# Artificial Cooperative Search Algorithm based Load Frequency Control of Interconnected Power Systems with AC-DC Tie-lines

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**Abstract— A maiden effort for optimal tuning of load frequency controller parameters using Artificial Cooperative Search (ACS) algorithm for a two area interconnected power system with AC-DC parallel tie-lines has been presented in this paper. ACS is a recent swarm intelligence algorithm developed for solving numerical optimization problems. The swarm intelligence philosophy behind ACS algorithm is based on the migration of two artificial superorganisms as they biologically interact to achieve the global minimum value pertaining to the problem. The HVDC link in parallel with AC tie-line is used as system interconnection to effectively damp the frequency oscillations of the AC system. An integral square error criterion (ISE) has been used as performance index to design the optimal parameters. A comparative study of tuned values has been presented to show the effectiveness of the Artificial Cooperative Search algorithm. The results demonstrate the success of ACS algorithm in solving Load frequency control (LFC) optimization problem.**

**Keyword-** AC-DC tie-lines, Artificial Cooperative Search algorithm, Interconnected Power System, Load Frequency Control.

## I. INTRODUCTION

Load Frequency Control (LFC) is a very important aspect in power system operation and control for efficient and reliable supply of electric power with good quality. The efficient control of area frequencies and inter area tie line power transfers is one of the main objectives of interconnected power system. Changes in these quantities arise due to the unpredictable variations of loads connected to it resulting in mismatch between the generator output and load demand. The function of load frequency controller is to minimize the deviations in frequency and tie line power to reduce the transient errors and to ensure zero steady state error [1].

Literature survey [2] reveals that most of the research works concerning the performance of power systems by implementing LFC have mainly concentrated on the interconnection between two areas through AC transmission network. HVDC transmission has gained importance in power scenario because of its economic and technical advantages [3]. HVDC transmission network has a DC link connected in parallel with AC link providing an improved system performance. Only a very few research works have been done on LFC of interconnected power system with HVDC link connected in parallel with AC link. So in this proposed work, an interconnected power system with AC-DC parallel tie line is considered.

Different types of controllers have been proposed for power system LFC problem in order to achieve a better performance. Among the various types of load frequency controllers, the PI controller is most widely applied for LFC scheme. An advantage of the PI controller is it reduces the steady-state error to zero by feeding the errors in the past forward to the plant [4,5]. Load Frequency Controller (LFC) designs with better performance have gained more importance because of the complex nature of the large power systems. The large modern power systems require an optimal and flexible operation. To design an efficient controller, the designer should expertise the behavior of the system which is quite complicated and time consuming. Because of these reasons, recently, a number of artificial intelligence based algorithms are used for the tuning of LFC parameters [6]. To improve the performance of modern control system, Artificial Cooperative Search algorithm (ACS) [7], a recent technique suggested in 2013 by Civicioglu, has been proposed in this paper. The proposed controller has been applied to an interconnected two area thermal power system with AC-DC parallel tie lines. Each area contains two thermal units.

## II. PROBLEM FORMULATION

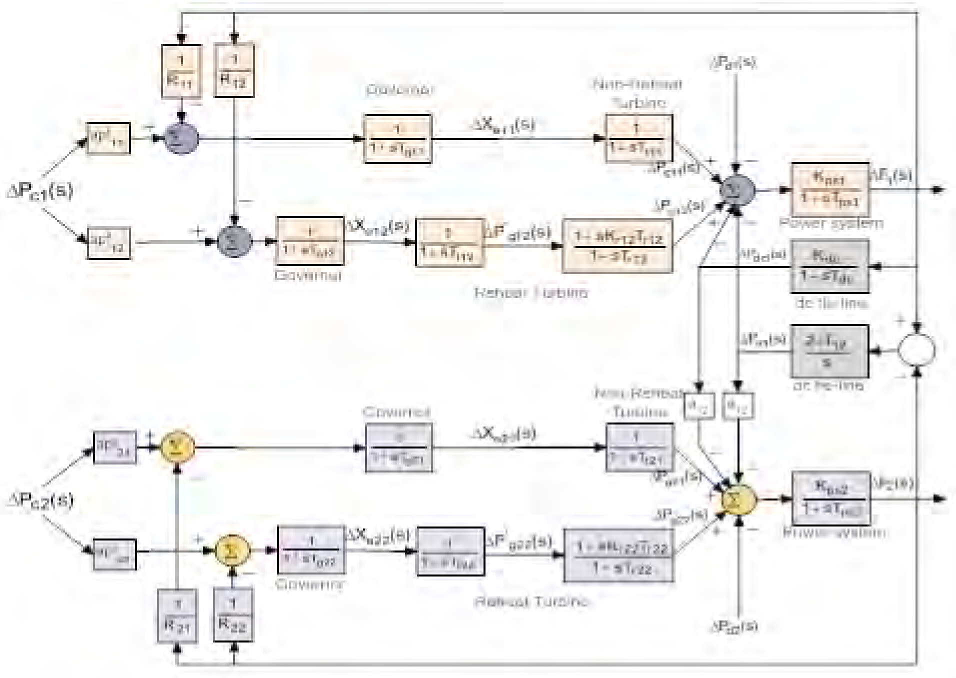


Fig.1. Block diagram of a two-area interconnected thermal power system with AC-DC parallel tie-lines

