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Abstract: Economic load dispatch (ELD) in the operation of electric power system is an essential task, since it is required to determine the optimal output of electricity generating facilities, supplying the power to meet load demand at minimum cost while satisfying transmission and operational constraints. Several techniques were applied to solve the economic load dispatch problem, both conventional and intelligent methods. Recently, researchers are paying more attention to intelligent techniques such as Swarm-based algorithms and their development in order to be used to successfully solve complicated real life optimization problems. This paper presents a survey on the novel modifications applied to swarm-based algorithms used in solving ELD problems and its variants. Swarm optimization algorithms used in this paper are: 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) and Grey Wolf Optimization (GWO).

Keywords: Economic load dispatch (ELD), 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) and Grey Wolf Optimization (GWO).

I. INTRODUCTION
Due to the increase in power demand and continuous rise in fuel costs in the recent years, decreasing the cost of operating and generating electrical power has become a necessity. The main objective of ELD is to meet load demand and reduce total operating costs while satisfying operational constraints of the generation resources available. The variants of the ELD problem include: Combined Heat and Power Economic Dispatch, Environmental Economic Dispatch and Dynamic Economic Dispatch. In practical, multiple fuel options, valve loading effect, security constraints, Prohibited Operating Zones and Ramp Rate Limit Constraints should be considered in solving the ELD problem [1, 2].

Many researchers have proposed and developed many techniques to solve the ELD problem. Conventional methods like Lambda iteration method and Newton’s method are fast and reliable yet have limitations in finding global optimum. To overcome such limitations, intelligent meta-heuristics methods have been developed. These state of the art algorithms could be categorized based on their inspiration into:

1) Evolutionary
- Evolutionary Programming
- Genetic Algorithm
- Differential Evolution

2) Swarm based
- Particle Swarm Optimization
- Ant Colony Optimization
- Firefly Algorithm

3) Physics and chemistry based
- Big Bang Big Crunch
- Gravitational Search Algorithm
- Simulated Annealing

4) Nature based
- Flower Pollination Algorithm
- Invasive Weed Optimization

Swarm Intelligence (SI), defined as “The emergent collective intelligence of groups of simple agents” by Bonabeau et al. [3] has drawn the attention of many researchers in different fields. SI is based on the mimicking of social behavior exhibited in nature such as: foraging of bees, bird flocking, nest building, fish schooling, hunting and microbial intelligence. The two principles in swarm intelligence are:

1- Self-organization which is based on: activity amplification/ balancing by positive/ negative feedback, random fluctuations and multiple interactions.

2- Stimulation by work which is based on: work being independent on specific individuals and division of labor amongst individuals.
II. PROBLEM FORMULATION
The Economic Load Dispatch problem is an optimization problem with the objective of minimizing fuel cost which is subject of some equality and inequality constraints.

A. Cost objective function
- Minimize \( F_T = \sum_{i=1}^{Ng} a_i + b_i P_i + c_i P_i^2 \) \$/hr
  
  Where
  
  \( F_T \): Total Quadratic cost function; it could be also a cubic function
  \( P_i \): Real power generated
  \( Ng \): Number of generation busses
  \( a, b, c \): Fuel cost coefficients for \( i \)-th unit

- If valve point effect is considered, the cost objective function becomes:
  Minimize \( F_T = \sum_{i=1}^{Ng} a_i + b_i P_i + c_i P_i^2 + \left| e_i \sin(f_i (P_i^{\text{min}} - P_i)) \right| \) \$/hr
  
  Where
  
  \( e_i, f_i \): Fuel cost coefficients for \( i \)-th unit considering valve point effects

- If Combined Emission Economic Dispatch, the problem becomes a multi-objective problem:
  Min [\( F_r, E_r \)]
  
  Where
  
  \( E_r = \sum_{i=1}^{Ng} \alpha_i + \beta_i P_i + \gamma_i P_i^2 + \eta_i e^{\delta P_i} \) \$/hr

  \( E_r \): Total Emission cost function
  \( \alpha, \beta, \gamma, \delta, \eta \): Emission coefficients for \( i \)-th unit

- In Combined Heat and Power Economic dispatch, the objective is to find optimum power and heat operation with minimal fuel cost. Heat and power demand must be satisfied and operation is bounded in a heat – power plane.

