Cuckoo Search Algorithm Optimization Approaches for Solving Economic Load Dispatch: A Review

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Authors’ contributions

This work was carried out in collaboration between all authors. Author GAA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors OSO and JOA managed the analyses of the study. Author JOA managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JENRR/2018/v1i29794

Editor(s):

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Complete Peer review History: http://prh.sdiarticle3.com/review-history/25531

Received 27th April 2018
Accepted 6th July 2018
Published 13th July 2018

ABSTRACT

Cuckoo search algorithm (CSA) is an effective and highly reliable swarm intelligence based optimization approach. It is a technique of determining the most efficient, low cost and reliable operation of a power system by dispatching the available electricity generation resources to supply the load on the system. This paper presents a comprehensive review of CSA application in Economic Load Dispatch (ELD) problem. This review will assist power system engineers with a view to enhancing the optimal operation of available thermal plants in electrical power systems.

Keywords: Cuckoo search algorithm; swarm intelligence; economic load dispatch; electrical power system; thermal plants; optimization approach.

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1. INTRODUCTION

The benefits of electricity to mankind nowadays cannot be over-emphasized. Its continual availability has the capability to foster socio-economic development of nations across the world. The energy mix of many nations is hydro-thermal, until recently that penetration of renewable energy sources is bringing progressive diversification from the conventional hydro-thermal power plants. Thermal power plants use fossil fuel to generate electricity, the cost of this fossil fuel is exorbitantly high; hence the need to minimize it without violating system constraints becomes a crucial issue that needs to be addressed in the electric power system. One of the ways to bring about a significant saving in cost of fossil fuel is economic dispatch [1]. ELD is concerned with finding the optimum generation among the existing units, in such a way that the total fuel cost of generating units decrease as minimally as possible without violating power units and system constraints [2,3]. ELD is a crucial tool in energy management system and for any given load demand, it provides power output of each unit in MW and it also evaluates the overall fuel cost of generating units [4].

The objective function of ELD problem can be modeled to capture loss minimization, fuel-cost minimization, profit maximization (fuel costs/load tariffs) [5]. These objective functions can be achieved either jointly or singly. The former is referred to as multi-objective while the latter is called single objective. The multi-objective functions have to be converted into single objective function using either weighted sum of individual objective or using price penalty function [6,7]. The ELD that takes into consideration practical characteristics of thermal plant such as ramp rate limits, emission of gases, valve-point loading effects, multi-fuel options, spinning reserve requirement, prohibited operating zones and security constraints is known as Convex ELD problem [8-12]. A simplified form of ELD problem is non-convex in which the fuel-cost curves of the generating units are piece-wise linear and increase monotonically. It is modelled in such a way that the power generated with the plants’ constant coefficients are represented using quadratic polynomial function [13]. The fuel cost curve of non-convex ELD is smooth convex while convex ELD has non-smooth (non-linear cost curves) fuel cost due to the inclusion of the above peculiar characteristics of a thermal generator [14,15].

ELD problem can be solved either by ignoring transmission loss or inclusion of transmission losses [16-18].

ELD, optimal power flow (OPF), unit commitment (UC) and load forecasting (LF) are crucial optimization problems in modern power system [19]. The solution methodologies for solving ELD problem can be broadly grouped into two; deterministic and non-deterministic optimization. The deterministic can otherwise be referred to as conventional or mathematical optimization technique while non-deterministic can be heuristics or meta-heuristic. The deterministic solution methodologies so far in used for solving ELD problem includes Lambda iteration method, dynamic programming method, Lagrange relaxation approach, decomposition and coordination method, mixed integer programming and Newton’s method. Artificial intelligence techniques form the basis of non-deterministic approach. It includes evolutionary programming, genetic algorithm, differential evolution, artificial immune system, Hopfield neural network, particle swarm optimization, artificial bee colony algorithm, firefly algorithm, harmony search algorithm and cuckoo search algorithm among others. Cuckoo search algorithm (CSA) is one of the latest metaheuristic natured inspired algorithms which came to existence through Yang and Deb in 2009. The algorithm is enhanced with levy flight search approach than normal isotropic random walks and by far efficient than PSO and GA. CSA is an hybridized version of differential evolution (DE), particle swarm optimization (PSO) and simulated annealing (SA). It has fewer parameters and very good convergence characteristics [18-22].