The proposed control methodology is implemented on a thermal power system comprising two areas with AC-DC parallel tie-lines as shown in Fig.1. Each area in the power system comprises of two thermal units, one reheat unit and one non-reheat unit. The dynamic behaviour of the LFC system is described by the state space equation

$$\dot{\mathbf{X}} = \mathbf{AX} + \mathbf{BU} + \mathbf{\Gamma D} \quad (1)$$

where,

$$\mathbf{X} = [\Delta F_1 \Delta P_{g11} \Delta X_{e11} \Delta P_{g12} \Delta P'_{g12} \Delta X_{e12} \Delta P_{tie1} \Delta P_{dc1} \Delta F_2 \Delta P_{g21} \Delta X_{e21} \Delta P'_{g22} \Delta X_{e22} \Delta P_{g22}]^T \quad (2)$$

$$\mathbf{U} = [\Delta P_{c1} \Delta P_{c2}]^T \quad (3)$$

$$\mathbf{D} = [\Delta P_{d1} \Delta P_{d2}]^T \quad (4)$$

**X**, **U** and **D** are the state, control and disturbance vectors and **A**, **B** and **Γ** are respectively system state matrix, control input matrix and disturbance input matrix of appropriate dimensions [4].

Data for the system is taken from [8] and is given in Appendix. The single line diagram of a two area power system is shown in Fig.2. The transfer function block diagram describing the incremental DC link power flow is shown in Fig.3. Where $\Delta F_1$ is the frequency deviation of area 1 and $\Delta P_{dc}$ is the incremental power flow through DC link. $K_{dc}$ is the gain associated with DC link and $T_{dc}$ is the DC link time constant in seconds. Incremental DC power flow is considered as an additional state variable in the LFC.

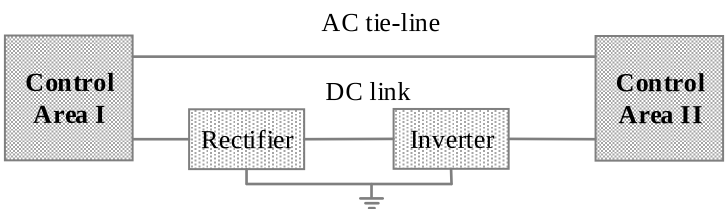


Fig.2.Single line diagram of a two-area system with ac-dc tie lines.

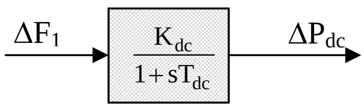


Fig.3. Transfer function block diagram of incremental DC link power flow

## III. ARTIFICIAL COOPERATIVE SEARCH ALGORITHM

Artificial Cooperative Search algorithm (ACS) [7] is a swarm intelligence algorithm developed for solving real valued numerical optimization problems. A mutualism based biological interaction exists between different living species in nature. The living species involved in a mutualism based biological interaction try to derive mutual benefits from the mentioned interaction. Cooperation is the interaction of homogenous living species that adopt mutualism. Mutualism and cooperation based biological interaction of two eusocial superorganisms living in the same environment inspired the ACS algorithm. The habitat concept in ACS algorithm matches the search space concept that belongs to the related problem.

ACS is based on the migration of two artificial super organisms as they biologically interact to achieve the global minimum value to the problem. The quantity of food that can be obtained from a surrounding environment is generally dependent on seasonal climate, a change which varies rapidly. This climatic change has developed seasonal migration behavior for different feeding environments. Prior to migration, majority of the members group together to form a superorganism. The superorganisms that exhibit seasonal migration behavior have the ability to move and find more rich food habitat. Prior to the migration, many superorganisms also organize into subgroups known as sub-superorganisms. During such conditions, the character of a superorganism is determined with the coordination of sub-superorganisms. Explorers are used to search in detail a new place before attempting to migrate to a new area. The explorers then relay the data pertaining to the new migration area to the superorganism. If the superorganism considers the area proposed suitable for migration, then the relevant superorganism moves to this newly discovered area, stops and feeds there for a period, in the meantime, it repeats its behavior to find more fruitful areas and migrates again. In this manner, the living species biologically interact with each other to find their feeding and reproduction needs.

