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Optimal Load Dispatch Using Ant Lion Optimization

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Abstract
This paper presents Ant lion optimization (ALO) technique to solve optimal load dispatch problem. Ant lion optimization (ALO) is a novel nature inspired algorithm. The ALO algorithm mimics the hunting mechanism of ant lions in nature. Five main steps of hunting prey such as the random walk of ants, building traps, entrapment of ants in traps, catching preys, and re-building traps are implemented. Optimal load dispatch (OLD) is a method of determining the most efficient, low-cost and reliable operation of a power system by dispatching available electricity generation resources to supply load on the system. The primary objective of OLD is to minimize total cost of generation while honoring operational constraints of available generation resources. The proposed technique is implemented on 3, 6 & 20 unit test system for solving the OLD. Numerical results shows that the proposed method has good convergence property and better in quality of solution than other algorithms reported in recent literature.
Keywords—ALO; Optimal load dispatch; transmission loss

Nomenclature:
a_i, b_i, c_i : fuel cost coefficient of i^{th} generator, Rs/MW^2 h, Rs/MW h, Rs/h
$F(P_g)$: total fuel cost, Rs/h
n : number of generators
P_{gi}^{min} : Minimum generation limit of i^{th} generator, MW
P_{gi}^{max} : Maximum generation limit of i^{th} generator, MW
P_l : Transmission losses, MW
P_d : Power demand, MW

I. INTRODUCTION

The operating cost of a power plant mainly depends on the fuel cost of generators and is minimized via optimal load dispatch. Optimal load dispatch(OLD) problem can be defined as determining the least cost power generation schedule from a set of on line generating units to meet the total power demand at a given point of time [1]. The main objective of OLD problem is to decrease fuel cost of generators, while satisfying equality and inequality constraints. In this problem, fuel cost of generation is represented as cost curves and overall calculation minimizes the operating cost by finding a point where total output of generators equals total power that must be delivered plus losses.

In conventional optimal load dispatch, cost function for each generator has been approximately represented by a single quadratic function and is solved using lambda iteration method, gradient-based method,dynamic programming etc. [1]. Generally, these approaches have hitches in finding an overall optimum, usually offering local optimum point only. Furthermore, traditional approaches require calculating derivatives and certain inspection on derivability and continuity conditions of function belonging to optimization model. To overcome these shortcomings quite a lot of nature based optimization techniques were applied. Particle swarm optimization [2] is one of the famous meta-heuristics applied to solve OLD problem. Other approaches used for solving OLD problems are: evolutionary programming (EPs) [3], tabu search and multiple tabu search (TS, MTS) [4], differential evolution (DE) [5,6], hybrid DE (DEPSO) [7], artificial bee colony algorithm (ABC) [8], simulated annealing [9],biogeography-based optimization [10],genetic algorithms [11], intelligent water drop algorithm[12] ,hybrid harmony search[13] , differential HS (DHS) [14]gravitational search algorithm[15],firefly algorithm[16],hybrid gravitational search[17],cuckoo search (CS) [18],.have been successfully applied to OLD problems.

II. PROBLEM FORMULATION

The objective function of the OLD problem is to minimize the total generation cost while satisfying the different constraints, when the necessary load demand of a power system is being supplied. The objective function to be minimized is given by the following equation:

$$F(P_g) = \sum_{i=1}^{n} (a_i P_{gi}^2 + b_i P_{gi} + c_i) \quad \ldots (1)$$

The total fuel cost has to be minimized with the following constraints:

1) Power balance constraint

The total generation by all the generators must be equal to the total power demand and system's real power loss.

$\sum_{i=1}^{n} P_{gi} - P_d - P_l$ ….. (2)

2) Generator limit constraint

The real power generation of each generator is to be controlled within its particular lower and upper operating limits.

$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max}$ I =1,2,...,ng …..(3)

III. ANT LION OPTIMIZATION

Ant Lion Optimizer (ALO)[22] is a novel nature-inspired algorithm proposed by SeyedaliMirjalili in 2015.The ALO algorithm mimics the hunting mechanism of ant lions in nature. Five main steps of hunting prey such as the random walk of ants, building traps, entrapment of ants in traps, catching preys, and re-building traps are implemented.

