

# Performance of Cuckoo Search Algorithm in Optimal Power Flow Problems

D.Thangaraj<sup>1</sup>, S.Sakthivel<sup>2</sup>M.E Scholar, Dept. of EEE, Muthayammal Engineering College, Salem, India<sup>1</sup>Professor, Dept. of EEE, Muthayammal Engineering College, Salem, India<sup>2</sup>

**ABSTRACT:** Optimal power flow (OPF) problem is an important task in power system operation and planning. An efficient algorithm is necessary for solving the OPF problem as it nonlinear in nature. In this paper, cuckoo search based meta heuristic algorithm (CSA) is developed and proposed to solve different optimal power flow problems. To prove the effectiveness of the proposed method, it has been demonstrated on standard IEEE 30-bus test system for four different objectives that are related to fuel cost minimization of generators that has convex or non-convex fuel cost characteristics. The results obtained by using the proposed method are compared with those obtained by other different methods followed in the literature. It is evident from the comparison that the cuckoo based algorithm performs better and found to be encouraging.

**KEYWORDS:** optimal power flow, cuckoo search algorithm, power system optimization

## 1. INTRODUCTION

The vast majority of the tools for optimization of power system operation and control are appropriately formulated as some sort of optimization problem. Optimal power flow (OPF) is the basic tool that has been widely used since its introduction. The term OPF was first introduced by Dommel and Tinney in 1968 as discussed in OPF problem is a large-scale highly constrained non-linear non-convex optimization problem. There are numerous OPF models are developed and utilized to formulate different types of optimization problems using different sets of control variables and under different types of constraints.

The OPF problem has been rigorously analyzed in the past few decades, and many optimization techniques have emerged and been applied to solve this problem. In the past, many conventional optimization techniques have been successfully applied for OPF problems. Some of those methods were gradient-based methods, Newton-based method, the simplex method, sequential linear programming, sequential quadratic programming, and interior point methods. Even though some of these techniques have excellent convergence behaviour, they suffer from some shortcomings. Some of the drawbacks are that they cannot ensure global optimality.

The recent rapid developments in computational intelligence tools have motivated research in the area of metaheuristic optimization methods. Most of these techniques have been applied to OPF problems, such as the genetic algorithm (GA), particle swarm optimization (PSO), ant colony optimization (ACO), bacterial foraging algorithms (BFAs), biogeography-based optimization (BBO), simulated annealing (SA), and tabu search (TS). These methods are known for their capabilities of finding global best solutions and avoiding being trapped into local ones and their ability of fast searching of large solution spaces. References review some of these optimization techniques applied to solve the OPF problem.

The cuckoo search algorithm, is a new optimization algorithm based on the food foraging behavior of cuckoo. This method is suitable for nonlinear problems with bounded variables. Owing to its characteristics and performances, the

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algorithm has been gaining attention and been extended and applied in many works, with most reporting its promising performance.

The following sections are as follows: section-2 formulates the OPF, section-3 is devoted for the CSA and its implementation for OPF problem. Next, the CSA is applied to solve the OPF problem to optimize the power system operating conditions in section-4. Finally, in section-5, some final remarks and points concluded.

## II. OPF PROBLEM FORMULATION

OPF is a type of power flow problem that gives the optimal values of the control variables for a given amount of load by optimizing a preset objective function while satisfying some constraints. Hence, the OPF problem can be mathematically formulated as a non-linear constrained optimization problem as follows

$$\begin{aligned} &\text{minimize} && f(\mathbf{x}, \mathbf{u}), \\ &\text{Subject to} && g(\mathbf{x}, \mathbf{u}) = 0, \\ &\text{and} && h(\mathbf{x}, \mathbf{u}) \leq 0, \end{aligned}$$

where  $f(\mathbf{x}, \mathbf{u})$  is the objective function,  $g(\mathbf{x}, \mathbf{u})$  is the set of equality constraints,  $h(\mathbf{x}, \mathbf{u})$  is the set of inequality constraints,  $\mathbf{u}$  is the vector of independent variables or control variables and  $\mathbf{x}$  is the vector of dependent variables or state variables respectively. Four different objectives are considered here for the OPF problem. These four cases are discussed below.

