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Optimization Algorithms for Solving Combined Economic Emission Dispatch: A Review

[1]John Kobbina Arthur -*Member, IAENG*, [2]Emmanuel Asuming Frimpong, [3]Joe Oteng Adjei

Abstract- **This paper presents a review of various optimization algorithms for solving combined economic emission dispatch (CEED). As a result of rising public concerns about the environmental impact of fossil-fueled electric power stations and its global warming and greenhouse gas emission effect, a solution based only on the minimization of the economic cost is no longer acceptable and need to consider minimization of emissions as well. This multi-objective problem becomes more complex in large scale power systems, as it is hard to find out an optimal solution because it is a non-smooth and non-convex function, and it contains several local optima. This review will help researchers for providing better techniques for CEED optimization in a practical power system.**

Index Terms- **Combined Economic Emission Dispatch, Differential Evolution, Economic Dispatch, Heuristics, Optimization**

I. INTRODUCTION

The planning and operation of a modern power system in an optimal way involves the integration of variable renewable energy sources, system security, the consideration of economy of operation, emissions at fossil-fuel plants, optimal release of water at hydro power plants, power purchase agreement etc. all in the problem formulation for a practical power system. Several optimization algorithms have been used to analyze the economic and environmental dispatch problem. Conventional methods such as dynamic programming [10], Lagrange's technique [20], and lambda-iteration [3], [16] have been reported in the literature to find the global optimal solution for economic and environmental dispatch problem. However, these techniques usually suffer from slow convergence rate, large computation time, poor local optima avoidance, and algorithm complexity. More recently, improved heuristic and meta-heuristic techniques like Artificial Bee Colony Method [5], [9], Binary Particle Swarm Optimization technique [7], Egyptian Vulture Optimization Algorithm [13], Spiral Optimization Algorithm [14], Genetic algorithm [15], Simulated Annealing [24], Differential Evolution [22], [24], Evolutionary Programming [11], Improved Teaching Learning Based Optimization algorithm [17] and neural networks are being used to find global or near global optimal solution of the CEED problem.

Optimization techniques provide a better solution for the ED problem. Better optimization approaches can be used for providing promising results, especially in cases where the processes are very complex to be analyzed by traditional methods.

Although the aforementioned techniques offer a significant performance of the system, they still have some drawbacks. Majority of the preceding algorithms suffer from slow convergence rate, poor local optima avoidance, and require large computation time. Additionally, there is fuzziness in the selection of algorithm-specific control parameters. For example, SA talks about global convergence in an infinite time. This is practically wrong because resources are very limited in real-world applications. Also, DE is mostly dependent on mutation and crossover factors. Again, the effective implementation of PSO wants an unerring value of acceleration coefficients and weighting factors for social and cognitive components.

The paper is divided into four sections. Section I, highlights the brief introduction, Section II, review the various optimization algorithm for solving combined economic emission dispatch (CEED). Section III, discusses the reviewed work. Section V, provides the conclusion of the extant paper.

II. REVIEW OF VARIOUS OPTIMIZATION TECHNIQUES FOR SOLVING CEED

Over the past decade, stochastic based meta-heuristic optimizations methods have been given more emphasis to find a global solution. Scores of methods, based on swarm and evolutionary techniques, have been used to get solution for multi-objective CEED problems. Some of the techniques are described here to show the effectiveness of the given problem.

B.Y. Qu et al. [1] have used a summation based multi-objective differential evolution (SMODE) algorithm to optimize the economic emission dispatch problem with stochastic wind power. The Weibull probability distribution function is used to model the stochastic nature of the wind power, and the uncertainty is treated as the system constraints with stochastic variables. To validate the effectiveness of the proposed method, the standard IEEE 30-bus 6-generator test system with wind power (with/without considering losses) is studied with fuel cost and emission as two conflicting objectives to be optimized at the same time. The results

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J. K. Arthur is a doctoral researcher at the Electrical/Electronic Engineering Department of the Kwame Nkrumah University of Science and Technology, Kumasi-Ghana, (email: arthurjohnkobbina@gmail.com).

