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Solving of Non-Smooth ELD Problem with Valve-Point Effect Using MPSO

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Abstract: *Electrical power networks are built and maintained to fulfill the fluctuating demand for electricity. The running expenses of a power grid must be kept as low as possible. Dynamic Economic Load Dispatch (DELD) is a strategy for scheduling power generator outputs based on load requirements and managing the power system as efficiently as feasible. To put it another way, the fundamental goal of economic load dispatch is to distribute the maximum amount of power provided by varied units at the lowest possible cost while fulfilling all system constraints. Under regular operating conditions, power plants in a realistic power grid are not positioned at the same distance from the centre of loads, and their fuel prices fluctuate. Furthermore, the whole load demand is exceeded by the producing output, resulting in losses. However, the most important considerations for a system should be security, cost effectiveness, and dependability. This paper proposes a modified particle swarm optimization (MPSO) technique for dealing with equality and inequality constraints in ELD problems using Gaussian and Cauchy probability distributions. The MPSO method introduces a new diversification and intensification strategy into the particles, preventing the PSO algorithm from achieving premature convergence.*

Keywords: Power Grid, Valve-point effect, Emission Loss, Loss in Transmission, Fuel Cost, ELD, GA, PSO etc.

Introduction

The electrical power system is divided into three parts: generation, transmission, and distribution. The generation sector is in charge of creating electric power, while the transmission segment is in charge of transmitting electricity from generating plants to the distribution grid, which is in charge of supplying electric energy to clients [1]. Electric power generation necessitates the conversion of diverse energy sources into electrical energy via a suitable conversion mechanism. This comprises the employment of interconnected equipment to convert potential energy (hydro), thermal energy, nuclear energy, solar energy, and kinetic energy (wind) into electrical energy. In general, power plants are interconnected networks that often function in tandem to create electricity. Power stations are often called for the type of electricity utilized to generate electricity from the plant. Because of the many energy sources, there are electric, hydro, gasoline, diesel, coal (steam), solar, geothermal, wind, and other types of power plants. Thermal power stations, on the other hand, include coal (steam) power plants, as well as gas and diesel power plants [2]. The cost of fuel and the amount of pollutants vary depending on the source of power. The cost of fuel in thermal power plants is relatively expensive when compared to other types of power plants. Because fuel costs fluctuate, electric power must be dispatched depending on the fuel cost of each power plant in order to lower total generation costs. Furthermore, when dispatching electric energy from thermal power

plants to reduce air emissions, the challenge of controlling the amount of leakage to the environment is typically taken into account. Both factors are determined by the type of fuel utilized by the power plant in issue, as well as the power plant's efficacy.
Coal is the most important source of energy for electric power, accounting for 42 % of total worldwide electricity generation [4], but it is also the most expensive [5]. In general, the price of fossil fuels, which include coal, natural gas, and oil, has been changing at a greater level, subjecting the energy market to high operational costs due to high import expenses. Thermal power plants, in general, generate polluting gaseous pollutants such as COx, NOx, and SOx, which substantially contribute to environmental pollution, ozone depletion, and global warming [6][7]. Due to an increase in pollutant gaseous pollution from power plants and industrial businesses, which endangers the existence of life on Earth, the Clean Air Act Amendments of 1990 (CAAA) were enacted, requiring worldwide emissions to be reduced by 12 million tons per year from 1980 levels [8]. To emphasize the Act, electrical power plants have been subjected to pollution costs, which are anticipated to be assessed based on the quantity of pollutants generated by the specific facility [9]. The cost of energy generation now covers the cost of fuel, pollution fees, and fixed expenditures, according to the 1990 Clean Air Act Amendments. Estimating the trajectory of greenhouse gas emissions, of which carbon dioxide is the principal source, the amount of emissions from human activity has been increasing year after year since the 1990 Clean Air Act Amendments were introduced. The primary contributors to the carbon issue are electricity generation, AFOLU, and the industrial sectors. When compared to other sectors, the electric generating market, which is primarily reliant on fossil fuels such as coal, oil, and natural gas, is the biggest emitter [11]. Coal power stations account for 28% of worldwide carbon dioxide (CO2) emissions [4]. Actually, in order to lower the cost of power generation, both the cost of fuel and the pollution charges are optimized combined in order to reduce the cost of power generation, which has a positive influence on emission reduction [9]. As a result, studies of economic dispatch that consider pollution were born. Carbon optimization has two positive outcomes: environmental and cost-cutting implications. As a result of lower generating costs, the ecology is safeguarded through pollution reduction, which is a global critical endeavor [12].

