Hybrid Approach to Solve Thermal Power Plants Fuel Cost Optimization Using Ant Lion Optimizer with Newton-Based Local Search Technique

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Introduction/Importance of Study: The optimization of the power system is a complicated problem that is extremely non-convex, nonlinear, and important for reducing the cost of production.
Novelty Statement: Despite the fact that several metaheuristic algorithms are proposed for solving power system optimization problems, the strength of hybridized global search-based techniques has not commonly been applied to power system optimization.
Material and Method: Deterministic power system optimization strategies are unable to yield global optimal outcomes because of the entrapment in local optimum zones. Stochastic approaches like those in which Ant-Lion Optimizer is used and hybridization algorithms with local search methods SQP, IPA, and active set give better results.
Result and Discussion: Hybridized global search-based techniques have been successfully applied to power system optimization with economic load dispatch in particular. Results from findings hybridized-ALO outperforms modern optimization methods.
Concluding Remarks: Results from findings show 3 and 13 generator systems that hybridized-ALO outperforms modern optimization methods.
Keywords: Economic Load Dispatch (ELD); Ant Lion Optimization (ALO); Valve point loading (VPLE), Fuel cost, and Objective function.

Introduction:

Due to the rising cost of producing electricity and the depletion of fossil fuels utilized in thermal power generating units, optimal Economic Load Dispatch (ELD) has gained significant attention in today's modern power system. The primary goal of the ELD problem is to distribute thermal power generating units' active power generation output as efficiently as possible while accounting for power system operational restrictions. The overall energy capabilities of electrical energy generation grow through the reduction of the generation cost and the enhancement of system reliability through optimum active power allocation. Because there are so many real-world power system scenarios, the research community is more interested in taking a realistic approach to solving the conventional ELD problem [1]. Due to the multilevel steam-generating valves connected to contemporary steam-powered thermal power generating units, also known as the valve point loading effect (VPLE), the input-output fuel cost generation curve is essentially non-differentiable, non-convex, and non-linear. These steam valves open systematically, which causes ripples in the fuel-cost characteristics curve. Conventional fossil fuel-based thermal power plants emit a variety of harmful gases (SOx, NOx, and COx) into the atmosphere, contributing to environmental pollution and global warming [2]. Some of the generating unit shaft's bearings are subject to physical constraints known as prohibited operating zones (POZs) because of enhanced vibrations in specific areas along the rotating axis of the shaft. In recent years, there has been a lot of focus on renewable energy generation sources while optimal power flow is taken into account for transporting electrical power over long distances to avoid power losses, optimal generation allocation and sizing are important factors in power system optimization for electrical power generation to lower fuel generation cost. Due to power losses from long-distance transmission lines and poor voltage regulation from a heavily loaded network, the efficiency of the power system effectively decreases. On the other hand, by lowering generation costs and power losses, taking into account the integration of renewable energy sources and their ideal placement inside conventional power systems can improve system reliability. Appropriate planning is required for the integration of renewable energy into conventional systems in order to prevent operational issues that could compromise system performance and dependability. In order for the power system to run efficiently and affordably, a number of generating units made up of thermal units renewable energy sources should be managed optimally considering practical constraints of real-world power system [3]. A genetic algorithm was applied in [4] for economic load dispatch to reduce the fuel cost. With the incorporation of emissions, the cost of production is increased [5] using hybrid PSO with SQP to solve the economic emission problem. The main aim of our work is to reduce the cost of production for a three- and thirteen-unit system incorporating hybrid methods.

Material and Methods:

Mathematical Model Fuel Cost equation:

The economic load dispatch problem is presented by a quadratic equation. The values of cost coefficients can be taken from [6] fuel cost is related to power as:

$$\boldsymbol{F(P)=\sum\left(up^2+vP+w\right)} \qquad (1)$$

In equation 1, F (p) presents the total generation cost in \$/hr whereas u, v, and w, are fuel cost equations. Includes loading on generators on value openings. While second equation 2 models the cost function with value point loading cost multiplied with sin function.

$$f_{WV}(P)=\sum_{j=1}^{ng}\left(u_j p_j^2+v_j P_j+w_j+\left|x_j\times\sin(y_j\times(P_j^{\min}-P_j))\right|\right) \qquad (2)$$

In equation 2, F_{wv}(p) presents total generation cost with value point loading effect in \$/hr whereas u, v, and w, are fuel cost equations x and y are value point coefficients which are non-linearity associated with loading and operating of governor system generators on value openings.