Ant lions (doodlebugs) belong to class of net winged insects. The lifecycle of ant lions includes two main phases: larvae and adult. A natural total lifespan can take up to 3 years, which mostly occurs in larvae (only 3–5 weeks for adulthood). Ant lions undergo metamorphosis in a cocoon to become adult. They mostly hunt in larvae and the adulthood period is for reproduction. An ant lion larvae digs a cone-shaped pit in sand by moving along a circular path and throwing out sands with its massive jaw.After digging the trap, the larvae hides underneath the bottom of the cone and waits for insects (preferably ant) to be trapped in the pit. The edge of the cone is sharp enough for insects to fall to the bottom of the trap easily.

Once the ant lion realizes that a prey is in the trap, it tries to catch it.

Fig. 1. Cone-shaped traps and hunting behavior of ant lions[22]

Random walks of ants: Random walks are all based on the Eq.4

$X(t) = [0, cumsum(2r(t_1) - 1), cumsum(2r(t_2) - 1), \dots\dots.., cumsum(2r(t_n) - 1)]$ ……(4)

Where cumsum calculates the cumulative sum, n is the maximum number of iteration, t shows the step of random walk and r(t) is a stochastic function defined as follows:

$r(t) = \begin{cases} 1 & if\ rand > 0.5 \\ 0 & if\ rand \leq 0.5 \end{cases}$ ……(5)

however, above Eq. cannot be directly used for updating position of ants. In order to keep the random walks inside the search space, they are normalized using the following equation (min–max normalization):

$X_i^t = \frac{(X_i^t - a_i) \times (d_i - c_i^t)}{(d_i^t - a_i)} + c_i$ ……(6)

Where ai is the minimum of random walk of i[th] variable, bi is the maximum of random walk in i[th] variable, c_i^t is the minimum of i[th] variable at t[th] iteration, and d_i^t indicates the maximum of i[th] variable at t[th] iteration

Trapping in ant lion's pits: random walks of ants are affected by antlions' traps. In order to mathematically model this assumption, the following equations are proposed:

$C_i^t = Antlion_j^t + C^t$ ….(7)

$d_i^t = Antlion_j^t +$ …(8)

where C^t is the minimum of all variables at t[th] iteration, d^t indicates the vector including the maximum of all variables at t[th] iteration, C_j^t is the minimum of all variables for i[th] ant, d_j^t is the maximum of all variables for i[th] ant, and Antliont j shows the position of the selected j-thantlion at t[th]iteration

Building trap: In order to model the ant-lions's hunting capability, a roulette wheel is employed. The ALO algorithm is required to utilize a roulette wheel operator for selecting ant lions based of their fitness during optimization. This mechanism gives high chances to the fitter ant lions for catching ants.

Sliding ants towards ant lion: With the mechanisms proposed so far, ant lions are able to build traps proportional to their fitness and ants are required to move randomly. However, ant lions shoot sands outwards the center of the pit once they realize that an ant is in the trap. This behavior slides down the trapped ant that is trying to escape. For mathematically modelling this behavior, the radius of ants' random walks hyper-sphere is decreased adaptively. The following equations are proposed in this regard:

$C^t =$

…(9)

$d^t =$

…(10)

where I is a ratio, ct is the minimum of all variables at t-th iteration, and dt indicates the vector including the maximum of all variables at t-th iteration.

Catching prey and re-building the pit: The final stage of hunt is when an ant reaches the bottom of the pit and is caught in the antlion's jaw. After this stage, the antlion pulls the ant inside the sand and consumes its body. For mimicking this process, it is assumed that catching prey occur when ants becomes fitter (goes inside sand) than its corresponding antlion. An antlion is then required to update its position to the latest position of the hunted ant to enhance its chance of catching new prey. The following equation is proposed in this regard:

$Antlion_j^t = Ant_i^t \;\; if \; f(Ant_i^t) > f$ …(11)

where t shows the current iteration, Antliont j shows the position of selected j-thantlion at t-th iteration, and Antti indicates the position of i-th ant at t-th iteration.

