Metaheuristic Optimization Techniques' Application to Economic Dispatch Problem- A Review

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In present days, the environmental economic dispatch, which is an extension of traditional economic dispatch problem, is one of the preliminary objectives of the modern power system operation. For solving this objective with various considerations, such as valve point effects, non-convexity, piecewise linearity, combined heat and power flow and complex emission constraint etc, enormous metaheuristic optimization techniques have been extensively reviewed in the present paper. Also, a brief survey on some recently introduced hybrid metaheuristic optimization methods have been covered in present paper.

Keywords: Economic Load Dispatch (ELD), Emission Constrained Economic Dispatch (ECED), Metaheuristic Optimization, Hybrid Metaheuristic Optimization.

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1 Introduction

In recent years, efficient power operation has become increasingly important. The generation cost of a fossil fuel-based system is nearly entirely responsible for optimal electricity operation. Optimal dispatch and emission control are distinct from one another and work in tandem. For a single objective function, traditional approaches make it difficult to tackle this problem. An alternative way for solving this type of problem is to use traditional optimization techniques, to turn a function of unit objective into a bi-objective problem by giving relative weight values. This type of optimization problem is considered as economic dispatch considering emission constraints [1-3] to regulate environmental effect and optimal generation. ELD is concerned with the economic technique of distributing the needed load amongst the generators, while taking into account system restrictions. The objective of economic dispatch with emission constraint is to keep pollution from fossil fuels out of the environment. When non-smooth, non-convex functions of cost and complex emission constraints are used in the model with all the other constraints, the emission constrained economic dispatch issue might get complicated.

2 Problem formulation

2.1 Classical ELD

Following equations have been used to model the traditional ELD with limits of generation and power balance constraints:

$$\text{Minimize } F_t = \sum_{i=1}^{n} F_i(P_i) \tag{1}$$

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \tag{2}$$

or for considering valve point effect, the function becomes

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + |e_i sin(f_i * (p_{min,i} - P_i))| \tag{3}$$

where, F_t represents the total fuel cost of system, $F_i(P_i)$ is the fuel cost function of i^{th} generator,P_i is the generated active power from i^{th} generator, a_i, b_i, c_i, e_i and $f_i$are i^{th} generating unit's fuel cost coefficients, $n$indicates the total thermal units present in the network.

2.2 Emission constraint economic dispatch

$$Minimize\ [FC, E] = \sum_{i=1}^{n}(a_i P_i^2 + b_i P_i + c_i) + \lambda_1 \sum_{i=1}^{n}(\alpha_i P_i^2 + \beta_i P_i + \gamma_i) \tag{4}$$

With considering valve point effect and complex emission function it becomes:

$$Minimize\ [FC, E] = \sum_{i=1}^{n} a_i P_i^2 + b_i P_i + c_i + |e_i sin(f_i * (p_{min,i} - P_i))| + \lambda_1 \sum_{i=1}^{n}(\alpha_i P_i^2 + \beta_i P_i + \gamma_i) + \zeta_i exp(\lambda_i P_i) \tag{5}$$

where, $\alpha_i, \beta_i, \gamma_i, \zeta_i$ *and* λ_i are i^{th} generating unit's emission coefficients.

2.3 Equality Constraints

$$\sum_{i=1}^{n} P_i - P_D - P_L = 0 \tag{6}$$

2.4 Inequality Constraint

$$p_{min,i} \leq P_i \leq p_{max,i} \quad (7)$$

$$Q_{min,i} \leq Q_i \leq Q_{max,i} \quad (8)$$

$$V_i^{(min)} \leq V_i \leq V_i^{(max)} \quad (9)$$

where, (7), (8) and (9) respectively show the real power, reactive power and voltage stability constraints.

3 Various Metaheuristic techniques applied to economic dispatch problem

3.1 Genetic Algorithm (GA)

The problem of economic dispatch considering the discontinuities of valve point has been solved using a genetics-based method in [4]. To determine, if a candidate solution is optimum, the algorithm uses reward information. As a result, the following generation can utilize any sort of unit characteristic cost curve. In GA, genetic operators are critical for updating population. In addition to reproduction, the crossover operator is used. Within two parent strings, crossover picks a locus point and switches the gene data from that place to the end of the string. During the reproduction-crossover phase, the mutation operator randomly alters the values. Probabilities of occurrence of crossover operation and mutation operation are adjustable.

3.2 Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) algorithm has been adopted to solve various economic dispatch (ED) problems in modern power systems, ED with consideration of environmental constraint, multiple fuel options, prohibited operating zones and multi-area ED considering tie line limits [5]. The modeling of social systems, such as birds flocking and fish schooling have inspired PSO.

