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Implementation of Particle Swarm Optimization for Dynamic Economic Load Dispatch Problem

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***Abstract*— The economic operation of the generating systems has always occupied an important position in the electric power industry. It is one of the complex problems of the power system. The aim of the dynamic economic load dispatch problem is to find the optimal combination of generators in order to minimize the operating costs of the system. The load demand must be appropriately shared among the various generating units of the system. This work is done by using the particle swarm optimization (PSO) algorithm. PSO is applied to search for the optimal schedule of all the generator units that can supply the required load demand at minimum fuel cost while satisfying all system constraints such as Generator constraints, Ramp rate limits, Transmission losses and valve point effect. The PSO method was developed through the simulation of a simplified social system. The simulations were performed over various test systems with 5 generation units. So by using PSO we have done the dynamic economic load dispatch thereby reducing the operating costs of the system**

Keywords— ***Dynamic economic load dispatch, Particle swarm optimization, generator constraints, ramp-rate limits, valve point effect.***

I. INTRODUCTION

As we know it is the responsibility of the electric power system or the electric utilities to provide the smooth electric energy to the consumers in order to fulfill their load demands. The engineers are in charge of the efficient and reliable operation of these electric power generation systems. The cost of the generation and operation of the electric systems has become a fundamental issue of the power industry. It has become crucial to adopt an efficient and reliable method for the load dispatch for the development of the power market. The economic load dispatch is used to allot the load demand to the various committed generators while reducing the running costs. The economic load dispatch has always occupied an important position in the electric power industry as a complex problem of the power system [5, 6]. It has always been desirable to obtain the efficient and economic operation of the system. With the passage of time, the consumer load demands are increasing and also the fuel costs are booming day by day, so the operating costs of the system also enhances with time. Due to these high rises there is a sudden urge to maintain the economical operation of the system. It has become a crucial issue to reduce the operating costs. The operation costs include the fuel costs and other costs like service and maintenance costs. The service and maintenance costs are small and a just a fixed proportion, so we can say the operating costs are mainly the fuel costs and here in this work we have to minimize these costs. The main aim is to operate the system at minimum costs while satisfying the consumer demands. For this the consumer load demand is divided into the various available generating units of the system. We can say that each unit is assigned or allotted a particular load value. The dynamic economic load dispatch allots each generating unit a particular load demand and the electrical power system is thus operated economically. Thus the aim of the DELD is to contribute in the profit-making of the electric power industry.

In the last decades a lot of research has been done and various methodologies and techniques have been proposed in the technical literature for this purpose. These techniques majorly include the Evolutionary Programming (EP), Simulated Annealing (SA),Tabu search, Linear and Dynamic programming, Hopfield neural network, lambda iteration method etc. and the evolutionary computation technique such as Genetic Algorithm, Adaptive Genetic Algorithm, Artificial Neural Network (ANN), Particle Swarm Optimization (PSO) etc. PSO is one of the latest heuristic techniques which can be used to solve continuous non-linear optimization techniques [14, 15, 16, 17, 18, 19]. This method is a very efficient and a robust optimization technique to solve various kinds of problems. This method outperforms the other algorithms with respect to the computational time and its accuracy. PSO is also found out to be effective in locating the optimal point even in the static and the dynamic environments [1, 2].

The method used here is the particle swarm optimization technique (PSO). The main objective of the work done here is to minimize the total cost of generation (operating costs) while satisfying the various constraints while fulfilling the customer load demand. So, by implementing the PSO algorithm, the optimal combination of generator units is thus obtained in order to minimize the operating costs of the system.

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This paper is organised in the various sections as defined. In section II, A brief review of the Dynamic Economic Load Dispatch is done. In section III, the technique used to solve the problem i.e, Particle swarm optimization (PSO) is discussed along with the algorithm and flowchart. In section IV the test system and the experimental results are shown. Finally the conclusions are drawn in section V followed by references.