E. A. Frimpong is a senior lecturer at the Electrical/Electronic Engineering Department of the Kwame Nkrumah University of Science and Technology, Kumasi-Ghana, (email: frimponge@yahoo.com).

J. O. Adjei was the former Minister for Energy of the Republic of Ghana. He is currently with the Kwame Nkrumah University of Science and Technology, Kumasi-Ghana, Electrical/Electronic Engineering Department as an adjunct professor, (email: jotengadjei@gmail.com).

generated by SMODE were compared with those obtained using NSGAII as well as several techniques reported in the literature. The results reveal that SMODE generates superior and consistent solutions. The technique did not include power purchase agreement in the model. This is likely to affect the optimal solution in a real power system.

In [2], Huifeng Zhang et al. proposed an adaptive grid-based multi-objective Cauchy differential evolution (AGB-MOCDE) combining with scenario-based technique to solve the dynamic economic emission dispatch DEED problem. In order to enhance the optimization efficiency, Cauchy mutation operation is utilized to improve differential evolution by adjusting the population diversity during the population evolution process, and an adaptive grid is constructed for retaining diversity distribution of Pareto front. With consideration of a large number of generated scenarios, the reduction mechanism is carried out to decrease the number of the scenario with covariance relationships, which can greatly decrease the computational complexity. To validate the effectiveness of the proposed technique, three test systems were used. The simulated results obtained reveal that in comparison with other alternatives, the proposed AGB-MOCDE can optimize the DEED problem while handling all constraint limits, and the optimal scheme of stochastic DEED can decrease the conservation of interval optimization, which can provide a more valuable optimal scheme for real-world applications. The proposed model did not consider constraints such as power purchase agreement, and valve-point loading effect. Hence, using this technique for optimal dispatch may not be helpful.

Bindu and Kumar [3] investigated three techniques, i.e., one Conventional Technique- Lambda Iteration Technique and two AI Techniques- Particle Swarm Optimization (PSO) and Random Drift Particle Swarm Optimization (RDPSO) Techniques to solve Combined Economic and Emission Dispatch (CEED) problem. The investigation was carried out on 15- Generating Unit Test Systems with respect to Total Operating Cost, Total Emission, and System Losses to ascertain its robustness. Results show that in solving Combined Economic and Emission Dispatch (CEED) problem, Random Drift Particle Swarm Optimization (RDPSO) Technique is superior to the other two techniques in terms of reduced operating cost. Constraints such as integration of renewable sources, power purchase agreement, tie-line limits were ignored in the problem formulation. This is likely to degrade the method practical application.

M. Rajkumar et al. [4] discussed the application of evolutionary multi-objective optimization algorithms namely Non-dominated Sorting Genetic Algorithm-II (NSGA-II) and Modified NSGA-II (MNSGA-II) for solving the Combined Economic Emission Dispatch (CEED) problem with valve-point loading. IEEE 57-bus and IEEE 118-bus systems were taken to validate the effectiveness of NSGA-II and MNSGA-II. To compare the Pareto-front obtained using NSGA-II and MNSGA-II, reference Pareto-front is generated using multiple runs of Real-Coded Genetic Algorithm (RCGA) with a weighted sum of objectives. Numerical results show that MNSGA-II algorithm performs better than the NSGA-II algorithm to solve the CEED problem effectively.

Gitanjali Mehta et al. [5] have applied Artificial Bee Colony Method to solve the Combined Economic Emission Dispatch Problem. An IEEE 30 bus test system was used to obtain the exact total operating cost and emission reduction. Simulation results reveal that the computational time is high for convergences. It was recommended that hybridization of this technique with some other optimization methods could make it more effective in achieving the global optimum.