3.3 Differential Evolution (DE)

In [6], a solution approach has been provided with the Differential Evolution (DE) technique for the economic power shipping issue when non-convex, discontinuous and very non-linear costs are applied. This is the case with regard to loading effects of valve points, switching of fuel and forbidden operational areas. DE enhances the population of people by mutation, crossover and selection operators over multiple generations.

3.4 Chaotic sine–cosine algorithm

In [7], a novel strategy for addressing the EED problem that incorporates wind farms is presented. To consider the randomness of wind power due to wind velocity variations, the problem is framed as a chance-constrained problem. A new chaotic sine–cosine algorithm (CSCA) is suggested to offer the best scheduling of generators, while minimizing both generation cost and emission. Some flaws in the conventional sine cosine algorithm's exploitation and exploration capabilities have been discovered (SCA). As a result, the chaos is included in the basic SCA to enhance its performance. Also, SCA gains a novel mutation strategy.

3.5 Improved Jaya (IJaya) algorithm

In [8], for solving ELD, taking into consideration the valve-point impact and multi-fuel choices, an improved Jaya (IJaya) algorithm was devised. For accelerating the convergence of IJaya, the distance-varying acceleration coefficient (DVAC) has been utilized and to increase the diversity of population as compared to simple Jaya algorithm, a self-adaptive population mechanism (SAPM) is adopted. Also, IJaya is helped to come out of local optima using Gaussian and Cauchy mutation (GCM).

3.6 Multi-Objective Grey Prediction Evolution Algorithm (MOGPEA)

This is a unique multi-objective evolutionary algorithm, which has been developed in [9], for enhancing the uniformity and variety and quality of Pareto solutions, for Environmental Economic Dispatch (EED). In MOGPEA, firstly, even grey model (EGM(1,1)) based a new grey prediction evolution algorithm (GPEA) is created. GPEA, unlike the other evolutionary algorithms, treats the evolutionary algorithms' population series as a time series and constructs a reproduction operator in terms of an exponential function using the EGM(1,1) model. Furthermore, the MOGPEA employs two techniques to increase the uniformity and variety of Pareto optimum outcomes of environmental economic dispatch. The first is a strategy of updating leader and second is strategy of guiding leader. The first uses the greatest distance of every outcome in an external archive, and second uses one solution in each external archive.

3.7 Kernel Search Optimization algorithm

A new meta-heuristic method based on kernel techniques has been proposed in [10] for solving the Economic Emission Dispatch (EED) issue without the need to modify hyper parameters. The novel approach can solve a non-linear goal function by converting it into a higher-dimensional linear objective function. As a result, the optimization method may be changed to a linear one, which is more likely to yield the best result.

3.8 Improved fireworks algorithm

In [11], an enhanced fireworks method with two efficient techniques of cross-generation mutation is suggested and adopted in implementation for handling non-linear, non-convex, non-smooth, multi-constraints, multi-dimensional, and multi-area dynamic economic dispatch (MADED). Upper and lower limitations of generation, DPZs, valve point effect, generator ramp rates, spinning reserve, losses in transmission line and tie line constraints are among the numerous constraints.

3.9 Chaotic self-adaptive interior search algorithm

The CEED must be managed after taking into account two difficult goals, such as the costs of emissions and gasoline. In [12], a chaotic self-adaptive internal search algorithm (CSAISA) has been suggested for addressing CEED issues while taking into account the nonlinearities of generators by considering the valve point effects, security restrictions and restricted operating zones. To generate chaotic variables, the suggested methodology employs a logistic map-based method.

3.10 Ant lion optimizer (ALO)

A new optimization method, ALO, has been recommended for solving ELD in [13]. It is robust, simple, and dependable. ELD is critical for the efficient and secure functioning of a power system. ALO illustrates an ant lion's complex, cooperative, and intelligent hunting activity in order to solve various power system difficulties. It proposes the use of DR to solve ELD. DR is implemented as a virtual power plant that is considered in the same way as traditional power plants.

3.11 Hurricane optimization algorithm (HOA) and Sine-cosine algorithm (SCA)

A comparison of two current optimization methods for solving the non-smooth economic/ecological emission load dispatch (EELD) problem is presented in [14]. The hurricane optimization algorithm (HOA) and the sine cosine algorithm are two optimization approaches (SCA). For the competing algorithms, a module of multi-objective optimization is created in stages. In competitive algorithms, randomly the starting population of candidates is formed with the goal of concurrently maximizing the EELD problem's conflicting objectives, economic and emission. Based on Pareto principles, multi-objective optimum solutions are obtained.