2. MATHEMATICAL FORMULATIONS OF ECONOMIC LOAD DISPATCH

The objective functions for ELD problem could be single or multi-objective depending on the objectives to be achieved. A simplified fuel cost model for ELD is given as:

\[ C_{F_i} = a_i P_{Gi}^2 + b_i P_{Gi} + c_i \]  

(1)

where;

- \( C_{F_i} \) = the fuel cost of generator \( i^{th} \) (Naira/hours),
- \( P_{Gi} \) = the power generated at generator \( i^{th} \),
- \( a_i, b_i \) and \( c_i \) = constant fuel cost coefficients for the \( i^{th} \) generator.
For a power system with N number of generators, the total fuel is the sum of the cost model for each generator given by:

\[ F_{Gi} = \sum_{i=1}^{N} (a_iP_{Gi}^2 + b_iP_{Gi} + c_i) \]  

(2)

The objective function for convex ELD minimizes equation (2) given as:

\[ \text{Min. } F_{Gi} = \sum_{i=1}^{N} (a_iP_{Gi}^2 + b_iP_{Gi} + c_i) \]  

(3)

The inclusion of valve point loading effect which introduces ripple in generating units with multi-valve steam turbine transformed equation (1) into equation (3) thus;

\[ C_{Gi} = a_iP_{Gi}^2 + b_iP_{Gi} + c_i + \text{abs}(e_i\sin(f_i(P_{i,\text{min}} - P_i))) \]  

(4)

where:
e and f are the constant coefficients of unit i due to inclusion of valve point loading effect.

A pictorial illustration of effect of valve point loading effect is as shown in Fig. 1;

Equation (1) can be extended with inclusion of multiple fuels option and is represented as;

\[
C_{Gi} = \begin{cases} 
  a_iP_{Gi}^2 + b_iP_{Gi} + c_i & \text{if } P_{i,\text{min}} \leq P_i \leq P_{i,1} \\
  a_iP_{Gi}^2 + b_iP_{Gi} + c_i & \text{if } P_{i,1} \leq P_i \leq P_{i,2} \\
  a_iP_{Gi}^2 + b_iP_{Gi} + c_i & \text{if } P_{i,n-1} \leq P_i \leq P_{i,\text{max}} 
\end{cases}
\]  

(5)

A pictorial illustration of multiple-fuel option is as shown in the Fig. 2 below

Generally, CO2, SO2 and NO2 are the major contaminants of fuel, to show the total emission in ELD problem formulation; it is expressed as:

\[ E_{Ti} = \sum_{i=1}^{n} \left( \alpha_iP_i^2 + \beta_iP_i + \gamma_i + \delta_i \times e^{(\theta_iP_i)} \right) \]  

(6)

where: \( \alpha_i \) [kg/MW·h], \( \beta_i \) [kg/MWh] and \( \gamma_i \) [kg/h] are the gas emission coefficients.

The reactive power has nothing to do with fuel cost of generation; the fuel cost is solely a function of real power generated. The main constraints are the real power generated and limits on physical devices (such as generators, tap changing transformers and phase shifting transformers etc. [24].

Equality Constraint:-

\[ \sum_{i=1}^{n} P_{Gi} = P_d + P_L \]  

(7)

where;

\( P_{Gi} \) = real power generated at generator i, \( P_d \) = Total real power demand and \( P_L \) = Power transmission loss

![Fig. 1. Incremental fuel cost curve for 5 valve steam turbine units [22]](image1)

![Fig. 2. Piecewise quadratic and incremental fuel cost function [23]](image2)
\[ P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} B_{ij} P_i P_j + \sum_{i=1}^{n} P_i B_0 + B_{00} \]  

where;

\( n \) = number of generation buses,
\( P_i \) = active power delivered at bus \( i \),
\( P_j \) = active power delivered at bus \( j \),
\( B_{ij} \) = loss coefficients with the units of reciprocal of Watt/Mwatt,
\( B_0 \) and \( B_{00} \) = generalized loss coefficients.

**Inequality Constraint:-**

The limit on the generator output is expressed as:

\[ p_{gl}^{min} \leq P_{gi} \leq p_{gl}^{max} \]  

(9)

Security range of bus voltage is given by:

\[ V_{i, min} \leq V_i \leq V_{i, max} \]  

(10)

where;

\( p^{min} \) and \( p^{max} \) = lower and upper limits for active power generation,
\( V^{min} \) and \( V^{max} \) = minimal and maximal acceptable voltage levels at each bus.

Generator ramp rate limit is given as;

\[ \text{max}(P_{i,max}^o, P_i^o - DR_i) \leq P_i < \text{min}(P_{i,max}^o, P_i^o + UR_i) \]  

(11)

where;

\( P_i^o \) = previous operating point of the \( i^{th} \) generator,
\( DR_i \) = Down ramp limit
\( UR_i \) = Up ramp limit

The prohibited operating zone constraint is given as;

\[ P_i \in \begin{cases} p_{i,k}^{min} \leq P_i < p_{i,k}^{U} \\ p_{i,k}^{U} \leq P_i < p_{i,k}^{L} \\ p_{i,k}^{L} \leq P_i \leq p_{i,k}^{max} \end{cases} \]  

(12)

where;

\( Z_i \) = no. of prohibited zones in the \( i^{th} \) generator,
\( k \) = index of prohibited zones of the \( i^{th} \) generator,
\( p_{i,k}^{L} \) = lower limit of the \( k^{th} \) prohibited zone,
\( p_{i,k}^{U} \) = upper limit of the \( k^{th} \) prohibited zone of the \( i^{th} \) generator.

