Utilizing Particle Swarm Optimization Algorithms for Solving Economic Load Dispatch

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***Abstract*—** Economic Load Dispatch (ELD) stands as a crucial optimization task, offering an economically efficient state for power systems. In this study, Particle Swarm Optimization (PSO) emerges as a powerful and efficient evolutionary-based technique proposed to address the challenging problem of constrained economic load dispatch. The proposed approach excels in determining optimal power generation outputs for all generating units, effectively minimizing the overall cost constraint function. In this article, a piecewise quadratic function is adopted to represent the fuel cost equation for individual generation units, while the B-coefficient matrix is employed to account for transmission losses. To validate the effectiveness of the proposed method in addressing constraint-related challenges, it is evaluated across four power system test cases, encompassing scenarios with 3, 6, 15, and 40 generation units. Notably, this assessment includes cases where transmission losses are neglected. Comparative analysis against alternative methodologies, such as Genetic Algorithm (GA) and Quadratic Programming (QP), underscores the superior performance of the proposed approach. It not only offers mathematical simplicity but also demonstrates rapid convergence and robustness, thus showcasing its capability to deliver high-quality solutions for complex optimization challenges.

Keywords *- Economic Load Dispatch (ELD); Particle Swarm Optimization (PSO); Quadratic Cost Function; Generation unit; transmission losses.*

I. INTRODUCTION

Electrical power systems are capable to produce sufficient electrical power to feed a bounded and certain range of load demand. In all practical power systems, minimizing the total operation costs is very important. Thus, the ELD technique is applied for allocating power generation among the committed units, so that the total generation cost of the system and also transmission power losses are minimized, while satisfying all the constraints [1]. The input-output characteristic of generators in a power system are nonlinear, and there are some multiple local minimum points and a global minimum point in this curve, therefore, the characteristic of ELD problem (objective function) are multi model and highly nonlinear. The common mathematical practices to solve constraint optimization problems such as ELD problem are lambda iteration method, base point and participation factor method, gradient method, etc. These techniques require the incremental cost curves to be monotonically increasing. To use these mathematical methods in optimization problems it is necessary to select a suitable initial starting point for their algorithms. The wrong initial starting point may cause the divergence or convergence of the algorithm to some local optimum points rather than the global point. [1, 3, 8, 15]. It has been found that Newton based algorithms will face problem in having large number of inequality constraints. Beside it have been approved short coming of Linear programming methods is associated with the piecewise linear cost approximation. On the other hand Non linear programming methods have also been applied to solve the convergence problem. Evolutionary Programming (EP) technique, evolutionary computation technique such as Genetic Algorithm (GA), Artificial Neural Network (ANN), Particle Swarm Optimization (PSO), etc, are some of the proposed methods to solve ELD problem for a power system [2, 4]. The proposed PSO method is composed of a set of particles called individuals, which are able to follow a certain algorithm to obtain the best solution for a optimization problem. These particles explore the search space with different velocities and positions. Each particle of swarm presents a potential solution for the optimization problem. The performance of individuals, evaluated by a fitness function (objective function). The particle swarm's algorithm is able to obtain local optimum points for multi variable optimization problems, in the multi dimension search space [5].

II. PROBLEM FORMULATION

The main goal in this optimization problem is to obtain a particular set of points, including all outputs of the power generation units, such that all equality and inequality constraints are satisfied. In addition, the total cost function is minimized. In this paper, the equality and inequality constraints indicate the real power balance and limitation of power generation of each unit, respectively. Some of the other constraints including voltage level and security are assumed to be constant. Equation (1) denotes the total fuel cost for a power system which is an equal summation of all generation units cost functions, in a power system

F=\sum_{i=1}^{N}{F_i{(P}_i)}
(1)

By approximating the fuel cost for each generation unit(Fi (Pi)), to a quadratic function, (2) can be obtained, thus the total cost function will be changed into the following equation

F=\sum_{i=1}^{N}{{a_ip_i^2+b}_iP_i}+c_i
(2)

Pi –output power generation of unit i

ai ,bi ,ci: Fuel cost coefficients of unit i

By using the matrix form, the losses formula can be shown as in the following equation.