- In Dynamic Economic Dispatch problem, the objective is to find optimum power and minimize fuel cost over a dispatch period. All dynamic constraints should be satisfied such as: prohibited operating zones and ramp rate limits are included in the inequality constraints and valve point effects are also considered.

B. Constraints
1) Equality constraint- Energy balance equation
   
   \[ P_D + P_L = \sum_{i=1}^{Ng} \sum_{j=1}^{Ng} B_{ij} P_j \]

   \( P_D \): Load demand
   \( P_L \): Power transmission losses
   \( B_{ij} \): Loss coefficients (constants)
   \( P_i, P_j \): Real power injection at the \( i \)-th and \( j \)-th busses

2) Inequality constraint- Generating limits
   
   \[ P_i^\text{min} \leq P_i \leq P_i^\text{max} \]

III. META-HEURISTIC ALGORITHMS
This paper outline nine SI-based algorithms and the modifications applied to them in order to solve the economic load dispatch problem and its variants

A. Ant Colony Optimization
Ant Colony Optimization (ACO) was proposed by Marco Dorigo in 1992 in his Ph. D. thesis [4]. It is inspired by the foraging behavior of ants constructing the shortest path between their colony and food source using pheromone trails as shown in Fig. 1.

In reference [6], I. Karakonstantis and A. Vlachos developed an Ant Colony Optimization for Continuous Domains (ACOR) algorithm approach. The proposed method will solve the Economic Load Dispatch problem (ELD), the Minimum Emission Dispatch problem (MED), the Combined Economic and Emission Dispatch problem (CEED) which is a multi-objective optimization problem and the Emission Controlled Economic Dispatch problem (ECED). The effectiveness of the proposed method was tested on 6 generators for...
demands 500 MW, 700 MW, 900 MW and 1100 MW while taking into consideration the power losses. These test systems results were compared to those obtained by Genetic Algorithm, Hybrid Genetic Algorithm and Quadratic Programming showing that the proposed method can handle complex problems producing feasible and high quality solutions.

In reference [7], D. C. Secui successfully implemented a method based on ACO (MACO) in solving the DED problem with inequality and equality constraints and with cost functions which take into consideration the valve-point effects is proposed. The efficiency of the proposed method was tested on 10, 13 and 30 thermal generating units and the results were compared to those obtained by MDE, HDE, DE, MHEP- SQP, DGPSO, PSO-SQP(C), IPSO, GA, PSO, ABC, AIS and other techniques. The numerical results show that the proposed method has better convergence and shows superiority over the other techniques in terms of the quality of the solutions in solving the DED problem with valve-point effects.

In reference [8], A. Vlachos, I. Petikas and S. Kyriakides developed a Continuous Ant Colony (C-ANT) algorithm to solve the ELD Problem. The proposed method will be used in continuous workspaces to obtain high quality solutions. It will be able to work quickly with complicated problems, thus achieving global optimization and avoiding local optima. The efficiency of the proposed method was tested on 4 generators and was compared to those obtained by conventional Particle Swarm Optimization (PSO) algorithms. The numerical results show that the proposed method obtains high quality solutions in less time.

In reference [9], N. A. Rahmat, I. Musirin, and A. F. Abidin solved weighted economic load dispatch problem using a Differential Evolution Immunized Ant Colony Optimization (DEIANT) technique. The effectiveness of the proposed method was tested on IEEE 30-Bus Reliability Test System (RTS) with 6 generators. Comparison with the results obtained by ACO and Evolutionary Programming (EP) technique show that the proposed method outperforms ACO and EP in achieving lower operating cost, power loss, and emission level and computation time.

**B. Particle Swarm Optimization**

Particle Swarm Optimization (PSO) is a population based search procedure developed by Kennedy and Eberhart in 1995 [10]. It was inspired by cognitive and social behavior of swarms of birds, school of fish etc, to maximize the survival of the species. Particles adjust their position according to their own best performance and their neighbors’ best performance according to the model in Fig. 2.