II. Background of Work

The economic functioning of an electric power system involves unit commitment (UC) and economic load dispatch (ELD). The first is concerned with the optimal selection of generating units from available options in order to economically supply a specific load demand, whereas the second is concerned with the optimal power generation from each committed (selected) generating unit in order to economically supply dynamically varying load demand. Proper handling of these two issues not only reduces fuel consumption costs, but also transmission losses and environmental pollutants.

This section provides a detailed overview of the various methods utilized to solve ELD problems in power systems.
A successfully applied predator–prey optimization (PPO) to solve a single-objective non-linear economic load dispatch (ELD) problem to optimize the generation cost of a large-scale power system, taking non-linearity in the generating units such as valve points and prohibited operation zones into account (POZs) in [13]. An improved orthogonal design particle swarm optimization (IODPSO) approach for tackling single-area and multi-area ELD issues with nonlinear generator properties such valve-point is discuss in [14] A non-smooth and non-convex optimization problem with linear and nonlinear constraints such as valve point effect, load equality, generator constraints, prohibited operational zones, spinning reserve, ramp up rate, ramp down rate, and multiple fuel consumption constraints is developed in [15]. Operation and control process that deals with allocation of generation among committed

units in order to satisfy energy demand and constraints with reduced fuel cost of generation by appropriate load dispatch schedule is discuss in [16]. Explore a convex Economic Load Dispatch (ELD) issue for a three-generation five-bus system with equality and inequality constraints in [17]. A parallel hurricane optimization algorithm (PHOA) for addressing the problem of economic emission load dispatch (EELD) in contemporary power systems is developed in [18]. The whale optimization algorithm (WOA), a population-based meta-heuristics technique for restricted economic load dispatch situations is developed in [19]. A comprehensive solution to restricted economic load dispatch difficulties is to provide a continuous and dependable supply of power while retaining the system's optimal cost of production and operation. A new computational optimization algorithm based on the cultural algorithm (CA), improved with local search techniques such as simulated annealing and Tabu search, on data from a real power plant with ten generators and the IEEE system with thirteen generators is discussed in [20]. A distributed economic model predictive control (EMPC) technique for linked power systems' economic load dispatch and load frequency management is discussed in [21. Jaya method which is used to solve economic load dispatch issues (ELDPs is developed in [22]. Economic load dispatch issues with transmission losses, ramp rate constraints, valve-point loading effects, and banned operating zones using an enhanced particle swarm optimization is solved in [23]. Competitive Swarm Optimizer (CSO) to solve the bid-based dynamic economic dispatch (BBDED) issue while accounting for transmission line loss using multiple bidding strategies is developed in [24]. Dynamic economic load dispatch (DELD) in isolated microgrids, where responsive load curtailment and renewable power curtailment are permitted, and load shedding is utilised as a last option for balancing generation and demand is discussed in [25]. An implementation of a new evolutionary optimization technique known as the equilibrium optimizer (EO) to handle an economic dispatch issue with a valve point effect, actual power constraints, transmission line losses, ramp rate restrictions, and banned zones of operation is discussed in [26]. The metahuristic approach BAT algorithm to reduce the cost of electricity generation is developed in [27].] GBO's based evaluate for effectiveness in handling ELD and CEED issues is discussed in [28]. An application of TLBO to tackle the non-linear problem of economic load dispatch. Many traditional and recent optimization techniques are presented in [29].