PL = PT BP

$\sum_{i=0}^{N}\sum_{j=0}^{N}{P_iP_jB_{ij}}$ (3)

Where

P is matrix of the output powers of units.

B is square matrix of transmission coefficients.

The method used in this paper for considering the

transmission losses, has been developed by Kron and adopted by Kirchmayer, which is the loss coefficient method [6, 8, 13].

The output power of each generation unit is bounded

between two limitations

Pi(min)<Pi <Pi(max)

For i=1,2…….N

Where Pi(min),Pi(max)denote the minimum and maximum output power generation of unit i.

III. PARTICLE SWARM OPTIMIZATION

The PSO algorithm which was first proposed by Kennedy and Eberhart has been inspired by the Social behavior of a simple system (flock of birds). This algorithm can be effectively useful in solving many non linear hard optimization problems [5]. Unlike the mathematical methods for solving optimization problems, this algorithm does not

need any gradient information about objective or error function and it can obtain the best solution independently [7]. According to the PSO algorithm, a swarm of particles that have predefined restrictions starts to fly on the search space. The performance of each particle is evaluated by the value of the objective function and considering the minimization

problem, in this case, the particle with lower value has more performance. The best experiences for each particle in iterations is stored in its memory and called personal best (Pbest). The best value of Pbests (less values) in iterations determines the global best (Gbest). By using the concept of Pbest and Gbest the velocity of each particle is updated

Vik+1 =Vik +c1r1(XPbest –Xik)+c2r2(XGbest -Xik)(4)

Where

Vik+1 = Particle velocity at current iteration (k+1)

Vik = Particle velocity at iteration k

R1,r2 = random number between [0, 1]

C1,c2= acceleration constant

After this, particles fly to a new position:

Xik+1 =Xik + Vik+1

Where

Xik+1 = Current particle position at iteration k+1

Xik = Particle position at iteration k

Vik+1 = Particle velocity at iteration k+1

IV. INCREASE CONVERGENCE RATE

a) Inertia weight

In attempting to increase the rate of convergence of the standard PSO algorithm to global optimum, the inertia weight is proposed in the velocity equation [10, 11].By using the new equation for velocity, according to this modification, the suggested particle velocity in (5) will be changed to:

Vik+1 = WVik +c1r1(XPbest –Xik)+c2r2(XGbest -Xik) (5)

W is the inertia weight

Applying this factor in (5) causes some of the particle's velocity in the previous iteration to remain in the new iteration. In order to use the inertia weight in this paper, a descending linear function is used. The best range for changing this function value for the convergence and obtaining the best possible solution is between 0.9 and 0.4.

Using the inertia weight in velocity equation enables the swarm to fly in larger area of the search space (W = 0.9) and at the end of the iterations, the search space will be smaller (W = 0.4).By using the inertia weight the chance to obtain a best solution for a optimization problem will be more. In general, a linear descending function for inertia weight

equation is shown in the following equation [13, 18].

W= Wmax –iter * [(Wmax – Wmin)/itermax]

Where W= inertia weight factor

Wmax = maximum value of weighting factor

Wmin = minimum value of weighting factor

itermax = maximum number of iteration

iter = current number of iteration

b) initial global best position

One of the important things to increase the convergence rate is choosing a correct initial position for global minimum. In this paper, the initial global best is placed in a certain area of the search space. This location is determined regarding to the constraints. In general, the PSO flowchart for unconstraint optimization is shown below:

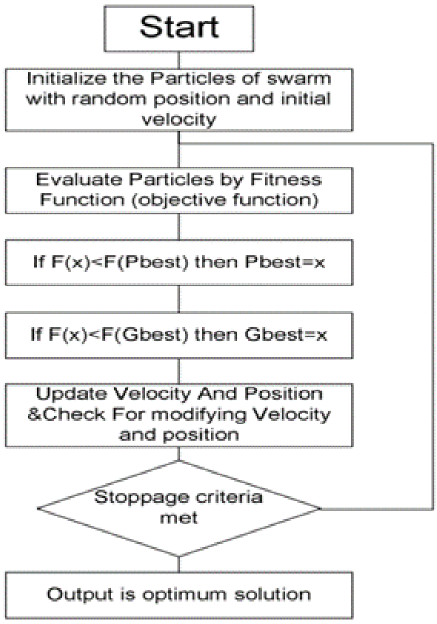
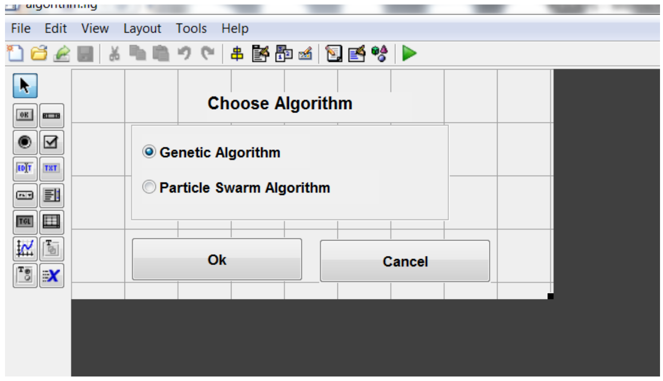
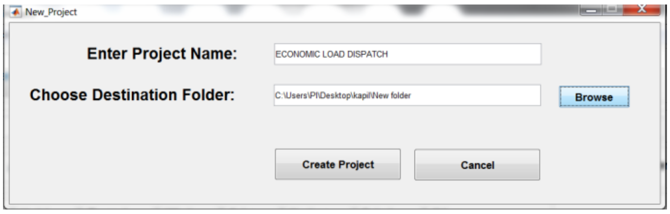
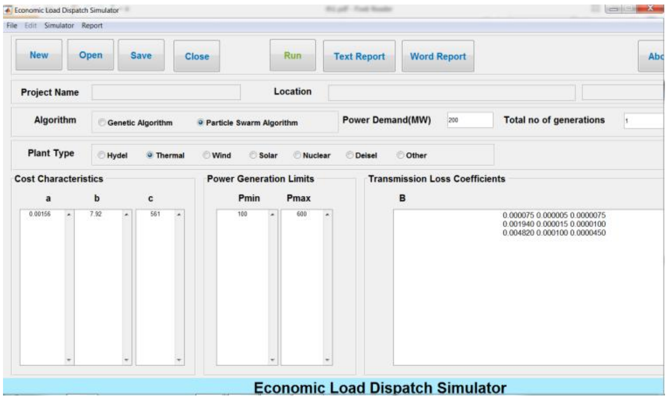


Figure 1: PSO flow chart







IV. RESULTS AND DISCUSSION

The different methods discussed earlier are applied to two cases to find out the minimum cost for any demand. We have studied and implemented three generator units systems. Results of Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) are compared with the conventional lambda iteration method. In the first case transmission losses are neglected and then transmission line losses are also considered. All these simulations are done on MATLAB 9.2/MATLAB 2018 environment.

CASE-1

Table 1: Cost Function Coefficient

Plant	a	b	c	P_{min}(MW)	P_{max}(MW)	Power Demand	Total Cost(Rs/Hr)	Transm. Losses(MW)
1	0.00156	7.92	561	100	600	200	2210.40 2285.00 2400.20	3.00 77.60 192.80
1	0.00156	7.92	561	100	600	300	3084.15 3252.00 3511.20	6.75 174.60 433.80
1	0.00156	7.92	561	100	600	400	3979.80 3980.20 3985.80	1.20 1.60 7.20
2	0.00194	7.85	310	100	400	150	1532.84 1574.80 1531.26	1.69 43.65 0.11

