Economic Load Dispatch Using Multi Verse Optimization

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***Abstract*—** *This paper presents Multi Verse optimization (MVO) technique to solve convex economic load dispatch (ELD) problem. Multi Verse Optimization (MVO) is a new meta-heuristic. The MVO algorithm is inspired from three terms white hole, black hole, and wormhole in the space. To perform exploration, exploitation, and local search, respectively white hole, black hole, and wormhole are mathematical modeled. The objective of ELD problem is to minimize the total cost of generation meeting the linear and non linear constraints and to supply load demand. The proposed technique is applied for solving the ELD supplying different load demands to two different test problems and after that MVO is applied for solving the ELD considering effects of valve point loading to another two different test problems. At the end of this paper, the results obtained from MVO for solving ELD problem were compared with other well known existing methods which show MVO better than other techniques.*

***Keywords*— MVO, economic load dispacth, transmission loss.**

I. INTRODUCTION

In the modern world to survive and to meet various demands the electrical power plays very important role. So the generation, transmission and distribution of electrical power must be optimized to meet the power demand. Electrical power is generated by different power plants. The planning and operation of electric power generation system requires the economic scheduling of all generators to meet the required demand. The Economic Load Dispatch (ELD) problem is the most important optimization problem in scheduling the generators of steam power plants. In ELD problem, the ultimate goal is to minimize the total cost of generation meeting the linear and non linear constraints and to supply load demand. To solve ELD problem conventional methods include the linear programming method, gradient method, lambda iteration method and Newton's method. Dynamic programming is one of the techniques to solve ELD problem, but it suffers from problem of irritation of dimensionality or confined optimality. Meta-heuristic techniques, such as genetic algorithms, differential evolution, tabu search, simulated annealing, particle swarm optimization (PSO), biogeography-based optimization, intelligent water drop algorithm, harmony search, gravitational search algorithm, firefly algorithm, hybrid gravitational search, cuckoo search (CS), modified harmony search, grey wolf optimization have been successfully applied to ELD problems. Recently, a new meta-heuristic technique called multi verse optimization has been proposed by Seyedali Mirjalili et al,. In this paper the ELD problem has been solved by using multi verse optimization.

II. PROBLEM FORMULATION

The objective function of the ELD problem is to minimize the total cost of generation while meeting the different linear and non linear constraints, when the required load demand of a power system is being supplied. The objective function to be minimized is given by the following equation:

$$F(P_g) = \sum_{i=1}^{n} (a_i P_{gi}^2 + b_i P_{gi} + c_i) \tag{2.1}$$

The equality and inequality constraints for the minimization of total fuel cost are following:

1) Equality (Power balance) constraint

The total output power by all the generators must be equal to the load demand and system's transmission losses.

$$\sum_{i=1}^{n} P_{gi} = P_d + P_l \tag{2.2}$$

2) Inequality (Generator limit) constraint

The real power output of each generator must be lies between its minimum and maximum operating values.

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max} \quad i=1,2,...,ng \tag{2.3}$$

Where

a_i, b_i, c_i : fuel cost coefficient of i^{th} generator in Rs/MW^2 h, Rs/MW h, Rs/h respectively

$F(P_g)$: 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

III. MULTI VERSE OPTIMIZATION (MVO)

The MVO is firstly proposed by Seyedali Mirjalili et al.[26]. According to multi-verse theory MVO algorithm inspired from three terms white holes, black holes, and wormholes. A white hole has not actually exists in our universe, but scientist assume that the big bang can be act as a white hole and may be the main cause of creation of a universe. In multi-verse theory model it is assumed that when the parallel universes are collides with each other there is creation of big bangs/white holes. Black holes, which have been seen normally, behave completely opposite to white wholes. They attract and absorb objects, stars, planets or even light beams with high force of gravity. Wormholes are those holes which interconnect different corners of a universe. In the multi-verse theory wormholes act as time/space travel paths where objects are able to move instantly from one part to any other part of a universe (or even objects are able to move from one universe to another universe) The mathematical modeling of MVO algorithm for solving ELD problem is developed as follows:

3.1 Implementation

The major chore of ELD is to assign the loading amongst operating generators at least likely price devoid of breaching constraints of system. The MVO is applied to the real power generation from thermal power stations. The ELD problem is defined by Eq. (3.1) and transmission losses are defined by Eq. (3.2)

$$F_t = \sum_{i=1}^{n} A_i P_{gi}^2 + B_i P_{gi} + C_i \tag{3.1}$$

$$P_L = \sum_{i=1}^{n} P_{gi} B_{ij} P_{gj} + \sum_{i=1}^{n} B_{0i} P_{gi} + B_{00} \tag{3.2}$$

3.2 Universe Position Representation

Generators real power outputs are the verdict parameter for ELD issue. Position matrix configuration is done by generators real power outputs. The universes position in the matrix is imitation of the set of real output power of all committing generators. Let us take the system consists of NG generators, the development of the universe position matrix would be NG number of rows. Let us assume that there are NP universes in the search space, the illustration of universe position matrix as noted below:

$$U = \begin{bmatrix} P_{11} & P_{12} & \dots & P_{1NG} \\ P_{21} & P_{22} & \dots & P_{2NG} \\ \dots & \dots & P_{ij} & \dots \\ P_{NP1} & P_{NP2} & \dots & P_{NPNG} \end{bmatrix} \tag{3.3}$$

3.3 Initialization of position of Universes

The initialization of each component of universe position matrix is occurred arbitrarily and lies between minimum and maximum limit depend upon Eq. (3.4). This inequality starts the process of initialization of the universe positions.

$$P_j^{min} < P_{ij} < P_j^{max} \quad (i=1,2...NP ; j= 1,2...NG) \tag{3.4}$$

$$P_i = P_i^{min} + rand()(P_i^{max} - P_i^{min}) \tag{3.5}$$

3.4 Evaluation of Objective function

To meet the constraints, one generator is selected as a slack generator d out of all committed generators and this is given by

$$P_d^j = Z^j (i=1, 2...NP; j= 1, 2...NG) \tag{3.6}$$

Where

$$Z = P_d - \sum_{i=1, i\neq d}^{NG} P_i \tag{3.7}$$

If there is the infringement regarding the selection of slack generator in respect to minimum and maximum generation limit then it is defined by equation below:

$$P_i^j = \begin{cases} P_i^{min}; & P_i^j < P_i^{min} \\ P_i^{max}; & P_i^j > P_i^{max} \\ P_i^j; & P_i^{min} < P_i^j < P_i^{max} \end{cases} \quad (i=1,2...NG ; i\neq d; j= 1,2...L) \tag{3.8}$$

After selecting the proper operating range of dependent/slack generator, objective function is modified with addition of extra term of penalty factor which is given by

$$f^j = F(P_i^j) + \emptyset \tag{3.9}$$

3.5 MVO algorithm working

Based on the normalized inflation rate white holes are selected and determined with the help of the roulette wheel method. Lesser expansion rate, higher chances of moving objects through white/black hole channels. Since the objects goes on moving from one universe to other universe so causes the abrupt changes occurs which leads to the exploration and exploitation in search space.

Between every solution and best solution evolved so far, wormhole tunnels are established for moving objects within the each universe to perform the local changes in search space and ultimately stabilize the inflation rate. The mechanism formulated for this is as follows:

$$x_i^j = \begin{cases} \begin{cases} Xj + TDR \times ((ub_j - lb_j) \times r4 + lb_j) \; ; r3 < 0.5 \\ Xj - TDR \times ((ub_j - lb_j) \times r4 + lb_j); \; r3 \geq 0.5 \end{cases} ; & r2 < WEP \\ x_i^j & r2 \geq WEP \end{cases} \tag{3.10}$$

where Xj denotes the jth variable of best universe formed so far, TDR and WEP is are two coefficients, lbj stands the lower bound of jth variable, ubj is the upper bound of jth variable, x_i^j indicates the jth parameter of ith universe, and r2, r3, r4 are random numbers having values lies between [0, 1].