### Case 1: Minimization of fuel cost(FC)

It represents the smooth or the quadratic cost function whose objective function is expressed as follows:

$$f_1 = FC = \sum_{i=1}^{Ng} (a_i + b_i P_{gi} + c_i P_{gi}^2)$$

where FC is the total fuel cost;  $a_i$ ;  $b_i$  and  $c_i$  are fuel cost coefficients of the  $i$ th unit. The quadratic cost coefficients are obtained.

### Case 2: Minimization of valve point effect cost (VPE)

$$f_2 = VPE = (a_i + b_i P_i + c_i P_i^2 + |d_i \sin \{e_i (P_i^{min} - P_i)\}|),$$

Where FC is the total fuel cost;  $a_i$ ;  $b_i$  and  $c_i$  are fuel cost coefficients of the  $i$ th unit. The quadratic cost coefficients are obtained.

### Case 3: Minimization of piecewise fuel cost (PWC)

$$f_3 = PWC = a_{ik} + b_{ik} P_{Gi} + c_{ik} P_{Gi}^2$$

The total generating fuel cost is given by,

$$f(\mathbf{x}, \mathbf{u}) = \sum_{i=1}^{Ng} f_i(\mathbf{x}, \mathbf{u})$$

where  $k$  is the fuel option. In this study, generators 1 and 2 have two fuel options ( $k = 2$ ).

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## Case 4: Minimization of emission (EM)

$$f_4 = Em = \sum_{i=1}^{Ng} (\alpha_i + \beta_i P_{gi} + \gamma_i P_{gi}^2 + \xi_i e^{\lambda_i P_{gi}})$$

where **Em** is the total emission cost (ton/h); **ai**; **bi**; **ci**; **ni** and **ki** are the emission coefficients of the **i**th unit .Its results are presented in the minimum emission obtained by ARCBBO is0.2048 ton/h, which is better than that reported.

## III.CUCKOOO SEARCH ALGORITHM

Cuckoo search algorithm (CSA) is a recent metaheuristic search algorithm inspired by hatching behaviour of the cuckoo bird for solving optimization tasks. The basis of this algorithm is on the obligate brood parasitic behavior of some cuckoo species in combination with the Lévy flight behaviour. In nature, cuckoo birds usually lay their eggs in nests of the other bird species (host nests). There are some cases which can happen. The birds of host nests know the eggs of cuckoo birds (alien eggs) and they can reject it throw out their nests or they leave their nests and build new one. The birds of host nests do not know alien eggs and it will become cuckoo birds. Following cuckoo behavior, CSA described as three main steps.

A cuckoo lays one egg (a solution) at a time and dumps its egg in a randomly chosen nest among the fixed number of available host nests;

The best nests with high a quality of egg will be carried over to the next generation; - A host bird can discover an alien egg in its nest with a probability of  $pa \in [0, 1]$ . In this case, it can simply either throw the egg away or abandon the nest and find a new location to build a completely new one.

The Lévy flight distribution

In nature, animals can search for food in a random/quasi-random manner. Generally, the foraging path of an animal is effectively a random walk since the next move is based on the current location state and the transition probability to the next location. The chosen direction depends implicitly on a probability which can be mathematically modeled. Recent various studies have shown that the flight behavior of many animals and insects has demonstrated the typical characteristics of Lévy flights following step:

$$\text{Lévy} \sim u = t - \lambda, 1 < \lambda \leq 3$$

### Implementation of CS algorithm

Step-1: Assume the NP host nests  $X_i$  ( $i= 1, 2, \dots, NP$ ) and maximum number of iteration.

Step-2: Check for maximum number of iterations and select a cuckoo randomly by levy flights evaluate the fitness or cost function ( $f_i$ ).

Step-3: Select a nest among NP on random basis, say ( $j$ ).

Step-4: Compare if  $f_i$  is less than  $f_j$  replace  $j$  by the new solution.

Step-5: Best nests are maintained. A fraction ( $Pa$ ) of worst nests is abandoned and new ones are built.

Step-6: Rank the nests based on their quality and find the current best.

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Step-7: Repeat this in all the iterations and end when the maximum iterations are reached.

Step-8: Print the results.

