_i\Delta F_i(s) \quad (12)$$

$ACE_i(s)$ = Area Control Error of area ***i***

From the above equations the three area model can be simulated in MATLAB, simulink and proper controller can be place in their relevant locations. The objective functions from the three are model of thermal plant can be taken in the arrange of ITAE which taken into account of $\Delta P_{tiei}(s)$ and $\Delta F_i(s)$ as follows.

$$\text{ITAE} = \int_0^{t_{sim}}(|\Delta F_1| + |\Delta F_2| + |\Delta F_3| + |\Delta P_{tie1}| + |\Delta P_{tie2}| + |\Delta P_{tie3}| \quad (13)$$

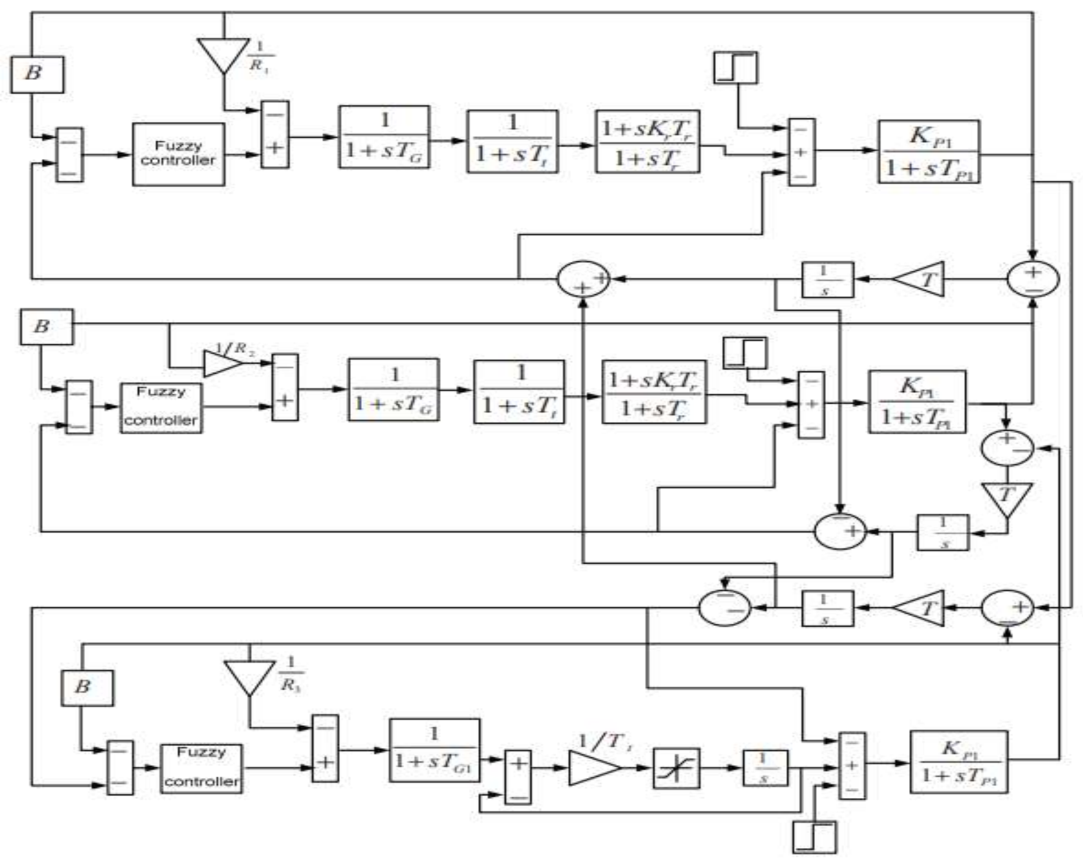

Fig. 1 Simulink Model for Three Area LFC

FUZZY LOGIC CONTROLLER

To control the frequency, fuzzy pi control is provided in each area. The structure of fuzzy pi control is shown in fig.2. Fuzzy controller uses errors and derivative of errors as input signals. The output of the fuzzy controllers is the controller input to the power systems. The input scaling factors are the tunable parameters K_1&K_2. The proportional and integral gains of fuzzy controller are represented by K_P and K_I respectively. Triangular membership function are used with fuzzy Linguistic variables such as large negative (Ln), small negative (Sn), medium negative (Mn), zero (Ze), small positive (Sp) and medium positive (Mp) and large positive (Lp) for both the input and the output. For the area control error ***(e)*** and derivative of error (**Δ*e***), the rules are interpreted as if ***(e)*** is Ln and derivative of error***(Δe)*** is Ln then the output is Ln. member ship functions for error and error deviation shown in fig.3 . The interface engine for the proposed work is Mamdani interface. The Centre of gravity method of defuzzificztion is considered for the output of FLC. . The two-dimensional rule base for error, error derivative and FLC output is shown **Table.1**

III. CROW SEARCH ALGORITHM

From the smart behavior of flocks of crows, Askarzadeh[16] developed the algorithm which was able to solve many mathematically complex optimization problems. The results to the benchmark functions show that this algorithm was indeed one of best of its kind. The application to the load frequency control gives satisfactory results among DE-PSO algorithm as described. The various steps involved in Crow Search Algorithm are

Step 1: Starting of algorithm and adjusts the variables

In this steps the flock population(N), maximum number of iteration($iter_{max}$), awareness probability(AP), flight length(fl) and number of decision variable(d) is defined.