3.12 Stochastic fractal search (SFS) algorithm

The Stochastic fractal search (SFS) method is recommended in [15] to handle the highly nonlinear economic dispatch considering environmental constraint in power system operations while taking physical limitations of generator, transmission line losses and limits and gas emission level into account. The diffusion characteristic that is commonly employed in random fractals is used by the particles in this approach to traverse the search space effectively. The diffusion and updating processes are the two primary processes that occur in the SFS algorithm. To ensure exploitation property, each particle in the former diffuses around its current location. The diffusion process avoids the solutions' chances of trapping in local optima and increases the chances of obtaining the global solution. The algorithm in second phase depicts adjustment of a point's position in a group that is dependent on the other points' positions in the group.

3.13 Interior search algorithm (ISA)

An Interior search algorithm (ISA) has been described in [16] to solve multi-objective combined economic emission despatch (CEED) problem. ISA is a metaheuristic optimisation method which segregates to the inventive art of interior designing and consists of two phases: the first is a composition phase in which in the vicinity of the best possible fitness value, numerous solutions are rearranged and the second is a mirror inspection technique in which a mirror is situated in the centre of every solution and the best solution to set aside a conjure viewpoint.

3.14 Multi-objective squirrel search algorithm (MOSSA)

The primary objective of Combined Economic and Environmental Power Dispatch (CEEPD) is to reduce the entire cost of power generation with taking into account the environmental impact caused by the release of gaseous pollutants from fossil energy. Squirrel Search Algorithm (SSA), a new swarm intelligence approach, has been described in [17] to solve multi-objective CEEPD problem in power systems. The SSA mimics squirrel foraging behaviour that is based on dynamic leaping and gliding approaches. For identifying the Pareto front solutions set, the Multi-Objective SSA (MOSSA) technique utilises the Pareto dominance and crowding distance ideas. To maintain Pareto front solutions obtained throughout the optimisation process, an external elitist repository mechanism is used. The best option is then determined using a fuzzy decision maker based on optimality.

3.15 Moth-flame optimization (MFO)

In [18], a competent method namely, moth-flame optimisation (MFO) has been developed to solve the emission constrained economic despatch problem for hydro-thermal-wind (HTW) scheduling. The system of hydropower-integrated thermal power plant that also associates the wind power, non-linear, non-convex problem due to rate of discharge of water, constraint of hydraulic continuity, varying wind velocity, reservoir storage limits, scheduling time linkage, power balance constraints, delay due to water transport and operation ranges of wind units.

The MFO is inspired by a moth's everyday lifestyle. For direction finding or navigation, they use a technique known as transverse orientation. However, these insects are engrossed in a deadly spiral route. Moths update their positions in the best outcome areas, and the distortion of the flames sequence is dependent on the best solution obtained in each iteration.

3.16 Hybrid Approaches

3.16.1 Hybrid adaptive simulated annealing and genetic algorithm

In large power system, to address the problem of economic dispatch (ED) that considers nonconvex cost function, [19] has proposed a resilient adaptive hybrid optimization strategy that takes advantage of two algorithms. As a result, the proposed hybrid optimization framework uses the key idea of adaptive simulated annealing (ASA) and the ability of operators of genetic algorithm to evaluate economic power dispatch issue, because these operators can speed up convergence and minimize the evaluations.

3.16.2 Civilized Swarm Optimization

In [20], a novel civilized swarm optimization technique is suggested. For solving economic power dispatch with multi-minima solution space, this method was created by combining the society-civilization algorithm with the conventional particle swarm optimization. Individuals are divided into tiny societies (clusters) in SCA, with the best performers in each cluster serving as society leaders (SL). All of these societies make up the civilization, which is led by the finest society leader (CL). The members of the society follow their SL to execute optimization, whereas the society leaders follow the CL. Particles in PSO, on the other hand, adjust their locations based on their best experiences and the swarm's. SCA differs from PSO because its members exclusively obey their leaders, ignoring their own experiences.

3.16.3 Cauchy-Gaussian quantum-behaved bat algorithm (CGQBA)

The problem of economic dispatch has been solved using a new Cauchy-Gaussian quantum-behaved bat algorithm (CGQBA) in [21]. Because of its effectiveness, the bat algorithm (BA) has become a well-known metaheuristic optimization method. The traditional BA, on the other hand, has certain flaws, including early convergence. To overcome the BA's limitations, quantum mechanics theories, as well as Cauchy and Gaussian operators, are included in the conventional BA.

