PARTICLE SWARM OPTIMIZATION TECHNIQUE FOR DYNAMIC ECONOMIC DISPATCH

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Abstract

Economic Dispatch (ED) Problem is critical in power system operations as it gives the optimal schedule of the generators so that total operating cost of generation is minimum, while satisfying the generator constraints and the system constraints. The traditional ED doesn't take into account the valve point loading on the cost curve, ramp up and ramp down capability of the thermal generating units. The above said issues can't be over looked as they are a more realistic approach to the ED problem. The ED problem considering the Ramp limits and valve point effects is called Dynamic Economic Dispatch (DED). The present work aims to solve DED problem of a five generator system using Refined Genetic Algorithm (RGA) and Particle Swarm optimization (PSO) technique. The Solution obtained by PSO gives a better optimal solution compared to RGA, the results obtained are duly discussed.

Keywords: *Dynamic Economic Dispatch, Particle Swarm Optimization Technique, Refined Genetic Algorithm, Valve Point Loading, Ramp Up and Ramp Down Capability.*

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1. INTRODUCTION

Electrical energy cannot be stored in bulk quantity; therefore the power generated should be consumed instantaneously. In other words the demand for electrical power should be met at each and every instant of time precisely. Any imbalances in the power will drastically affect the power system parameters. Therefore the power produced should be equal to the sum of power consumed and power loss in the power system. Every utility in general will always aim for higher profits by utilizing the available resources effectively, so does the power sector companies. The power system companies have to maintain the stringent technical constraints like the balance in power, apart from maximizing the profits. The load dispatch centers may use Economic Dispatch(ED) Program to arrive at a technically feasible and economically optimal solution [1][2][3]. But the ED problem has some handicaps like considering the load to be static but it is not true in real life situations. The load varies at every instant.

To overcome the handicaps of the ED problem Dynamic Economic Dispatch (DED) has been devised which considers the load to be quasi static over an hour which is a better approximation of the problem. The generators should be rescheduled every hour. The reschedule of the generators may sometime give absurd solution that the generators have to change their power generation drastically within a short time which may not be possible. To look after such anomalies, the present work considers the capability of the generators rate of increase or decrease the output power. This can be considered by designing the rate at which the output power can be changed as a constraint known as ramp and down limits [6].

The traditional way of modeling the objective function of the ED problem as a quadratic function of real power is also not a good approximation as it does not consider the effects of valves in the steam turbines [3]. As the power production of the generator has to increase obviously the steam input of the turbines should be increased. In a multi stage turbine there will be a number of valves in the steam path as the power output of the turbine has to be increased the number of valves which has to be opened also increases. The effect of opening and closing of steam valves on the cost of generation cannot be ignored if an exact optimal solution of the problem is desired. The expenses of opening and closing of the steam valves can be modeled as a sinusoidal component in the cost function as they involve additional running cost and maintenance costs. The present work considers the effect of the valves in the overall cost of generation.

In the recent past many methods have been applied to solve the ED problem for a variety of test systems [1]-[20]. The methods to solve the ED problem can be classified as conventional methods [1]-[4] and non conventional methods [5]-[20]. The conventional methods include Newton's method, Lambda Iteration method, Gradient methods, etc [1] are able to solve the ED problem effectively. But the classical dispatch algorithms have the drawback that the cost curve has to be modeled as a linear function [2]. The classical modeling of the cost function as a quadratic will not represent the effects of valves in the cost function. This makes the ED problem non linear and getting a solution by the classical method become more difficult and may not be possible for larger size systems. The classical optimization methods may also fail to solve the DED problem and in many cases may converge to the local optima or may fail to converge at all. The latest and more advanced optimization techniques based on natural theories have the capability of attaining the global optima due to their cognitive nature of the techniques. Of late Genetic Algorithm based techniques [7]-[11] and Particle Swarm optimization Techniques [17][19] are gaining popularity in solving multi objective non linear optimization problems. In spite of larger computational burden and more execution time compared to the classical methods these nature imitating techniques converge to near global optima or global optima regardless of complexity in the problem.

In the present paper DED problem is solved for a three unit and five unit systems for twenty four hours of a day using Refined Genetic Algorithm (RGA) and particle Swarm optimization (PSO). Programs are developed for the methods to solve DED problem in GNU Octave which is an open source alternative to MATLAB®. The solutions obtained by the developed programs are presented and are properly interpreted.