Two main coefficients are wormhole existence probability (WEP) and travelling distance rate (TDR). The WEP coefficient gives the information about how much wormhole's present in universes. WEP should increase linearly over the iterations in order to perform the function of exploitation as the optimization is going on. Travelling distance rate is coefficient which gives the information about variation due to the movement of an object through wormhole tunnels around the best solution obtained so far. Unlike WEP, TDR is decreased over the iterations to provide more precise exploitation/local search around the optimal solution obtained. The adaptive formulae for these coefficients are as follows:

$$WEP = \min + l \times \left(\frac{\max - \min}{L}\right) \tag{3.11}$$

Where min is the minimum value (0.2 in this paper), max is the maximum value (1 in this paper), l indicates the current iteration, and L shows the maximum number of iterations

$$TDR = 1 - \frac{l^{1/p}}{L^{1/p}} \tag{3.12}$$

Where p (=6) denotes the accuracy of exploitation over the iterations. The higher value of p, more accurate and quick response to perform exploitation/local search.

In the MVO algorithm, the optimization course of action starts with generating a set of random universes. At each and every iteration, there is continuous movement of objects from universes having high probability of white hole to universes having high probability of black holes. In the meantime, each and every universe under gone the local changes due to random movements of its objects via wormhole channels towards the best universe. This process is repeated and repeated until the stable universe (solution) reached.

3.6 Stopping Criterion

There are many ways to stop a theoretical optimization process like maximum number of iterations, number of functions evaluated and capacity to withstand. In this case, maximum number of iterations is taken.

IV. RESULTS & DISCUSSIONS

MVO technique is applied for solving the ELD supplying different load demands to two different test problems and after that MVO is applied for solving the ELD considering effects of valve point loading to another two different test problems along with meeting the various constraints and supply the demand with transmission losses.

4.1 ELD without considering valve point loading effects

MVO is applied to two different test systems for ELD neglecting effects of valve point loading. The number of iterations performed for each test system are 500 and number of search agents (population) taken in both test system is 30.

Test system I: Three generators unit system

The cost coefficients for three generators and loss coefficient matrix B_{mn} is taken from reference [20] and is given in table 4.1.The economic load dispatch problem for 3 generators is solved with MVO and results are shown in table 4.2 and also results are compared with lambda iteration and cuckoo search methods in table 4.3.

TABLE 4.1
GENERATOR S DATA FOR TEST SYSTEM 1

Unit	a_i	b_i	c_i	P_{gi}^{min}	P_{gi}^{max}
1	0.03546	38.30553	1243.5311	35	210
2	0.02111	36.32782	1658.5696	130	325
3	0.01799	38.27041	1356.6592	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 4.2
MVO RESULTS FOR 3-UNIT SYSTEM

Sr. no.	Techniques	Power demand (MW)	P1(MW)	P2(MW)	P3(MW)	PLoss (MW)	Fuel Cost (Rs/hr)
1	CS[20]	350	70.3012	156.267	129.208	5.77698	18564.5
	MVO		70.30259	156.289	129.184	5.77696	18564.483
2	CS[20]	450	93.9374	193.814	171.862	9.6127	23112.4
	MVO		93.9362	193.8043	171.872	9.6127	23112.363
3	CS[20]	500	105.88	212.728	193.306	11.9144	25465.5
	MVO		105.8848	212.7137	193.3157	11.91434	25465.469