Elitism: Elitism is an important characteristic of evolutionary algorithms that allows them to maintain the best solution(s) obtained at any stage of optimization process. Since the elite is the fittest antlion, it should be able to affect the movements of all the ants during iterations. Therefore, it is assumed that every ant randomly walks around a selected antlion by the roulette wheel and the elite simultaneously as follows:

$Ant_i^t = \frac{R_A^t + R_E^t}{2}$ … (12)

where R_A^t is the random walk around the antlion selected by the roulette wheel at t-th iteration, $R_E^t$is the random walk around the elite at t-th iteration, and Ant_i^tindicates the position of i-th ant at t-th iteration

IV. RESULTS & DISCUSSIONS

ALO has been used to solve the OLD problems in three different test cases for exploring its optimization potential, where the objective function was limited within power ranges of the generating units and transmission losses were also taken into account. The iterations performed for each test case are 500 and number of search agents (population) taken in both test cases is 30.

1) Test system I: Three generating units

The input data for three generators and loss coefficient matrix B_{mn} is derived from reference [19] and is given in table 4.1.

Table 4.1: Generating unit data for test case I

Unit	a_i	b_i	c_i	P_{gi}^{min}	P_{gi}^{max}
1	0.03546	38.30553	1243.531 1	35	210
2	0.02111	36.32782	1658.569 6	130	325
3	0.01799	38.27041	1356.659 2	125	315

$$B_{mn}=\begin{bmatrix}0.000071 & 0.000030 & 0.000025\\ 0.000030 & 0.000069 & 0.000032\\ 0.000025 & 0.000032 & 0.000080\end{bmatrix}$$

Table 4.1: Optimal load dispatch for 3 unit system

	Without Loss			With Loss		
Power Demand (MW)	**400**	**500**	**600**	**400**	**500**	**600**
P1	75.724	97.225	118.73	82.078	105.88	130.02
P2	174.04	210.16	246.28	174.99	212.73	250.85
P3	150.23	192.62	235	150.5	193.31	236.44
Power loss	-	-	-	7.568125	11.91438	17.30402
Cost(Rs/hr)	20480.29 695	24924.12631	29520.44334	20812.2936	25465.4691	30333.9858

Table 4.2: Power loss comparison

Sr. no.	Power demand	Power losses

		FFA[19]	ALO
1	400	7.56813	7.568125
2	500	11.9144	11.91438
3	600	17.3040	17.30402

Table 4.3: Fuel cost comparison with other methods

Sr.no.	Power demand (MW)	Fuel Cost (Rs/hr)		
		Lambda iteration[19]	FFA[19]	ALO
1	400	20817.4	20812.3	20812.2936
2	500	25495.2	25465.5	25465.46914
3	600	30359.3	30334.0	30333.9858

