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Crow Search Algorithm Tuned Fuzzy PI Controllers of Multi Source Multi Area Load Frequency Control

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Abstract

As the power demand in the present day changes so does the network is getting more and more complex which results in more interconnected areas with varieties of generation techniques. Automatic load frequency control (LFC) is needed in power system for the sake of stability and reliability. It regulates the power output to maintain the frequency balanced when there is a sudden change in load occurs. This paper introduces a new metaheuristic algorithm known Crow search algorithm (CSA) based Fuzzy-PI controller for the optimal tuning of controller parameters. The power system model is to be considered in this paper is a two area six units type multi source one. Both the areas have a thermal reheat generation, a hydro generation and a gas turbine. The superiority of the proposed controller is compared with differential evolution(DE) and CSA based PID controller taking the settling time (Ts), peak overshoot (Osh) and peak undershoot (Ush) of tie line power and the frequencies of concerned areas.

Index Terms—LFC, Fuzzy-PI, CSA, Area Control Error(ACE)

Introduction

The objective of LFC is to maintain tie line power and change in frequency within predefined limits during small perturbation in the system. In a large interconnected area, there are numbers of generators operating synchronously to form a coherent group or area or region. . Tie lines are the connecting medium between various areas [1] Tie lines are used for exchanging energies and inter-area support in the event of emergency situations [2]. When there is a sudden load change occurs in the system, the areas frequencies and tie line power deviates from their nominal value. This deviation is sensed by the LFC and generator output is regulated to bring back the original system frequency [3].

Numerous researchers have used the conventional controller and optimal PID controller for controlling frequency deviation and Tie-Line power. In this paper, a two area six units comprises of thermal, hydro and gas turbine is designed for frequency, and power deviation control and the fuzzy parame- ters are optimized with CSA. The proposed Fuzzy logic gives the superior results than the conventional controller like PID; the intelligent controller results are compared with classical controller Using MATLAB software, The power deviation and 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 logic controller provides a better result as contrast to the conventional controller optimized with DE and CSA.

Concordia was the first to investigate the behavior of system frequency when the load changes in 1950. He proposed AGC whose objective was to stabilize system frequency and the tie line power of an interconnected system [4]. In [5] a hybrid PSO-PS algorithm was used to tune the Fuzzy PI parameter of two area four units hydrothermal system. Rahman proposed an AGC with hybrid thermal with solar and wind turbine in [6] Out of various methodologies like genetic algorithm [7], particle swarm optimization [8] and bacteria foraging optimization algorithm [9], Artificial Neural Network(ANN) have been suggested for load frequency control.

MODELLING OF POWER SYSTEM

A two equal area power system connected by a tie line is shown in Fig. 1. The data to the proposed model are taken from [11] as given in the appendix Each area has thermal,

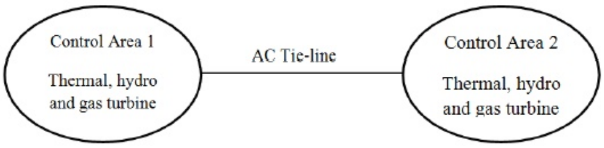

Fig. 1. System under study: Areas connected by tie-lines

hydro and gas turbine generations [11]. A Fuzzy PI controller is designed for each unit of both the areas. The block diagram model for the power system is shown in Fig. 2. The input to the controller is known as area control error (ACE). The controller processes the ACE under small disturbances and gives the output as the input to the respective units. The ACE can be provided as below

ACE1 = ΔF1 + ΔPtie

ACE2 = ΔF2 − ΔPtie

The objective function is to be taken as ITAE (Integral Time Absolute Error) which is mathematically defined as equation (1) J

$$J = \int_0^{t_{sim}} | ACE_i | .t.dt \qquad (1)$$

or

$$J = \int_0^{t_{sim}} (| \Delta F_1 | + | \Delta F_2 | + | \Delta P_{tie} |).t.dt \qquad (2)$$