2. DYNAMIC ECONOMIC LOAD DISPATCH

A power system usually has abundant power resources than the power demand keeping in view the system security and reliability. There are many generators to supply the loads. The generators are scheduled so that the total generation is equal to the total load plus losses. This schedule of the powers can be done considering the cost curves of the generators and scheduling them using optimization techniques while minimizing the total operating cost. This is conventional Economic dispatch problem. In the ED problem quadratic cost curve is considered and load is considered as static. But in actual practice the load is not constant and is varying instantaneously. The modeling of the cost function as a quadratic will not consider the expenses of cost and maintenance of the steam valves. In the present work the cost curve of the generators considering the expenses of steam valve is used. The load is considered as dynamic for each hour of the day. The maximum permissible capability of the generators to increase or decrease the output power is also considered, which is known as ramp up and ramp down limits of the generator [20].

2.1. Valve Point Effects [20][19]:

The conventional ED problem which can be solved by the classical methods is to minimize the total operating cost of the power system for a particular loading. The total operating cost of a generator is usually approximated as a quadratic. This modeling of the cost function does not consider the expenses of a multistage turbine with valves. The running cost of a multistage steam turbine is non linear and include sinusoidal components in the cost function as shown in the figure 1.

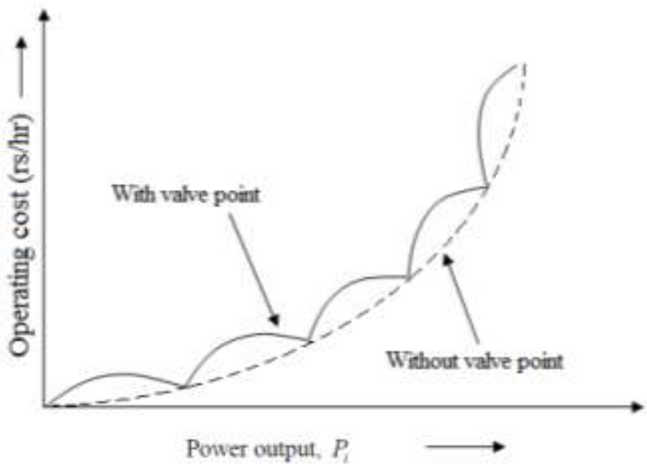

Fig.1: Cost characteristics considering valve point loading [20]

2.2. Ramp Limit Constraints [19]:

The Thermal Generating units cannot change their output power more than a specified amount due to the mechanical inertia of the mechanical components of the generating units. These limits are called ramp up and ramp down capability of a generator. These ramp up and down limits of the generators have to be considered in the DED problem to get a practical solution of ED for time varying loads. The time varying loads are approximated as quasi static for one hour.

3. MATHEMATICAL MODELING

The generating units with multi-valve steam turbines has generator cost curve as a sum of quadratic and sinusoidal function in terms of the real power generated. The total cost of generation for the entire power system can be modeled as here under which will be the objective function of the problem.

$$F(P_i) = \sum_{i=1}^{NG} (a_i P_i^2 + b_i P_i + c_i + |d_i \sin\left(e_i \times \left(P_i^{min} - P_i\right)\right)|$$

Where ai ,bi ,ci ,di and ei are fuel cost coefficients. 'a' signifies the interest and profit for the investment towards generation, 'b' signifies the fuel and maintenance cost, 'c' accounts for the salaries and fixed costs of the employees and plant respectively, 'd' & 'e' account for the cost of using the valves of the steam turbines, 'NG' number of generators in the system, 'i' is the i^{th} generator unit, P_i^{max} is the maximum generation of the i^{th} generating unit and P_i^{min} is the minimum generation of the i^{th} generating unit. .

The objective function has to be minimized subjected to the constraints.

(i) Equality constraint: For the system frequency to be maintained constant and the system to be intact the amount of real power generation should be equal to the sum of power consumption and system real power loss.

$$\sum_{i=1}^{NG} P_i = P_D + P_L$$

Where PD is the total real power demand of the power system, PL is the total real power loss of the system.

PL can be calculated by using Kron's Loss formula [2]

$$P_L = P'BP + B_0'P + B_{00}$$

Where P is the real power generation of the generators written as row matrix, B, B_0, B_{00} are loss coefficient matrices.

(ii) Inequality constraint: every generator can't generate beyond a certain limit and below the specified limit for technical and economic reasons respectively.

$$P_i^{min} \le P_i \le P_i^{max}$$

If violations are found the real power schedule P_i should be set to the boundary values.

(iii). Ramp Limit Constraints:
The rate at which the output power generated can't change beyond a certain rate due to mechanical inertia in the thermal units.