3. CUCKOO SEARCH ALGORITHM

One of the latest metaheuristic optimization algorithms is cuckoo search algorithm, its birth was credited to [25]. It needs to be emphasized that CSA revolved around the obligatory brooding parasitic behavior of some cuckoo species in conjunction with the Lévy flight behavior of some birds and fruit flies [26]. Its efficiency in solving complex engineering optimization problems is not unconnected with the fact that it is a hybrid of three different powerful optimization algorithms. The algorithms are DE, PSO and SA [27]. The essential attributes of CSA are global convergence characteristics, it combines both the local and global in exploration and exploitation of search space and its global search technique use levy flight approach than normal isotropic random process used by many other metaheuristic algorithms [28,29]. Understanding CSA better, three basic idealized rules were formulated [30-33];

- Each cuckoo lays one egg (a design 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 a high quality of egg (better solution) will be carried over to the next generation.
- The number of available host nests is fixed and a host can discover an alien egg with a probability \( p_a \in [0, 1] \). In this case, the host bird can either throw the egg away or abandon the nest so as to build a completely new nest in a new location.

CSA uses fewer parameters and these parameters are; the number of nests \( N_p \), maximum number of iterations (Iter\(_{max}\)) and the probability of an alien egg to be discovered \( p_a \) can have its value chosen in the range \([0, 1]\). These parameters have to be predetermined; the stopping criterion for the algorithm is the maximum number of iterations. In addition, solution quality of the algorithm depends largely on the number of nests and the higher number of \( N_p \) is chosen as higher probability for a better optimal solution to be obtained [34-37].

CSA uses Lévy flights a sequence of straight flight paths with sudden 90\(^\circ\) turn [38]. The step-lengths are generally distributed based on a heavy-tailed probability distribution. A Lévy flight is performed, if new solution \((x_t+1)\) is to be generated and is given by;
\[ x_i^{(t+1)} = x_i^t + \alpha \odot \text{Levy}(\gamma) \]  

where;

\[ \alpha = \text{step size (usually } \alpha > 0) \]

\[ \odot = \text{entry wise multiplications.} \]

4. ADVANTAGES OF THE COCKOO SEARCH ALGORITHM (CSA)

Cockoo search algorithm is very efficient when compared with performance of other optimization methods such as Differential Evolution (DE) and Particle Swarm Optimization (PSO) [39]. In addition, cuckoo search algorithm has proved to satisfy the global convergence requirements and thus has guaranteed global convergence properties [40].

Additionally, cuckoo search algorithm consists of two components: local and global. The local component is projected for improving the best solution via directed random walk and it is very intensive with about 1/4 of the search time, while the global component maintains the diversity of population via Lévy flights rather than standard random walks and it takes about 3/4 of the total search time. This allows that the search space to be explored more efficiently on the global scale and consequently the global optimality can be found with a higher probability [41].

These advantages make cuckoo search algorithm to be very effective and efficient. Therefore, cuckoo search algorithm can be characterized by the following features:

- It satisfies the global convergence requirements
- It supports local and global search capabilities
- It uses Lévy flights as a global search strategy.

5. APPLICATIONS OF CUCKOO SEARCH ALGORITHM IN SCIENCE AND TECHNOLOGY

Cuckoo search algorithm has been applied in many areas of optimization and computational intelligence with promising efficiency including Neural Network, finding optimization cluster centers, job scheduling and many more in the different domains including industry, health sector, wireless sensor network and image processing [42].

In the engineering design applications, cuckoo search has superior performance over other algorithms for a range of continuous optimization problems such as spring design and welded beam design problems [43]. In addition, CSA has demonstrated to be very efficient for solving nonlinear problems such as mesh generation, optimized semantic web service composition processes, optimal design for reliable embedded system and design of steel frames.

In addition, cuckoo search algorithm has been used to solve many scheduling problems, to generate independent paths for software testing and test data generation. Cuckoo search algorithm has been shown to be very efficient in the context of data fusion and wireless sensor network [44].

Furthermore, a variant of cuckoo search algorithm combined with quantum-based approach has can be used to solve Knapsack problems efficiently. In addition, CSA offers a reliable method for solving thermodynamic calculations and for designing engineering applications (Yang and Deb, 2014).

6. REVIEW OF CSA IN ELD PROBLEM

Tran et al. [45] proposed an efficient oppositional-CSA (OCSA) for solving economic power dispatch (EPD). OCSA is a variant of CSA with good exploitation strategy compared to original CSA, to overcome the shortcoming of original CSA which lacks intensification phase on the exploited search space, OCSA was proposed. The proposed algorithm was evaluated on 10, 13 and 40 power system in order to prove the efficiency of OCSA. For validating the performance of OCSA, different variants of CS and some of the novel evolutionary algorithms were tested under the same simulation environment. The results showed that the proposed OCSA outperforms existing algorithms and other variants of CS in terms of fuel cost consumption. In addition, convergence of OCSA towards optimal solution was found to be higher as compared to other algorithms.