III. Economic Load Dispatch

Economic load dispatch is a method of calculating the power output of each generator station in a power system in order to minimize fuel costs while meeting the system's equality and inequalities constraints. This is required to meet machine load at the lowest possible fuel expense, with the primary aim of decreasing operating costs [3]. In general, each generating unit has its own characteristics based on its reliability and the type of fuel used, which determines the relationship between the cost of fuel and the amount of power produced. The mechanism that connects fuel cost and induced power is commonly referred to as the cost function; depending on the type of structure, this function may be a quadratic function or a quadratic function with ripples [19]. Figure 1 portrays a quadratic cost function that compares the input and output of power plants based on the cost of fuel and the volume of power produced.

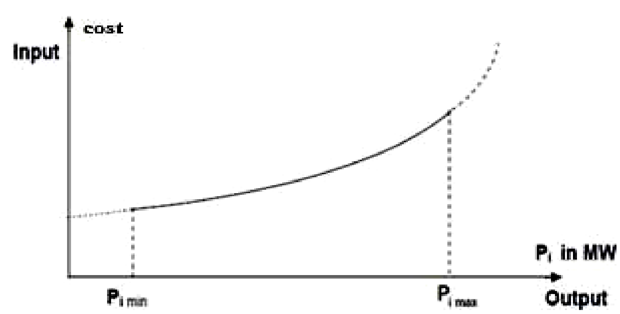

Fig. 1: Input-output curve of generating unit [19].

The key aim of economic dispatch is to gain the same per unit cost as incremental or marginal cost while retaining the total power output that is expected to be supplied to the machine load [3]. So, it is stated as:

$$L = F + \lambda\left(P_D - \sum_{i=1}^{N} P_{Gi}\right) \qquad [1]$$

Where, L is Lagrange Eqn, F is Cost Function, λ is Incremental Cost, P_D is demand Power and P_{Gi} is power generated in i[th] Unit.

The objective cost of the function for the optimum load dispatch is:

$$Cost = \sum_{i=1}^{NG} a_i P_i^2 + b_i P_i + c_i \qquad [2]$$

Where a_i,b_i and c_i , are fuel cost coefficient of ith unit and Pi is generated power by i[th] unit.
So the objective function of economic load dispatch is given as:

$$\min(Cost) = \sum_{i=1}^{NG} a_i P_i^2 + b_i P_i + c_i \qquad [3]$$

IV. ELD with Valve Point Effect

The generators' engines are built with valve point effects to increase the performance of power plants. This is the system that controls the opening of the valves in response to variations in power demand in order to balance the generator input with the required power. This mechanism is usually governed by a generator governor, which regulates the opening of input valves based on the output required. The cost mechanism adapts the ripple form due to valve opening and closing [24]. The cost feature of economic dispatch with valve-point effect is depicted in Figure 2.

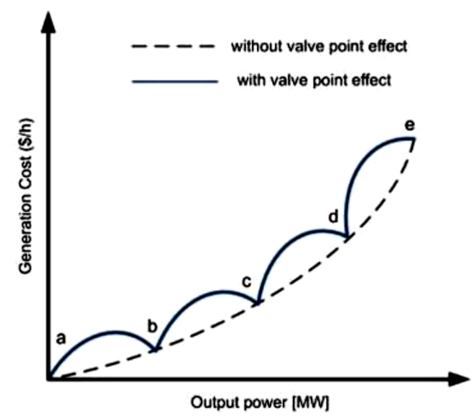

Fig. 2: Fuel cost function with valve-point effect [25].

The economic dispatch objective function formulation with valve-point loading effect is as follows;

$$Cost = \sum \left(a_i P_i^2 + b_i P_i + c_i + \left|e_i \sin\left(f\left(P_i^{\min} - P_i\right)\right)\right|\right) \quad [4]$$

Objective Function is now

$$\min(Cost) = \sum \left(a_i P_i^2 + b_i P_i + c_i + \left|e_i \sin\left(f\left(P_i^{\min} - P_i\right)\right)\right|\right) [5]$$

Under Constraints

$$P_i = \sum_{i=1}^{NG} P_D + P_L \qquad [6]$$

$$P_{i(\min)} \le P_i \le P_{i(\max)} \qquad [7]$$

Where e_i and f_i are constants of valve-point effect

V. Modified PSO

The modified particle swarm optimization technique incorporates a well-defined adjustment in the velocity of each particle in the swarm after its local best and global best location at the end of each iteration. Table I shows the flow chart of the MPSO. Every particle in the swarm attempts to improve its velocity and position based on the distance between its local best value and current position using an!-factor, which allows it to easily achieve the optimal solution, and the distance between its current position and the global best solution using a "-factor, which allows it to exploit the solution to converge to better results.