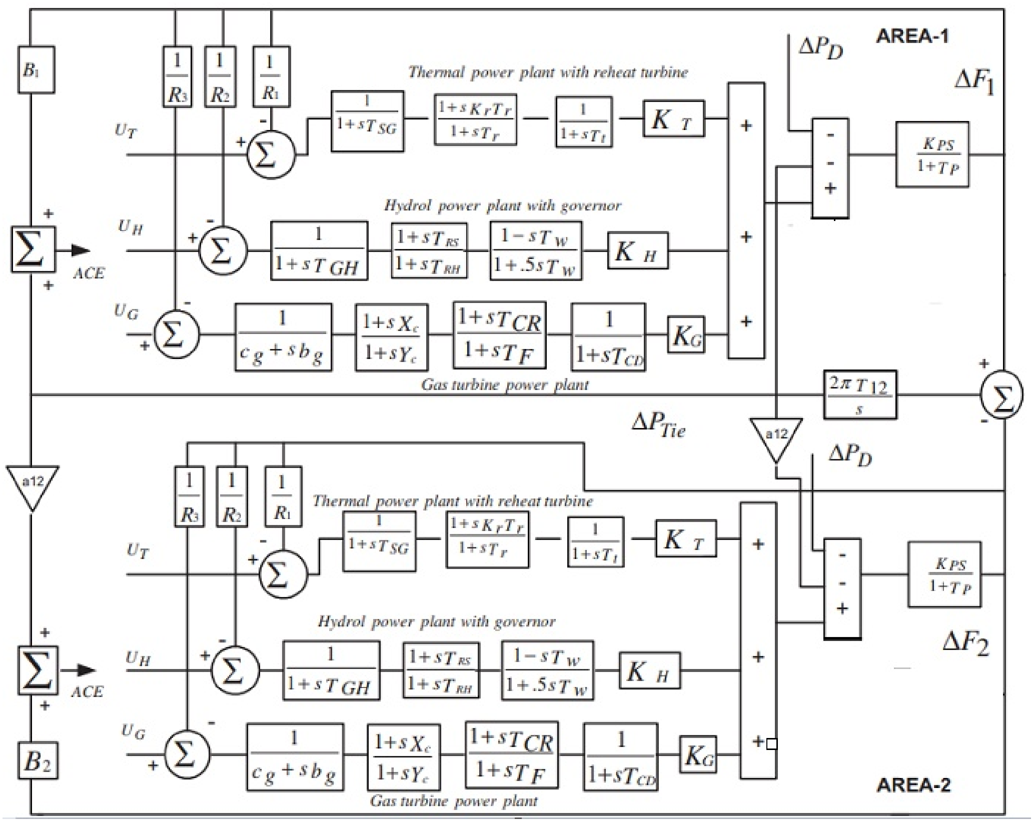

Fig. 2. Block Diagram model of the system

Where ΔF1 = Frequency deviation in area-1, ΔF2 = Frequency deviation in area-2, ΔPtie = Deviation in tie-line power.

CROW SEARCH ALGORITHM

From the smart behaviour of flock of crows, Askarzadeh developed the algorithm which was able to solve many mathematically complex optimization problems. The results to the benchmark functions shows that this algorithm was indeed one of best of its kind [12]. The application to the load frequency control gives satisfactory results among other metaheuristics results as described.

Step 1: Starting of algorithm and adjusts the variables

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

Step 2: Define memory of crows and locations

In this steps the N number 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 memory 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 found by the cases below

$$x^{i,iter+1} = \begin{cases} x^{i,iter} + r_i \times fl^{i,iter} \times (m^{j,iter} - x^{j,iter}), \\ \text{if } r_j \geq AP^{j,iter} \\ \text{arbitary location, otherwise} \end{cases}$$

Where,

r_i = Any random number uniformly distributed between 0 to 1.

$m^{j,iter}$ = best position of crow j at iteration iter.

Step 5: Calculate objective function of fresh locations

The objective function value for the fresh location of each crow is figured out.