ANT LION Optimizer:

ALO design was inspired by the hunting style of Ant- lions. Ant lions originated from the Myrmeleontid family. Ant-lions life span in adulthood lasts only for 3 to 5 weeks out of the 3 years of age in which they spend the rest of their life it reproduces their offspring. Ant lions are known for their different style of preying on ant insects. Ant-lions dig out special cone (v) shaped traps in mud to hunt the ants [7]. The edges of the cone are sharp Ant-lions try to catch the prey within trap range and place itself in the middle of the cone under sand. Ants tend to slip at sharp edges while ant lions through the sand grains at the edge of the cone. When an ant tries to leave the trap during random movement, the Ant-lions trap size depends on the hunger. The ants move randomly in the trap and are shown as

$$x(T) = \left[0, cummsum\left(2S\left(T^{1}\right)-1\right), \cdots cummsum\left(2S\left(T^{N}\right)-1\right)\right] \quad (3)$$

- In the above equation,
- x(T) denotes the moment of ants
- N shows the total iteration number.
- T is for step of walk-in random way.
- S is a random weight ranging from 0 to 1.

Initializing Position Matrix of Ants:

Random position matrix of ants is generated denoted by ANT^{pos} Each ant will move in different dimensions d and are equal to the number of generators for the ELD problem [5] also uses matrix, Position matrix of ants shown below

$$ANT^{pos} = \begin{pmatrix} a^{11} & a^{12} & a^{13} \cdots\cdots a^{1d} \\ a^{21} & a^{22} & a^{23} \cdots\cdots a^{2d} \\ \vdots & \vdots & \vdots \\ a^{n1} & a^{n2} & a^{n3} \cdots\cdots a^{nd} \end{pmatrix}; \quad (4)$$

Fitness Value Calculation for Ants:

Each ant is passed through the required objective function that will return the fitness value of each ant saved in the column vector denoted by OA.

$$OA = \begin{pmatrix} oa^{11} \\ oa^{21} \\ \vdots \\ oa^{n1} \end{pmatrix}; \quad (5)$$

Fitness Value Calculation for Ant-Lions:

Each ant is passed through the required objective function that will return the fitness value of each and saved in a column vector denoted by OAL

$$OAL = \begin{pmatrix} oal^{11} \\ oal^{21} \\ \vdots \\ oal^{n1} \end{pmatrix}; \quad (6)$$

Random Walk of Ants:

During the optimization process, each updates its position by adopting a random walk in a random direction. equation 1 cannot be directly adopted to update its position. The randomness of the walk is normalized within range with a specific constant.

Trapping in Ant-Lions Pits:

Random walk of ants is affected by ant lion. Ants random walk in hypersphere defined by vectors e and d

$$e_d^t = Ant - lion_j^t + e^t \quad (7)$$

$$d_d^t = Ant - lion_j^t + d^t \quad (8)$$

e^t is minimal of variable d at t-th number iteration and d^t shows vector presenting maxima of a variable at t-th number iteration.

Building Trap:

Each ant is trapped by a single ant lion whose Selection is on fitness during optimization.

Sliding Ant Toward Ant-Lion and Catching Pray:

Once an ant comes in the range of the trap ant lions through sand to detract and slips ants toward the center while ant tries to escape.

Elitism:

Elitism is the solution, which is best at any instant of optimizer running. Best ant lions are considered elite so every ant moves randomly around that ant lion.

Results:

The first case is applied to a 3-unit system having a power demand of 850 MW Economic load dispatch with Value point loading shows the total cost is 8234.07174 ($/hr.) In the case of three Units-based ELD test systems, Optimizer was set with an initial setting of 15000 search agents. Each case is run on 20 independent trials and the best results are shown in Figure 1. Complete simulation results are shown in Table 1.

Table 1: Optimized values of power and fuel price for Three Units using A.L.O (Pd =850 M Watt)

Unit	With V_P_L_EE
	Best
Unit 1 (MW)	300.26687
Unit 2 (MW)	399.99999
Unit 3 (MW)	148.73312
Fuel Cost ($/hr.)	8234.07174
Total Power TP (MW)	850

Each generator has to produce specific power depending on coefficients with ALO optima alone results are shown in the convergence curve it can be seen that after 100 iterations results are very close also test function is plotted.