Tran et al. [46] presented CSA to solve constrained ELD problems on 13 and 40 generating units respectively. The proposed
approach handled efficiently, the non-smoothness of cost function caused by the use of valve point effects. Penalty factor was used to convert the multi-objective function into single objective function. MATLAB optimization tool box was used as implementation tool. The performance of the algorithm was evaluated by comparing the result obtained with other heuristic methods found in the literatures using fuel cost minimization as performance metric. Based on the findings, the work established that the method outperforms the existing techniques, and can be a promising alternative approach for solving practical power system ELD problems.

Yang and Deb [47] presented CSA for solving non-convex ELD problems of fossil fuel fired generators considering transmission losses and valve point loading effect. The proposed approach was tested and validated on the standard IEEE 14-bus, 26-bus and 30-bus system with several heuristic load patterns. The results obtained were compared to those of FA, PSO and harmony search algorithm (HSA). The authors concluded that the performance of the proposed approach appears to be a powerful and efficient optimization technique to solve highly nonlinear discontinuous cost functions of ELD problem and to achieve globally better optimum solution.

Yang [48] proposed and implemented CSA on combined economic-emission load dispatch problem using six thermal generators as test case system. Penalty factor was used to convert the bi-objective function into single objective problem. It was implemented using MATLAB optimization toolbox. The result obtained using the proposed approach was compared to that of GA; it was revealed that CSA is more effective than GA. In similar vein, the work concluded that cost at the minimum condition produced high emission and minimum cost and vice-versa.

Yang and Deb [49] applied CSA to address both ELD and OPF incorporating FACTS devices. The proposed algorithm was tested on IEEE 9 bus test power system to demonstrate its effectiveness. The simulation results indicated the robustness of the CSA in solving OPF problem of power systems with and without FACTS. The results obtained revealed that STATCOM and SVC used reduced both the transmission losses, system voltage deviation and minimized the total fuel cost of generation. The work suggested scope expansion by incorporating other FACTS devices such as unified power flow controller (UPFC) and thyristor controlled series capacitor (TCSC).

Yang and Deb [50] proposed application of a One Rank-CSA (ORCSA) to bi-objective ELD problem. ORCSA is a variant of CSA that has an improvement over original CSA in terms of exploration of search space. The two objective functions formulated are fuel and emission of gas fossil fired power plants. The performance of the proposed ORCSA was validated by using a three-unit system with one load case and a six-unit system with three load cases. The obtained results were compared with other methods that were used before. The work concluded that the ORCSA was very efficient for the problem in that it offered better solution and faster simulation time as compared to others.

Ajenikoko et al. [1] presented application of modified-CSA (MCSA) for solving ELD problems. MCSA was proposed to improve the search ability and solution quality of the conventional CSA. The proposed method was tested on 13-unit system with valve point loading effects having a total load demand of 1800 MW and 2520 MW, 20-unit system with quadratic cost function and transmission losses and systems with multiple fuel options and valve point loading effects. The minimum cost and computational time were used as performance metrics and based on the analysis carried out MCSA method outperforms conventional-GA, (CGA) in terms of the stated performance metrics.

Arul and Rengarajan [2] presented a solution for ELD problem considering valve point loading on fuel cost function using cuckoo search algorithm (CSA). The work aimed mainly to minimize the fuel cost for meeting the power demand considering constraints such as valve loading effect, generator limits, power balance constraint without exclusion of transmission losses. The proposed approach was tested on 3, 6 and 13 thermal units having a power demand of 850MW, 800MW and 1800MW respectively. The performance metrics used were the execution time and total fuel cost of generation. The work concluded that many non-linear characteristics of the generators can be handled efficiently by the proposed method. In addition, the computational time obtained was relatively lesser and the appreciable minimization of total fuel cost of meeting the total load demand was obtained with the proposed approach.
Balamurugan and Subramanian [3] presented an outline nine swarm intelligence-based algorithms and the modifications applied to them in order to solve the ELD problem and its variants. The reviewed algorithms were ant colony optimization (ACO), particle swarm optimization (PSO), bacterial foraging optimization algorithm (BFOA), shuffled frog leaping algorithm (SFLA), artificial bee colony (ABC), firefly algorithm (FA), cuckoo search algorithm (CSA), bat algorithm (BA), grey wolf optimization (GWO). Theoretical implementation of ACO was somewhat difficult. The computational time was comparatively large and its application is limited to discrete problems. The highlighted shortcomings of PSO were limited local/global searching capabilities, solution updating without considering both the quality of solutions and the distance between solutions. BFOA has swarming effect on complex ELD problem most especially for large multi-dimensional space with constraints. SFLA solution got trapped at local optimal and it had poor convergence characteristics. ABC, though very good optimizer with fewer parameters, suffered large computational time. FFA has fixed parameters which did not change during the iteration and improper setting of these parameters result in solution getting trapped in local optimal. CSA had fewer parameters; improper choice of its parameter can also result in solution getting trapped at local optimal. BA, though very simple, flexible and easy to implement, if rapidly switched from exploration to exploitation stage, it may lead to stagnation. GWO is simple to implement with fewer parameters and faster convergence. The work concluded that although these algorithms have successfully solved the ELD problem, yet further improvements to the algorithms were needed.