Step 6: Update memory

Up gradation of memories of crows are computed as follows -

$$m^{i,iter} = \begin{cases} x^{i,iter+1} & \text{if } f(x^{i,iter+1}) \leq m^{i,iter} \\ m^{i,iter}, & \text{otherwise} \end{cases}$$

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 itermax is achieved. When the execution task completes, the best value of objective function is reported as the global solution and the memory information are reported as global feasible points of the optimization problem.

FUZZY LOGIC CONTROL

The algorithm behind fuzzy logic controller is fuzzy logic which converts linguistic control strategy based on expert knowledge into automatic control [13]. It is mostly comes into play when the information is uncertain. There are four types of components used in fuzzy logic namely

1) Fuzzification
2) Fuzzy Inference System (FIS)
3) Knowledge Base
4) Defuzzification

Components of Fuzzy Logic Controller

1) Fuzzification

In fuzzification the crisp input variables are scaled and mapped into linguistic variables into the corresponding fuzzy universe of discourse. For the proposed paper the inputs are fuzzified into triangular membership function.

2) Fuzzy Inference System(FIS)

Here output is obtained in fuzzy logic from the input fuzzy logic and rules provided. In this paper seven linguistic variables are defined for both the input e and Δe comprising 49 rules. Mamdani inference engine is used and inputs are processed to give seven linguistic output variables.

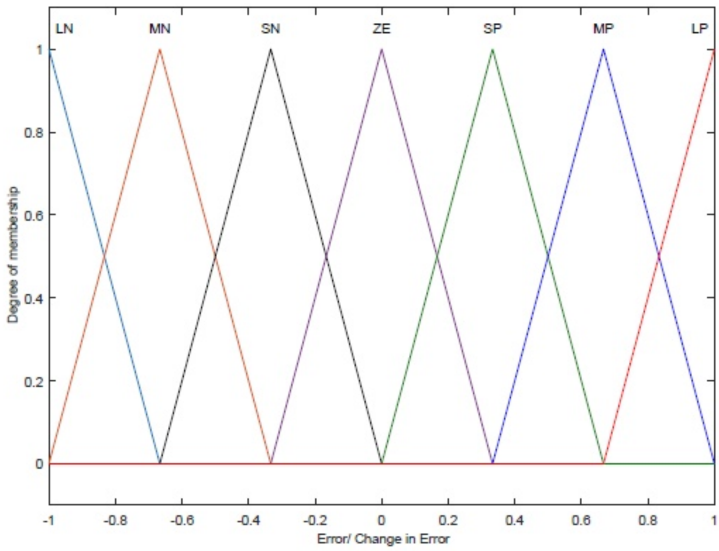

Fig. 3. Membership Function

3) Knowledge Base

The knowledge base has a data base and a rule base. Data base gives information about the proper functioning of fuzzification, inference mechanism and defuzzification. The data base gives a value to the linguistic variables. The rule base contains the rules of how the operation is done. It consists of few if-else statements which manipulates the input variables to provide output variables

TABLE I
RULE BASE FOR FUZZY LOGIC

Error(e)	Derivative of Error(Δe)						
	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

4) Defuzzification

In defuzzification the linguistic output variables are converted into crisp number. To get this job done the centroid method is used in this paper.

The rule is to be interpreted as if error(e) is Ln and derivative of error(Δe) is Ln then the output is Ln.

Structure of Fuzzy Logic Controller

The proposed Fuzzy controller structure diagram is shown in the Fig. 4. The inputs to the controller are ACE1 and ACE2 for the area-1 and area-2 respectively. The inputs are scaled with gain K1;K2 for area-1 and K3, K4 for area-2. The KP and KI) represents the proportional and integral gains of the controller.[sahu 2015]