$P_i^t - P_i^{t-1} \le U_i$

$P_i^{t-1} - P_i^t \le D_i$

Where P_i^t is output current power schedule of generating unit i and P_i^{t-1} is output power schedule of the i^{th} generator at previous hour. U_i is up ramp limit of generating unit 'i' (MW/Hr) and D_i is down ramp limit of generating unit 'i' (MW/Hr). If there is any violation of the limits P_i^t have to be adjusted to avoid violation of the constraints.

4. REFINED GENETIC ALGORITHM (RGA)

Over the recent years Genetic Algorithm based Search methods are in the lime light due to their dominance in terms of convergence characteristics and their adaptability to a variety of optimization problems especially in electrical engineering [10][11][17][20].

Genetic Algorithm works by the philosophy of mimicking nature's theory of evolution. According to the theory of evolution, in a certain population the off springs of two mating parents will have the characteristics of the two parents. The off springs which have better characteristics will have better chances of survival. The survived off springs will be parents of the next generation. This is the basis of Darwin's theory of evolution. Genetic Algorithm mimics this theory of evolution with the help of three basic operations i.e., selection, crossover and mutation so as to maximize the objective function which is called the fitness function. These three operations can be easily performed on binary numbers easily. One such type of number system which suits the above said operations is Binary Coded Decimal (BCD). These operations can also be performed using real number system as well [21].

Genetic Algorithm is a population based search method. The first step in GA is to generate a random population of points within the solution space. Convert these points from real number system to BCD and then apply the three genetic operations to get the off springs. The off springs are called one generation. The algorithm is repeated for several generations and the algorithm is stopped after the preset number of generations.

There are several types of selection techniques [23]. Of these Roulette wheel Technique (RWT), Tournament selection are most significant. The present work uses Roulette wheel technique. The roulette wheel technique involves developing a roulette wheel with the most fit population member occupies more space on the roulette wheel. The roulette wheel is rotated and will randomly select a population member for the next genetic operation. The number of parents is held constant during the process. Kalyanmoy Deb [22] detailed the roulette wheel selection procedure with example.

Crossover is done on the selected population members. The bits of BCD are exchanged between the two parents during the crossover. The crossover can be done from a single point or between two points. The crossover point is chosen randomly. The crossover is also done with a probability called crossover probability. A random number is generated between [0,1] and if the generated random number is less than the crossover probability then only the crossover is done or else the crossover operation is bypassed. The crossover operation helps in preserving the best solution in the parents.

Mutation is a bit wise operation. It is done for every bit of the chromosome. Mutation is done if a generated random number is less than the mutation probability. Mutation is usually done with a probability of less than 0.1. The mutation helps in dispersing the population to far ends of the search space. This helps in avoiding the convergence of solution to local minima [22].

The GA has the disadvantage of unstable solution. The solution may not converge to the same point for every run especially for non linear, non convex optimization problems. Therefore modifications are made to the simple GA to improve the convergence characteristics. The improvements are maintaining an elite set of population in every generation on which no operation is done, this is known as elitism [21]. The crossover probability is exponentially increased and mutation probability is exponentially decreased for every generation. The flowchart for RGA is given in fig.2.