3.16.4 Hybrid PSO and BA algorithm

In [22], a hybrid metaheuristic technique has been devised to tackle the Economic Dispatch found in various power plants' arrangements. The technique is created by combining the best characteristics of Particle Swarm Optimization (PSO) and the Bat Algorithm (BA), and it reduces cost and improves convergence while requiring less computing time. The suggested technique provides a new parameter "α" (dependent on BA and PSO) which is effectively used in equation of updating velocities in PSO algorithm. The developed method is evaluated using power system that is based on an all-RES (without restrictions, with variable demands, and multi-area economic dispatch).

3.16.5 Multi-Objective Neural Network trained with Differential Evolution (MONNDE)

A new Multi-Objective Neural Network trained via Differential Evolution (MONNDE) has been suggested in [23]. To handle dynamic multi-objective optimization issues, MONNDE employs Neural Network function approximators. Differential Evolution (DE) is a cutting-edge method for solving single-objective global optimization problems that has been utilized to develop neural networks able to create Pareto fronts. The suggested MONNDE method is having an extra benefit of generating a problem approximation which creates more Pareto fronts with no more optimization required, when the environment changes. The Dynamic Economic Emission Dispatch (DEED) problem is solved using the MONNDE framework.

3.16.6 Hybrid ACO–ABC–HS optimization algorithm

In [24], a novel designed hybrid optimization method for tackling the multi-generator system's Economic Dispatch (ED) has been given. To discover the best solution for the system, the ACO–ABC–HS hybrid algorithm combines the frameworks of Ant Colony Optimization (ACO), Artificial Bee Colony (ABC) and Harmonic Search (HS). The ACO is adopted for initializing the solutions, the ABC is used to check and enhance the quality of every ACO module's likely solution, and the module of HS is utilized to remove the poorer outcomes from the group of outcomes and substitute those by superior outcomes.

3.16.7 Innovative hybrid algorithm (ihPSODE)

In [25], an innovative hybrid method (dubbed ihPSODE) was presented to tackle a non-convex economic load dispatch issue without or with consideration of the valve point effects. It has been combined with proposed novel PSO (nPSO) and DE (nDE) to handle the sluggishness of traditional PSO and immature convergence of classical DE, respectively. The acceleration coefficient, inertia weight and the equation of updating the positions in nPSO, as well as mutation technique and nDE algorithm's crossover rate helps to grab consistently the dealing properties. At every iteration stage, after calculating the ihPSODE population, the best half candidate is selected and used nPSO then nDE, ensuring enhanced ability of local and global search and obtaining higher quality solutions.

3.16.8 Improved TLBO (TLBO-PSO)

In [2], the Improved TLBO (TLBO–PSO) is used for economic dispatch via renewable energy resources while taking emission limitations into account. In two respects, improved TLBO is an enhanced form of standard TLBO. Conventional TLBO analyses just the difference between mean values while updating the population, however Improved TLBO incorporates the important characteristic of PSO by including the difference between teacher's knowledge and learners' knowledge to enhance the TLBO's learning efficiency. Furthermore, in standard TLBO, theoutcome may become caught in any local optimal value. Improved TLBO addresses this issue by utilizing the mutation operator.

3.16.9 A Modified Hybrid Particle Swarm Optimization with Bat Algorithm Parameter Inspired Acceleration Coefficients (MHPSO-BAAC)

For obtaining the global optimal solution for problem of economic dispatch that is solved for conventional and hybrid system with renewables [26] has proposed a modified hybrid particle swarm optimization with bat algorithm parameter inspired acceleration coefficients (MHPSO-BAAC). While solving ELD for thermal power plants, limits of prohibited operating zones, transmission line losses and ramp rate limits have been considered. For solving hybrid economic dispatch problem, various combinations of renewable energy resources that are wind power, PV power and biofuel along with thermal power plants have been considered.

3.16.10 Improved and Chaotic Population-Based Polar Bear Optimization Algorithm

To solve emission constrained economic power dispatch, improved polar bear optimization algorithm has been presented in [27]. In this algorithm, the very important characteristic of polar bears that is sharp sense of smell for finding food during extreme conditions has been utilized. For this purpose, in existing polar bear optimizer a two-tier global search stage has been introduced. In this stage one solution from the 30 % least fit bears are selected to find global optimal solution with the help of smell sensing capability, under the condition of food shortage.

4 Conclusion

This study offers a comprehensive literature review of several metaheuristic optimization approaches in the application of the economic dispatch issue, as well as a brief description of the problem of economic power dispatch with various practical limitations. Various test systems have been explored in various articles for evaluating optimization strategies on actual issues. The recent research area of economic dispatch problem is to extend the problem with the inclusion of various renewable energy resources along with some storage devices' involvement or plug-in vehicles, considering the relevant constraints. For solving aforesaid problem, the approaches that have been discussed in the paper, along with their key strengths, can be utilized.

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