Basu and Chowdhury [4] presented an adaptive-Cuckoo Search Algorithm (ACSA) for solving economic emission load dispatch (EELD) problem with quadratic fuel function. ACSA was proposed to enhance the convergence speed and quality solution of the conventional CSA. It was developed by performing two adaptive updated step size parameters on conventional CSA. Weighted function was used to transform the multi-objective into single objective function. The proposed approach was assessed using electricity generation fuel cost and emission released as performance metrics. The test case systems used one load case and a six unit system with three load cases which are 800, 1200 and 1800 MW. It was discovered that the ACSA gave better solution and faster simulation time than TS, FCGA, CGA, NSGA –II and BBO. The work recommended that the proposed approach should be applied to economic emission dispatch where multi-thermal units and multi-pollutants are considered.

Chellappan and Kavitha [5] proposed adaptive Cuckoo Search Algorithm (ACSA) for solving ELD problem on thermal units with inclusion of multiple fuel options and valve point loading effect. The updated step-size in ACSA at the first new solution generation via lévy was adaptive at each iteration with careful choice of other parameters of CSA. The proposed approach was tested on a ten-unit system with load demands of 2,400 MW to 2,700 MW in steps of 100 MW. The performance metrics used were the fuel cost minimization and programing execution time. The results obtained were compared to Enhanced Lagrangian neural network (ELANN), adaptive differential evolution (ADE), augmented Lagrange Hopfield network (ALHN) and multi-PSO (MPSO). The comparison showed that ACSA was very efficient for solving ELD problem with multiple fuel options considering either quadratic or non-convex fuel cost.

Chowdhury [6] solved ELD problem in power system operation with wind farm (WF) connected using CSA. The test case system used IEEE 30 buses system with a total load demand of 289.3 MW and WF power of 100 MVA and 189.3 MW with the power of 16 MVA. The main constraints considered were power balance, power loss and generator limits. The implementation tool was MATPOWER 4.1 Toolbox and the performance metrics were the total fuel cost minimization and program execution time. Based on the analysis CSA is capable of solving ED problem with WF connected within shortest CPU time. The author inferred that CSA was a best method when power system was connected since it gave exact results. The work recommended that future work should focus more on cost optimization that need mathematical methods to solve ED problem with big power system.

Civicioglu Besdok [7] presented optimization of ELD using CSA. The proposed approach was used for ELD with and without considering transmission losses. A non-convex ELD problem was proposed which took into consideration, both valve point effect and emission constraints. The work stated the three norms that needed to be captured in practical ELD which were minimization of fuel cost, emission cost and scheduling generator units. The proposed
approach was tested on 3, 6 and 10 unit systems for ELD without valve point effect on 3 and 13 unit systems for ELD with valve point effect and on 3 unit system for emission dispatch. The load demand on 3, 6, 10 and 13 thermal units were 850 MW, 283.4 MW, 1036 MW and 2520 MW respectively. The results obtained were compared to that obtained via PSO, conventional-PSO (CPSO), Differential evolution (DE) and Evolution Programming (EP). Both total fuel and emission cost obtained using the proposed approach was found to be less as compared to PSO, CPSO, DE and EP. The execution time was comparatively better compared to other techniques. The work concluded that CSA had ability to provide global solution and high convergence rate for both small and large scale systems. Thus, CSA was found to be more proficient, robust and finds real word applications nowadays.

Nguyen et al. [32] presented two modified versions of CSA. In their work, new solutions were generated with the aid of Gaussian and Cauchy distributions alongside with ELD optimization constraints. Convex ELD considering multiple fuel options were solved. CSA-Cauchy and CSA-Gauss were tested on 10-unit and two unit system respectively considering multiple fuel options and valve point effect on thermal units. Several load cases were used to validate the effectiveness of the proposed approach. The performance metrics were the CPU computational time and total fuel cost of generation. The simulation results obtained were compared to CSA- Lévy, conventional genetic algorithm (CGA) with mutliplier updating (CGA-MU) and new particle swarm optimization with a simple local random search (NPSO-LRS). The computational time obtained with the proposed methods was faster and slightly slower than CGA-MU, NPSO-LRS, CSA- Lévy and NPSO-LRS. The work concluded that the proposed methods were more efficient and faster than most of the methods for solving ELD problem with multiple fuel options.

Pentapalli and Varma [35] evaluated and demonstrated ELD with inclusion of transmission losses using GA, PSO and CSA. A comparative analysis of the three methods was done using 62-bus Indian utility system with a total load demand of 2300MW. The performance metrics used were total fuel cost and power losses reduction. Based on the comparative analysis carried out, CSA emerged best not only for faster convergence but also for better economy; and as the system size increased, CSO provided the vast economic difference. The work concluded that CSA yielded less transmission losses and appreciable minimized fuel cost compared to other techniques.