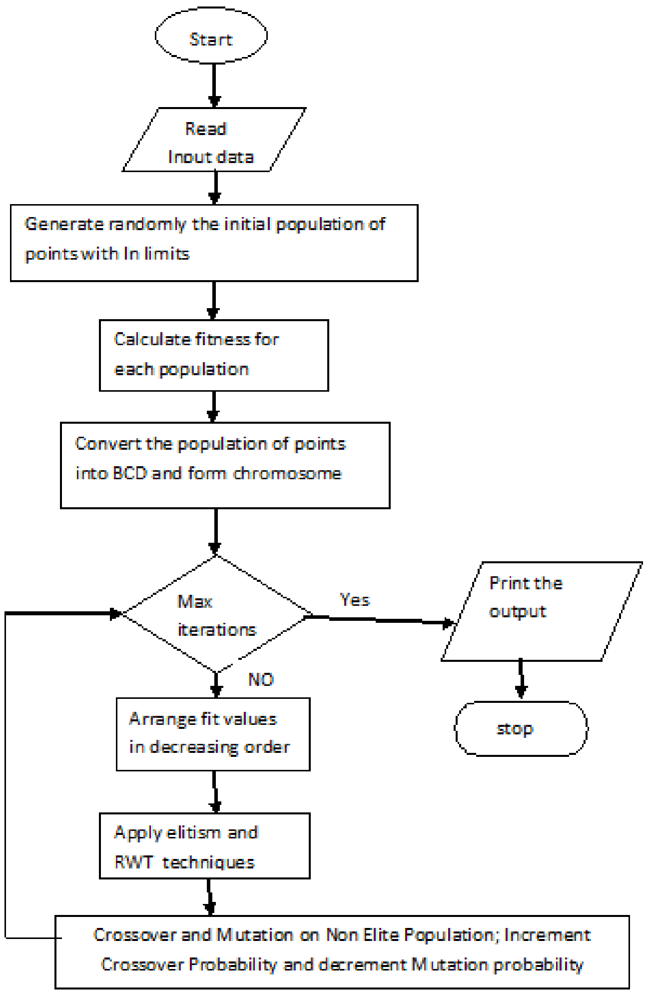

Fig 2: Flow chart for Refined Genetic Algorithm

This procedure has been repeated for every hour considering the violations in ramp limits of the generating units. If any violations in the constraints are found the generator real power schedules are adjusted to satisfy the ramp limits.

5. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is a modern heuristic population based swarming algorithm. It is developed by Eberhart and Kennedy [16]. It is derived for the survival strategies of schooling of fishes and flocking of birds. These swarming beings survive by their own experience and cognitive behavior of the flock's leader. The same behavior can be incorporated in a group of points in the search space of an optimization problem.

The population of points in the search space is developed to mimic the school of fishes or flock of birds. Each point in the population is called particle. The algorithm mimics the swarming behavior by remembering and updating the best position of every particle as personal best and best position among all the particles as global best. The particles are made to move simultaneously in the search space. The direction and velocity of movement of all the particles is influenced by three factors, i.e., inertia, personal best position of the particle and global best position of the group. The Personal best position of individual particles and global best position of the swarm is updated for every movement of the particles position. The inertia is varied depending on the iteration number. Therefore the velocity of each particle is given by the following equation

$$V_i^{t+1} = W_t V_i^t + C_1 R_1 \left(X_{pbest,i} - X_i^t \right) + C_2 R_2 \left(X_{gbest} - X_i^t \right)$$

Where

$V_{i,}^{t}$ is velocity of particle 'i' at iteration t

W_t is Inertia Weight

C_1,C_2 are accelerating constants

R_1,R_2 are random number between 0 and 1

X_i^t is current position of particle 'i' at iteration t

P_{besti} is personal best of particle 'i'

P_{Gbest} is global best of the group.

The position of the particles is updated by the following equation:

$$X_i^{t+1} = k * V_i^t + X_i^t$$

Where k is a constant, having units of time to make the above equation dimensionally correct. It should be noted that the dimensions of the particles and velocities is equal to the number of variables considered.

In the present work C1&C2 are taken as equal to two. Swarm size is taken as ten and maximum iterations are considered as two hundred. The inertia weight is increased linearly with iteration count, so that the acceleration towards optimal solution is rapid during the final stages. This can be done by using the following equation for inertia weight. W_{max} is taken as ten percent of X_{max} and W_{min} is ten percent of X_{min}. 'Itermax' is the maximum number of iterations allowed and't' is the iteration number.