![Particle Swarm Model](image)

In reference [12], J. Lin, C. L. Chen, S. F. Tsai, and C. Yuan combined an intelligent PSO (INPSO) with a direct search method (DSM) to solve ED with valve-point effect. The developed method will help increase the possibility of exploring the search space where the global optimal solution exists. Local optimization will be done by DSM and global optimization will be done by INPSO, where the starting points are current INPSO solutions. The efficiency of the proposed method was tested on two test systems where valve-point effects are considered, one with 13 generators and another with 40 generators. These test systems results were compared to different variants of PSO: conventional PSO, PSO with inertia weight, PSO using common another particle behavior, CNPSO with a diversity-based judgment mechanism and INPSO with local optimization. The numerical results show that the proposed method is superior to other existing techniques in terms of the quality of the solutions.

In reference [13], M. Basu developed a modified particle swarm optimization where Gaussian random variables in the velocity term are used. The proposed method will improve search efficiency and guarantee obtaining the global optimum with a good speed of convergence. The efficiency of the proposed method was tested on 15-unit system with prohibited operating zones and transmission losses, 40-unit system with valve-point effects, 10-unit system considering multiple fuels with valve-point effects and 140-unit Korean power system with valve-point effects and prohibited operating zones. These test systems results were compared to those obtained by self-organizing hierarchical particle swarm optimizer with time varying acceleration coefficients (HPSO-TVAC) and particle...
swarm optimization with time-varying inertia weight (PSO-TVIW). Hence, showing that the proposed method overcomes premature convergence, thus obtaining better results compared to other methods. In reference [14], S. Duman, N. Yorukeren and I. H. Altas proposed a novel modified hybrid Particle Swarm Optimization (PSO) and GSA based on fuzzy logic (FL) method. The proposed method will control ability to search for the global optimum and increase the performance of the hybrid PSOGSA. The proposed method was validated using the well-known 23 benchmark test functions and its efficiency tested on IEEE 5-machines 14-bus, IEEE 6-machines 30-bus, 13 and 40 unit test systems; with and without the losses. Comparing these test systems results to those obtained by PSO, GSA and PSOGSA show that the proposed method can converge to the near optimal solution, thus, improving the performance of the standard hybrid PSOGSA approach.

In reference [15], V. K. Jadoun, N. Gupta, K. R. Niazi and A. Swarnkar developed a Modulated Particle Swarm Optimization (MPSO) that will enhance exploration and exploitation of the search space. The efficiency of the proposed method was tested on 6 generators, 10 generators and 40 generators systems considering several operational constraints like valve point effect, and prohibited operating zones (POZs) and compared to those obtained by PSO, BBO, DE/BBO, LMPSO and SMPSO. Linearly Modulated PSO (LMPSO), Sinusoidal Modulated PSO (SMPSO) The numerical results show that the proposed method is superior to other existing techniques in term of searching capability and convergence rate.

In reference [16], Z. Yu and F. Zhou proposed a new index, called iteration best, is incorporated into particle swarm optimization, and chaotic mutation with a new Tent map approach. The proposed method will balance global and local search of particles avoiding premature convergence and being trapped into local optimal. The efficiency of the proposed method was demonstrated for test cases of 6 and 15 generators systems. These test systems results were compared to those obtained by IPSO, CPSO, PSO and SOH-PSO to confirm that the proposed method has high convergence rate reaching more accurate global optimal solution.

In reference [17], S. Prabakaran, V. Senthilkumar G. Baskar proposed a new Hybrid Particle Swarm Optimization (HPSO) method that integrates the Evolutionary Programming (EP) and Particle Swarm Optimization (PSO) techniques. The efficiency of the proposed method was tested on 3, 6, 15 and 20 units systems. The numerical results illustrate that the proposed method is superior to EP, conventional PSO, GA, DSPSOTSA, BBO, HHS, HIGA and PSO-GSA in term of the quality of the solutions; therefore, it could be useful in solving non-linear economic dispatch problems. The proposed method will be capable of finding the most optimal solution for the non-linear optimization problems, since the best features of PSO and EP are combined.

In reference [18], N. Yousefi developed a particle swarm optimization with time varying acceleration coefficients. The proposed method can solve non-convex ELD problems with different constraints like transmission losses, dynamic operation constraints, and prohibited operating zones. The efficiency of the proposed method was tested on 3-machines 6-bus, IEEE 5-machines 14-bus, IEEE 6-machines 30-bus systems and 13 thermal units power system. The numerical results show that the proposed method has a faster convergence rate reaching global optimum solutions and avoid premature convergence when compared to those obtained by GA, APO and HGA-APO.