Kiran et al. [6] have provided a comprehensive review of the uses of different nature-inspired advanced optimization techniques for solving multi-objective Combined Economic Emission Dispatch Problem (CEED). Different formulation criteria of CEED problem such as quadratic and cubic function along with their major equality and inequality constraints have been presented to give a clear idea to the readers about the actual CEED problem. The study concluded that stand-alone nature-inspired meta-heuristic techniques are most successful, while hybrid techniques are found to be most prospective to optimize CEED problem.

Kumar and Reddy [7] proposed a Binary Particle Swarm Optimization technique to solve Combined Emission Economic Dispatch (CEED) using 13 PV plants and six thermal units. Two test cases of Static Combined Emission Economic Dispatch (SCEED) and Dynamic Combined Emission Economic Dispatch (DCEED) were considered. Simulation results demonstrate the satisfactory operation of the proposed model. The model only considered the convex characteristics of the thermal units. This is a major drawback of the proposed approached. Again, power losses and power purchase agreement were not considered in the model. This will limit the practical usefulness of the proposed algorithm.

Musau et al. [8] presented a review of the Multi-Objective Dynamic Economic Dispatch (MODED) problem on both quadratic and cubic cost functions. It was apparent from the review that cubic cost functions are found to be more accurate than quadratic ones. However, the presented work only looked at the minimization of the cost, which will not suffice in a real system.

Reference [9] applied Artificial Bee Colony technique to solve the combined economic and emission dispatch problem. The aim was to improve the efficiency of the power system. To ascertain the effectiveness of the applied method, an IEEE 30 bus test system was used. Simulation results revealed that the convergence abilities of the ABC method are better than that of the evolutionary and PSO methods. The study did not consider the integration of variable renewable energy, tie-line limits, and power purchase agreement in the problem formulation. This is likely to impacts on its practical usefulness.

Reference [10] presented a review of various techniques for solving combined economic and emission dispatch. The aim was to present a clear picture of what is available so that researchers in the area of generation dispatch can identify problems and seek their solutions. The period covered is 1990-2016. Results from the review show that convergence property

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was the most prominent criteria that distinguished the other techniques reported in the literature.

Tapas Kumar Panigrahi et al. [11] provided a review of various techniques for solving the combined economic emission dispatch problem. Evolutionary algorithm considering the different type of constraint in the respective methods were used. The optimization methods were applied to different type of test system based on IEEE test systems to verify the superiority with others technique.

Reference [12] proposed a Radial Basis Function Neural Network (RBFNN) approach for solving the Combined Economic and Emission Dispatch (CEED) problem. The proposed algorithm was tested on three test systems with three, six generating units and fifteen generating units to ascertain its robustness. Simulation results were compared with compared with conventional lambda iteration method considering Average Percentage Absolute Error. The RBFNN method provided a global optimal solution than the other techniques. The approach did not considered constraints such as power purchase agreement, tie-line limits, renewable energy integration etc. This is likely to limit its practicability for a real power system.

Si tayeb et al. [13] presented Egyptian Vulture Optimization Algorithm (EVOA) for multi-objective optimization problem in power system. The approach was applied to three, six and ten generating units test systems to test its efficiency. Results obtained were very satisfactory results (emission, fuel cost, total cost and losses) compared with results of previous studies relied on other methods (PSO, GA, FPA, NSGA-II, BA). EVOA is reported to be effective, easy to applied and able to search near total optimum solutions. Several constraints stochastic renewable energy sources integration, power purchase agreement, for a practical power system were ignored in this method. Hence, for realistic optimal dispatch, this technique will not be good.

Lahouaria Benasla et al. [14] proposed Spiral Optimization Algorithm (SOA) for solving the Combined Economic and Emission Dispatch (CEED) problem. Scheduling of generators to operate with both minimum fuel costs and emission levels simultaneously, while satisfying the load demand and operational constraints is the aim of the study. The proposed algorithm has been implemented on three test systems with 3, 6, and 40 generating units, with different constraints and various cost curve nature. To verify the effectiveness of the proposed technique, results obtained were compared to those reported in the recent literature. Result showed good applicability of SOA for CEED problem. Practically, constraints such as power purchase agreement, integration of renewable energy, valve point loading effect needs to be factored in the problem formulation. However, this was not done. Hence, applying this technique to a real power system will not yield the desire results.