II. DYNAMIC ECONOMIC LOAD DISPATCH

The main objective of the economic load dispatch is to reduce the operating costs or the generation costs of the system while satisfying the various system constraints. The DELD problem is formulated to find the optimal combination of the generators while satisfying the consumer load demands and also satisfying the various equality and inequality constraints. The problem here is to minimize the total generating cost function as defined in the equation (1). We have to minimize the objective function (total total cost of the power system) subjected to the various constraints.

$$min\ F = \sum_{t=1}^{T}\sum_{i=1}^{N} F_{it}(P_{it}) \quad (1)$$

Where,

F_t= Total operating cost of power system

$F_i(P_i)$ = The cost function of *ith* generator

P_i = Real power output of *ith* generator

N = The number of generators used

T= The no of intervals

The cost of each generator in the simplified DELD problem can be presented by a single quadratic cost function defined below:

$$F_{it}(P_{it}) = a_i P_{it}^2 + b_i P_{it} + c_i \quad (2)$$

Here a_i, b_i and c_i denote the cost coefficients of the ith generator.

This quadratic equation changes if we consider the valve point effects. A sinusoidal function is added to the existing equation (2) and the equation becomes:

$$F_{it}(P_{it}) = a_i P_{it}^2 + b_i P_{it} + c_i + \left|e_i \sin\left(f_i(P_{i\,min} - P_{it})\right)\right| \quad (3)$$

Here e_i and f_i are the cost functions corresponding to valve point loading. [11]

There are two types of constraints i.e, the equality and the inequality constraints

The following is the inequality constraint for each generator that should be satisfied:

$$P_{i\,min} \le P_i \le P_{i\,max} \quad (4)$$

These are also called the generator constraints.

The generation power for each generator should locate between the upper and lower limits.

The following is the equality constraint:

$$\sum_{i=1}^{N} P_i = P_L + P_D \quad (5)$$

This is the power balance equation. Here P_D is the demand and P_L is transmission loss.

The transmission loss can be calculated by the B-coefficients method or power flows analysis. B-coefficients used in the power system are:

$$P_L = P^T BP + P^T B_0 + B_{00} \quad (6)$$

The total transmission losses are :

$$P_L = \sum \sum P_m\ B_{mn} P_n \quad (7)$$

Where, B_{mn} is the square matrix transmission coefficients and P is a matrix of the power output of the Units. In some cases the transmission losses can be neglected while in some cases these are considered.

III. PARTICLE SWARM OPTIMIZATION

The particle swarm optimization is a population based stochastic optimization technique. This is based on the concept of swarms and their intelligence as well as their movement. This algorithm was developed in 1995 by James Kennedy and Russell Eberhart [3]. PSO comprises of a group of creatures (particles) performing the same action in a search space.

The swarms are basically the groups that serve the same purpose like food hunting. The PSO is inspired from the relative behaviour of the creatures that live and move in groups like swarm of birds or bees and school of fishes etc.

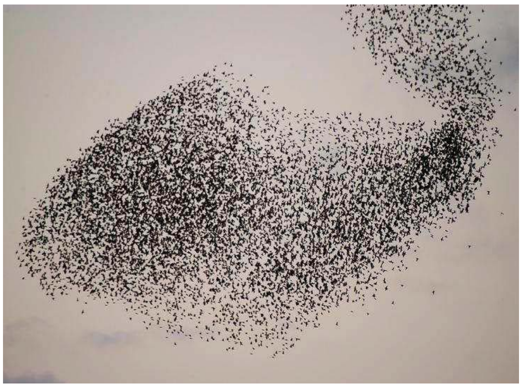

Fig. 1 Swarm of birds

The above figure demonstrates a swarm of birds. This concept is used in the PSO algorithm. Here the birds are analogous to the particles. In PSO there is huge multi-dimensional search space with particles within it. The particles move freely in the search space looking for the optimal solution. Each particle has a particular velocity and a position.

The particles and velocity are denoted by the vectors *v* and *x*.

$$\begin{bmatrix} v_1, v_2, v_3 \ldots\ldots\ldots v_n \\ x_1, x_2, x_3 \ldots\ldots\ldots x_n \end{bmatrix}$$

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Each particle represents a potential solution to the problem and they are responsible to search the solutions within the search space. All particles have a particular fitness value which is evaluated by the fitness function. The velocity as well as the particle position is updated by the velocity and position update rules. The position of the particles is updated with the flying experience of the particle and by that of its neighbours. The best values so far achieved by the particles are stored in the memory as *pbest* or personal best and the best among all the particles is called as *gbest* or global best. By using the concept of *pbest* and *gbest* the velocity of each particle is updated

$$v_i^{K+1} = w * v_i^K + c_1 * rand_1 * (P_{best} - x_i^K) + c_2 * rand_2 * (g_{best} - x_i^K) \quad (7)$$