$$W_i = W_{max} - \left(\frac{W_{max} - W_{min}}{\text{Itermax}} \right) * t$$

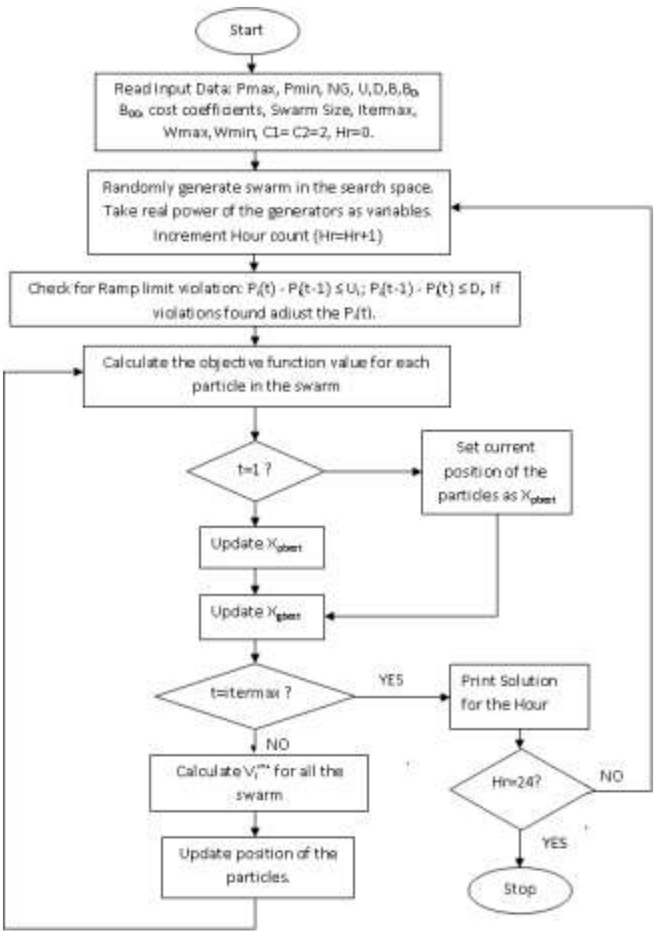

Fig 3: Flow Chart for PSO to solve DED

6. RESULTS & COMPARISION

Flowcharts are developed to solve DED problem. Programs are developed using the developed flowcharts in GNU Octave which is similar to MATLAB®. Octave is an open source alternative to its counterpart. The developed programs are used to solve DED problem for 5 unit system considering valve point effect and ramp limits. The system data is given below

Table -1: Cost Coefficient of Five Unit System

Unit	ai	bi	ci	di	ei
1	25	2.0	0.008	100	0.042
2	60	1.8	0.003	140	0.04
3	100	2.1	0.0012	160	0.038
4	120	2.0	0.001	180	0.037
5	40	1.8	0.0015	200	0.035

Table -2: Loss Coefficients of The Five Unit System

	1	2	3	4	5
1	0.000049	0.000014	0.000015	0.000015	0.000002
2	0.000014	0.000045	0.000016	0.000020	0.000018
3	0.000015	0.000016	0.000039	0.000010	0.000012
4	0.000015	0.000020	0.000010	0.000040	0.000014
5	0.000020	0.000018	0.000012	0.000014	0.000035

Table -3: Maximum, Minimum Power Limits, Upper and Down Ramp Limit of Fiv Unit System

Unit	Pmax	Pmin	U	D
1	75	10	30	30
2	125	20	30	30
3	175	30	40	40
4	250	40	50	50
5	300	50	50	50

For the above said test system the DED problem is solved for 24 Hours by using RGA and PSO and the results obtained are presented below

Table -4: DED of A Five-Unit System By RGA Method.

Hr	PD (MW)	Cost ($/hr)	PL (MW)
1	410	1239.83	3.582
2	435	1298.66	4.031
3	475	1393.62	4.798
4	530	1525.75	5.949
5	558	1593.77	6.599
6	608	1716.54	7.818
7	626	1761.15	8.289
8	654	1716.15	8.289
9	690	1921.69	10.07
10	704	1957.2	10.48
11	720	1997.97	10.96
12	740	2049.21	11.59
13	704	1957.21	10.49
14	690	1921.7	10.06
15	654	1831.06	9.061
16	580	1647.57	7.11
17	558	1539.76	6.593
18	608	1716.53	7.82
19	654	1831.02	9.047
20	704	1957.2	10.48
21	680	1896.41	9.783
22	527	1518.5	5.874
23	605	1709.11	7.743
24	463	1365.04	4.561

Table -5: DED of A Five-Unit System By PSO Method.

Hr	Pd(MW)	Cost($/hr)	PL(MW)
1	410	1256.22	3.542
2	435	1340.86	4.161
3	475	1443.99	4.899
4	530	1562.397	6.3719
5	558	1637.02	6.43
6	608	1810.8	7.91
7	626	1727.113	8.2206
8	654	1904	9.04
9	690	1953.28	10.15
10	704	2230.199	10.700
11	720	1988.423	10.9586
12	740	2113.58	11.55
13	704	1940.63	10.51
14	690	1954	10.15
15	654	1903.95	8.94
16	580	1736.13	7.02
17	558	1632.18	6.43
18	608	1763.43	8.39
19	654	1897.99	9.055
20	704	1943.59	10.51
21	680	1950.1	9.9
22	605	1759.59	7.83
23	527	1567.51	6.312
24	463	1344.8	4.659

6. CONCLUSIONS

In this paper, the PSO method was employed to solve the DED problem. Form Table IV and V it can be clearly observed that the PSO method gives better optimal solution compared to RGA to solve DED problem for the 5 generator system considered. The total cost for 24 Hrs for the solution obtained by PSO method is $41062.65 and that by RGA method is $42361.78, which clearly shows that PSO method gives better optimal solution compared to RGA in terms of solution quality in solving DED.

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