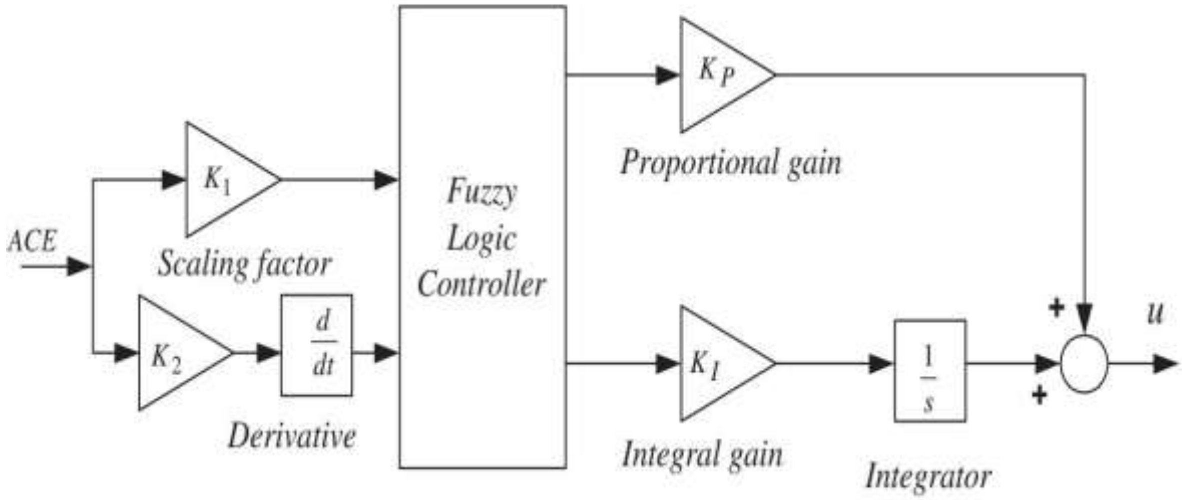

Fig.2

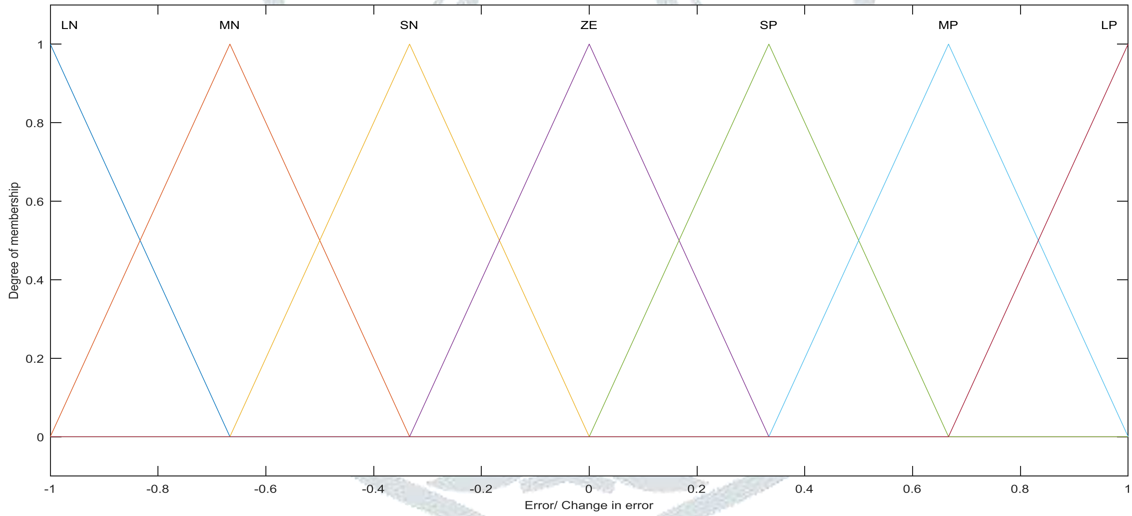

Fig.3

	Derivative of Error(Δe)						
Error(e)	**Ln**	**Mn**	**Sn**	**Ze**	**Lp**	**Mp**	**Sp**
Ln	Ln	Ln	Mn	Ln	Mn	Sn	Ze
Mn	Ln	Ln	Ln	Mn	Sn	Ze	Mp
Sn	Ln	Ln	Mn	Sn	Ze	Lp	Mp
Ze	Ln	Mn	Sn	Ze	Lp	Mp	Sp
Lp	Mn	Sn	Ze	Lp	Mp	Sp	Sp
Mp	Sn	Ze	Lp	Mp	Sp	Sp	Sp
Sp	Ze	Mp	Mp	Sp	Sp	Sp	Sp

Table.1

Step 2: Define memory of crows and locations allocation

In this step the N numbers of crows are randomly placed in d-dimensional search space. Each position of crows defines a possible solution to the algorithm. Initially as the crows have no memory, the starting position is taken as best memory in the problem. That is at first iteration the crow has initial position as allocated location.

Step 3: Calculation of objective function
The quality of each crow's position is determined by dropping the variables into the objective function.

Step 4: Generation of fresh location.

Crows produce fresh location in the environment as follows: assume crow ***i*** needs to produce a fresh location. To do this propose, this crow arbitrarily chooses one of the flock crows (for example crow ***j***) and chases it to determine the location of the environment best position by this crow (m^j). The fresh location of crow ***i*** is found by the equation below

$$x^{i,iter+1} = x^{i,iter} + r_i \times fl^{i,iter} \times (m^{j,iter} - x^{i,iter}) \text{ if } r_j \geq AP^{j,iter}$$
$$= \textbf{arbitrary location} \quad \text{else}$$

Where r_i = Any random number uniformly distributed between 0 to 1.
$m^{j,iter}$ = best position of crow j at iteration iter.

Step 6: Calculate objective function of fresh locations
The objective function worth for the fresh location of each crow is figured out.
Step 7: Update memory
Up gradation of memories of crows are computed as follows:

$$m^{i,iter} = x^{i,iter+1},\ f(x^{i,iter+1}) \text{ is better than } f(m^{i,iter})$$
$$m^{i,iter},\ \ else$$

Where ***f(.)*** depicts the fitness function value. if the fitness function value of memory is poorer to the fitness function value of the fresh location, the crows update their memory with present position
Step 8: Verification of execution of criterion
All the above steps are reiterated until $iter^{max}$ is achieved. When the execution task completes, the best value of objective function is reported as optimization problem.