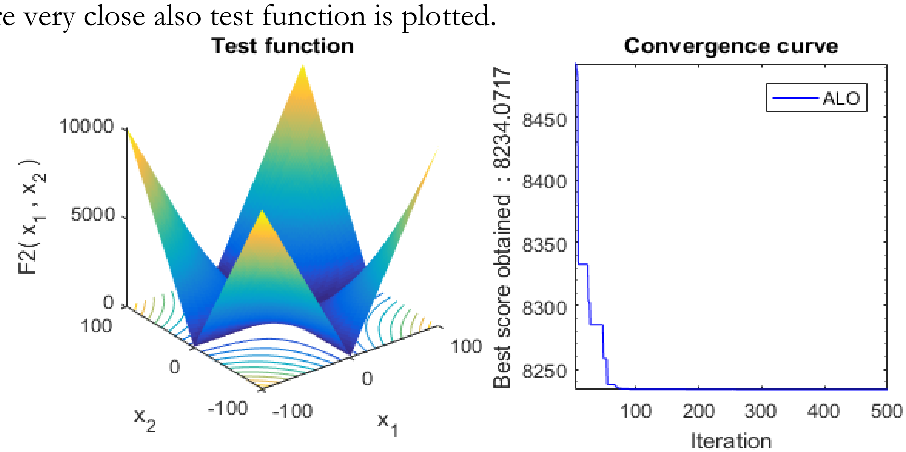

Figure 1: Convergence curve of A.L.O for three units

The second case is applied to 13 13-unit system having a power demand of 1800 MW Economic load dispatch with Value point loading shows the total cost is 17934.3211 ($/hr.)In the case of the 13-unit ELD test system, Optimizer was set with an initial setting of 15000 search agents and three dimensions equaling to number of generators. Each case is run on 20 independent trials and the best results are shown in Figure 2. 1000 iterations were set but can be seen that after 100 iterations solution starts to converge.

Table 2: Optimized values of power and fuel price for Thirteen Units using A.L.O (Pd =1800 M Watt)

Units	Without V_P_L_EE
	Best
Unit 1 (MW)	548.3007
Unit 2 (MW)	260.8828
Unit 3 (MW)	235.9395
Unit 4 (MW)	90.0035
Unit 5 (MW)	101.4202
Unit 6 (MW)	98.2217
Unit 7 (MW)	99.5210
Unit 8 (MW)	88.5453
Unit 9 (MW)	87.1620
Unit 10 (MW)	38.0000
Unit 11 (MW)	41.0032
Unit 12 (MW)	56.0000
Unit 13 (MW)	56.0001
Total Power (MW)	1800.0000
fc ($/hr.)	**17934.3211**

Complete simulation results are presented in Table 2 Moreover, the fine-tuning is carried out by Hybridizing procedures.

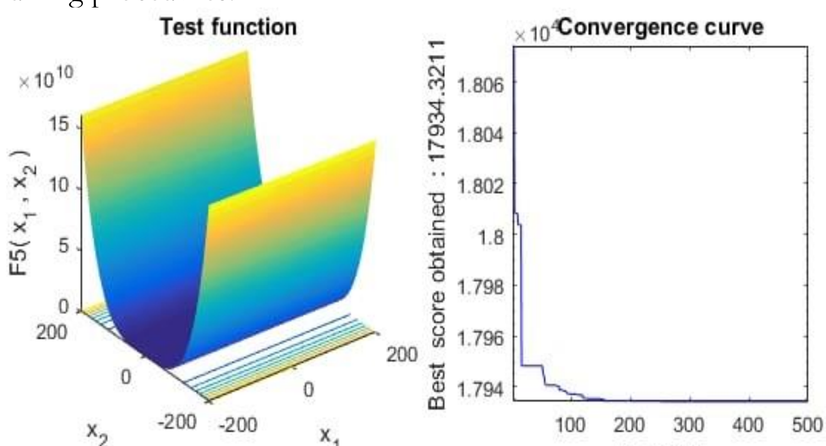

Figure 2: Convergence curve of A.L.O for Thirteen units

Comparison and Discussion:

Hybridizing procedures ALO-SQP, ALO-ASA, and ALO-IPA by taking the best results of ALO as a starting point and continuing with the refined values. Moreover, the results are summarized in Table 3 for each scenario. For every three approaches compared, one may observe that the results of ALO-IPA are better in terms of convergence and accuracy while ALO-SQP gave better outcomes as tabulated in Table 3 considering the ELD problem with VPLE.

Each generator has to produce specific power depending on coefficients with ALO optima alone results are shown in the convergence curve it can be seen that after 100 iterations results are very close also test function is plotted. The active set finds equality constraints in inequality constraints in consideration and uses a small delta after initial point gain throughout global search in this case ALO it can be seen that after 100 iterations results are very close also test function is plotted results are shown in Figure 4.