Where,

vi^{k+1} : Particle velocity at current iteration *(k+1)*

v^{ik} : Particle velocity at *k*th iteration

$rand_1$, $rand_2$: Random number between [0, 1]

c_1, c_2: Acceleration constant

w: Inertia weight

In the equation (7) the inertia weight w is introduced to enable the swarm to fly in the larger search space. The suitable value of w should be chosen so as to provide balance between the local and the global explorations. This thus reduces the number of iteration to find the optimal solution.

In the equation (7) the second part of the equation ($c_1 * rand_1 * (P_{best} - x_i^K)$) is the particle memory influence and the third part ($c_2 * rand_2 * (g_{best} - x_i^K)$) is the swarm influence.

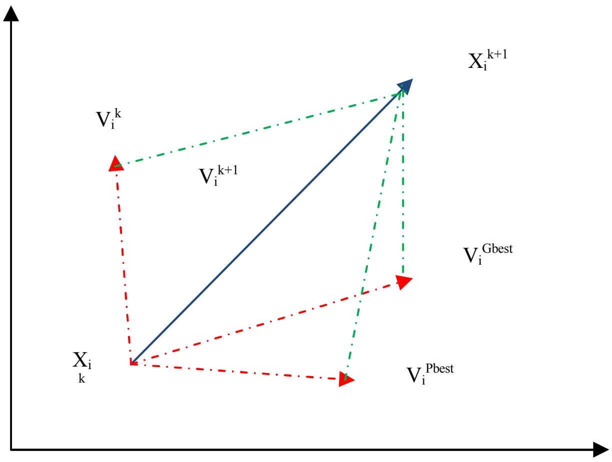

Fig. 2 Position and velocity updating in PSO

After this, the particles fly to a new position according to the position update rule:

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (8)$$

Where,

Xi^{k+1} *:* Current particle position at iteration k+1

X^{ik} : Particle position at iteration k

Vi^{k+1} : Particle velocity at iteration k+1

In general, the inertia weight W can be set according to the following equation

$$W = W_{max} - \left[\frac{(W_{max} - W_{min})}{ITER_{max}}\right] ITER \quad (9)$$

Where,

W - Inertia weight factor

W_{max} - Maximum value of weighting factor

W_{min} - Minimum value of weighting factor

$ITER_{max}$ - Maximum number of iterations

$ITER$ - Current number of iteration

The value for W_{max} is usually 0.9 and that of W_{min} is 0.4. We can say the value of W reduces linearly during a run. [1, 2]

A. PSO Algorithm

The sequential steps of the proposed PSO method which is used to solve DELD problem are as given below:

Step 1: Read the system input data which comprises of the fuel cost curve coefficient and the various constraints like the generator constraints, ramp rate limits, transmission loss coefficients, the number and the duration of the intervals etc.

Step 2: Initialize the particles of the population in a random manner. This should be according to the limits of each unit which includes the individual dimensions, velocities and the search points. Also set the iteration counter.

Step 3: Next evaluate the fitness function for each particle.

Step 4: Now the comparison is done. For each individual particle compare the fitness with *pbest*. If the value of fitness is better then *pbest* then set this value as *pbest*.

Step 5: Identify the particle with best fitness value which is *gbest.* The best value among the *pbest* of all particles is *gbest.*

Step 6: Update and modify the velocity of each particle according to the velocity update rule defined by

$$V_i^{k+1} = V_i^k + c1r1\,(X_{pbest} - X_i^k) + c2r2\,(X_{gbest} - X_i^k) \quad (10)$$

Also, the particles fly to a new position using the position update rule

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$$X_i^{k+1} = X_i^k + V_i^{k+1} \qquad (11)$$

Step 7: If the number of iterations reaches the maximum, then go to step 8 other wise, set the iteration count to the next value and go to step2.

Step 8: The particle that generates the latest best is the solution of the problem**.** This is the optimal solution.