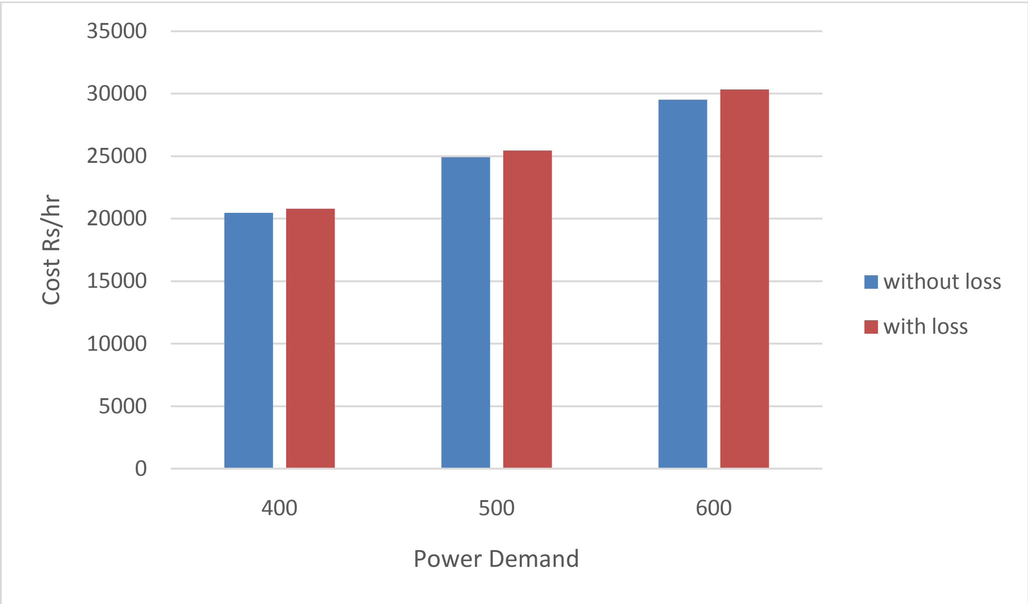


Fig 4.1. Fuel cost with and without losses for 3 unit system

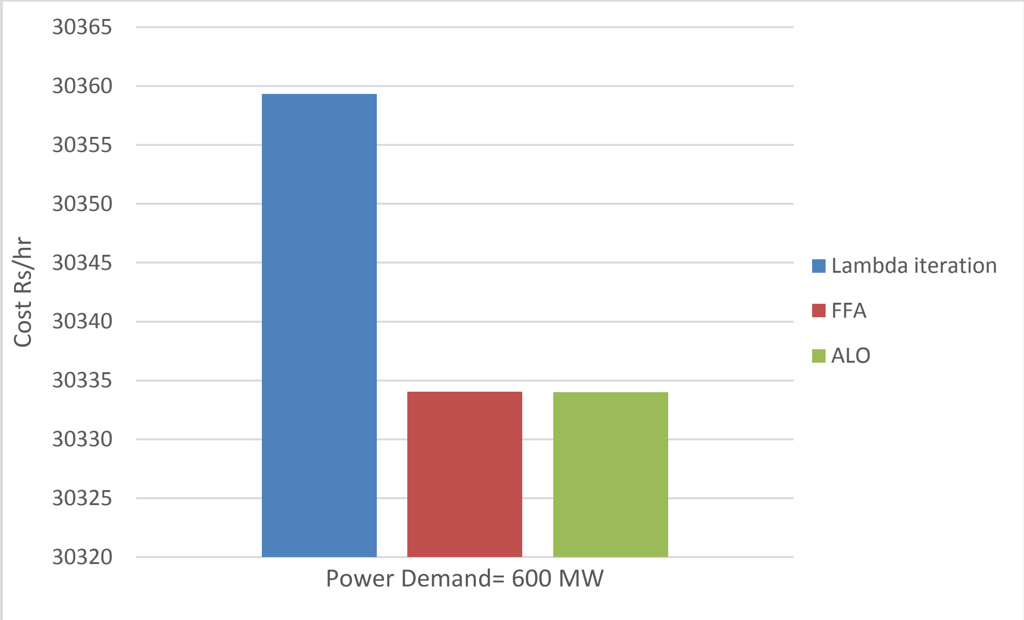


Fig 4.2. Fuel cost comparison for 3 unit system

2) Test system II: Six generating units

The input data for six generators and loss coefficient matrix B_{mn} is derived from reference [19] and is given in table 4.4.

Table 4.4: Generating unit data for test case II

Unit	a_i	b_i	c_i	P_{gi}^{min}	P_{gi}^{max}
1	0.15240	38.53973	756.79886	10	125
2	0.10587	46.15916	451.32513	10	150
3	0.02803	40.39655	1049.9977	35	225
4	0.03546	38.30553	1243.5311	35	210
5	0.02111	36.32782	1658.5596	130	325
6	0.01799	38.27041	1356.6592	125	315

$$B_{mn}=\begin{bmatrix} 0.000014 & 0.000017 & 0.000015 & 0.000019 & 0.000026 & 0.000022 \\ 0.000017 & 0.000060 & 0.000013 & 0.000016 & 0.000015 & 0.000020 \\ 0.000015 & 0.000013 & 0.000065 & 0.000017 & 0.000024 & 0.000019 \\ 0.000019 & 0.000016 & 0.000017 & 0.000072 & 0.000030 & 0.000025 \\ 0.000026 & 0.000015 & 0.000024 & 0.000030 & 0.000069 & 0.000032 \\ 0.000022 & 0.000020 & 0.000019 & 0.000025 & 0.000032 & 0.000085 \end{bmatrix}$$