C. Bacterial Foraging Optimization

Bacterial Foraging Optimization Algorithm (BFOA) was introduced by Passino in 2002 which was inspired by the foraging behavior of the E. Coli bacteria living in the human intestine [19]. Bacteria search for nutrients (chemotaxis) to maximize energy obtained per time communicating with each other using signals. The movement of bacteria is achieved by swimming or tumbling as illustrated in Fig.3.

![Fig. 3. Movement of bacteria](image)

In reference [21], E. E. Elattar proposed a hybrid genetic algorithm and bacterial foraging (HGABF) approach. For larger constrained problems, bacterial foraging (BF) optimization algorithm has poor convergence characteristics. To overcome such
shortage, BF algorithm and genetic algorithm (GA) are integrated together. The efficiency of the proposed method was assessed on 5, 10, and 30-unit test systems and compared to those obtained by adaptive particle swarm optimization (APSO) algorithm, simulated annealing (SA) algorithm, artificial immune system (AIS), Maclaurin series-based Lagrangian (MSL) method, GA, PSO, artificial bee colony (ABC) algorithm time varying acceleration coefficients improved particle swarm optimization (TVAC-PSO) and hybrid immune-genetic algorithm (HIGA). The numerical results show the efficiency and superiority of the proposed method to determine the global or near global solutions for the DED problem over other methods.

In reference [22], M. S. Li, Y. Hu and X. Zhang proposed an improved Bacterial Swarm Algorithm (BSA) which has an increased computational complexity compared to other conventional dispatch methods. When tested on an IEEE 30-bus system with uncertain load, which represents a portion of the American Electric Power System; consisting of 30 buses, 6 generators, and 40 branches, it showed excellent convergence performance compared to most Evolutionary Algorithms (EAs) such as GA and PSO.

D. Shuffled Frog Leaping Algorithm

Shuffled Frog Leaping Algorithm (SFLA) is population based cooperative search simile introduced by Eusuff and Lansey in 2003 [23]. SFLA was motivated by the memetic evolution of a group of frogs seeking food. It is a combination of PSO and memetic algorithm shuffling and generating virtual frogs (Fig. 4).

In reference [25], M. K. Karimzadeh proposed an improved shuffled frog leaping algorithm for solving combined heat and power economic dispatch problem that is robust and will help global exploration. The effectiveness of the proposed method was tested on the 4 units system which consists of a conventional unit, two co-generation units and ahead alone unit with power demand PD and heat demand HD as 200 MW and 115 MW respectively. The numerical results showed the efficiency and superiority of the proposed method in terms of CPU time and solution precision compared to PSO, ABC and DE.

In reference [26], M. R. Narimani proposed a Modified Shuffle Frog Leaping Algorithm for Non-Smooth Economic Dispatch which will help reduce computational time and avoid being trapped in local optima by generating mutant vectors; thus, improve the quality of solutions. The effectiveness of the proposed method was tested on 6 and 40 thermal units and was compared to those obtained by conventional approaches such as Genetic Algorithm (GA), Tabu Search Algorithm (TSA), PSO and others in literatures. The numerical results revealed the capability of the algorithm to reach a reliable and superior solution in a faster computational time.

In reference [27], P. Roy, et al., developed a hybrid modified shuffled frog leaping algorithm (MSFLA) with genetic algorithm (GA) crossover approach for solving the economic load dispatch problem of generating units considering the valve-point effects. The proposed method will help to overcome the slow searching speed of the shuffled frog leaping algorithm (SFLA) in the late evolution and easily being trapped in local optima. The proposed method was tested on four test systems: IEEE standard 30 bus test system, a practical Eastern Indian power grid system of 203 buses,264 lines, and 23 generators, and 13 and 40 thermal units systems whose incremental fuel cost function take into account the valve-point loading effects. These test systems results were compared to those obtained by CEP, FEP, BBO, DEC-SQP, ICAPSO,MFEP, IFEP, and QPSO demonstrating the superiority of the proposed method in terms of solution quality, computational efficiency and robustness.

In reference [28], Y.N. Vijayakumar and Dr. Sivanagaraju combined the benefits of shuffled frog leaping algorithm and differential evolution by proposing a hybrid shuffled differential evolution (SDE) algorithm approach for the economic load dispatch problem. The SDE algorithm integrates a novel differential mutation operator specifically

Fig. 4. Shuffled behavior of leaping frogs in search of food [24]
designed for effectively addressed the problem. The efficiency of the proposed method was tested on three standard test systems having 3, 13, and 40-units. The numerical results showed that the proposed approach gives more accurate solution and converges better in less computation time compared to the GA and MPSO methods.