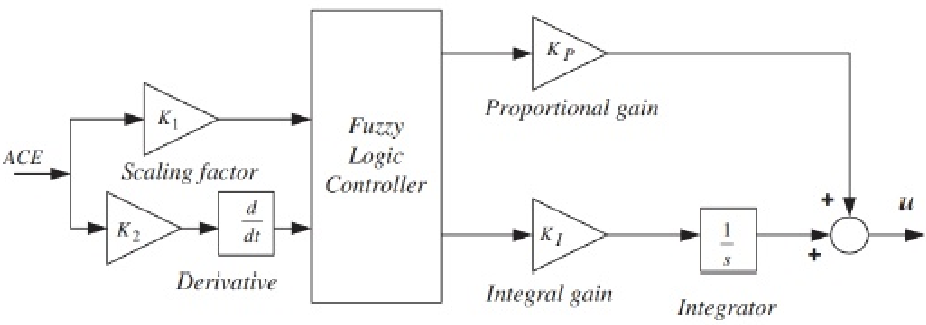

Fig. 4. Controller Structure of Fuzzy PI

RESULTS AND DISCUSSION

A. Design of Fuzzy PI controller

The proposed model of Fig.2 was designed in MATLAB Simulink. The data parameters for the design has been notified in APPENDIX section. The CSA was written in another .m file where the objective function taken to be ITAE (Integral Time Absolute Error) is also written. The fl is taken as 2 and AP as 0.1. The population(N) is taken to be 20 and number of runs(itermax) equals to 30.
The parameters for the Fuzzy PI controller is taken to be in range of [0; 2]. The two DOF controllers parameters DW and PW are set between [0; 5] while the KP ;KI ;KD varies between [□2; 2] and the filter coefficient is to be varied between[10-300] for both the areas.

B. Analysis of Results

To study the dynamic performance of the proposed controller, a step load of 1% is applied in area-1. The performance characteristics are shown in table 2 which is compared with different controllers as given in literature. It is clear that the proposed CSA optimized Fuzzy PI controller gives least ITAE value = 0.1253 as compared to other controllers with different optimization techniques.

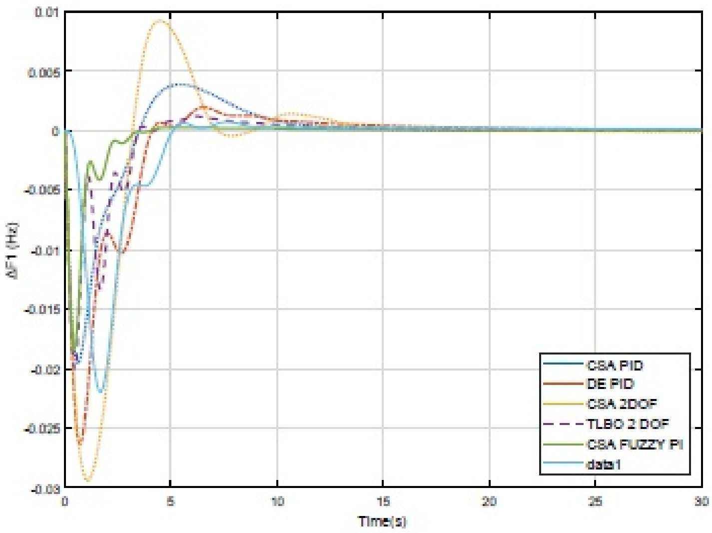

Fig. 5. Change in frequency of area-1 for 1% step load increase

TABLE II: NO VERTICAL LINES, FEWER BUT WELL-SPACED HORIZONTAL LINES

	Settling Time (T_s)			Overshoot(O_{sh})			Undershoot(U_{sh})			ITAE
	ΔF_1	ΔF_2	ΔP_{tie}	ΔF_1 ($\times 10^{-5}$)	ΔF_2 ($\times 10^{-5}$)	ΔP_{tie} ($\times 10^{-5}$)	ΔF_1 ($\times 10^{-2}$)	ΔF_2 ($\times 10^{-2}$)	ΔP_{tie} ($\times 10^{-3}$)	
CSA Fuzzy	3.155	6.679	8.551	26.808	9.353	5.417	1.850	0.878	2.362	0.125
CSA 2DOF	13.374	14.287	15.825	926.429	1354.197	107.807	2.940	3.611	4.530	0.667
TLBO 2DOF [11]	10.691	10.987	10.265	121.642	142.376	–	2.004	1.819	2.555	0.233
DE PID [11]	12.322	8.257	14.092	198.544	74.603	19.306	2.640	2.195	4.734	0.524
CSA PID	11.710	14.543	22.100	387.339	258.346	44.908	1.955	1.418	3.457	0.416