Table 4.5: Optimal load dispatch for 6 unit system

	Without Loss			**With Loss**		
Power Demand (MW)	**600**	**700**	**800**	**600**	**700**	**800**
P1	21.19	24.974	28.758	23.8713	28.3031	32.6003
P2	10	10	10	10	10.00	14.4830
P3	82.086	102.66	123.24	95.6365	118.9550	141.5440
P4	94.371	110.63	126.9	100.7064	118.6728	136.0413
P5	205.36	232.68	260	202.8285	230.7596	257.6587
P6	186.99	219.05	251.1	181.1945	212.7411	243.0033
Power loss	-	-	-	14.2372	19.4317	25.3307
Cost(Rs/hr)	31445.62289	36003.12394	40675.96798	32094.6783	36912.1444	41896.6286

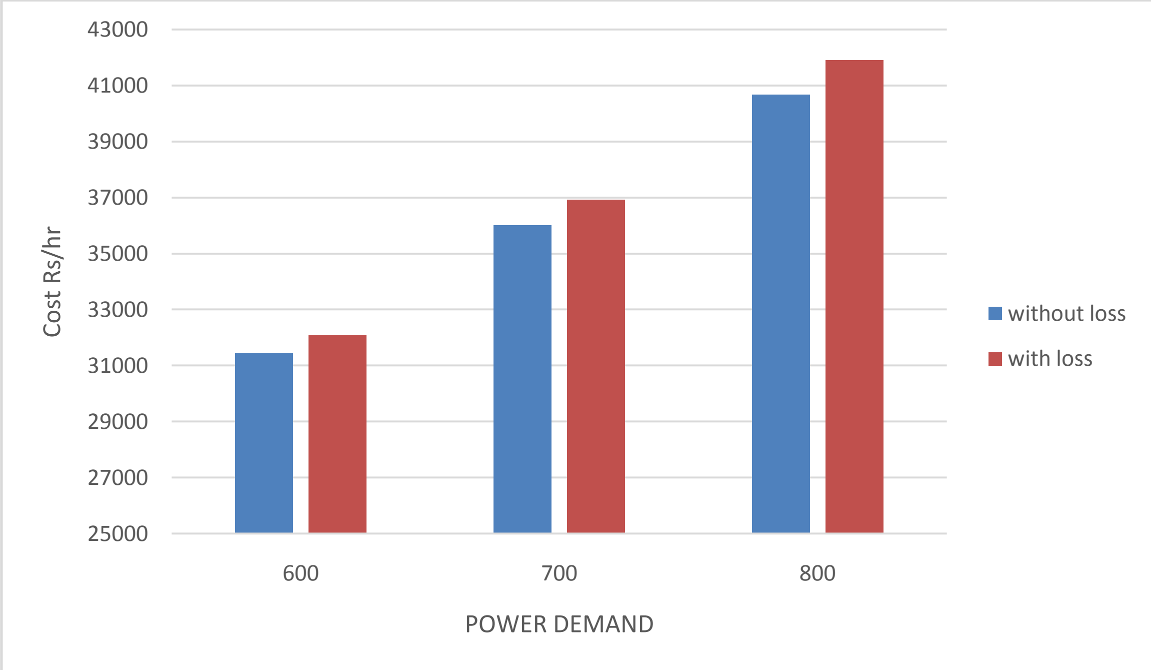


Fig 4.3 fuel cost for 6 unit with and without loss

Table 4.6: comparison of power losses.

Sr. no.	Power demand	Power losses			
		Conventional[2]	PSO[2]	FFA[19]	ALO
1	600	15.07	14.2374	14.2374	14.2372
2	700	19.50	19.4319	19.4319	19.4317
3	800	25.34	25.3309	25.3312	25.3307

Table 4.7: Comparison of fuel cost with other methods

Sr.no.	Power demand (MW)	Fuel Cost (Rs/hr)				
		Conventional Method[2]	PSO[2]	Lambda iteration[19]	FFA[19]	ALO
1	600	32096.58	32094.69	32129.8	32094.7	32094.6783
2	700	36914.01	36912.16	36946.4	36912.2	36912.1444
3	800	41898.45	41896.66	41959.0	41896.9	41896.6286