**E. Artificial Bee Colony**

Artificial Bee Colony (ABC) is a population based search procedure proposed by Dervis Karaboga in 2005 [29]. It was motivated by foraging behavior of honeybees to find food sources and communicate the information amongst other bees in the hive. The artificial agents are classified according to their tasks into employed bees, the onlooker bees, and the scout bees, as shown in Fig. 5.

![Fig. 5. Foraging behavior of honeybees to find food sources](image)

In reference [31], D. C. Secui proposed a new modified artificial bee colony algorithm (MABC) to solve the economic dispatch problem, taking into account the valve-point effects, the emission pollutions and various operating constraints of the generating units. To avoid premature convergence and find stable and high quality solutions, a new relation for the solutions update within the search space. The MABC is endowed with a chaotic sequence generated by both a cat map and a logistic map to enhance its performance. The effectiveness of the proposed method was tested on 6, 13, 40 and 52 units systems. Also it is assessed when it is endowed with three modalities for generating random sequences (Cat, Log and Random) and two selection schemes of the solutions (disruptive selection and classical proportional selection). These test systems results were compared to those obtained by ABC, PSO, HS, DE, BBO, FA, GA etc. The numerical results showed that the proposed methods obtain high quality solutions, meeting all of the equality and inequality constraints with high accuracy.

In reference [32], A. N. Afandi and H. Miyauchi developed a Harvest Season Artificial Bee Colony algorithm to improve performance in terms of the search mechanism and convergence speed. The effectiveness of the proposed method was tested on IEEE-62 bus system and compared to those obtained by ABC, SFABC, SBABC, MOABC and IABC. The numerical results showed that the proposed method reduced the number of iterations.

In reference [33], S. Arunachalam, R. Saranya and N. Sangeetha combined the faster computation of ABC and robustness of SA algorithm to improve global search capability, thus creating a hybrid ABC and SA algorithm for solving the combined economic and emission dispatch problem including valve point effect. The effectiveness of the proposed method was tested on IEEE 30 bus six generator systems and a 10 generating unit system. When compared to numerical results obtained by ABC, SA and Hybrid ABCPSO method, the proposed method provided better solution with reasonable computational time.

In reference [34], H. Shayeghi and A. Ghasemi improved modified ABC based on chaos theory (CIABC) and effectively applied it for solving a multi-objective EED problem. The proposed method uses a Chaotic Local Search (CLS) to enhance the self-searching ability of the original ABC algorithm for finding feasible optimal solutions of the EED problem. Also, many linear and nonlinear constraints, such as generation limits, transmission line loss, security constraints and non-smooth cost functions are considered as dynamic operational constraints. Moreover, a method based on fuzzy set theory is employed to extract one of the Pareto-optimal solutions as the best compromise one. The effectiveness of the proposed method was tested on standard IEEE 30 bus 6 generators, 14 generators and 40 thermal generating units, respectively, as small, medium and large test power system. The numerical results showed that the proposed method surpasses the other available methods in terms of computational efficiency and solution quality.

In reference [35], M. S. Rathinaraj and P. Prakash developed an artificial bee colony algorithm with dynamic population size (ABCDP) algorithm from the ABC algorithm inspired by the foraging behavior of honey bee swarm giving a solution procedure for solving economic dispatch problem. The effectiveness of the proposed method was tested on IEEE 30 bus 6 generators unit system having total load of 283.4 MW considering power loss. The numerical results
demonstrated that the proposed method has a faster convergence rate, less computational time, consistent, simple and easy to implement with high quality solutions and is applicable on large scale systems when compared to those obtained by with PSO, GA, IABC, IABC-LS algorithms

**F. Firefly Algorithm**

Firefly Algorithm (FA) was developed by Yang in 2008 which was inspired by the behavior of fireflies using flashing light to attract each other [36, 37]. Fireflies are unisexual, their attractiveness is proportional to their brightness which is inversely proportional to distance and with no brighter firefly, it will move randomly (Fig. 6).

