International Journal of Engineering & Technology, 7 (1.2) (2018) 37-42

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Comparative performance analysis of one rank cuckoo search technique based optimization for automatic generation control of interconnected power systems

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Abstract

This paper presents a one rank cuckoo search optimization technique is proposed to design classical PID Controllers for Automatic Generation Control (AGC) of interconnected power systems. This method is proposed based on the original cuckoo search method. It was found in original cuckoo search the convergence speed is comparative lesser in reaching optimal solutions. To overcome the above mentioned problem one rank cuckoo search algorithm has been proposed which uses a bound by best solution technique to get the valid dimension so as to improve the system performance and rate of convergence. The proposed approach is applied to a four area hydro-thermal system in which area-1 and area-2 are steam reheat power plant and area-3 and area-4 are hydro power plant. The controller gains are derived using original cuckoo search and one rank cuckoo search methods. The superiority of the proposed approach is compared with the results obtained with original cuckoo search algorithm.

Keywords: *Automatic Generation Control (AGC); Cuckoo Search; Interconnected Power System; One Rank Cuckoo Search; Classical PID Controller.*

1. Introduction

The main objective of the Automatic Generation Control (AGC) is to ensure that the system is in equilibrium working condition which means that there is a balance established between power-generated and power demand. Any mismatch between the above two powers due to rise and fall of load demand will result in the deviation of real and reactive power balance, which in turn leads to the deviation of system frequency and tie-line power interchange from their scheduled value.

Apart from the main objective, there are other objectives that AGC ensures. They are [1]:

1) Steady state frequency change should be zero due to step change in the load.
2) The change in tie-line power flow following a step load change should be zero.
3) The transient frequency and time errors should be small.
4) During an emergency, area in need of power should get assistance from other areas.

In order to achieve the above control objectives, a conventional Proportional Integral Derivative (PID) controller is used. PID controller is considered owing to its simplicity in implementation and its better dynamic response. But, their performance deteriorate when the complexity in the system increases due to disturbances in the load variation boiler dynamics [2], [3].

Over the last few decades, various controllers like Integral (I), Proportional Integral (PI), Integral Derivative (ID), PID [4], adaptive controller [5], robust controller [6], intelligent controllers using neural network [7], fuzzy logic [8-10], fractional order controller [11], internal mode controller [12], hybrid neuro-fuzzy controller [13] have been implemented to prevent frequency and tie-line power flow deviation.

Several control strategies have also been proposed to ensure the normal working of the power system. Meta-heuristic optimization techniques such as particle swarm optimization (PSO) [14], genetic algorithm (GA) [15], biogeography-based optimization (BBO) [16], [17], krill herd algorithm (KHA) [18], teaching learning based optimization (TLBO) [19,20], bacteria foraging optimization (BFOA) [21], gravitational search algorithm (GSA) [22], hybrid PSO-pattern search (hPSO-PS) algorithm [23], hybrid FA-PS [24], Tabu search algorithm (TSA) [25], quasi-oppositional harmony search algorithm (QOHSA) [26], [27], BAT algorithm [28], backtracking search algorithm (BSA) [29] have been proposed.

It is observed from the literature survey that the implementation of newly proposed optimization techniques for the frequency and tie-line power control yielded good results than the older optimization techniques. Therefore, the field of AGC always welcomes the application of recently proposed optimization techniques.

One Rank Cuckoo Search (ORCS) Algorithm in the year 2013 is developed by Ahmed tweaking the rules associated with the cuckoo search optimization for better results. This optimization technique has been implemented in the field of feed forward neural-network training [30] and optimal reactive powerdispatch [31]. The optimization technique successfully yielded better results in the above mentioned fields. This proves that ORCS algorithm is efficient and outperforms other meta-heuristic algorithms.

In view of the above discussion, a maiden attempt has been made in this project for the application of ORCS for the AGC of multi-area interconnected power system. The ability of ORCS is demonstrated against four area interconnected hydro-thermal power system. The superiority of ORCS is shown by comparing the results with cuckoo search.