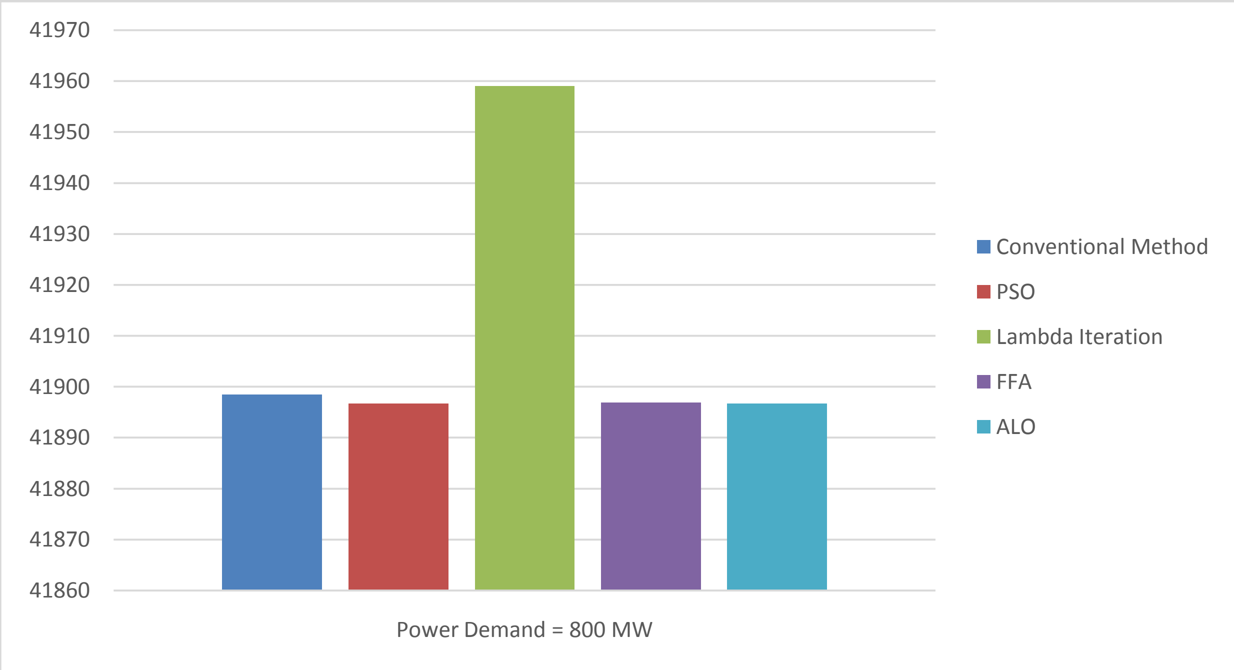


Fig 4.4. Fuel cost comparison for 6 unit system

3) Test system III: Twenty generating units

The input data for six generators and loss coefficient matrix Bmn is derived from reference [20] and is given in table 4.8.