![Firefly Algorithm](image)

**Fig. 6.** Brighter fireflies attract less bright ones [38]

In reference [39], G. Chen and X. Ding proposed an improved firefly algorithm (FA) to solve economic dispatch (ED) problem that will help overcome the highly nonlinear characteristics, such as prohibited operating zone, ramp rate limits, and non-smooth property. The effectiveness of the proposed method was validated by six benchmark functions, which include Sphere, Schwefel, Rosenbrock, Rastrigin, Ackley and Griewank and then applied on ELD system with 3, 13, and 40 thermal units. These test systems results were compared to those obtained by GA, PSO, EP, BBO and FA etc. The numerical results revealed that the proposed method was capable of improving the search ability, achieving higher quality solution with high diversity and avoiding premature.

In reference [40], A. Jalili, A. Noruzi, M. Yazdani and M. Mirzayi presented a hybrid method based on Firefly Algorithm (FA) and Fuzzy Mechanism (FM) for solving Economic Load Dispatch (ELD) problem by considering the valve point in power system. The efficiency of the proposed method was tested on six and forty generating units, considering the ramp rate limits and prohibited zones of the units. These test systems results were compared to those obtained by PSO, IPSO, Hybrid GAPSO, Chaotic PSO (CPSO), self-organizing hierarchical PSO (SOH-PSO), New PSO and BBO and the proposed method was found to efficiently reach optimum with a rapid convergence rate with high accuracy.

In reference [41], T. Malini used the Firefly Algorithm (FA) to solve the multi objective optimization for Economic and Environmental Dispatch (EED) problem considering security constraint described by Voltage Profile Index (VPI). The proposed method algorithm is capable of solving and determining the exact output power of all the generating units and minimizes the total cost function of the generation units. The efficiency of the proposed method was tested on IEEE 30 bus system 6 generators, 41 lines and 24 load buses and compared to those obtained by GA. The numerical results demonstrated that the proposed method is very efficient and accurate in obtaining global optima with high success rates for the given constrained optimization problem.

In reference [42], G. Maidl, D. S. de Lucena and L. dos Santos Coelho proposed a modified firefly algorithm (MFA) based on the situational knowledge source (memories of successful solutions) and used to solve non-convex ED optimization problem including practical aspect like valve-point. The effectiveness of the proposed method was tested on a 13 thermal units whose incremental fuel cost function takes into account the valve-point loading effects. These test systems results were compared to those obtained by improved evolutionary programming, Hybrid genetic algorithm, Particle swarm optimization, improved genetic algorithm, Self-tuning hybrid differential evolution, improved particle swarm optimization; thus revealed that the proposed method has the ability to converge to a better quality near-optimal solution and possesses better convergence characteristics and robustness.

In reference [43], M. M. Loona, M. S. Mehta and M. S. Prashar introduced a new metaheuristic nature-inspired Hybrid algorithm called DE-Firefly Algorithm (FFA) is to solve ELD problem. The efficiency of the proposed method was validated on a 3 unit test system and compared to the results obtained by Firefly Algorithm showing that it is efficient and robust reaching a more optimal solution than FFA.

**G. Cuckoo Search Algorithm**

Cuckoo Search Algorithm (CSA) was introduced by Yang and Deb in 2009 which was inspired by a special species of bird called cuckoo [44]. Each cuckoo lay an egg in a host bird’s nest chosen randomly. Eggs that
aren’t discovered by host bird (high quality) continue in the iterations with a probability [0, 1]; whereas discovered eggs are thrown or the host abandons the nest, as illustrated in Fig. 7.

![Cuckoo Egg and Nest Solution](image)

**Fig. 7.** Representation of a nest solution in the Cuckoo Search Algorithm [45]

In reference [46], C. D. Tran, T. T. Dao, V. S. Vo and T. T. Nguyen proposed two modified versions of CSA, where Gaussian and Cauchy distributions generates new solutions and impose bound by best solutions mechanism. The (CSA-Gauss) and (CSA-Cauchy) has fewer parameters and fewer equations than CSA with Lévy distribution. The effectiveness of the proposed method was tested on two 10-unit systems: System with Multiple Fuel Options (2400, 2500, 2600 and 2700 MW) and without Valve Point Effect and another System with Multiple Fuel Options (2700 MW, neglecting losses) and Valve Point Effect. These test systems results were compared to those obtained by various techniques and by those obtained by (CSA-Gauss) and (CSA-Cauchy). The numerical results revealed that the proposed method is highly effective and faster for solving ELD problem with multiple fuel options with/without valve point effect.