2	0.00194	7.85	310	100	400	250	2398.44 2515.00 2394.06	4.69 121.25 0.31
2	0.00194	7.85	310	100	400	350	3304.34 3532.80 3295.76	9.19 237.65 0.61
3	0.00482	7.97	78	50	200	60	573.82 580.54 573.57	0.27 6.98 0.02
3	0.00482	7.97	78	50	200	120	1104.89 1131.74 1103.88	1.08 27.94 0.07
3	0.00482	7.97	78	50	200	180	1671.20 1731.62 1668.93	2.43 62.86 0.16

Experimental Results

Following results obtained during simulation

Test Simulation1

Algorithm: Particle Swarm Optimization

Power Demand = 200.000000 MW

No of generation = 1

Type of plant: Thermal

Cost Characteristics

F = 0.00156000 7.92000000 561.00000000

Generation Lower Limit:

Pmin (1) = 100.00000000 MW

Generation Upper Limit:

Pmax (1) = 600.00000000 MW

B-Coefficient Matrix

B = 0.00007500

Generation Schedule:

P (1) = 200.00000000

Cost and Transmission Lost Details:

Total Cost, F = 2210.40 Rs/hr

Total Cost, F = 2285.00 Rs/hr

Total Cost, F = 2400.20 Rs/hr

Total Cost, F = 2207.60 Rs/hr

Total Cost, F = 2208.00 Rs/hr

Total Cost, F = 2211.40 Rs/hr

Total Cost, F = 2207.70 Rs/hr

Total Cost, F = 2207.80 Rs/hr

Total Cost, F = 2209.20 Rs/hr

Transmission Loss, PL = 3.00 MW

Transmission Loss, PL = 77.60 MW

Transmission Loss, PL = 192.80 MW

Transmission Loss, PL = 0.20 MW

Transmission Loss, PL = 0.60 MW

Transmission Loss, PL = 4.00 MW

Transmission Loss, PL = 0.30 MW

Transmission Loss, PL = 0.40 MW

Transmission Loss, PL = 1.80 MW

Time taken to execute program, t = 0.10000000 Seconds

Test Simulation2

Algorithm: Particle Swarm Optimization

Power Demand = 400.000000 MW

No of generation = 1

Type of plant: Thermal

Cost Characteristics

F = 0.00156000 7.92000000 561.00000000

Generation Lower Limit:

Pmin (1) = 100.00000000 MW

Generation Upper Limit:

Pmax (1) = 600.00000000 MW

B-Coefficient Matrix

B = 0.00007500

Generation Schedule:

P (1) = 400.00000000

Cost and Transmission Lost Details:

Total Cost, F = 3990.60 Rs/hr

Total Cost, F = 4289.00 Rs/hr

Total Cost, F = 4749.80 Rs/hr

Total Cost, F = 3979.40 Rs/hr

Total Cost, F = 3981.00 Rs/hr

Total Cost, F = 3994.60 Rs/hr

Total Cost, F = 3979.80 Rs/hr

Total Cost, F = 3980.20 Rs/hr

Total Cost, F = 3985.80 Rs/hr

Transmission Loss, PL = 12.00 MW

Transmission Loss, PL = 310.40 MW

Transmission Loss, PL = 771.20 MW

Transmission Loss, PL = 0.80 MW

Transmission Loss, PL = 2.40 MW

Transmission Loss, PL = 16.00 MW

Transmission Loss, PL = 1.20 MW

Transmission Loss, PL = 1.60 MW

Transmission Loss, PL = 7.20 MW

Time taken to execute program, t = 0.20000000 Seconds

Test Simulation3

Algorithm: Particle Swarm Optimization

Power Demand = 150.000000 MW

No of generation = 1

Type of plant: Thermal

Cost Characteristics

F = 0.00194000 7.85000000 310.00000000

Generation Lower Limit:

Pmin (1) = 100.00000000 MW

Generation Upper Limit:

Pmax (1)= 400.00000000 MW

B-Coefficient Matrix

B = 0.00007500

Generation Schedule:

P (1)= 150.00000000

Cost and Transmission Lost Details:

Total Cost, F = 1532.84 Rs/hr

Total Cost, F = 1574.80 Rs/hr

Total Cost, F = 1639.60 Rs/hr

Total Cost, F = 1531.26 Rs/hr

Total Cost, F = 1531.49 Rs/hr

Total Cost, F = 1533.40 Rs/hr

Total Cost, F = 1531.32 Rs/hr

Total Cost, F = 1531.38 Rs/hr

Total Cost, F = 1532.16 Rs/hr

Transmission Loss, PL = 1.69 MW

Transmission Loss, PL = 43.65 MW

Transmission Loss, PL = 108.45 MW

Transmission Loss, PL = 0.11 MW

Transmission Loss, PL = 0.34 MW

Transmission Loss, PL = 2.25 MW

Transmission Loss, PL = 0.17 MW

Transmission Loss, PL = 0.23 MW

Transmission Loss, PL = 1.01 MW

Time taken to execute program, t = 0.10000000 Seconds

Test Simulation4

Algorithm: Particle Swarm Optimization

Power Demand = 350.000000 MW

No of generation = 1

Type of plant: Thermal

Cost Characteristics

F = 0.00194000 7.85000000 310.00000000

Generation Lower Limit:

Pmin (1) = 100.00000000 MW

Generation Upper Limit:

Pmax (1) = 400.00000000 MW

B-Coefficient Matrix

B = 0.00007500

Generation Schedule:

P (1) = 350.00000000

Cost and Transmission Lost Details:

Total Cost, F = 3304.34 Rs/hr

Total Cost, F = 3532.80 Rs/hr

Total Cost, F = 3885.60 Rs/hr

Total Cost, F = 3295.76 Rs/hr

Total Cost, F = 3296.99 Rs/hr

Total Cost, F = 3307.40 Rs/hr

Total Cost, F = 3296.07 Rs/hr

Total Cost, F = 3296.38 Rs/hr

Total Cost, F = 3300.66 Rs/hr

Transmission Loss, PL = 9.19 MW

Transmission Loss, PL = 237.65 MW

Transmission Loss, PL = 590.45 MW

Transmission Loss, PL = 0.61 MW

Transmission Loss, PL = 1.84 MW

Transmission Loss, PL = 12.25 MW

Transmission Loss, PL = 0.92 MW

Transmission Loss, PL = 1.23 MW

Transmission Loss, PL = 5.51 MW

Time taken to execute program, t = 0.10000000 Seconds

Test Simulation5

Algorithm: Particle Swarm Optimization

Power Demand = 60.000000 MW

No of generation = 1

Type of plant: Thermal

Cost Characteristics

F = 0.00482000 7.97000000 78.00000000

Generation Lower Limit:

Pmin (1) = 50.00000000 MW

Generation Upper Limit:

Pmax (1) = 200.00000000 MW

B-Coefficient Matrix

B = 0.00007500

Generation Schedule:

P (1) = 60.00000000

Cost and Transmission Lost Details:

Total Cost, F = 573.82 Rs/hr

Total Cost, F = 580.54 Rs/hr

Total Cost, F = 590.90 Rs/hr

Total Cost, F = 573.57 Rs/hr

Total Cost, F = 573.61 Rs/hr

Total Cost, F = 573.91 Rs/hr

Total Cost, F = 573.58 Rs/hr

Total Cost, F = 573.59 Rs/hr

Total Cost, F = 573.71 Rs/hr

Transmission Loss, PL = 0.27 MW

Transmission Loss, PL = 6.98 MW

Transmission Loss, PL = 17.35 MW

Transmission Loss, PL = 0.02 MW

Transmission Loss, PL = 0.05 MW

Transmission Loss, PL = 0.36 MW

Transmission Loss, PL = 0.03 MW

Transmission Loss, PL = 0.04 MW

Transmission Loss, PL = 0.16 MW

Time taken to execute program, t = 0.10000000 Seconds

Test Simulation6

Algorithm: Particle Swarm Optimization

Power Demand = 180.000000 MW

No of generation = 1

Type of plant: Thermal

Cost Characteristics

F = 0.00482000 7.97000000 78.00000000

Generation Lower Limit:

Pmin (1) = 50.00000000 MW

Generation Upper Limit:

Pmax (1) = 200.00000000 MW

B-Coefficient Matrix

B = 0.00007500

Generation Schedule:

P (1) = 180.00000000

Cost and Transmission Lost Details:

Total Cost, F = 1671.20 Rs/hr

Total Cost, F = 1731.62 Rs/hr

Total Cost, F = 1824.94 Rs/hr

Total Cost, F = 1668.93 Rs/hr

Total Cost, F = 1669.25 Rs/hr

Total Cost, F = 1672.01 Rs/hr

Total Cost, F = 1669.01 Rs/hr

Total Cost, F = 1669.09 Rs/hr

Total Cost, F = 1670.23 Rs/hr

Transmission Loss, PL = 2.43 MW

Transmission Loss, PL = 62.86 MW

Transmission Loss, PL = 156.17 MW

Transmission Loss, PL = 0.16 MW

Transmission Loss, PL = 0.49 MW

Transmission Loss, PL = 3.24 MW

Transmission Loss, PL = 0.24 MW

Transmission Loss, PL = 0.32 MW

Transmission Loss, PL = 1.46 MW

Time taken to execute program, t = 0.100000000 Seconds

Results of PSO method without losses

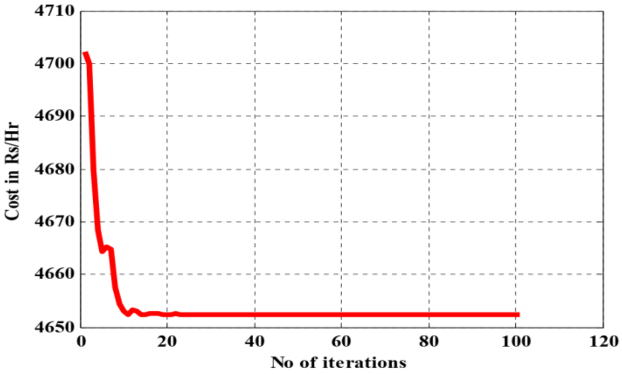


Fig 2: Cost curve of 450 MW demand by PSO method without loss

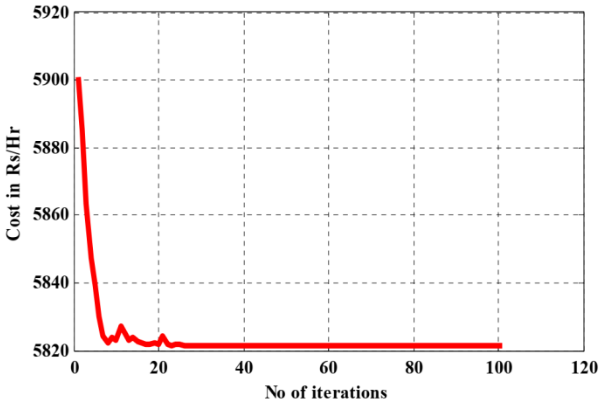


Fig 3: Cost curve of 585 MW demand by PSO method without loss

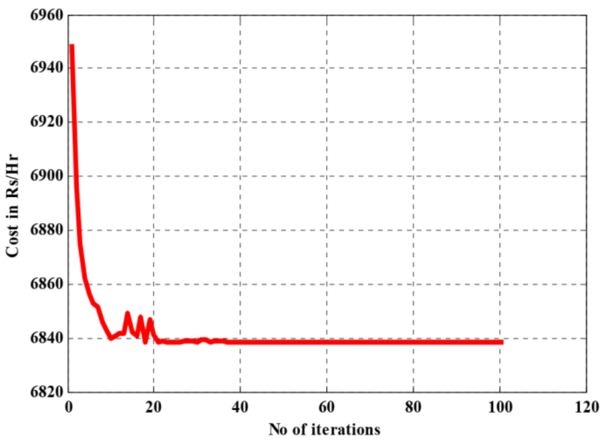


Fig 4: Cost curve of 700 MW demand by PSO method without loss

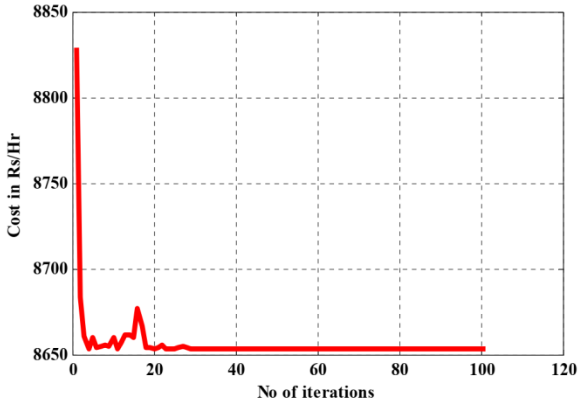


Fig 5: Cost curve of 900 MW demand by PSO method

Results for PSO with losses

In this method the initial particles are randomly generated within the feasible range. The parameters c1, c2 and inertia weight are selected for best convergence characteristic. Here, c1 = 1.99 and c2 = 1.99 Here the maximum value of w is chosen 0.9 and minimum value is chosen 0.4.the velocity limits are selected as vmax= 0.5*Pmax and the minimum velocity is selected as vmin= -0.5*Pmin. There are 10 nos of particles are selected in the population. For different value of c1 and c2 the cost curve converges in the different region. So, the best value is taken for the minimum cost of the problem. If the no of particles is increased then cost curve converges faster. It can be observed the loss has no effect on the cost characteristic.