Table 4.8: generating data for 20 units

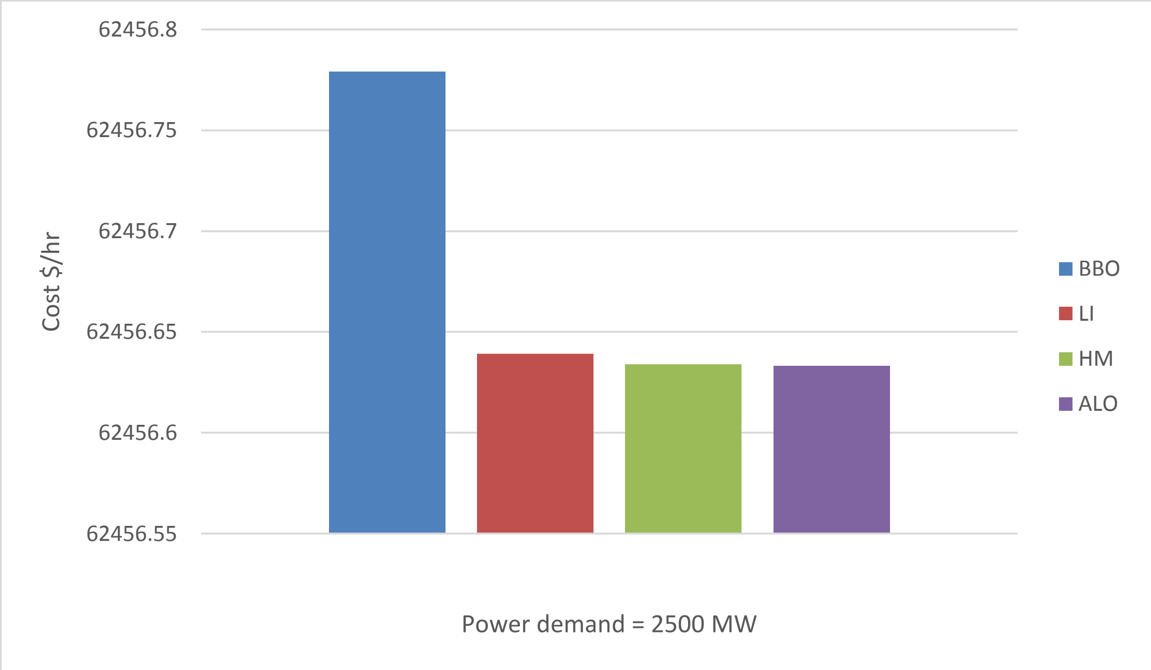
Unit	a_i($/MW2)	b_i ($/MW)	c_i ($)	P_{gi}^{min}	P_{gi}^{max}
1	0.00068	18.19	1000	150	600
2	0.00071	19.26	970	50	200
3	0.00650	19.80	600	50	200
4	0.00500	19.10	700	50	200
5	0.00738	18.10	420	50	160
6	0.00612	19.26	360	20	100
7	0.00790	17.14	490	25	125
8	0.00813	18.92	660	50	150
9	0.00522	18.27	765	50	200
10	0.00573	18.92	770	30	150
11	0.00480	16.69	800	100	300
12	0.00310	16.76	970	150	500
13	0.00850	17.36	900	40	160
14	0.00511	18.70	700	20	130
15	0.00398	18.70	450	25	185
16	0.07120	14.26	370	20	80
17	0.00890	19.14	480	30	85
18	0.00713	18.92	680	30	120
19	0.00622	18.47	700	40	120
20	0.00773	19.79	850	30	100

Table 4.9: optimal load dispatch for 20-generating units **without loss** (PD = 2500 MW)

Unit	**ALO**
P1	600
P2	172.85
P3	50
P4	50.481
P5	95.285
P6	24.17
P7	124.81
P8	50
P9	91.891
P10	44.961
P11	275.5
P12	427.35
P13	123.15
P14	59.795
P15	101.7
P16	36.26
P17	36.342
P18	34.196
P19	71.267
P20	30
Total generation (MW)	2500.00
Total generation cost ($/h)	60160.71425

Table 4.10: optimal load dispatch for 20-generating units withloss (PD = 2500 MW)

Unit	BBO [21]	LI [20]	HM [20]	ALO
P1	513.0892	512.7805	512.7804	512.78
P2	173.3533	169.1033	169.1035	169.11
P3	126.9231	126.8898	126.8897	126.89
P4	103.3292	102.8657	102.8656	102.87
P5	113.7741	113.6386	113.6836	113.68
P6	73.06694	73.5710	73.5709	73.568
P7	114.9843	115.2878	115.2876	115.29
P8	116.4238	116.3994	116.3994	116.4
P9	100.6948	100.4062	100.4063	100.41
P10	99.99979	106.0267	106.0267	106.02
P11	148.9770	150.2394	150.2395	150.24
P12	294.0207	292.7648	292.7647	292.77
P13	119.5754	119.1154	119.1155	119.12
P14	30.54786	30.8340	30.8342	30.831
P15	116.4546	115.8057	115.8056	115.81
P16	36.22787	36.2545	36.2545	36.254
P17	66.85943	66.8590	66.8590	66.857
P18	88.54701	87.9720	87.9720	87.975
P19	100.9802	100.8033	100.8033	100.8
P20	54.2725	54.3050	54.3050	54.305
Total generation (MW)	2592.1011	2591.9670	2591.9670	2591.967
Total transmission loss (MW)	92.1011	91.9670	91.9669	91.9662
Total generation cost ($/h)	62456.77926	62456.6391	62456.6341	62456.63309



V. CONCLUSION

In this paper optimal load dispatch problem has been solved by using ALO. The results of ALO are compared for three ,six and twenty generating unit systems with other techniques. The algorithm is programmed in MATLAB(R2009b) software package. The results displayefficacy of ALO algorithm for solving the optimal load dispatch problem. The advantage of ALO algorithm is its simplicity, reliability and efficiency for practical applications.

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