TABLE 4.3
COMPARISON OF MVO RESULTS FOR 3-UNIT SYSTEM

Sr. no.	Power demand (MW)	Fuel Cost (Rs/hr)		
		Lambda Iteration Method [20]	Cuckoo Search Algorithm [20]	Multi Verse Optimization
1	350	18570.7	18564.5	18564.483
2	450	23146.8	23112.4	23112.363
3	500	25495.2	25465.5	25465.469

Test system II: Six generators unit system

The cost coefficients for six generators and loss coefficient matrix B_{mn} is taken from reference [20] and is given in table 4.4.The economic load dispatch problem for 6 generators is solved with MVO and results are shown in table 4.5 and also results are compared with lambda iteration method, conventional quadratic programming, , particle swarm optimization and cuckoo search in table 4.6.

TABLE 4.4
GENERATORS DATA FOR TEST SYSTEM 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
MVO RESULTS FOR 6-UNIT SYSTEM

Sr. no.	Techniques	Power Demand (MW)	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	Ploss (MW)	Fuel Cost (Rs/hr)
1	Conventional [9]	600	23.90	10.00	95.63	100.70	202.82	182.02	15.07	32096.58
	CS[20]		23.8603	10	95.6389	100.708	202.832	181.198	14.2374	32094.7
	MVO		23.911	10	95.571	100.740	202.752	181.261	14.2373	32094.67
2	Conventional [9]	700	28.33	10.00	118.95	118.67	230.75	212.80	19.50	36914.01
	CS[20]		28.2908	10.00	118.958	118.675	230.763	212.745	19.4319	36912.2
	MVO		28.3514	10.00	118.887	118.748	230.704	212.737	19.4308	36912.14
3	Conventional [9]	800	32.63	14.48	141.54	136.04	257.65	243.00	25.34	41898.45
	CS[20]		32.5861	14.4843	141.548	136.045	257.664	243.009	25.3309	41896.7
	MVO		32.5408	14.8660	141.5021	136.0254	257.518	242.8632	25.3165	41896.63

TABLE 4.6
COMPARISON RESULTS OF MVO FOR 6-UNIT SYSTEM

Sr. no.	Power demand (MW)	Fuel Cost (Rs/hr)				
		Lambda Iteration Method[20]	Conventional Method[9]	PSO[2]	Cuckoo Search Algorithm[20]	Multi Verse Optimization
1	600	32129.8	32096.58	32094.69	32094.7	32094.67
2	700	36946.4	36914.01	36912.16	36912.2	36912.145
3	800	41959.0	41898.45	41896.66	41896.9	41896.632

4.2 ELD considering valve point loading effects

MVO is applied to two different test systems for solving ELD problem considering effects of valve point loading. The number of search agents (population) taken in both test system is 30.

Test system I: Thirteen generators unit system

The cost coefficients for thirteen generators and loss coefficient matrix B_{mn} is taken from reference [1] .The iterations performed for this test system is 800.The economic load dispatch problem for 13 generating units is solved with MVO and results are shown in table 4.7 and also results are compared with other techniques in table 4.8.

TABLE 4.7
MVO RESULTS FOR 13-UNIT SYSTEM

Generator	Generator Output(MW)
P_1	538.5316321
P_2	224.4509578
P_3	299.1897508
P_4	60.01063252
P_5	109.9378795
P_6	60
P_7	110.0208618
P_8	60.06256007
P_9	110.1635
P_{10}	40.24324059
P_{11}	40
P_{12}	92.38898475
P_{13}	55
Total power generation	**1800**
Minimum Cost(Rs/hr)	**17982.927**

TABLE 4.8
COMPARISON OF MVO RESULTS FOR 13-UNIT SYSTEM

Methods	Minimum Cost (Rs/hr)	Mean Cost (Rs/hr)	Maximum Cost (Rs/hr)
CEP[1]	18048.21	18190.32	18404.04
FEP[1]	18018.00	18200.79	18453.82
MFEP[1]	18028.09	18192.00	18416.89
PSO[2]	18,030.72	18,205.78	--
IFEP[1]	17994.07	18127.06	18267.42
MVO	17982.92	18090.49	18205.62

Test system II: Forty generators unit system

The cost coefficients for forty generators and loss coefficient matrix B_{mn} is derived from reference [1] .The iterations performed for this test system is 2000.The economic load dispatch problem for 40 generators is solved with MVO and results are shown in table 4.9 and also results are compared with other techniques in table 4.10.