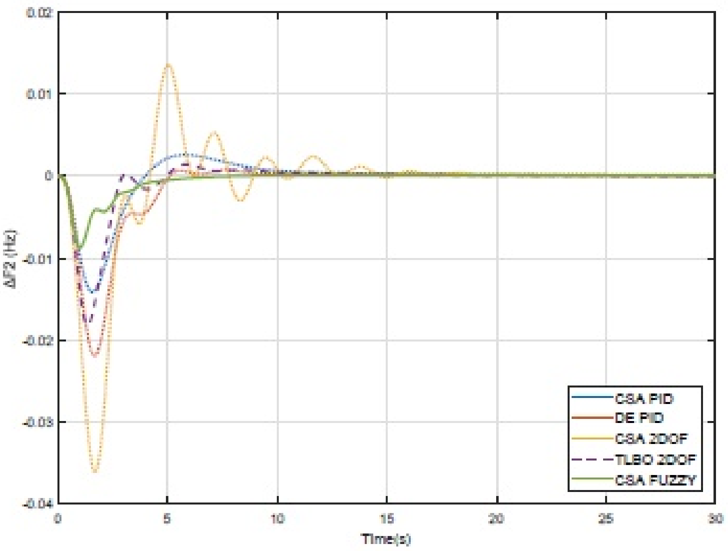

Fig. 6. Change in frequency of area-2 for 1% step load increase

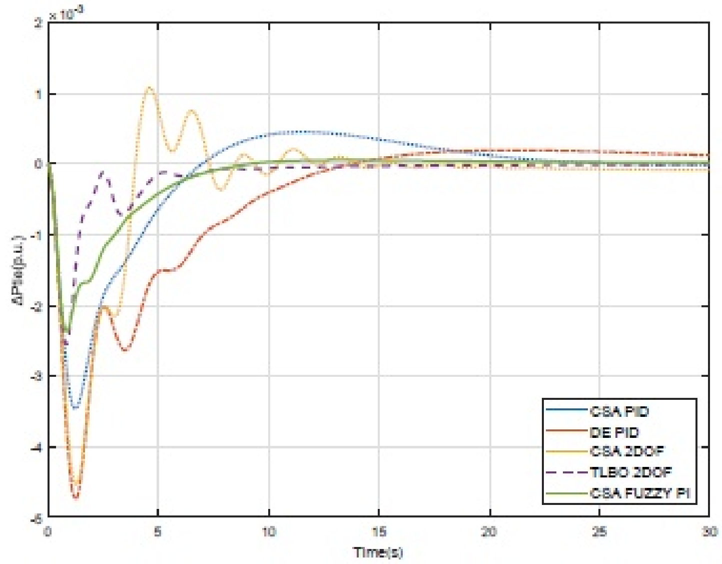

Fig. 7. Change in tie-line power for 1% step load increase

APPENDIX

R1 = R2 = R3 = 2:4Hz=p:u:; TGH = 0:2s; TW = 1:0s; TRH = 28:75s; bg = 0:05s; cg = 1; TF = 0:23s; YC = 1s;XC =0:6s; TCD = 0:2s; TCR = 0:01s; TRS = 5s;KPS = 68:9566Hz=p:u:MW;R1 = R2 = R3 = 2:4Hz=p:u:; TT = 0:3s; TSG = 0:08s;Kr = 0:3; Tr = 10s; TPS = 1:49s; T12 = 0:0433; a12 = 1; ;KT = 0:543478;KH = 0:326084;KG = 0:130438:

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