Sahoo et al. [36] presented solution to economic load dispatch problem using cuckoo search algorithm on 3, 6, 10 and 13 thermal unit systems. A multi-objective function was formulated which captured minimization of fuel cost and emission constraints. The results of the proposed approach were compared to GSA, genetic algorithm (GA), evolutionary programming (EP), Differential evolution (DE) and particle swarm optimization (PSO). Based on the analysis, the total fuel cost and emission cost obtained by CSA was found to be less when compared to other methods. The computational time was comparatively lesser compared to other approaches. The work concluded that CSA had ability to provide global solution and high convergence rate both for small and large scale systems.

Sapra [38] presented CSA for solving environmental-ELD problem with quadratic fuel function. The effectiveness and feasibility of the proposed method was tested on 3 and 6 thermal units having a total load demand of 800 MW, 1200 MW and 1800 MW. The performance metrics were fuel cost, emission and computation time. The results obtained were compared to Non-dominated Sorting Genetic Algorithm - II (NSGA-II), Tabu Search (TS), fuzzy logic controlled genetic algorithm (FCGA) and conventional-GA (CGA). The comparison result indicated that the proposed method was very efficient for solving EELD problem. The work suggested that future work should consider non-smooth fuel cost function of thermal units by dividing the emission objectives into three emission objectives, to determine the best compromise solution for two, three and four objectives.

Sharma and Mahor [40] presented an evolutionary algorithm called CSA to solve non-convex ELD problems. The robustness of the proposed algorithm was verified incorporating constraints like valve point loading, ramp rate limits, prohibited operating zones, multiple fuel options, generation limits and losses into the system. The proposed approach was tested on 6, 15, 40 bus power system of Korea having 140 and 320 thermal units using different load demand of 750 MW, 850 MW, 950 MW, 1050
MW, 49,342 MW and 86,400 MW. The results obtained were compared with GA and PSO. The work concluded that CSA converged better than PSO and GA and generated cheapest generation schedule, thus making it quite an efficient algorithm and less time consuming for online applications.

Sinha et al. [41] presented solution to convex ELD problem using CSA. The proposed approach was implemented on three and six-generating units with a total load demand of 150 MW and 700 MW respectively. The simulation results obtained for the proposed approach was compared to PSO, Shuffled Frog Leaping Algorithm (SFLA), Bacterial Foraging Optimization (BFO), Artificial Bee Colony (ABC), Harmony Search (HS) and Firefly Algorithm (FA). Results of the comparison revealed the superiority of the CSA convergence and efficiency in solving ELD problem.

Thang et al. [42] presented CSA for solving convex and nonconvex ELD problems of fossil fuel fired generators in single and multiple areas considering transmission losses, multiple fuels, valve-point loading, prohibited operating zones and tie line power flow. The effectiveness and feasibility of the proposed algorithm was verified on four different single areas based test systems and three different multiple area based test systems, both small and large, involving varying degree of complexity. The result obtained was compared to ABCO, DE and EP. The quality of the solution obtained was superior with the proposed algorithm producing minimal fuel cost and lesser computational time than other techniques. The work concluded that the proposed approach seemed to be a promising alternative approach for solving ELD problems in practical power system.

Yang and Deb [49] introduced a solution to ELD problem using CSA. The proposed approach was tested on 3 and 6 thermal units and the results of LIM and CSA were compared using total fuel cost and computational time as performance evaluation metrics. CSA outperformed LIM giving minimal fuel cost and lesser value of computational time was recorded.

Yang and Deb [50] presented CSA for solving both convex and non-convex ELD problems of fossil fuel fired generators. The constraints were transmission losses, multiple fuels, valve point loading and prohibited operating zones. The work covered dispatch of power on microgrid. The effectiveness and feasibility of the proposed algorithm was verified on 6, 10 and 20-generator system and their respective total load demands were 1263 MW, 2700MW and 2500 MW. The simulation results obtained with the proposed approach implemented in MATLAB was compared to PSO, biogeography based optimization (BBO), new particle swarm optimization-local random search (NPSO-LRS), new particle swarm optimization (NPSO), and improved genetic algorithm (IGA). Number of iteration was used as the stopping criteria for the algorithm. The work concluded that the proposed algorithm was a promising alternative approach for solving the ED problems in practical power system and micro grid power dispatch problem.

Table 1 gives a summary of CSA in ELD problem. It reflects the most important decision variables, ELD optimization problem, the most common objective function and the most common constraints.