TABLE 4.9
MVO RESULTS FOR 40-UNIT SYSTEM

Generator	Generator Output(MW)	Generator	Generator Output(MW)
P_1	113.874	P_{21}	528.626
P_2	113.619	P_{22}	533.123
P_3	100.872	P_{23}	523.368
P_4	180.409	P_{24}	525.198
P_5	89.982	P_{25}	523.337
P_6	140	P_{26}	538.055
P_7	272.359	P_{27}	11.834
P_8	284.852	P_{28}	10.059
P_9	291.423	P_{29}	10.405
P_{10}	131.037	P_{30}	96.198
P_{11}	168.806	P_{31}	182.411
P_{12}	168.848	P_{32}	187.490
P_{13}	125.057	P_{33}	189.925
P_{14}	304.542	P_{34}	167.730
P_{15}	305.958	P_{35}	199.673
P_{16}	484.071	P_{36}	188.594
P_{17}	491.939	P_{37}	104.813
P_{18}	489.589	P_{38}	95.675
P_{19}	511.346	P_{39}	89.732
P_{20}	511.469	P_{40}	513.676
Total power generation(MW)		**10500**	
Minimum Cost(Rs/hr)		**122173.426**	

TABLE 4.10
COMPARISON OF MVO RESULTS FOR 40-UNIT SYSTEM

Method	Minimum Cost (Rs/hr)	Mean Cost (Rs/hr)	Maximum Cost (Rs/hr)
CEP[1]	123488.29	124793.48	126902.89
PSO [2]	123930.45	124154.49	---
FEP[1]	122679.71	124119.37	127245.59
MFEP[1]	122647.57	123489.74	124356.47
IFEP[1]	122624.35	123382.00	125740.63
MVO	122173.42	122720.34	123981.72

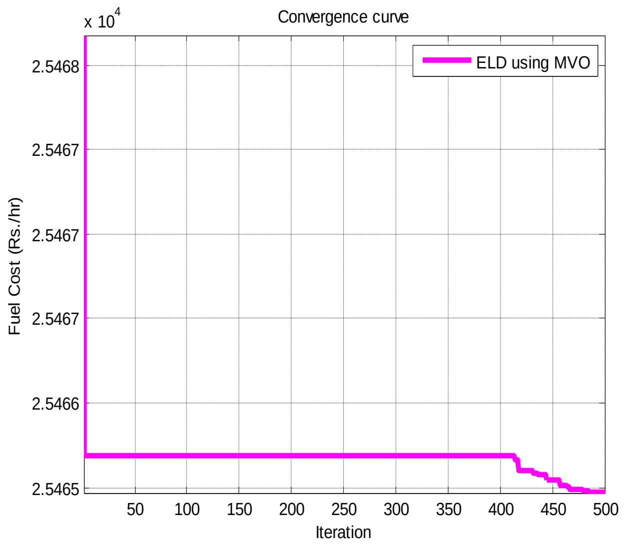

FIG 4.1: CONVERGENCE CURVE OF TEST SYSTEM I (WITHOUT CONSIDERING VALVE POINT LOADING EFFECTS)