IV. RESULTS & DISCUSSION

A crow search algorithm is used in this work to optimally tune the parameters of Fuzzy PI controllers and is compared with the DE-PSO algorithm. The scaling factors are ranged from 0 to 2 for the controller. Number of population is taken as 20 and maximum number of iterations is taken as 50. The flight length (fl) is taken as 2 and the awareness probability is taken as 0.1. ITAE is taken as objective function for the proposed controllers.. To study the dynamic response of the system a step load of 1% is applied in area-1. In the table 2 the optimum values of the proposed controller is considered with the optimum values of DE-PSO. Finally from the ITAE section it can be seen that proposed controller outperforms the hybrid DE-PSO optimized fuzzy controller. The performance compression is given in table.3.

	DE-PSO			CSA		
Gains	***Area-1***	***Area-2***	***Area-3***	***Area-1***	***Area-2***	***Area-3***
K1	2.0000	1.1308	1.4209	1.4719	0.9156	1.1591
K2	0.1728	1.6775	2.0000	1.3270	1.4882	1.3284
K3	2.0000	1.4766	1.8508	1.4378	1.2729	1.1300
K4	2.0000	1.9165	0.8575	1.8823	0.3184	1.8233
ITAE		0.1543			**0.0637**	

Table 2: Optimized values of DE-PSO and CSA
The frequency deviations in area-1, area-2, area-3 with tie line power respectively are shown in figure below.