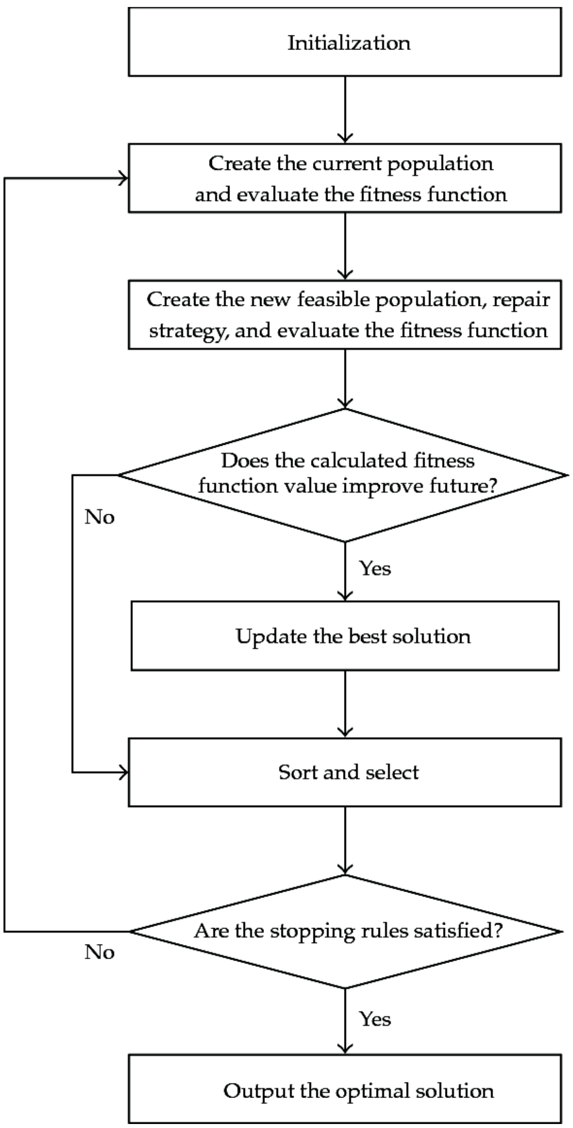

Fig. 3: Flow Chart of MPSO.

As a result, the updated velocity equation achieves a superior convergence by striking a balance between exploring and utilizing the searched areas. Modified Particle Swarm Optimization (MPSO) is a new heuristic method that is being used successfully to tackle nonlinear engineering optimization issues. These particles' positions can be updated by using their current velocity and the distance between their respective local best and global best values. For the aim of applying the modified PSO method, the following procedural steps are taken

VI. ELD using MPSO

The ELD issue entails generating scheduling while keeping costs to a minimum and all other requirements met. In general, the power system deals with such aims in order to realize economic operations. The economic load dispatch issue with a quadratic cost function is combined with some of the equality and inequality restrictions that must be handled in a systematic way. An approach used to handle such load dispatch issues is modified particle swarm optimization. Constraint management mechanism should be added into the modified PSO methodology. A modified PSO may be used to the given issue by allocating optimally the power generation within its operating constraints, therefore fulfilling the entire demand for the system.