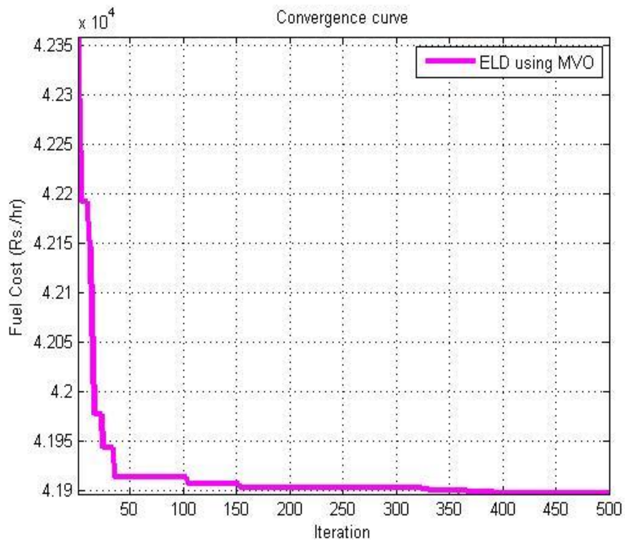

FIG 4.2: CONVERGENCE CURVE OF TEST SYSTEM II (WITHOUT CONSIDERING VALVE POINT LOADING EFFECTS)

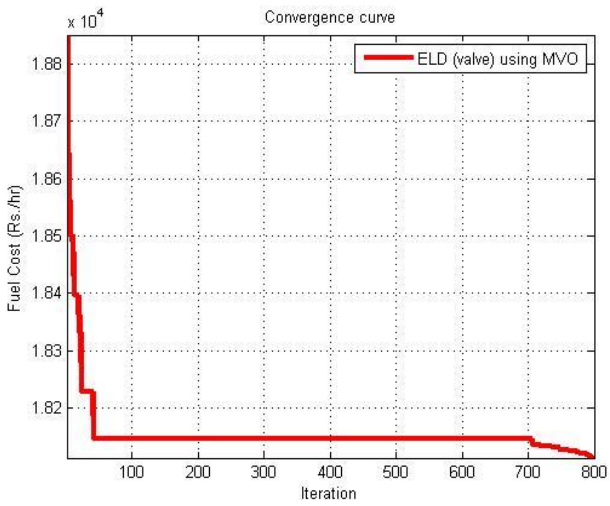

FIG 4.3: CONVERGENCE CURVE OF TEST SYSTEM I WITH 1800MW DEMAND (CONSIDERING VALVE POINT LOADING EFFECTS)

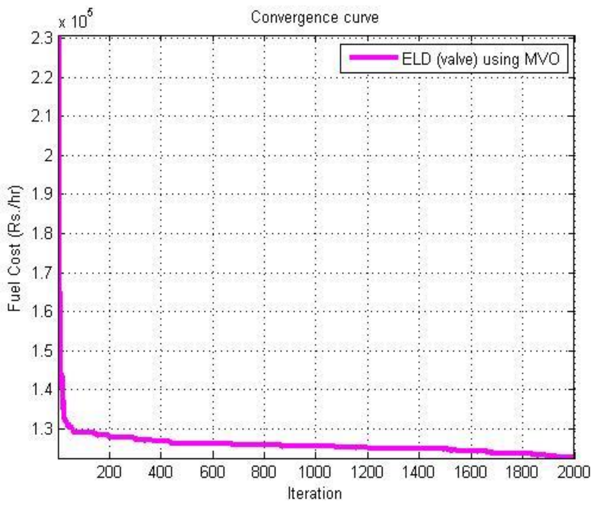

FIG 4.4: CONVERGENCE CURVE OF TEST SYSTEM II WITH 10500MW DEMAND (CONSIDERING VALVE POINT LOADING EFFECTS)

V. CONCLUSION

In this paper economic load dispatch problem has been solved by using MVO. The results of MVO are compared for three and six generating unit systems with other techniques for solving ELD and for thirteen and forty generating units with other techniques for solving ELD considering valve point loading effects. MATLAB (R2009b) software is used to develops the program for implementation of MVO algorithm. The results show effectiveness of MVO algorithm for solving the economic load dispatch problem. The advantage of MVO algorithm is its simplicity, reliability and efficiency for practical applications.

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