Table 3: Hybridized with a.l.o 13 bus (pd =1800 M Watt)

Unit	With V_P_L_EE		
	ALO-SQP	**ALO-Active Set**	**ALO-IPA**
Unit 1 (MW)	539.5587	538.6576	538.5587
Unit 2 (MW)	74.7998	79.2048	88.1070
Unit 3 (MW)	299.1993	300.1728	299.1993
Unit 4 (MW)	59.0000	60.0000	60.0004
Unit 5 (MW)	159.7331	180.0000	159.7332
Unit 6 (MW)	109.8666	109.8846	108.8666
Unit 7 (MW)	109.8666	109.8666	110.8666
Unit 8 (MW)	60.0000	60.0000	60.0004
Unit 9 (MW)	109.8666	60.0000	109.8666
Unit 10 (MW)	40.0000	40.0001	40.0005
Unit 11 (MW)	90.7094	114.8132	77.4000
Unit 12 (MW)	92.3999	92.4003	92.4002
Unit 13 (MW)	55.0000	55.0000	55.0005
Power Total	1800.0000	1800.0000	1800.0000
Fuel Cost	**18118.1679**	**18558.4847**	**18122.5229**

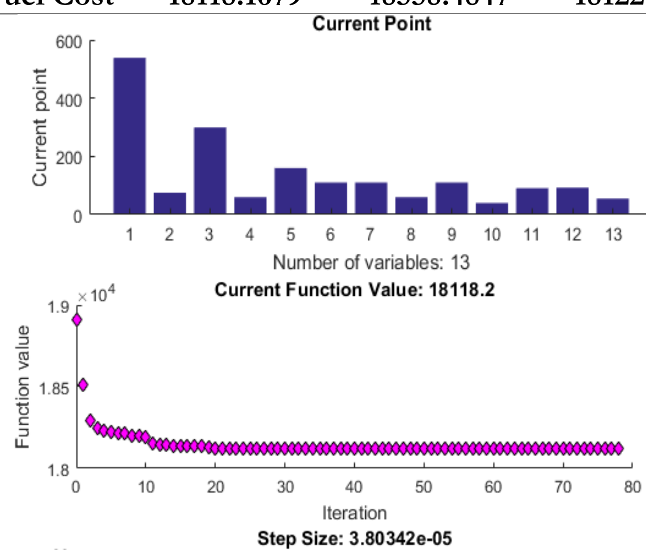

Figure 3: Simulated illustration of integrated ALO-SQP for 13 units with V-P-L-E

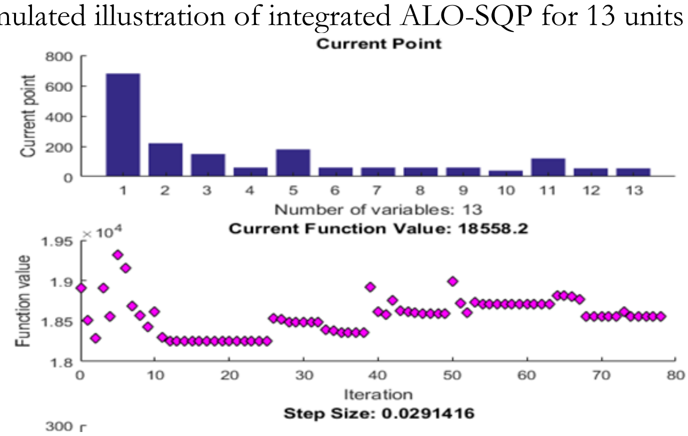

Figure 4: Simulated illustration of integrated ALO-Active set for 13 units with V-P-L-E

IPA approach combines the best features of perturbation analysis and sequence quadratic programming in a unified framework it can be seen that after 100 iterations results are very close also the test function is plotted.