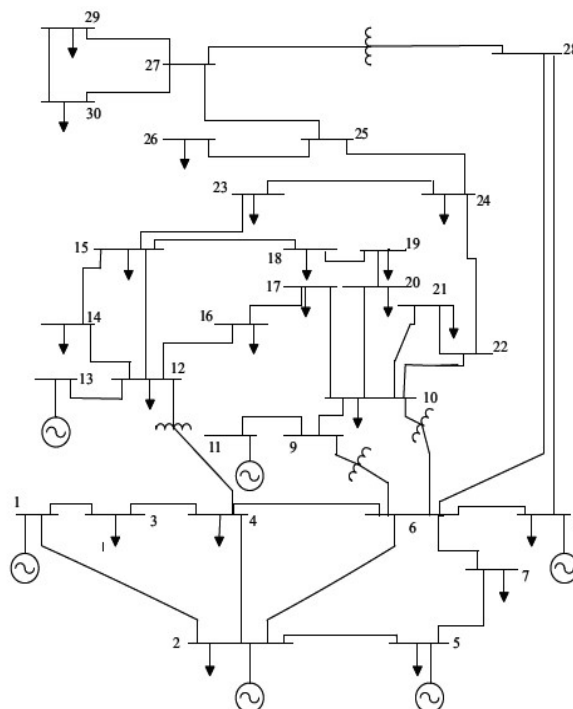
## IV. RESULTS AND DISCUSSION

To examine the effectiveness of the proposed CS method, it is applied to solve the OPF problems with different objectives is tested on the standard IEEE 30-bus system. To exhibit the improvements made using the CS based method, the results are presented along with those of the other methods for the test case.

The developed CS based algorithm is coded using the MATLAB 7.9b computing environment, on a 2.20-GHz i5 laptop with 4.00 GB of RAM. The parameters of the CSA are selected as follows: the number of nest  $NP = 50$ , probability for an alien egg to be discovered  $P_a = 0.5$ , maximum number of iterations = 500. For obtaining the optimal solution, the algorithm is performed 30 independent runs.

### The IEEE 30-bus Test System

IEEE 30 bus system is a medium size test case. It has 24 load buses and 6 generator buses and 41 transmission lines in its configuration. The control variables in OPF problems are: real power generation from generators, generator bus voltages, transformer tap settings and VAR outputs from shunt compensators. Figure shows the one-line diagram of the IEEE 30 bus test case.



**Figure.1** One line diagram of IEEE 30 bus system

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### Case 1: Minimization of Generation Fuel Cost.

The quadratic cost function is used in this case for calculation of total generation cost. The proposed algorithm is applied for minimizing the total fuel cost. The best control variable values corresponding to minimum fuel cost is tabulated in table 1. The cost reported by the CSA based method is compared with the other algorithms like BBO, IEM and RBBO in the table. It is evident that the proposed algorithm minimizes the fuel cost in a better way.

**Table 1.** Best control variables in minimization of fuel cost

Variable	CSA	BBO [1 ]	IEM [2 ]	RBBO[3 ]
P <sub>g1</sub>	175.2680	177.0177	174.4387	177.1590
P <sub>g2</sub>	47.4494	48.6410	48.1710	48.5610
P <sub>g5</sub>	21.2466	21.2390	20.8907	21.4289
P <sub>g8</sub>	20.6761	21.1360	20.5925	21.2958
P <sub>g11</sub>	12.5242	11.9440	13.4993	11.9803
P <sub>g13</sub>	12.0587	12.0540	14.4318	12.0004
V <sub>g1</sub>	1.1000	1.1000	1.0908	1.0851
V <sub>g2</sub>	1.0823	1.0876	1.0788	1.0651
V <sub>g5</sub>	1.0543	1.0614	1.0520	1.0331
V <sub>g8</sub>	1.0624	1.0695	1.0604	1.0384
V <sub>g11</sub>	1.0986	1.0982	1.0853	1.1000
V <sub>g13</sub>	1.1000	1.0998	1.0845	1.0408
T <sub>11</sub>	1.0215	1.0500	1.0359	1.0974
T <sub>12</sub>	0.9041	0.9000	0.9227	0.9006
T <sub>15</sub>	0.9794	0.9900	1.0049	0.9663
T <sub>36</sub>	0.9640	0.9700	0.9814	0.9760
Q <sub>c10</sub>	4.6993	5.0000	3.6724	2.2567
Q <sub>c12</sub>	4.4397	5.0000	4.4120	4.2353
Q <sub>c15</sub>	3.9944	5.0000	3.9357	4.2998
Q <sub>c17</sub>	2.6044	5.0000	4.4873	4.9446
Q <sub>c20</sub>	3.9043	5.0000	4.5202	3.7381
Q <sub>c21</sub>	4.8652	5.0000	3.7935	4.9901
Q <sub>c23</sub>	5.0000	4.0000	3.9689	2.6502
Q <sub>c24</sub>	4.7552	5.0000	4.5687	5.0000
Q <sub>c29</sub>	2.0956	3.0000	3.3512	2.3967
Fuel cost (\$/hr)	<b>799.0603</b>	799.1116	800.0781	800.5159