B. PSO Flowchart

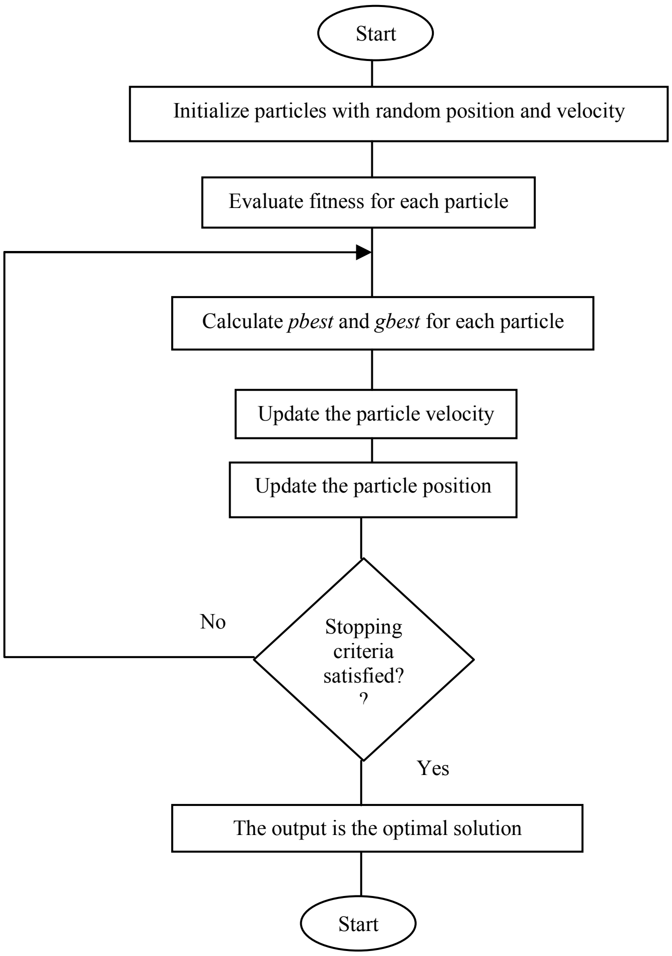

Fig. 3 Flowchart of PSO

IV. RESULTS AND DISCUSSION

In this work we have considered a test system with 5 generating units. Now the load demand is to be allotted to these units while minimizing the costs of generation subjected to the various constraints. Here the constraints like the transmission losses, the ramp rate limit and valve point loading effect are considered for the load demand over the 24 hour time interval. After conducting many experiments in the wide range to obtain the fuel cost value, the PSO parameters are selected. The initial position of the particles is random and the parameters like the acceleration constants (c1 and c2), the inertia weight factors (w_{min} and w_{max}), the number of iterations and the population size are defined. The population size must be such set that it is not too small or too large. If it is small there will be insufficient number of particles so there will be difficulty in producing the best possible solution. If the population size is too large then the algorithm will become slow. The initial position of the particles is random. The final values of the various parameters which are considered in this work are defined in the tables. [11, 12, 13]

TABLE I

PARAMETERS OF PSO

Parameters	**Value**
Initial position	Random
Population size	100
No of iterations	300
Acceleration constants: c_1, c_2	2.0
Inertia weight: W_{min}, W_{max}	0.3, 0.9

TABLE III

DATA OF FIVE GENERATING UNITS

Generation units	**Cost function coefficients**			$\mathbf{P_{min}}$	$\mathbf{P_{max}}$
	$\mathbf{a_i}$	$\mathbf{b_i}$	$\mathbf{c_i}$		
G1	0.0015	1.8	40	50	300
G2	0.0030	1.8	60	20	125
G3	0.0012	2.1	100	30	175
G4	0.0010	2	40	40	250
G5	0.0080	2	10	10	75

This is the B_{mn} matrix i.e, the matrix for transmission losses.

B_{mn} matrix=

$$\begin{bmatrix} 0.49 & 0.14 & 0.15 & 0.15 & 0.20 \\ 0.14 & 0.45 & 0.16 & 0.20 & 0.18 \\ 0.15 & 0.16 & 0.39 & 0.10 & 0.12 \\ 0.15 & 0.20 & 0.10 & 0.40 & 0.14 \\ 0.20 & 0.18 & 0.12 & 0.14 & 0.35 \end{bmatrix}$$

The simulation is performed for over 50 trials and the best optimal power generation schedule obtained for 5 generators in the 24 hour scheduling horizon is obtained. This optimal combination of generator fulfills the objective i.e, we can fulfill the load demand at the minimum costs of production. The optimal combination of generating units is obtained from the proposed PSO as shown in Table III.