2. Mathematical model of the power system

2.1. System under study

A four area hydro-thermal power system interconnected with tie-lines is the system understudy. The power system consists of many control areas. The power system consists of many control areas with complex and multi-variable structures. Also, they consists of different control blockswhich are either non-linear time variant or non-minimum phase system. Each area is associated withstudy. The power system consists of many control areas with complex and multi-variable structures. Also, they consists of different control blocks which are either non-linear time variant or non-minimum phase system. Each area is associated with individual system frequency and tie-line power flow. The detailed Power System scheme is shown in Fig. 1. The parameter values for both thermal and hydro power system is given in Appendix.

Frequency and tie-line power flow in any power system is achieved by two different control actions

I.e. primary speed control and supplementary or secondary control. Primary control is achieved by selecting proper $R_i$and B_i values and they cannot be influenced much. Hence, usually secondary control method is used for control actions.

Secondary control action is achieved by varying the PID parameters in each area. It results in minimizing the Area Control Error (ACE). The Area Control Error is a linear combination of frequency and tie-line power given by:

$$e_i(t) = ACE_i = B^a{}_i \Delta f^a{}_i + \Delta P^a{}_{Tie\ i} \quad (1)$$

In Eq. (1) i= 1, 2, 3, 4; a = 1

Where $B^a{}_i$'s are the frequency bias parameters, $\Delta f^a{}_i$'s are the frequency deviations and $\Delta P^a{}_{Tie\ i}$are the tie-line power flow out of areas.

ACE is considered to be the controlled parameter which determines any mismatch between power generation and power demand. Hence, the selection of objective function is done by either taking a few points from the time response or the entire time response i.e. Integral Criterion.

In literature, there are four commonly used integral performance criterion. They are Integral Square Error (ISE), Integral Absolute Error (IAE), Integral Time multiplies of Square Error (ITSE) and Integral Time Absolute Error (ITAE). ISE returns answer by integrating the square of the error and IAE returns the value by taking the absolute value of the error. Hence, both of these are not accurate. ITSE provides large control output for a sudden change in load. Hence, it is not a good choice for controller design. ITAE reduces peak overshoot and the result is obtained by integrating the product of absolute error time over time.

Therefore, ITAE is considered as the objective function in this paper. It is defined as:

$$J = \int_0^{t_{simulation}} t.\left(\left|\Delta f^a{}_i\right| + \left|\Delta P^a{}_{Tie-i-k}\right|\right)dt \quad (2)$$

Where $\Delta f^a{}_i$ is the change in frequency in corresponding area i, $\Delta P^a{}_{Tie-i-k}$ is the change in tie line power connecting between area i and area k.

3. Cuckoo search

Cuckoo search is a meta-heuristic technique, created by Xin-She Yang and Suash Deb in 2009. CS was enlivened by the behaviour of a few cuckoo species, in blend with the Lévy flights irregular strolls. Cuckoos are getting researchers' advantage in light of their forceful generation methodology. A few bird types lay their eggs in homes of other host winged creatures (different species), and may evacuate others eggs to build the likelihood of their own eggs. CS idealized rules can be summarized as:

i). Each cuckoo lays an egg at any given moment, and dumps its egg in an arbitrarily picked nest/home.

ii). The best homes with high calibre of eggs will persist to the following steps.

iii). The number of accessible host homes is settled, and the egg laid by a cuckoo is found by the host winged creature with a likelihood, where the host feathered creature can either discard the egg, or desert the home and assemble a totally new home.

While investigating new arrangements, it is important to control the Levy flights random walks, to stay away from extensive moves, making the arrangements hop outside of the search space. A stage measure consider that is characterized by the size of the issue of intrigue ought to be utilized for this reason.