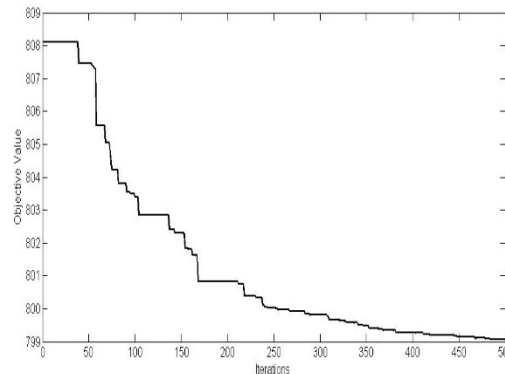
The algorithm is run for 500 iterations in optimizing the fuel cost the results are converged in 450 iterations. The convergence quality of algorithm is proved in the figure 2.

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**Figure 2** Convergence quality of CSA in quadratic fuel cost minimization

## Case 2: Cost with valve point effect

In this case, the valve point effects are taken in to account in cost calculations. For performance comparison, TLBO, GSA and BBO are taken. The results are compared in table 2 for understanding the strength of the proposed algorithm. The valve point effect cost reported by CSA is **920.3103**, which much less than the cost reported by the other algorithms in the table.

**Table 2.** Best control variables in minimization of valve point effect cost

Variable	CSA	TLBO [ 4 ]	GSA [ 5 ]	BBO [6]
$P_{g1}$	196.222	194.1673	199.59943	197.426
$P_{g2}$	20.0000	44.3449	51.94640	52.037
$P_{g5}$	23.9881	20.6902	15.00000	15.000
$P_{g8}$	19.4821	13.1553	10.00000	10.000
$P_{g11}$	15.9055	10.0000	10.00000	10.001
$P_{g13}$	13.6247	12.0000	12.00000	12.000
$V_{g1}$	1.0870	1.0500	1.099002	1.0371
$V_{g2}$	1.0708	1.0287	1.099002	1.0130
$V_{g5}$	1.0478	1.0024	1.018042	0.9648
$V_{g8}$	1.0681	1.0163	1.052247	1.0320
$V_{g11}$	1.1000	1.0999	0.950000	1.0982
$V_{g13}$	1.0873	1.1000	0.963430	1.0890
$T_{11}$	0.9175	1.0065	0.950702	1.0969
$T_{12}$	1.0884	0.9073	0.918200	1.0909
$T_{15}$	1.0292	0.9936	0.909096	1.0991
$T_{36}$	1.0044	0.9485	0.945975	1.0021
$Q_{c10}$	2.8915	0.0000	-	-
$Q_{c12}$	0.2075	0.0000	-	-
$Q_{c15}$	2.4165	0.0000	-	-