In reference [47], K. Chandrasekaran, S.P. Simon and N. P. Padhy used the CSA to solve the ERED (Emission Reliable Economic Multi-objective Dispatch) problem, which is formulated as a non-smooth and non-convex multi-objective ED problem incorporating valve point effects of thermal units. The fuzzy set theory is used to find a best compromise solution from the healthy distributed Pareto-optimal set. The efficiency of the proposed method was tested on a benchmark of 6-unit test system, IEEE RTS 24 bus system, and IEEE 118 bus system solving both EED and ERED problems. These test systems results were compared to those obtained by PSO and ABC showing similarity to PSO in terms of velocity and position equations (Fig. 8).

![Echolocation Behavior of Bats](image)

**Fig. 8.** Echolocation behavior of bats [51]

In reference [48], N. T. P. Thao and N. T. Thang implemented a Cuckoo Search Algorithm for solving environmental economic load dispatch. The effectiveness of the proposed method was tested on three and six thermal units with different loads and dispatches. Compared to Tabu Search, variants of GA and BBO the proposed method was very efficient obtaining lower fuel cost, emission and computation time.

In reference [49], E. Afzalan and M. Joorabian proposed a modified CS algorithm employing a new mutation scheme inspired by the DE/current-to-gr_best/1 and applied to determine the feasible optimal solution of the economic load dispatch problem considering various generator constraints. The efficiency of the proposed method was tested on 3, 6, 15, and 40 thermal units with generator constraints, such as: ramp rate limits, prohibited operating zones in the power system operation, and transmission losses. The numerical results revealed that the proposed method enriches the searching behavior and solution quality, thus, avoid being trapped into local optimum.

**H. Bat Algorithm**

Bat Algorithm (BA) was introduced by Yang and Gandomi in 2012 and is inspired by echolocation behavior of bats to recognize direction and differentiate between food and prey [50]. This algorithm shows similarity to PSO in terms of velocity and position equations (Fig. 8).
PSO, GA, SQP, and BF, it can be concluded that the proposed method is a promising alternative to existing techniques in obtaining better solutions.

In reference [53], T. K. Dao, T. S. Pan and S. C. Chu developed an evolutionary based approach Evolved Bat Algorithm (EBA) to solve the constraint economic load dispatched problem of thermal plants. The effectiveness of the proposed method was tested on six units and fifteen units of thermal plants and compared to those obtained by GA and PSO. The numerical results showed that the proposed method reaches better quality solution with higher efficiency, superior accuracy and less computational time.

In reference [54], P. S. K. Reddy, P. A. Kumar and G. N. S. Vaibhav used the bat algorithm to obtain the optimal solution of economic load dispatch (ELD). The effectiveness of the proposed method was tested on 3 and 6-unit system and compared to PSO and IWD confirming its superiority in terms of convergence, accuracy and computational time.

1. Grey Wolf Optimization
Grey Wolf Optimization (GWO) is the most recent algorithm introduced by Seyedali Mirjalili in 2014 which was inspired by the grey wolf (Canis lupus) hunting behavior [55]. Privileged wolves are alpha wolves – decision makers, then beta wolves – alpha assistant, and then delta wolves – lowest ranking and omega are inferior wolves preceded by scoffed kappa and lambda as in Fig. 9.

In reference [54], Dr. S. Sharma, S. Mehta and N. Chopra proposed to solve convex economic load dispatch problem using a new meta-heuristics inspired by grey wolves Grey Wolf Optimization GWO. The proposed method mimics the hunting mechanism and leadership hierarchy of the grey wolves. The efficiency of the proposed method was tested on three and six unit systems. These test systems results were compared to those obtained by Lambda Iteration Method, Conventional Method, PSO and Cuckoo Search Algorithm. The numerical results showed that the proposed method is simple, reliable and efficient.

In reference [56], L. I. Wong, M. H. Sulaiman and M. R. Mohamed applied the newly developed Grey Wolf Optimizer to solve economic load dispatch ED problems. The proposed method mimics the hunting mechanism and leadership hierarchy of the grey wolves. The effectiveness of the proposed method was tested on 6 units and 15 units systems. These test systems results were compared to those obtained by DS, BBO, GA and variants of PSO which proved that the proposed method is superior to other methods in terms of convergence, accuracy and computational time.