A. Formulation of Objective Function

The formulation of the ELD problem aims to reduce cost while satisfying all constraints. It is possible to do this by defining the provided issue and having it implemented by a modified PSO, which may include an objective function with a cost function component and error values. For each generator, the cost function related to the fossil fuel used is represented as a quadratic equation. As a result, the total cost of fuel in terms of power production is as follows:

$$F = \sum_{i=1}^{G} \left(a_1 P_i^2 + b_i P_i + c_i + \left| d_i \sin\left\{ e_1 \left(P_i^{\min} - P_i \right) \right\} \right| \right) \quad [8]$$

B. Equality and Inequality Constraint Handling

In order to meet the heat balance requirement, one of the producing units is chosen at random as a dependent operational unit. The power associated with this dependent generating unit is computed as follows:

$$P_l = \left\{ P_D - \sum_{i=1, i \neq dP} P_i \right\} \quad ; P_l = 0 \qquad [9]$$

If the dependent generating unit breaches the respective restriction as specified in the equation, it can be set to its respective limiting values.

$$P_i = \begin{cases} P_i^{\min} & ; P_i < P_i^{\min} \\ P_i^{\max} & ; P_i > P_i^{\max} \\ 0 & ; P_i^{\min} \leq P_i \leq P_i^{\max} \end{cases} \qquad [10]$$

If the answer is outside of the bounds, the related error can be calculated as follows

$$E(P) = \begin{cases} \left(P_{dP} - P_{dP}^{\max}\right)^2 & ; P_{dP} > P_{dP}^{\max} \\ \left(P_{dP}^{\min} - P_{dP}\right)^2 & ; P_{dP} < P_{dP}^{\min} \end{cases} \qquad [11]$$

As a result, for violations of the constraint regarding the power of the dependent unit, the inequality constraint management approach described in the equation above is used. If it exceeds the limit, an error term is calculated and a penalty term is integrated into the objective function once the value of the dependent generator is restricted within the limitations.

VII. Result and Discussion

A 13 unit system with valve-point effect and transmission with losses is considered for the testing of the proposed system. The whole work is simulated in MATLAB software. The system is made up of 13 generating units, and the input data for the 13-generator system are shown in Table I. To validate the proposed MPSO technique, a 13-unit system with non-convex solution spaces is used. The 13-unit system consists of thirteen generators with valve-point loading effects, with total load needs of 1800 MW and 2520 MW, respectively.

Table I: Generator Unit Capacity and their Coefficient (13- Gen Units).

Unit	Pmin (MW)	Pmax (MW)	a	b	c	e	f
1	0	680	0.00028	8.10	550	300	0.035
2	0	360	0.00056	8.10	309	200	0.042
3	0	360	0.00056	8.10	307	200	0.042
4	60	180	0.00324	7.74	240	150	0.063
5	60	180	0.00324	7.74	240	150	0.063
6	60	180	0.00324	7.74	240	150	0.063
7	60	180	0.00324	7.74	240	150	0.063
8	60	180	0.00324	7.74	240	150	0.063
9	60	180	0.00324	7.74	240	150	0.063
10	40	120	0.00284	8.60	126	100	0.084
11	40	120	0.00284	8.60	126	100	0.084
12	55	120	0.00284	8.60	126	100	0.084
13	55	120	0.00284	8.60	126	100	0.084

In Tables II gives comparative result for the best fuel cost results obtained from proposed MPSO and other optimization algorithms for load demands of 1800 MW.

Table II: Comparative Result Analysis of Previous work and Proposed Work for load demand 1800 MW

Unit of Power	DEC-SQP	NN-EPSO	EP-EPSO	MPSO
P1	526.1823	490.0000	505.4731	359.0434
P2	252.1857	189.0000	254.1686	149.6093
P3	257.9200	214.0000	253.8022	224.4315
P4	78.2586	160.0000	99.8350	109.8699
P5	84.4892	90.0000	99.3296	109.8653
P6	89.6198	120.0000	99.3035	109.8637
P7	88.0880	103.0000	99.7772	109.9456
P8	101.1571	88.0000	99.0317	159.734
P9	132.0983	104.0000	99.2788	109.8849
P10	40.0007	13.0000	40.0000	77.46699
P11	40.0000	58.0000	40.0000	95.41563
P12	55.0000	66.0000	55.0000	92.38888
P13	55.0000	55.0000	55.0000	92.48047
Total power	1800	1800	1800	1800
Total Cost ($/Hr)	18938.9521	18442.5931	18932.4766	18317.0118

Figure 4 shows the cost of the proposed MPSO for 13 unit generator set for the 1800 MW generation for optimized Economic Load Dispatch with Valve-point Effect.