4. One rank cuckoo search

The proposed technique, one rank cuckoo search (ORCS), applies two behavioural revisions to the first cuckoo technique, in expectations to enhance the rate of convergence, and thus accomplish a superior execution and precision. These practices are characterized in the accompanying subsections.

a) One Rank (Combined Evaluation)

The original cuckoo search technique creates new homes utilizing Levy flights (exploration stage) and assesses their fitness, then replaces a small amount of homes (exploitation stage) and assesses and positions their fitness yet again. Rather, the proposed technique creates new arrangements utilizing Levy flights, replaces a small amount of them, lastly assesses and positions their fitness without a moment's delay. This conduct permits a more moderate utilization of the function assessments, by consolidating the new arrangements produced by the exploration and exploitation stages before assessing them, and henceforth devouring (population measure) assessments per emphasis by the proposed technique against assessments by the first technique.

A one rank factor r_{orf} is started by 1, to permit the proposed technique to consolidate every one of the explorations and exploitations, until it neglects to discover better homes for t_{or} cycles, to trigger a progressive reduction of the one rank proportion as in 4.1, where t_c is the cycle number and D_m is the quantity of objective function measurement.

$$r_{orf}^{t_c+1} = (r_{orf}^{t_c} \times 1) - 0.5/D_m \quad (3)$$

b) Bound by Best Solutions

The proposed technique upholds the respectability over an out of requirements arrangement by supplanting its invalid measurements by the comparing measurements drawn from arbitrarily chosen answers among the present best answers.

A ratio of the supplanted measurements is using the present best arrangements discovered up until this point, and the rest is by and large arbitrarily drawn by further investigating the searchspace.

A bound by best ratio r_{bbb} is given as indicated in eq. (4)

$$r_{bbbr} = 1 - 1/\sqrt{D_m} \quad (4)$$

The proposed ORCS calculation presented one more parameter, one rank ratio update trigger t_{or}, along with the two parameters utilized by the first CS calculation, populace estimate N and abandon rate p_a. This parameter has not been optimized to choose the best performing setting; however the preparatory tests experienced amid the calculation improvement, exhibited cold-heartedness in this parameter to majorly affect the calculation execution.

5. Simulation and results

The block diagram shown in Fig. 1 is developed in Simulink and executed using MATLAB code files for Cuckoo Search and One Rank Cuckoo Search optimization techniques. 1% step load change is considered in the results and the outputs for frequency and tie line power flows are plotted for both Cuckoo Search and One Rank Cuckoo Search as shown in Figs. 2-8.