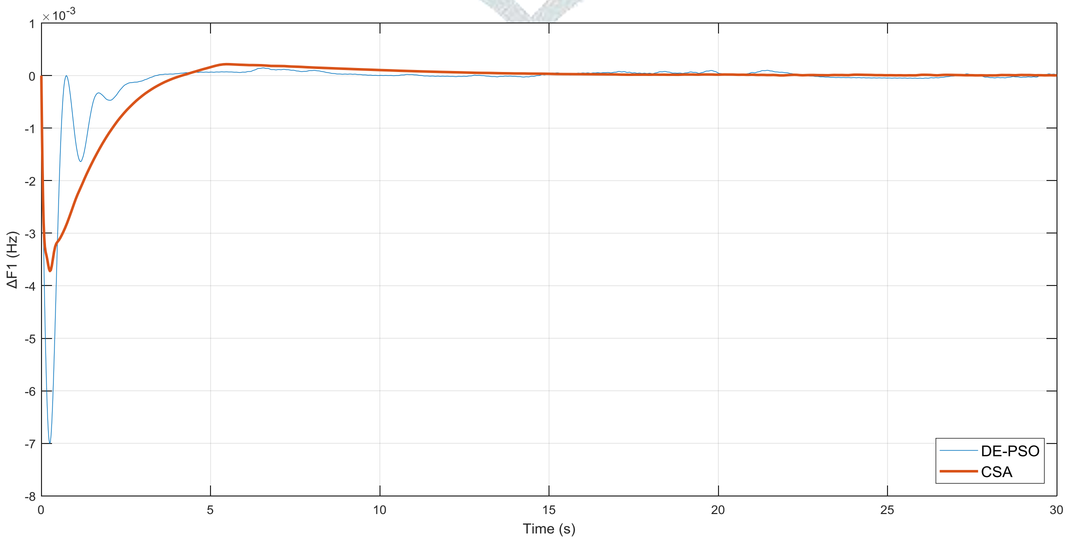

Fig.4: Frequency Deviation in Area-1 for a step load disturbance of 1%

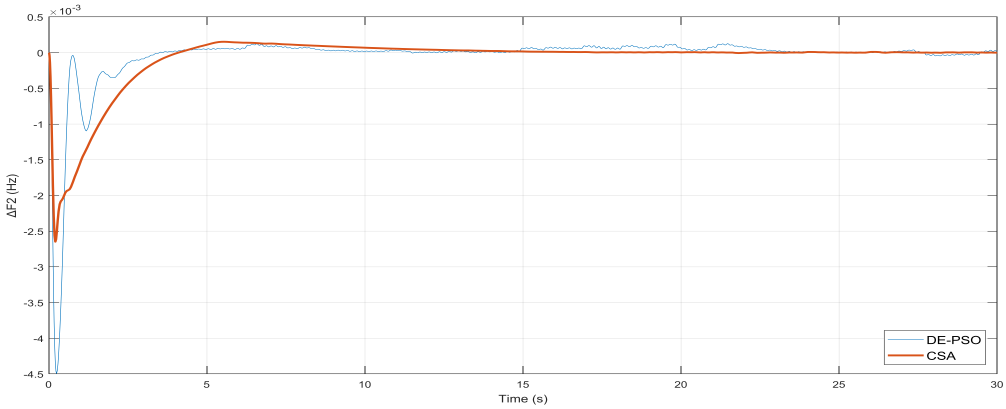

Fig.5: Frequency deviation in area-2 for a step load increase of 1%

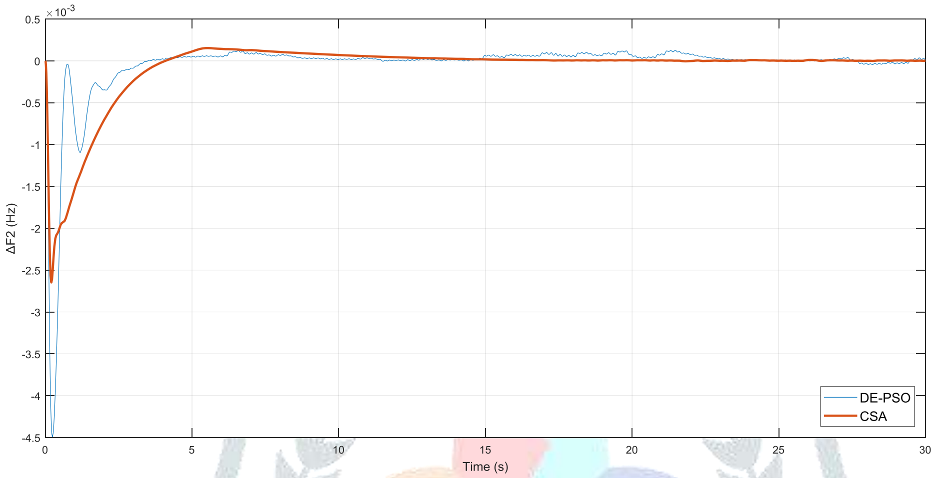

Fig.6: Frequency Deviation in area-3 for a step load increase of 1%

	DE-PSO			CSA		
	ΔF_1	ΔF_2	ΔF_3	ΔF_1	ΔF_2	ΔF_3
O_{sh} ($x\ 10^{-4}$)	1.025	1.271	1.638	2.146	1.522	1.337
U_{sh} ($x\ 10^{-4}$)	70.02	44.93	43.78	37.01	26.48	25.52
T_s ($x\ 10^{-4}$)	21.456	28.19	28.44	10.41	12.04	10.69

Table 3: Performance parameters comparison

V.CONCLUSION

In this paper Crow Search Algorithm (CSA) is implemented to tune fuzzy pi controller in multisource integrated type multi area power system providing automatic Generation Control. A three area interconnected power system which contains three thermal, with appropriate nonlinearities likes Generation Rate Constraint (GRC). Integral of time multiplied absolute error (ITAE) of frequency and tie line power deviation of all areas following a disturbance is taken as the objective function and the parameters of the controller are advanced utilizing CSA technique.. It can be seen that in all of the above cases the CSA optimized Fuzzy PI controller shows superior result than the DE-PSO.

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