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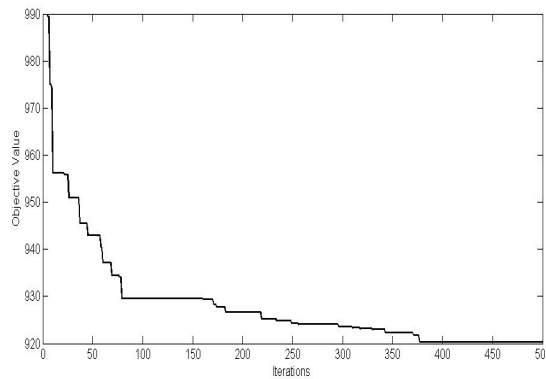
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Q <sub>c17</sub>	4.8092	0.0000	-	-
Q <sub>c20</sub>	3.7203	0.0000	-	-
Q <sub>c21</sub>	2.8520	0.0000	-	-
Q <sub>c23</sub>	2.6239	0.0000	-	-
Q <sub>c24</sub>	0.6967	0.0000	-	-
Q <sub>c29</sub>	3.9760	0.0000	-	-
VPE cost	<b>920.3103</b>	923.414	929.7240472	930.793

Taking 375 iterations, the algorithm has converged to the global best results showing the better reliability of the algorithm. The convergence behaviour of the CSA in valve point effect cost minimization is depicted in figure 3.



**Figure. 3** Convergence quality of CSA in valve point effect fuel cost minimization

### Case 3: piecewise cost minimization

When multi type fuels are used in a generator, the fuel cost is different for different fuels. This cost function is the piecewise cost function which is used here for calculation of generation cost. BBO, PSO and MDE algorithms are taken for comparison of the performance of CSA. It is clear from the table 3 that the cost reported by the proposed CSA is less than the cost reported by the other algorithms taken for comparison.

**Table 3.** Best control variables in minimization of piecewise quadratic fuel cost

Variable	CSA	BBO [ 6 ]	PSO [ 6 ]	MDE[ 6 ]
P <sub>g1</sub>	136.479	140.0000	140.0000	140.0000
P <sub>g2</sub>	54.7591	55.0000	55.0000	55.0000
P <sub>g5</sub>	32.5433	24.1500	24.1257	24.0000
P <sub>g8</sub>	32.5787	18.5100	35.0000	34.9890
P <sub>g11</sub>	10.0000	35.0000	18.6600	18.0440
P <sub>g13</sub>	22.8620	17.7900	17.6810	18.4620
V <sub>g1</sub>	0.9932	1.0500	1.0500	1.0500
V <sub>g2</sub>	0.9689	1.0412	1.0396	1.0400

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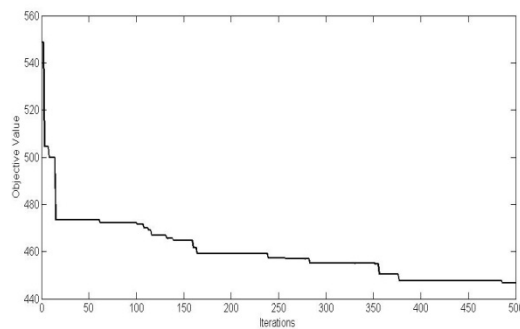
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V <sub>g5</sub>	0.9751	1.0170	1.0133	1.0139
V <sub>g8</sub>	0.9192	1.0282	1.0225	1.0259
V <sub>g11</sub>	0.9097	1.0910	1.0722	1.0940
V <sub>g13</sub>	1.0238	1.0876	1.0866	1.0773
T <sub>11</sub>	0.9000	1.0192	1.0060	0.9714
T <sub>12</sub>	1.0996	0.9573	0.9000	1.0046
T <sub>15</sub>	0.9966	1.0120	0.9645	0.9902
T <sub>36</sub>	0.9000	0.9505	0.9305	0.9494
Q <sub>c10</sub>	2.7397	-	-	-
Q <sub>c12</sub>	1.1946	-	-	-
Q <sub>c15</sub>	0.3887	-	-	-
Q <sub>c17</sub>	3.5836	-	-	-
Q <sub>c20</sub>	5.0000	-	-	-
Q <sub>c21</sub>	3.3025	-	-	-
Q <sub>c23</sub>	0.2000	-	-	-
Q <sub>c24</sub>	2.4263	-	-	-
Q <sub>c29</sub>	0.5560	-	-	-
Quadratic Fuel cost (\$/hr)	<b>446.5340</b>	647.69	647.7437	647.846

The algorithm converges to the best results in about 375 iterations in piecewise cost minimization and this is shown in figure 4.