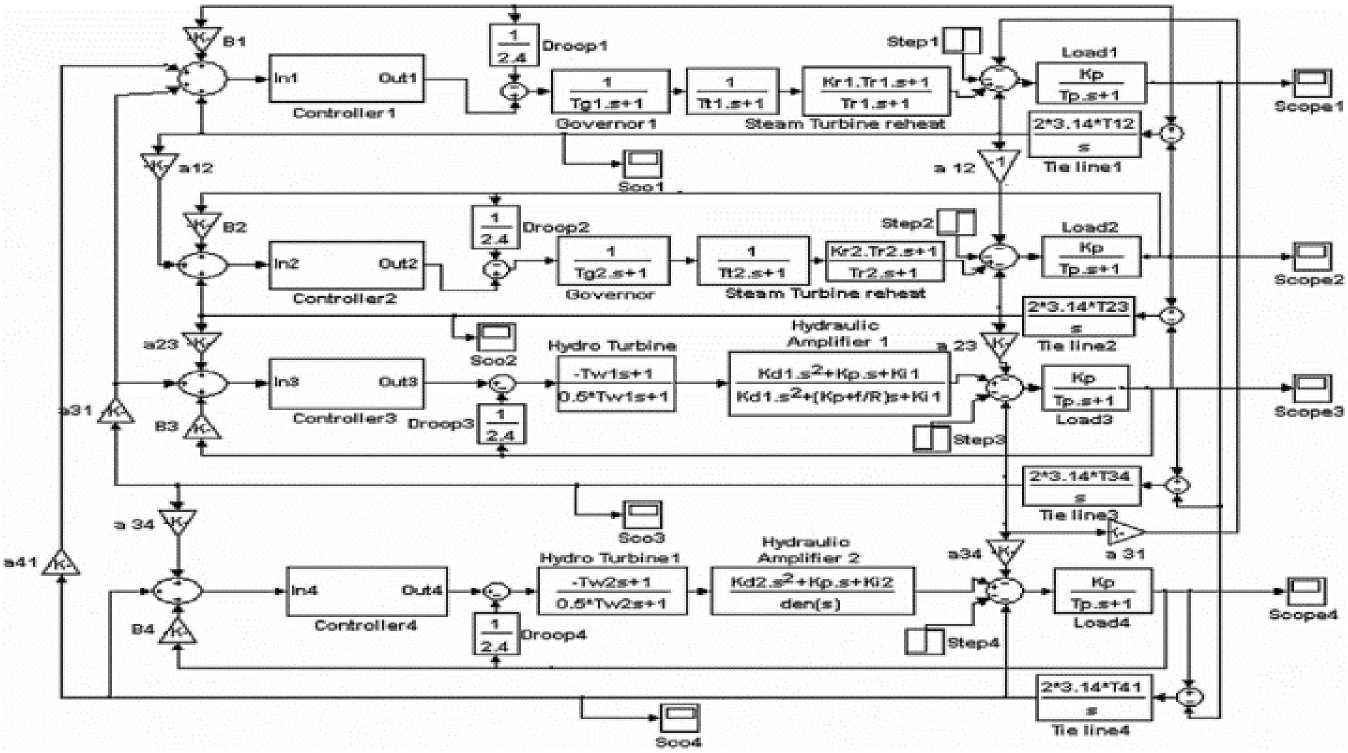

Fig. 1: Matlab/Simulink Model for 4-Area Hydro-Thermal Reheat Interconnected System.

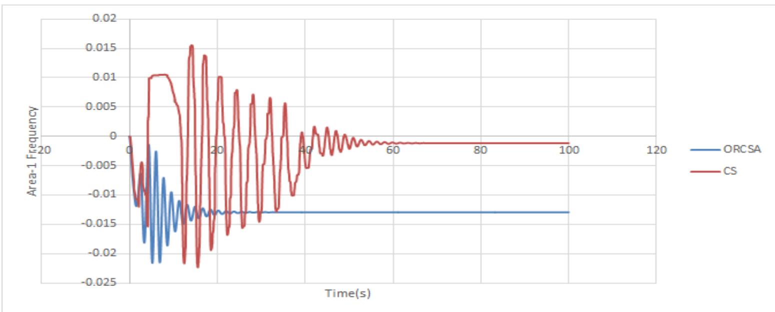

Fig. 2: Frequency Deviation Inarea-1.

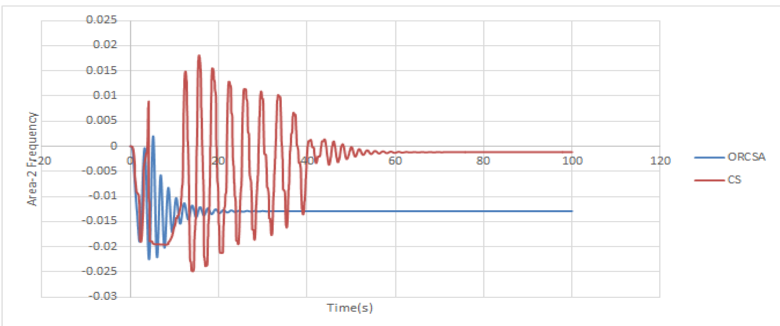

Fig. 3: Frequency Deviation Inarea-2.

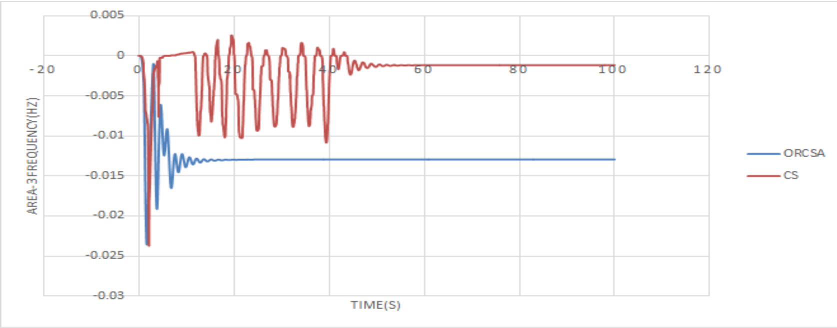

Fig. 4: Frequency Deviation Inarea-3.