In ACS algorithm, a superorganism consisting of random solutions of the related problem corresponds to an artificial superorganism migrating to more productive feeding areas. ACS algorithm contains two superorganisms; α and β that have artificial sub-superorganisms equal to the dimension of the population (N). The dimension of the problem (D) is equal to the number of individuals within the related sub-superorganisms. In ACS algorithm, α and β superorganisms are used for the detection of artificial Predator and Prey sub-superorganisms. The Predator sub-superorganisms in ACS algorithm can pursue the Prey sub-superorganisms for a period of time while they migrate towards global minimum of the problem. When the iterative calculation process of ACS algorithm that is named as co evolution process is considered, it can be seen that the two superorganisms looking for the global minimum of the related problem, establish cooperation based biological interaction between each other. In ACS algorithm the initial values of the individuals of $i^{th}$ sub-superorganism of α (i.e., α_(i,j)) and β (i.e., β_(i,j)) are defined by using (5) and (6) ;

$$\alpha_{i,j,g=0} = rand.(up_j - low_j) + low_j \quad (5)$$

$$\beta_{i,j,g=0} = rand.(up_j - low_j) + low_j \quad (6)$$

where i = 1, 2, 3, ... , N, j = 1, 2, 3, ... , D and g = 0, 1, 2, 3, ... , max cycle. The ‘g’ value here denotes the generation number expressing the co evolution level containing the related superorganisms. The rand shows a random number chosen from the uniform distribution with U~[0 1]. The $up_j$ and $low_j$ are the upper and lower limits of search space for $j^{th}$ dimension of the related problem. The productivity values (i.e., fitness values) obtained by the related sub-superorganisms are computed by using (7) and (8);

$$y_{i;\alpha} = f(\alpha_i) \quad (7)$$

$$y_{i;\beta} = f(\beta_i) \quad (8)$$

The biological interaction location, X, between Predator and Prey sub-superorganisms is modeled using the equation;

$$X = Predator + R(Prey - Predator) \quad (9)$$

where, R is the Scale factor that controls the speed of biological interaction. The probabilistic nature of ACS algorithm causes the superorganism that is determined as the predator to be changed in each generation. Therefore, ACS algorithm provides a cooperative/coevolution process for both of the superorganisms. The pseudo code of ACS algorithm is provided in [7]. The proposed algorithm can be implemented with convergence, iteration or tolerance as the stopping criteria. In this proposed study, iteration count has been taken as the stopping criteria.

## IV. OPTIMAL GAIN TUNING USING ACS ALGORITHM

ACS algorithm is applied for optimizing the gains of a proportional plus integral controller for a two area interconnected thermal power system. The swarm intelligence philosophy behind ACS algorithm is based on the migration of two artificial super organisms as they biologically interact to achieve the global minimum value pertaining to the problem.

The objective is to obtain the optimum values of the controller parameters which will minimize the performance index, J.

$$J = \int_0^t \left(\Delta F^2 + \Delta P_{tie}^2\right) dt \tag{10}$$

For LFC using ACS algorithm, the initial values of the two individuals namely $K_p$ and $K_i$ of the sub-superorganisms of α and β superorganisms are obtained using (1). The objective function J is calculated for each set of $K_p$ and $K_i$ in α and β. The corresponding productivity values (i.e. fitness values) are obtained using (2). The predator and prey sub-superorganisms are determined randomly in each generation by using α and β superorganisms. The biological interaction location, X, between predator and prey is updated by using active individuals. ACS algorithm provides a cooperative / coevolution process for both the superorganisms. The sub-superorganisms that provides the best solution at any time in ACS algorithm corresponds to the sub-optimal global minimizer of the problem. The process is repeated until optimum values of $K_p$ and $K_i$ corresponding to global minimum objective function value are obtained.

To simplify the analysis, the two interconnected areas are considered identical. The optimal parameter values are such that $K_{p1}=K_{p2}=K_p$ and $K_{i1}=K_{i2}=K_i$ [8].

## V. SIMULATION RESULTS AND DISCUSSION

The Artificial Cooperative Search algorithm is applied to the power system under study to obtain the optimal values for proportional and integral gains in a two area interconnected power system. The following ACS Algorithm parameters are used in this study; Total population = 10; Number of iterations = 30; Predator =10; Prey = 10; R= [0 4] and p =0.25. The optimum controller parameters are reported in table I. It is noted from table I that the performance index is less for the system with AC-DC parallel tie-lines. A step load perturbation of 0.01p.u. MW was applied in area 1 and the corresponding frequency and tie line power deviations are plotted with respect to time. For easy comparison, the system performance in terms of $\Delta F_1$, $\Delta F_2$ and $\Delta P_{tie}$ for a system without DC link are shown in figures 3, 4 and 5 respectively. It is observed from the graphs, that the settling time and oscillations are greatly reduced in the proposed model while applying the proposed Artificial Cooperative Search algorithm. Fig.6. shows the plot between objective function (J) and number of iterations of ACS algorithm. It is observed from Fig.6 that the ACS algorithm converges within 10 iterations.