<table>
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<tr>
<th>Meta-heuristic</th>
<th>Advantages</th>
<th>Disadvantages</th>
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| **Ant Colony Optimization**     | • Applicable to a broad range of optimization problems, such as: Traveling Salesman Problem  
• Since ants move simultaneously and independently without supervision, it can be used in dynamic parallel applications  
• Positive feedback favoring most taken path leads to discovering good solution rapidly  
• Distributed computation avoids premature convergence | • Theoretical analysis is difficult so research is experimental instead of theoretical  
• Although convergence is guaranteed, the time it takes is uncertain  
• Only applicable for discrete problems |
| **Particle Swarm Optimization** | • Simple concept and easy implementation  
• Robust in controlling the few parameters, computationally efficient and requires less memory  
• It can be easily applied to nonlinear non- | • It gets trapped in local optima when handling heavily constraint problems due to limited local/global searching capabilities  
• Updating is performed without |

Table 1. Advantages and disadvantages of Swarm-based meta-heuristic algorithms [57]-[64]
Fatma et. al., Solution of Economic Load Dispatch using Recent Swarm-based Meta-heuristic Algorithms: A Survey

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<tr>
<th>Algorithm Name</th>
<th>Features</th>
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<tr>
<td><strong>Bacterial Foraging Optimization Algorithm</strong></td>
<td>Self-adaptive, Global convergence avoiding premature convergence, Less computational time, Requires less memory, It can be widely applied to non-linear optimization problems and can handle more number of objective functions</td>
<td>Due to its biased random walk, swarming effect is not satisfactory for the ELD problem which is a complex problem in huge multi-dimensional space with constraints</td>
</tr>
<tr>
<td><strong>Shuffled Frog Leaping Algorithm</strong></td>
<td>Robust, accurate, efficient and fast, It combines the profits of the local search tool of PSO and the idea of mixing information from parallel local searches to move toward a global solution</td>
<td>It gets trapped in local optima, The convergence to proper target is very late</td>
</tr>
<tr>
<td><strong>Artificial Bee Colony</strong></td>
<td>It has few parameters, It is a global optimizer, Flexible</td>
<td>High computational time</td>
</tr>
<tr>
<td><strong>Firefly Algorithm</strong></td>
<td>It doesn’t only include self-improving process with the current space but also include improvement among its own space, Less computational time to reach optima or near optima, It has a higher convergence rate and much simpler</td>
<td>It can get trapped into local optima, Firefly algorithm parameters are set fixed and they do not change with the time, No memory or history of better solutions of previous iterations</td>
</tr>
<tr>
<td><strong>Cuckoo Search Algorithm</strong></td>
<td>Few parameters to control, It possesses a fine balance of intensification (local search) and randomization (exploration of whole search space), Convergence rate is insensitive to one of the parameters</td>
<td>It can get trapped into local optima</td>
</tr>
<tr>
<td><strong>Bat Algorithm</strong></td>
<td>Simple, flexible and easy implementation, Few parameters to control, Fast initial convergence, It can be easily applied to nonlinear non-continuous optimization problem</td>
<td>If it switches from exploration to exploitation stage rapidly, it may lead to stagnation after some initial stage</td>
</tr>
<tr>
<td><strong>Grey Wolf Optimization</strong></td>
<td>Easy to implement due to its simple structure, Faster convergence, Few parameters to control, Avoids local optima</td>
<td>The algorithm is still under research and development</td>
</tr>
</tbody>
</table>

**IV. CONCLUSION**

- Economic load dispatch (ELD) problem play a vital role in the operation of power system. This paper presents important variants and considerations of the ELD problem. First, the formulation for the ELD problem was outlined. The main objective of ELD is to determine optimum power generation and minimizing the fuel cost. Then a review of the swarm optimization algorithms was presented. Although these algorithms have successfully solved the ELD problem, yet further improvements to the algorithms were needed. Thus, updates and modifications were introduced to these algorithms. This paper reviewed the work reported in literature in the field of using swarm optimization algorithms and their recent updates to solve economic dispatch problems. A comparison is made to demonstrate the advantages and disadvantages of each meta-heuristic algorithm as shown in Table 1.
REFERENCES