Reference [15] presented Genetic Algorithm (GA) and Ant Colony Search Algorithm (ACSA) to solve the combined Economic and Emission dispatch (EED) problem with transmission losses. The feasibility of the proposed method was tested on a power system network and the experimental results of both GA and ACSA were compared with the solutions of conventional Lambda iteration method. Simulation results show that GA solution is found to be more optimal than the traditional Lambda iteration method. Several constraints needs to be considered in a practical system for realistic results to be achieved. However, constraints such as integration of renewable energy sources, valve point loading effect, power purchase agreement were not considered in the problem formulation.

Bindu and Kumar [16] investigated three algorithms, namely; Lambda Iteration Technique, Particle Swarm Optimization (PSO) and Random Drift Particle Swarm Optimization (RDPSO) Techniques to solve Combined Economic and Emission Dispatch (CEED) problem. This multi-objective CEED problem was converted into a single optimization problem using a Price Penalty factor approach. The investigation was carried out on 15- Generating Unit Test Systems with respect to Total Operating Cost, Total Emission, System Losses, and Computation Time. Results show that Random Drift Particle Swarm Optimization (RDPSO) Technique is superior to the other two techniques in terms of reduced operating cost. Constraints such as power purchase agreement, integration of stochastic renewable energy, and tie-line limits were not considered in the problem formulation. This is likely to impacts on the final solution of the CEED problem.

Thenmalar et al. [17] used Improved Teaching Learning Based Optimization algorithm to solve the combined economic emission load dispatch problem. The approach was verified by thirteen generating bus for different load demand and compared with other existing techniques reported in the literature. Simulation results found out that ITLBO is capable of finding the solution for attaining the global optimum. This technique is deficient in power purchase agreement and integration of renewable energy for a real power system.

Reference [18] proposed a Moth Flame Optimization (MFO) algorithm for the optimum solution of Economic and Emission Dispatch problem along with the valve point effect loading. An IEEE 30 bus system was used to verify the effectiveness of the proposed technique. The analysis shows good convergence property for MFO and provides better results in comparison with PSO. However, power purchase agreement and integration of stochastic renewable energy for a practical power system were not considered in the problem formulation. This will limit its practical suitability.

Reference [19] introduced a Novel Bat Algorithm (NBA) to be applied for solving the EED problem using max/max penalty factor. As a test system, a six generator bus having cubic cost function was used for verification. Simulations were performed for individual pollutant analysis, and combined pollutant analysis, considering different load demands. The results show that NBA performs better when compared with other algorithms available reported in the literature. This method was applied to a small power system. Determining its robustness for higher dimensional problems can be very challenging. Again, including renewable sources of energy in the model will also impact on its practical usefulness.

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Mahla et al. [20] proposed Lagrange's technique to optimize Economic Emission Dispatch Problem (EED) of thermal units. The proposed algorithm has been applied to a standard IEEE 30 bus test system with six generating units. The simulated results show that the Min-Max price penalty factor provides better optimization solution for the single area dispatch problem in comparison with Max-Max price penalty factor. The results also show that the power loss and emission values are less in Max-Max price penalty factor when compared to Min-Max price
penalty factor. Constraints such as Valve Point Effect Loading, power purchase agreement, and integration of renewable energy were not considered in the problem formulation. This will impact on the robustness of the technique in a real system.