Inspite of its dual superorganism (i.e. population) structure, ACS algorithm is able to obtain speedy results while sustaining diversity in both the population. Further, unlike other computational intelligence algorithms, ACS algorithm has only one control parameter, the probability of biological interaction p, which simplifies its structure. This demonstrates the effectiveness of the ACS algorithm in the optimization problem considered in this study.

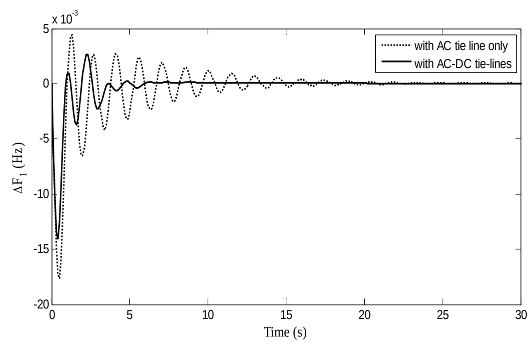


Fig.3: Change in frequency of first area

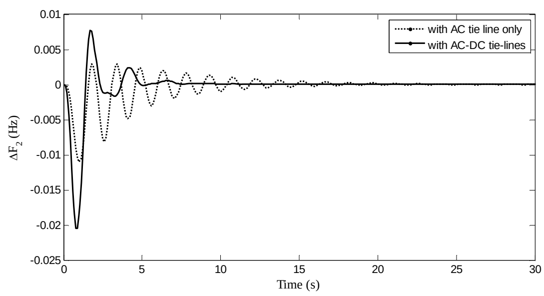


Fig.4: Change in frequency of second area

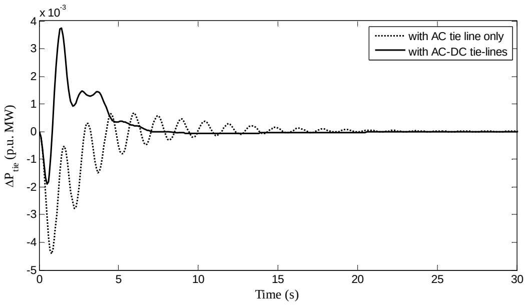


Fig.5: Change in AC tie-line power

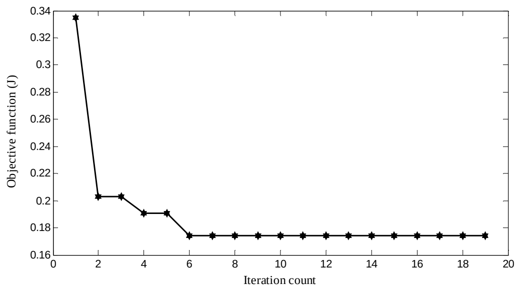


Fig.6: Iteration count versus objective function (J)

TABLE I
OPTIMUM CONTROLLER PARAMETERS

| | Proportional Gain ($K_p$) | Integral Gain ($K_i$) | Performance index |
|---|---|---|---|
| *with AC tie-line only* | 0.4249 | 0.9264 | 0.1721 |
| *with AC-DC tie-lines* | -0.3098 | 1.3947 | 0.1185 |

## VI. CONCLUSION

Artificial Cooperative Search (ACS) algorithm, a new artificial intelligent algorithm based on two populations, has been successfully applied to tune the parameters of PI controller for LFC of an interconnected power system. A two-area power system model with AC-DC parallel tie- lines is considered to reveal the effectiveness of ACS algorithm in solving LFC optimization problem. Simulation results reveal that the designed ACS algorithm tuned load frequency controller is robust in its operation and gives better damping performance both for frequency and tie line power deviations. Besides simple structure of the ACS algorithm, its problem solving success is found to be better than many of the existing artificial intelligent techniques.

## APPENDIX

Data of two-area interconnected power system

Rating of each area = 2000 MW

Base power = 2000 MVA

f = 60 Hz

$R_{11}= R_{12}= R_{21} =R_{22}$ = 2.4 Hz/ p.u. Hz.

$T_{g11}=T_{g12}=T_{g21}=T_{g22}$=0.08 s

$T_{t11}=T_{t12}=T_{t21}=T_{t22}$=0.3 s

$a_{12}$=-1

$\Delta P_{d1}$=0.01 p.u. MW/Hz

$K_{dc}$ = 1

$T_{dc}$=0.5 s

$T_{r12}=T_{r22}$=10 s

$K_{ps1} = K_{ps2}$ =120 Hz/p.u. MW

$K_{r12}=K_{r22}$=0.5

$T_{ps1}=T_{ps2}$=20 s

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