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TABLE IIIII

OPTIMAL SCHEDULING OF THE GENERATING UNIT

Time	G1 (Mw)	G2 (Mw)	G3 (Mw)	G4 (Mw)	G5 (Mw)	Loss (Mw)	Demand (Mw)	Operating Cost ($)
1.	10.9251	20.9251	112.3306	40.9251	229.5196	4.6254	410	1250.80
2.	35.8103	21.0011	112.6735	41.0011	229.5196	5.0057	435	1394.30
3.	65.8103	31.5400	112.6735	41.1358	229.5196	5.6792	475	1540.50
4.	75.0000	28.3201	112.6735	91.1358	229.5196	6.6490	530	1784.50
5.	75.0000	23.1328	112.6735	124.9079	229.5196	7.2338	558	1650.20
6.	75.0000	24.3220	112.6735	174.9079	229.5196	8.4230	608	1947.10
7.	61.1792	21.7970	112.6735	209.8158	229.5196	8.9851	626	1839.40
8.	75.0000	36.6221	112.6735	209.8158	229.5196	9.6310	654	1944.00
9.	75.0000	66.6221	119.5714	209.8158	229.5196	10.5289	690	2112.80
10.	66.3383	96.6221	112.6735	209.8158	229.5196	10.9693	704	2003.20
11.	75.0000	104.4010	112.6735	209.8158	229.5196	11.4099	720	2040.80
12.	75.0000	125.0000	112.6930	209.8158	229.5196	12.0284	740	2181.70
13.	64.4275	98.5398	112.6735	209.8158	229.5196	10.9762	704	1996.70
14.	50.0806	98.5398	112.6735	209.8158	229.5196	10.6293	690	1978.80
15.	22.0319	89.7157	112.6735	209.8158	229.5196	9.7564	654	1883.00
16.	11.5676	72.6939	112.6735	161.3834	229.5196	7.8380	580	1911.20
17.	11.4607	86.742	112.6735	124.9079	229.5196	7.3037	558	1626.90
18.	41.4607	107.8422	112.6735	124.9079	229.5196	8.4039	608	1827.90
19.	71.4607	124.972	112.6735	124.9079	229.5196	9.5337	654	1985.10
20.	75.0000	98.5398	136.8303	174.9079	229.5196	10.7976	704	2269.00
21.	47.0718	91.2785	112.6735	209.8158	229.5196	10.3592	680	1993.90
22.	18.7539	90.9653	112.6735	161.4978	229.5196	8.4101	605	1920.50
23.	11.3283	62.2937	105.5922	124.9079	229.5196	6.6417	527	1672.20
24.	11.0963	33.39	69.5678	124.9079	229.5196	5.4817	463	1576.80
Total minimum generating cost ($/day)								44331.30

In the dynamic economic load dispatch the load demand changes every hour. The operating costs changes with respect to the load and this load demand is divided within the generation units. We can see from the Table III, The optimal scheduling of the generating units has been done. The test system considered in this work was a system with five generating units and the load has been divided or allotted to these units such that the total generating costs are reduced. The division of load demand is done such that the total load demand is fulfilled and that too economically.

This will be extended by increasing the number of generating units and comparison of PSO method will be done with the other methods by comparing the results.

CONCLUSION

Economic load dispatch in electric power sector is an important task in the electrical power system as it is required to supply the power at the minimum cost which aids in profit-making. The total generation costs are minimized by dividing the load demand into the several units while satisfying the constraints. The Load dispatch problem here is solved for the five generating units system. The work is done by implementing Particle swarm optimization (PSO) in the MATLAB environment. The dynamic economic load dispatch can be done by the various other methods like the genetic algorithm, evolutionary programming, dynamic programming etc and the results can be compared to find which method is better.

ACKNOWLEDGMENT

I would like to give my sincere thanks to the Department of Electrical Engineering at School of Engineering of Gautam Buddha University for providing a solid background for the studies and research thereafter.

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