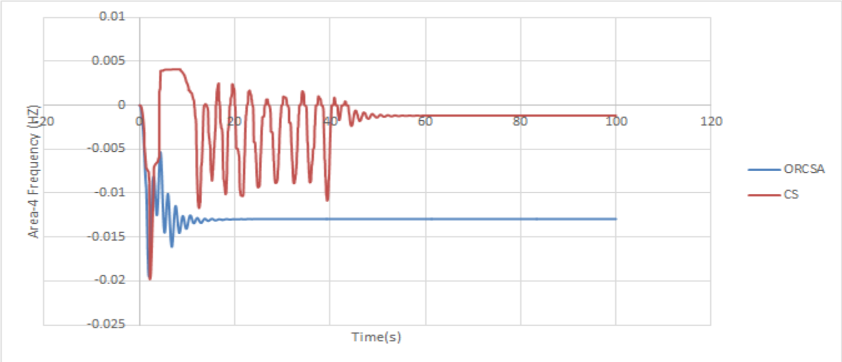

Fig. 5: Frequency Deviation Inarea-4.

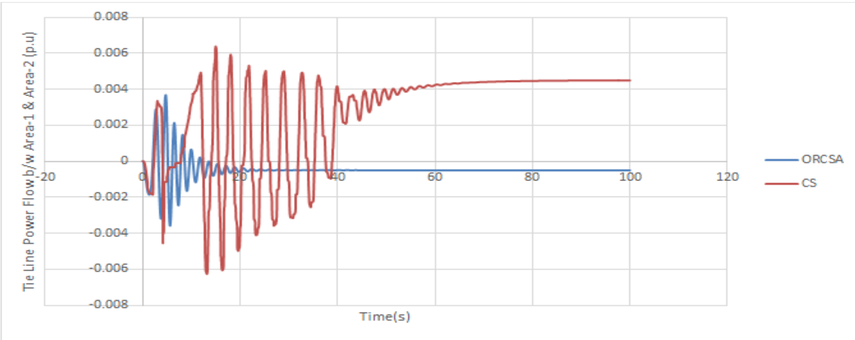

Fig. 6: Change in Tie-Line Power Flow between Area-1&2.

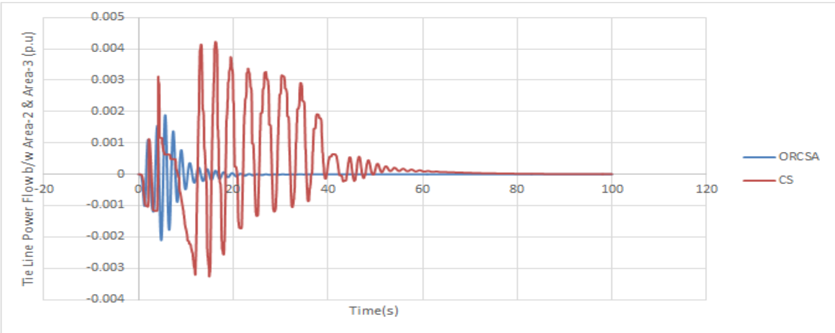

Fig. 7: Change in Tie-Line Power Flow between Area-2&3.

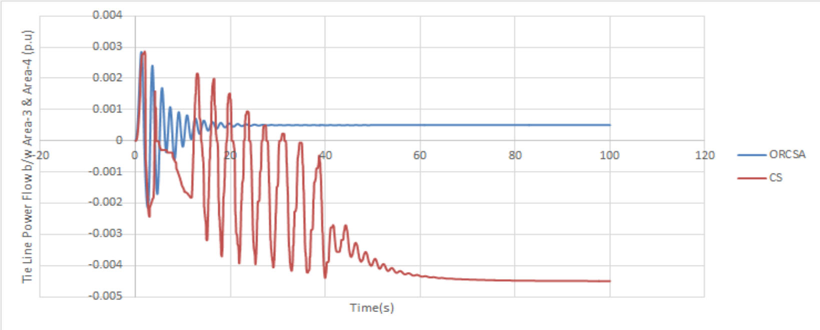

Fig. 8: Change in Tie-Line Power Flow between Area-3&4.