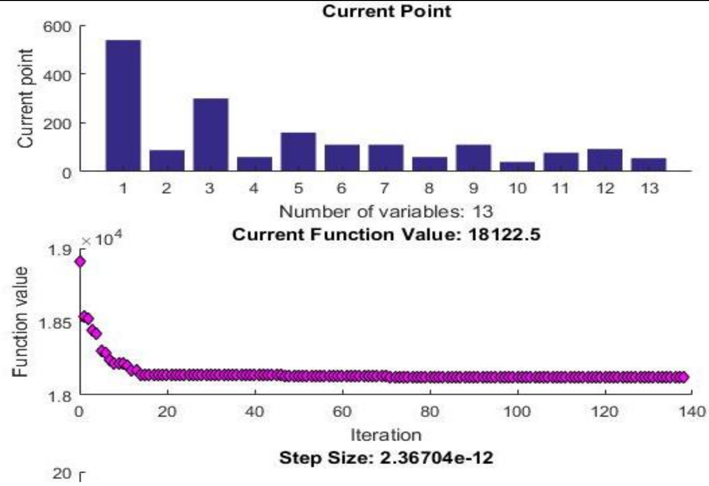

Figure 5: Simulated illustration of integrated ALO-IPA for a thirteen-unit system with V-P-L-E

The effectiveness of ALO is compared with the latest four techniques for the case of 13 units having a power demand of 1800MW. These methods include a teaching-learning optimizer [8], Harmony search optimizer [9], Quazi oppositional inertial weight [10], and Novel Heuristic optimizer [11] while comparison on fuel cost for the same operating constraints the results are shown in Table 4.

Table 4: Comparison with state of art methods

	TLBO [8]	H-S [9]	GPSO [10]	MPSO [11]	ALO
Unit 1 (MW)	364.9	628.3	628.3	628.2	548.30
Unit 2 (MW)	277.9	149.5	224.3	149.6	260.8
Unit 3 (MW)	217.4	222.7	148.7	222.7	235.9
Unit 4 (MW)	95.22	109.8	60	109.8	90
Unit 5 (MW)	106.6	60	109.8	60	101.4
Unit 6 (MW)	123.5	109.8	109.6	109.8	98.2
Unit 7 (MW)	112.5	109.8	60	109.8	99.5
Unit 8 (MW)	144.2	109.8	159.7	109.7	88.5
Unit 9 (MW)	126.7	109.6	109.5	109.8	87.1
Unit10 (MW)	60.23	40	40	40	38
Unit 11 (MW)	48.47	40	40	40	41
Unit 12 (MW)	91.36	55	55	55	56
Unit 13 (MW)	81.23	55	55	55	56
P total	1800	1800	1800	1800	1800
Cost ($/hr.)	**18141.2**	**17963.8**	**17978.6**	**17962.7**	**17934.3**

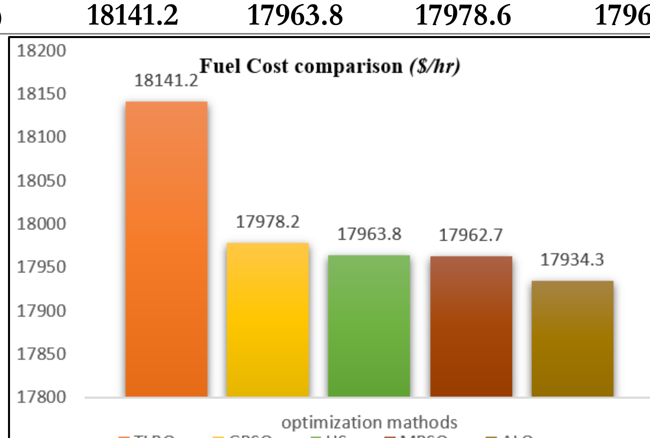

Figure 6: Fuel cost comparison chart

As seen from the chart below teaching learning optimizer [8] has the highest fuel cost of 18141.2 ($/hr), the Harmony search optimizer [9] is second, the Quazi oppositional inertial weight [10] is third and the Novel Heuristic optimizer [11] cost about 17962.7($/hr) while ALO performs best among all with least cost.

Conclusion:

This study explores the application of ALO with local search methods for economic load and emission dispatch, results of 3 generator systems show the strength of ALO also ALO is compared with four state-of-the-art optimizers in terms of fuel cost for 13 generating units' performance as best. With the optimum allocation of these generators, not only cost is reduced but emissions are reduced Furthermore, this work can be extended by applying it to more big generating units and also problems related to reactive power compensation and generator scheduling for day-ahead forecast. Also, other factors like the integration of wind and solar can be included in future work.

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Author's Contribution:

Babbar Sattar Khan presented the idea and modeled the system, Ejaz Ahmed drafted and made the code, Abdul Wadood included the hybridization portion Shahbaz Khan helped in the comparison portion and Husan Ali helped in drafting and modeling.

Conflict of Interest:

No conflict of interest for publishing this manuscript in IJIST.

Project Details:

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