<table>
<thead>
<tr>
<th>Name</th>
<th>Year</th>
<th>Method</th>
<th>Objective functions</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mustafa and Abdilahi</td>
<td>2017</td>
<td>CSA</td>
<td>ELD problems on 13 and 40 generating units</td>
<td>Fuel cost minimization</td>
</tr>
<tr>
<td>Karthik, Parvathy and Arul</td>
<td>2017</td>
<td>CSA</td>
<td>Non-convex ELD problems of fossil fuel fired generators</td>
<td>Transmission losses and valve point loading effect</td>
</tr>
<tr>
<td>Chellappan and Kavitha</td>
<td>2017</td>
<td>CSA</td>
<td>Economic-emission load dispatch problem</td>
<td>Cost minimization</td>
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<tr>
<td>Larouci, et al.,</td>
<td>2017</td>
<td>CSA</td>
<td>ELD problem and OPF incorporating FACTS devices</td>
<td>Transmission losses, system voltage deviation and minimized total fuel cost</td>
</tr>
<tr>
<td>Nagaraju et al.,</td>
<td>2016</td>
<td>CSA</td>
<td>ELD problem</td>
<td>Valve point loading on fuel cost function</td>
</tr>
<tr>
<td>Ly, Thang and Bach</td>
<td>2016</td>
<td>Adaptive-CSA (ACSA)</td>
<td>Economic emission Load dispatch (EELD) problem</td>
<td>Electricity generation, fuel cost and emission released</td>
</tr>
<tr>
<td>Name</td>
<td>Year</td>
<td>Method</td>
<td>Objective functions</td>
<td>Constraints</td>
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<tr>
<td>Ly et al.</td>
<td>2016</td>
<td>Adaptive Cuckoo Search Algorithm (ACSA)</td>
<td>ELD problem on thermal units</td>
<td>Fuel cost minimization and programming execution time.</td>
</tr>
<tr>
<td>Le and Vo</td>
<td>2016</td>
<td>CSA</td>
<td>ELD problem in power system operation with wind farm (WF)</td>
<td>Power balance, power loss and generator limits.</td>
</tr>
<tr>
<td>Kumar and Kumar</td>
<td>2016</td>
<td>CSA</td>
<td>Optimization of ELD</td>
<td>Minimization of fuel cost, emission cost and scheduling generator units.</td>
</tr>
<tr>
<td>Kaur and Gill</td>
<td>2015</td>
<td>CSA</td>
<td>ELD problem</td>
<td>Minimization of fuel cost and emission cost</td>
</tr>
<tr>
<td>Thao and Thang</td>
<td>2014</td>
<td>CSA</td>
<td>ELD problem</td>
<td>Fuel cost, emission and computation time.</td>
</tr>
<tr>
<td>Chowdhury</td>
<td>2013</td>
<td>CSA</td>
<td>Convex and non-convex ELD problems</td>
<td>Transmission losses, multiple fuels, valve-point loading, prohibited operating zones and tie line power flow.</td>
</tr>
<tr>
<td>Basu and Chowdhury</td>
<td>2013</td>
<td>CSA</td>
<td>Convex and non-convex ELD problems</td>
<td>Transmission losses, multiple fuels, valve point loading.</td>
</tr>
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7. REVIEW OF CSA

Demirel and Demiroren [8] presented a paper on nature-inspired optimization algorithms. It was highlighted that CSA was a more efficient algorithm when compared to PSO, DE and SA. Then, some studies carried out to improve the CS efficiency were reviewed. It was found that most CS efficiency improvement strategies were based on applying different probability distribution functions (Cauchy, Gauss and Gamma) to determine the random walk step sizes. Three CS algorithms using linear, exponential and power increasing switching parameters were developed and tested against the constant and linearly decreasing CS algorithms. The CSA using exponential increasing switching parameter was found to be more efficient than other CS algorithms.

Dutt and Dhamand [9] presented a brief review on CSA, its areas of application in Engineering and its hybridized version. The identified areas of application of CSA were traveling salesman problem (TSP), speech reorganization (SR), job scheduling (JS), and economic load dispatch (ELD) among others. Based on the review, the work concluded that CS was the best search algorithm.

Gigras et al. [12] proposed a CSA using Lévy Distribution, Cauchy Distribution and Gaussian distributions for solving the short-term hydrothermal scheduling (ST-HTS) problem with reservoir storage constraint on hydropower plants. The proposed techniques were tested on two different test systems with different power demand. The results obtained with the proposed approach were compared to EP, CEP, FEP, IFEP and RIFEP. The result obtained with three versions of the proposed method (CSA-Lévy, CSA-Cauchy, and CSA-Gauss) were faster than all methods. The work showed that among the three versions of CSA proposed in the paper, CSA-Lévy was the best producing the lowest minimum for the test systems. The work concluded that the proposed CSA methods, especially the CSA with Lévy distribution, were very favourable and powerful methods for solving short-term hydrothermal scheduling problem with reservoir volume constraint.

Hadi [13] presented application of CSA to the problem of multi-objective optimal power flow for the hydrothermal plant. The test case system used was IEEE 30-bus test system which consists of thermal plants and hydropower plants. The problem formulation combined both optimal power flow (OPF) and short-term hydrothermal scheduling (STHTS) problem. With this formulation, the problem became much more complicated than the two sub-problems due to all the constraints of the transmission grid and all hydraulic constraints. The result obtained with the proposed approach was compared to that of
PSO using minimization fuel cost and emission as performance metrics. The work concluded that based on the comparison made, CSA was very efficient for the problem since it was able to obtain better fuel cost for economic dispatch and better emission for emission dispatch. The results indicated that CSA was a very efficient method for solving the practical problem of MO-OPFHTS.