**Figure. 4** Convergence quality of CSA in piecewise quadratic fuel cost minimization

#### Case 4: Minimization of emission

The quality of the algorithm is tested in emission minimization. The emission reported is 0.2048 which is less than the emission level reported by the other algorithms compared in the table 4. Moreover, the VAR supplied by the shunt compensators for achieving this emission level is low indicating more reactive power reserve or system security.



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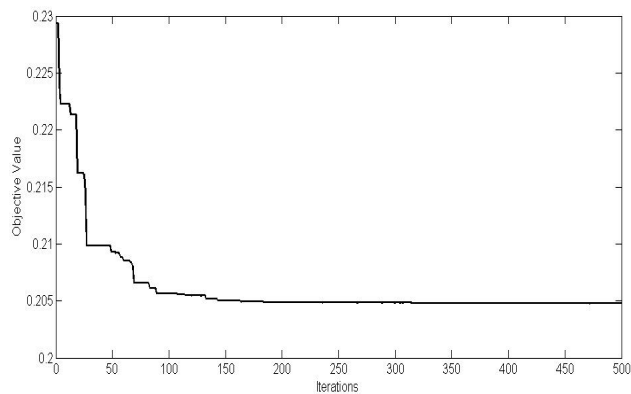
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**Table 4.** Best control variables in minimization of emission

Variable	CSA	IPSO [7]	IPSO [7]	BSO [ 8]
P <sub>g1</sub>	66.6800	67.1300	67.0400	112.9189
P <sub>g2</sub>	67.547	68.9400	68.1400	59.3719
P <sub>g5</sub>	50.000	49.8600	50.0000	27.6576
P <sub>g8</sub>	35.000	34.8900	35.0000	34.9989
P <sub>g11</sub>	29.999	29.6700	30.0000	27.0652
P <sub>g13</sub>	39.995	39.9400	40.0000	26.4502
V <sub>g1</sub>	1.0792	1.0287	1.0351	1.1000
V <sub>g2</sub>	1.0742	1.0341	1.0273	1.0855
V <sub>g5</sub>	1.0567	1.0387	1.0417	1.0606
V <sub>g8</sub>	1.0592	1.0254	1.0248	1.0757
V <sub>g11</sub>	1.0987	1.0317	1.0321	1.1000
V <sub>g13</sub>	1.0994	1.0395	1.0410	1.1000
T <sub>11</sub>	0.9810	1.0300	1.0300	1.0000
T <sub>12</sub>	0.9016	1.0200	1.0100	0.9500
T <sub>15</sub>	0.9568	1.0500	1.0600	1.0000
T <sub>36</sub>	0.9455	0.9900	0.9900	0.9625
Q <sub>c10</sub>	1.5556	11.8500	12.5300	3.4844
Q <sub>c12</sub>	3.5945	8.2510	8.7410	4.5129
Q <sub>c15</sub>	4.8219	77.1300	76.6700	4.7990
Q <sub>c17</sub>	1.6543	70.6700	66.5600	4.9965
Q <sub>c20</sub>	4.9593	67.1300	67.0400	3.9809
Q <sub>c21</sub>	3.8209	68.9400	68.1400	4.7684
Q <sub>c23</sub>	2.7699	49.8600	50.0000	3.8535
Q <sub>c24</sub>	4.9996	34.8900	35.0000	4.2332
Q <sub>c29</sub>	0.6613	29.6700	30.0000	1.6339
Emission cost	<b>0.2048</b>	0.2063	0.2058	0.2425



**Figure. 5** Convergence quality of CSA in emission minimization

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Figure 5 shows that the CSA algorithm is quick in convergence in emission minimization and produces the lowest level of emission. In this case also, the convergence strength of the algorithm is excellent.

### V.CONCLUSION

In this paper, the recently developed metaheuristic algorithm of cuckoo search algorithm is developed, employed and successfully tested in solving different OPF problems. The outperforming characteristic of the algorithm in four different optimization objectives is really encouraging. The simulation results demonstrate the effectiveness and robustness of the proposed method. Moreover, the results obtained using the CS method has been compared with those obtained from the other methods previously reported in the literature. The comparison shows the superiority of the proposed CS method over many other methods used for solving the OPF in terms of results quality. The results obtained are promising and implementing a multi-objective CS is a possible extension of the current work.

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