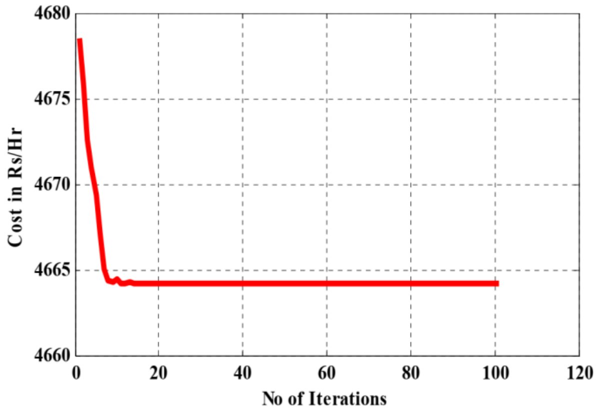


Fig 6: Cost curve of 450 MW demand by PSO method with loss

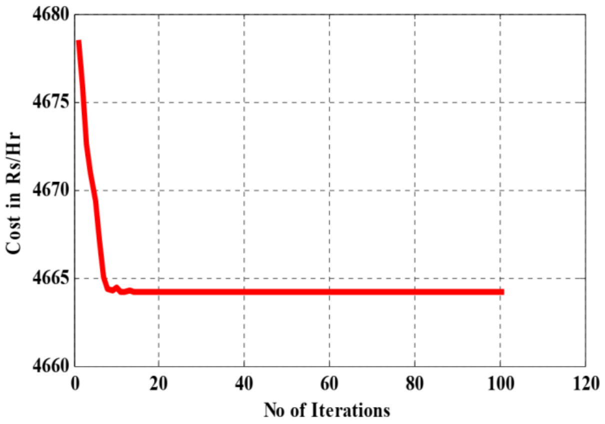


Fig 7: Cost curve of 585 MW demand by PSO method with loss

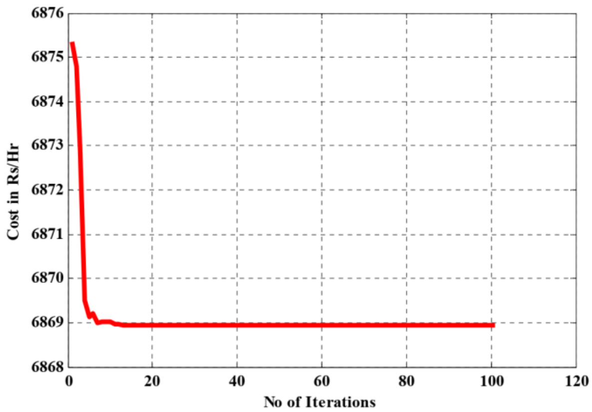


Fig 8: Cost curve of 700 MW demand by PSO method with loss

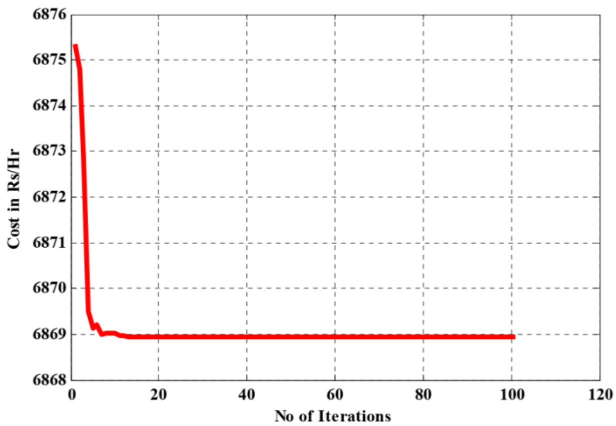


Fig 9: Cost curve of 900 MW demand by PSO method with loss

CONCLUSION

Economic load dispatch in electric power sector is an important task, as it is required to supply the power at the minimum cost which aids in profit-making. As the efficiency of newly added generating units are more than the previous units the economic load dispatch has to be efficiently solved for minimizing the cost of the generated power. Load dispatch problem here solved for one case i.e One with three units in generating stations. Each problem is solved by PSO method considering different cases in the MATLAB environment. Before the thesis draws to a close, major studies reported in this work and the general conclusions that emerge out from this work are highlighted. The conclusions are arrived at based on the performance and the capabilities of the PSO application presented here. This finally leads to an outline of the future directions for research and development efforts in this area.

The main conclusions drawn are:

Three-unit system:

Both the problem of three units' system without loss and with loss is solved by using PSO method. In old methods such as Lambda-iteration method some better cost is obtained but the problem converges when the lambda value is selected within the feasible range. But the cost characteristic takes many numbers of iteration converge. In PSO and GA method the cost characteristic converges in a smaller number of iterations. When transmission losses are considered in PSO method it gives a better result than the Lambda iteration method. In case of Lambda iteration method, the number of iterations to converge is also increases. But in PSO method no of iterations are not affected when the transmission line losses are considered. In PSO method selection of parameters c1, c2 and w is very much important. The best result obtained when c1 = 2.01 and c2= 2.01 and w value is chosen near 0.8. These results are similar when w is chosen according to the formula used.

FUTURE SCOPE

Here the loss co-efficient are given in the problem. The work may be extended for the problem where transmission loss co-efficient are not given. In that case the loss co-efficient can be calculated by solving the load flow problem.

The two methods apply in this work are giving better result but GA convergence characteristic is better than PSO and in some cases the PSO gives better result than GA method. So, both the methods can be combined to find a better solution.

In PSO method selection of parameters are important. So, the parameters may be optimized by using the ANN method. Any other method can be applied with PSO to improve the performance of the PSO method.

This work may be extended for new optimization techniques, like Bacterial Foraging (BFO) and Artificial Immune Systems (AIS). This may be used to compare and find out the better optimization technique.

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