Qu et al. [21] have presented a survey of the state-of-the-art of research related to multi-objective evolutionary algorithms (MOEAs) to solve environmental/economic dispatch (EED) problems. Although there have been numerous publications on the classical EED problems, the study of the EED problems using multi-objective evolutionary algorithms is still in its early stages. At present, there have been some achievements in solving the dynamic EED problem and the EED problem with wind power, while research on EED associated with micro-grids and EVs is limited. Modeling and solving of such EED problems are worthy of investigating using multi-objective evolutionary algorithms. The survey did not include a power purchase agreement. This implies that it is still a gray area in the literature.

Wu et al. [22] have proposed a multi-objective differential evolution (MODE) algorithm for environmental/ economic power dispatch (EED) problem. The proposed MODE technique adopts an external elitist archive to retain non-dominated solutions found during the evolutionary process. To preserve the diversity of Pareto optimality, a crowding entropy diversity measure tactic was developed. The IEEE 30- and 118-bus test system were used to investigate the effectiveness of the proposed MODE approach. Simulation results showed that the proposed MODE approach is efficient for solving multi-objective EED problems where multi-objective Pareto optimal solutions can be found in one simulation run. Constraints such as valve-point loading effect, power purchase agreement, ramp rate limits, and prohibited operating zones were ignored. The result’s practical usefulness will be degraded if the above constraints are neglected.

Qu et al. [23] have established an environmental-economic dispatch of integrated power and gas system incorporating diversified emission control, and a two-layer convex decentralized optimization was developed to solve the issue. The optimization results in two test systems validate the nearly global optimality and computational robustness of the two-layer convex decentralized optimization. Besides, through the initial point setting strategy for the lower-layer decentralized optimization, the convergence efficiency of the two-layer convex decentralized optimization is promoted. Different from the traditional centralized optimization, the two-layer convex decentralized optimization realizes a synergetic operation of integrated power and gas system with only a small amount of boundary information exchanged between these two sub-systems, which is more acceptable in practical considering information sharing difficulties. Applying the proposed techniques in real integrated power and gas system will not yield the desired results because a more precise diffusion model of air pollutants considering inversion layer, rainfall, and terrain conditions were neglected in the model.

Jorge de Almeida Brito Júnior et al. [24] have analyzed several optimization techniques (simulated annealing, ant lion, dragonfly, NSGA II, and differential evolution) and their application to economic-emission load dispatch (EELD). The model was implemented in MATLAB computing. All algorithms have presented good results. The SA achieves the lowest emission of pollutants, while DE obtained the lowest cost for the power plant of ten generating units.

Akkaş et al. [25] have addressed the problem of environmental economic load dispatch (EELD) in a power system by using a modified genetic algorithm and a modified artificial bee colony optimization techniques. Six generators were used to verify the effectiveness of the methods. The results of these modified algorithms were compared with those of the unmodified versions. The results demonstrate that the proposed new methods have better economic and environmental distribution performances. All the approaches used did not include a power purchase agreement and the integration of renewable resources. This is likely to degrade the results on a real power system.

Ehab E. Elattar [26] proposed a shuffle frog leaping algorithm (SFLA) which called modified SFLA (MSFLA) to solve the combined heat, emission and economic dispatch (CHEED) problem. To drive the proposed method both local and global search mechanisms in the original SFLA are modified. The local search mechanism is modified by introducing the movement inertia equation of particle swarm optimization (PSO). Again, the global search mechanism is modified using the crossover and mutation operators of genetic algorithm (GA). To show the effectiveness of the proposed MSFLA, different test systems with different scenarios were used. The numerical results of the proposed method were compared with the different heuristic and non-heuristic optimization techniques. The numerical results prove the ability of the proposed method to converge to quality of solutions with better convergence characteristics for both small-scale and large-scale test systems. The proposed technique did not consider power purchase agreement as a constraint in the model. This will impact its efficiency on a real power system.