Kamat and Karegowda [16] optimized total operation cost in microgrid cuckoo search algorithm. A microgrid is a localized group of electricity generation, energy storage connected to a centralized grid. The two main costs that constituted total fuel cost identified were the generation cost of local resources and cost of energy from main grid. The proposed approach was implemented on test case system having 3, 6 and 40 thermal generator units respectively. The simulation result from MATLAB for the proposed approach was compared to that obtained with ABC. CSA outperformed ABC based on the performance metric used.

Kaur and Gill [17] proposed CSA for solving short-term fixed-head hydrothermal scheduling (HTS) problem taking into consideration, both the power losses in transmission systems and valve point loading effects in fuel cost function of thermal units. The proposed approach was tested on 4 and 5 hydrothermal systems using different fuel cost functions of thermal units. MATLAB platform was used as implementation tool and ran on a 2 GHz PC with 2 GB of RAM. The work emphasized that different values of the probability led to the same optimal solution and that the best value of probability of alien egg being discovered (Pa) had to be tuned in its range [0, 1]. The work suggested that value of distribution factor should be in the range [0.3, 1.99] as it had significant impact on solution quality of CSA. The results obtained were compared to optimal gamma based genetic algorithm (OGB-GA), existing GA (EGA), artificial immune system (AIS), EP, PSO and DE. It was concluded based on the analysis that the proposed approach was a favorable method for solving the short-term hydrothermal scheduling problem, especially for non-smooth fuel cost function of thermal units.

Kumar and Kumar [18] proposed Gaussian distribution (CSA-Gauss) and Cauchy distribution (CSA-Cauchy) approach against Lévy flights random walk in original CSA to improve on the exploration and exploitation of original CSA. The proposed approach was tested on one test system consisting of ten generating units using 2400 MW, 2500MW, 2600 MW and 2700 MW as total load demand. Weighted sum was used to transform the multi-objective function into single objective function. The simulation results were compared to Hopfield Lagrange network (HLN) and lambda iterative method (LIM) using emission, total fuel cost and computational time as performance metrics. Both CSA-Gauss and CSA-Cauchy competed favorably and were very efficient for solving economic emission load dispatch with multiple fuel option.

Le and Vo [20] proposed CSA for solving OPF problem on practical IEEE-62 bus Indian utility system. The performance of the proposed approach was compared to the PSO and GA using fuel cost and execution time as performance metrics. The proposed approach was coded in MATLAB. Based on the results obtained, the following conclusion was drawn; GA required more number of iteration and convergence time, PSO needed more time but less reliability while CSA performed better in solution time and reliability.

8. ANALYSIS OF THE REVIEWED PAPERS

The analysis of the papers reviewed in this research paper is illustrated in Figure 3. The Figure shows the trends of the reviewed papers for a period of five years (2013-2017). In 2013, four prominent papers were reviewed. Each of the papers discussed the concept of Cuckoo search algorithm and the method used. In 2014, five research papers were reviewed with the model developed clearly explained and the results analyzed. The drawbacks of each approach were clearly pointed out. In 2015, four papers were reviewed on Cuckoo search algorithm while in 2016, eleven research papers were reviewed. This shows that the number of papers reviewed in 2016 was about three times the number of papers reviewed in 2015. In 2017, six papers were reviewed which was about 45.5% in reduction from the number of papers reviewed in 2016.

In addition, from the list of papers reviewed so far, eight papers were reviewed for CSA without much emphasis on ELD problem, while twenty two papers were reviewed for CSA as solution of ELD problems.
9. CONTRIBUTION TO KNOWLEDGE AND RECOMMENDATION

A comprehensive analysis of the various CSA optimization approaches that will assist system engineers in recommending the most appropriate optimization technique in solving ELD problem has been presented. In addition, future research will focus on CSA optimization techniques to solve various ELD problems.

10. CONCLUSION

This work presented an extensive review of the application of cuckoo search algorithm to economic load dispatch on hydro-thermal power plants. Samples of openly accessible literatures were reviewed from 2013 to 2017. It was discovered that CSA is a hybrid of PSO, DE and SA. Several attempts have been made by researchers to enhance the performance of original cuckoo search algorithm includes adaptive turning/switching of parameters of CSA at each iteration run as against initial static fixing of these parameters prior to iteration. Other researchers made wholistic efforts to improve the efficiency of CSA by applying different probability distribution functions (Cauchy, Gauss and Gamma) to determine the random walk step sizes as against using levy flight approach. The identified variants of CSA were adaptive cuckoo search algorithm (ACSA), modified cuckoo search algorithm (MCSA), oppositional-CSA (OCSA) and one rank-CSA (ORCSA). CSA can be applied to large dimensional ELD problems as well as complex problems of ELD. However, variants of CSA demonstrated greater and better capacity with excellent performance to solve ELD problems with smooth and non-smooth fuel cost. Based on the reviewed papers, CSA is yet to be employed to solve Nigerian economic load dispatch problems.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://prh.sdiarticle3.com/review-history/25531