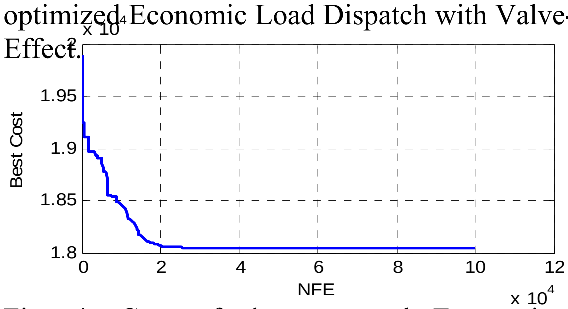

Fig. 4: Cost of the proposed Economic Load Dispatch for 13 unit of 1800 MW load Demand.

In Table III gives comparative result for the best fuel cost results obtained from proposed MPSO and other optimization algorithms for load demands of 2520 MW. Figure 5 shows the cost of the proposed MPSO for 13 unit generator set for the 2520 MW generation for optimized Economic Load Dispatch with Valve-point Effect.

Table III: Comparative Result Analysis of Previous work and Proposed Work for 2520 MW

Unit of Power	GA-SA	EP-SQP	PSO-SQP	MPSO
P1	628.23	628.3136	628.3205	628.3181
P2	299.22	299.0524	299.0524	360
P3	299.17	299.0474	298.9681	360
P4	159.12	159.6399	159.4680	109.8651
P5	159.95	159.6560	159.1429	159.7308
P6	158.85	158.4831	159.2724	159.7250
P7	157.26	159.6749	159.5371	133.1776
P8	159.93	159.7265	158.8522	109.8639
P9	159.86	159.6653	159.7845	159.7313
P10	110.78	114.0334	110.9618	114.7933
P11	75.00	75.0000	75.0000	40.0000
P12	60.00	60.0000	60.0000	92.39873
P13	92.62	87.5884	91.6401	92.39612
Total power	2520	2520	2520	2520
Total Cost ($/Hr)	24275.71	24266.44	24261.05	24019.8924

Figure 5 shows the cost of the proposed MPSO for 13 unit generator set for the 2520 MW generation for optimized Economic Load Dispatch with Valve-point Effect.

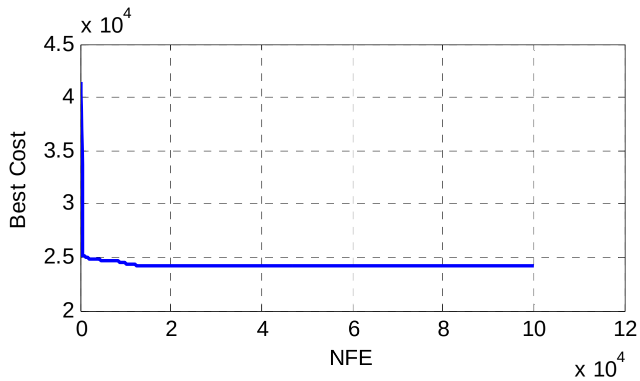

Fig 5: Cost of the proposed Economic Load Dispatch for 13 unit of 2520 MW load Demand.

VIII. Conclusion

This paper provides a novel method for solving the economic load dispatch (ELD) issue with valve-point effect by employing a modified particle swarm optimization (MPSO) strategy. Practical ELD issues include non-smooth cost functions with equality and inequality restrictions, making it challenging to determine the global optimum using any mathematical technique. The MPSO method introduces a new diversification and intensification strategy into the particles, preventing the PSO algorithm from achieving premature convergence. To illustrate the efficacy of the suggested technique, numerical analyses were conducted for two separate test systems, namely a thirteen generating unit system with 1800 MW load demand and a 2520 MW load demand. When compared to the results of various optimization methods described in the literature, the results demonstrate that the proposed methodology performs efficiently and robustly.

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