Thang Trung Nguyen et al. [27] have proposed an efficient and new modified differential evolution algorithm (ENMDE) for solving two short-term hydrothermal scheduling (STHTS) problems with available water constraints and reservoir volume constraints, in addition to the valve point loading effects of thermal units. The proposed ENMDE with two new proposed techniques, including self-tuned mutation and leading group selection, has effective search abilities, such as fast convergence to the optimal solution, a low total number of fitness evaluations and few control parameters. The superiority of the proposed method over conventional DE is not only the obtained results in terms of optimal solutions but also the reduction of computation, such as neglecting crossover operations and cutting the crossover factor. Compared to other existing methods, the proposed ENMDE is also more effective in terms of a better quality of solutions, the lower total number of fitness evaluations, and faster execution time. The study ignored the power purchase agreement constraints. This is likely to influence the quality of the solution on a real power system.

Nirbhow Jap Singh et al. [28] have proposed a combination of surrogate worth trade-off (SWT) method, chaotic differential evolutionary and Powell's pattern search (CDEPS) algorithm to solve multi-objective thermal power load dispatch (MTPLD) problem. The SWT plays the role of the compromised solution decision maker, whereas CDE is responsible for diversification and PS deterministically improves the quality of feasible solutions. Two chaos maps, namely Gauss map and Tent map, are considered for performance analysis of chaotic differential evolution and Powell's search (CDEPS). The comparison of CDE and CDEPS using generalized benchmark problems with Gauss and Tent map chaotic sequences indicates that the CDEPS is better in terms of convergence speed as well as solution quality.

Changzheng Shao et al. [29] have proposed a consumption-side carbon emission penalty scheme, where consumers are penalized based on their individual carbon emission responsibilities and penalty rates. Firstly, carbon emission responsibilities (CER) of consumers are determined after allocating the generators' carbon emission responsibilities to consumers through power flow tracing. Then, a low-carbon economic dispatch (LCED) model was developed with the incorporation of the emission penalty scheme, in which the penalty-related cost was considered as a part of the objective function. The simulation results demonstrate that: the emission penalty is an effective tool in reducing the carbon emissions; compared with the traditional generation- side carbon tax policy. The proposed consumption-side penalty scheme is better in reducing the carbon emissions with less social welfare losses; shifting the penalty burden from the consumer with low demand elasticity to the consumers with higher demand elasticity helps to reduce the social welfare losses.

Jain and Huddar [30] proposed a modified salp swarm optimization algorithm (MSSA) with artificial intelligence technique (AI) aided with particle swarm optimization (PSO) technique. The aim was to figure out the optimal power generated power from the thermal, wind farms, and hydro units by minimizing the emission level and cost of generation simultaneously. To validate the advantage of the proposed approach, six- and ten-units thermal systems were studied with fuel and emission cost. For minimizing the fuel and emission cost of the thermal system with the predicted wind speed factor, the proposed approach was used. The developed approach was implemented in MATLAB/Simulink, and the results were examined by considering generation units and compared with various solution techniques. The comparison revealed the closeness of the developed approach and proclaims its capability for handling multi-objective optimization problems of power systems. The model ignored the power purchase agreement. Practically, this approach will not yield the desired result.
Power.

III. DISCUSSION

Numerous conventional optimization approaches have been proposed in the literature to solve the CEED problem. The conventional approaches for solving economic dispatch problems such as lambda-iteration and gradient approach requires the unit input-output curves of generators. But, these curves do not increase monotonically due to operating zones of the approaches. Thus, the conventional dispatch algorithms cannot be directly used to optimize such non-linear cost function. The meta-heuristics or the hybrid techniques can handle the problems of the traditional approaches such as the risk of convergence, lower losses, faster computational time and ability to deal with nonlinear and nonconvex optimization problems in a practical setting.

IV. CONCLUSION

A review of papers addressing various aspects of solution for combined economic and emission dispatch (CEED) emission dispatch has been presented in this paper. The period covered is 2009-2019. This review is undertaken to explore and analyze the existing Economic and Emission Dispatch techniques present in the literature which is very much required to minimize the operating cost and emission while maintaining the system stability and consistency and provide better performance for practical engineers.

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