From the above figures, it can be concluded that the performance of ORCS trumps the performance of CS as the settling time of ORCS based AGC is very less than CS based AGC for the system under study.
The average controller values after running the system in MATLAB/SIMULINK environment for 15 different times is as given in Table 1:

Table 1: Average Controller Values for Cs and ORCS

Controller Parameters	Cuckoo Search	One Rank Cuckoo Search
K_{P1}	1.3180	1.3922
K_{I1}	1.2401	1.3404
K_{D1}	2	1.7537
K_{P2}	1.0319	1.9961
K_{I2}	1.1833	1.1233
K_{D2}	2	1.7317
K_{P3}	2	1.5502
K_{I3}	2	1.3188
K_{D3}	2	1.6797
K_{P4}	2	1.7127
K_{I14}	2	1.4168
K_{D4}	2	1.1280

The range of the controller values for developing both the optimization techniques were considered to be in the range of 0 to 2. Hence,if we observe the controllers value, we can see that most of the controller values in Cuckoo Search is showing the threshold value suggesting that the cuckoo search method is fairly shorthanded to handle it. But, the observation of controller values for One Rank Cuckoo Search shows that the values of control parameters are not saturated and they are well within the limits. This again concludes that ORCS is better than its predecessor Cuckoo Search.
In order to test the dynamic performance of ORCS method, the system under study is subjected to different load conditions using ORCS optimization technique and the results obtained are as shown in Table II.

Table 2: Comparison of Dynamic Performance

Step Load Pertubation		1% SLP	3% SLP	5% SLP	10% SLP
Settling times (sec)	Δf_1	18.62	20.20	21.79	22.32
	Δf_2	18.47	19.83	22.69	23.15
	Δf_3	18.47	19.52	22.18	23.9
	Δf_4	18.28	19.76	21.98	23.33
	ΔP_{tie-12}	22.66	24.56	26.12	28.84
	ΔP_{tie-23}	22.93	23.50	28.10	30.64
	ΔP_{tie-34}	22.62	24.73	26.58	30.81
	ΔP_{tie-41}	22.89	24.41	27.77	29.26

6. Conclusion

In this paper a new type of meta-heuristic algorithm has been proposed for automatic generation control of multi-area interconnected power systems to guarantee steady and acceptable operation of energy systems. In such manner, present day heuristic procedures, for example, Cuckoo Search (CS) and One Rank Cuckoo Search (ORCS) technique have been connected for AGC of interconnected power systems. Design and performance evaluation of CS and ORCS optimized PID) controller for Automatic Generation Control (AGC) of an interconnected power system is presented.
From the above results, it is evident that the performance of ORCS is better than its predecessor cuckoo search. So, it can be said that ORCS can successfully be used for AGC purposes as it gives better convergence.

7. Appendix

Nominal parameters of the system investigated are:

f = 60 (Hz); B_1 = 0.3483, B_2 = 0.3827, B_3 = 0.3692 (pu Hz); D_1 = D_3 = 0.015, D_2 = 0.016 (pu Hz); $2H_1$ = 0.1667, $2H_2$ = 0.2017, $2H_3$ = 0.1247, (pu s); R_1 = 3.0, R_2 = 2.73, R_3 = 2.82 (Hz/pu); T_{g1} = 0.08, T_{g2} =0.06, T_{g3} =0.07 (s); T_{t1} =0.4, T_{t2} = 0.44, T_{t3} = 0.3 (s); $K_{r1} = K_{r2} = K_{r3}$ =0.5; $T_{r1} = T_{r2} = T_{r3}$ = 10 (s), T_{12} = 0.2, T_{23} = 0.12, T_{31} = 0.25 (pu/Hz), P_{R1} = 2000 MW, P_{R2} = 4000 MW, P_{R3} = 8000 MW.

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