Particle Swarm Optimization Scheme for the Solution of Economic Dispatch

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Abstract*—Economic Dispatch is an important optimization task in power system. It is the process of allocating generation among the committed units such that the constraints imposed are satisfied and the energy requirements are minimized. More recently, the soft computing techniques have received more attention and were used in a number of successful and practical applications. Here, an attempt has been made to find out the minimum cost by using Particle Swarm Optimization (PSO) Algorithm using the data of three generating units. In this work, data has been taken such as the loss coefficients with the max-min power limit and cost function. PSO is applied to find out the minimum cost for different power demand. When the results are compared with the traditional technique, PSO seems to give a better result with better convergence characteristic. All the techniques are implemented in MATLAB environment.*

Keywords: Economic Dispatch, Particle Swarm Optimization, Prohibited Zones, Ramp Rate Limits, Simulated Annealing.

I. INTRODUCTION

Power systems should be operated under a high degree of economy for competition of deregulation. Unit commitment is an important optimization task addressing this crucial concern for power system operations. In essence, the objective of ED is to minimize total generation costs, while satisfying power demands and constraints.[1] The various mathematical programming methods and optimization techniques, such as the Lambda-iteration method,[2] base point and participation factors method,[3] the gradient method,[4] and the Newton method.[2] Therefore, dynamic programming,[5] nonlinear programming,[6] and their modification techniques for solving ED issues have been presented..

In the past decade, several computational algorithm techniques, such as genetic algorithms (GAs),[7, 8] simulated annealing (SA),[9] tabu searches (TS),[10] and artificial neural networks (ANNs),[11, 12] have been used to address power optimization issues. These algorithms are in the form of probabilistic heuristics, with global search properties.

Recently, a global optimization technique called particle swarm optimization (PSO)[13–15] has been used to solve real time issues and interest due to its flexibility and efficiency. The PSO, first introduced by Kennedy and Eberhart,[16] is a modern heuristic algorithm developed through the simulation of a simplified social system.

In general, the PSO method is faster than the SA method because the PSO contains parallel search techniques. The most significant characteristic of SA is its probabilistic jumping property, called the metropolis process.

The feasibility of the proposed method was demonstrated on four different systems and then compared with the real-coded PSO,[15] GA,[8, 30] and evolutionary algorithm[29] methods regarding solution quality and computational efficiency.

II. PROBLEM FORMULATION

The objective of ED is to minimize the total generation costs of a power system over an appropriate period (usually one hour), while satisfying various constraints. Cost efficiency is the most important sub problem of power system operations. The ED planning must perform the optimal generation dispatch among the operating units in order to satisfy the system load demands and practical operation constraints of generators, which include ramp rate limits, maximum and minimum limits, and prohibited operating zones.

Generally, the generation cost function is usually expressed as a quadratic polynomial. It is more practical to consider the valve-point effects for fossil-fuel-based plants. Let Ci mean the cost, expressed in dollars per hour, of producing energy in the generator unit I. The total controllable system production cost therefore will be,

$$C = \sum_{i=1}^{N} C(i) \qquad \ldots (1)$$

The generated real power P_{Gi} accounts for the major influence on C_i and this requires a cost of increased expenditure of fuel.

The individual production cost c_i of generators unit I is therefore for all practical purposes a function only of P_{Gi},

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and for the overall controllable production cost, we thus have

$$C = \sum_{i=1}^{N} C_i(P_{Gi}) \quad \ldots (2)$$

A. System Constraints

Broadly speaking there are two types of constraints

1. Equality constraints
2. Inequality constraints

1. *Equality Constraints*

From observation we can conclude that cost function is not affected by the reactive power demand. So the full attention is given to the real power balance in the system.

$$P_d = \sum_{i=1}^{N} C_i(P_{Gi}) \quad \ldots (3)$$

2. *Inequality Constraints*

Generator Constraints: The KVA loading in a generator is given by $\sqrt{P^2+Q^2}$ and this should not exceed a pre specified value of power because of the temperature rise conditions:

- The maximum active power generation of a source and minimum power generation is limited again by thermal consideration. If the power output of a generator for optimum operation of the system is less than a pre-specified value P min ,

$$P_{min} \le P \le P_{max}$$

- Similarly the maximum and minimum reactive power generation of a source is limited. The maximum reactive power is limited because of overheating of rotor and minimum is limited because of the stability limit of machine. Hence the generator powers Pp cannot be outside the range stated by inequality, i.e.

$$Q_{p\,min} \le Q_p \le Q_{p\,max}$$

Voltage Constraints: It is essential that the voltage magnitudes and phase angles at various nodes should vary within certain limits.

Running Spare Capacity Constraints: These constraints are required to meet

1. The forced outages of one or more alternators on the system and
2. The unexpected load on the system

$$G \ge P_p + P_{so}$$

Where G is the total generation and PSO is some pre-specified power. A well planned system is one in which this spare capacity PSO is minimum.

Transmission Line Constraints: The flow of active and reactive power through the transmission line circuit is limited expressed as,

$$Cp \le Cp\ max$$

Where Cp max is the maximum loading capacity of the line.

Network Security Constraints: If initially a system is operating satisfactorily and there is an outage, may be scheduled or forced one. The complexity of these constraints (in terms of 10 number of constraints) is increased when a large system is under study.

III. Proposed SA-PSO Method

A. PSO—An Optimization Tool

Particle swarm optimization (PSO) is a population based stochastic optimization technique Compared to GA, the advantages of PSO are that PSO is easy to implement.

B. Particle Swarm Optimization

PSO simulates the behaviours of bird flocking. a group of birds are randomly searching food in an area. All the birds do not know where the food is. But they know how far the food is in each iteration. So what's the best strategy to find the food? The effective one is to follow the bird, which is nearest to the food. PSO learned from the scenario and used it to solve the optimization problems. In PSO, each single solution is a "bird" in the search space. We call it "particle". The particles fly through the problem space by following the current optimum particles.

In every iteration, each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called gbest. After finding the two best values, the particle updates its velocity and positions with following equation (3.1) and (3.2).

$$V_i^{(u+1)} = w * V_i^{(u)} + C_1 * rand(\,) * (pbest_i - P_i^{(u)}) + C_2 * rand(\,) * (gbest_i - P_i^{(u)}) \quad \ldots (4)$$

$$P_i^{(u+1)} = P_i^{(u)} + V_i^{(u+1)} \quad \ldots (5)$$

In the above equation,

The term $rand(\,) * (pbest_i - P_i^{(u)})$ is called particle memory influence.

The term $rand(\,) * (gbest_i - P_i^{(u)})$ is called swarm influence.

$V_i^{(u)}$ is the velocity of i^{th} particle at iteration 'u' must lie in the range,

$$V_{min} \le V_i \le V_{max}$$

- If V_{max} is too high, particles may fly past good solutions. If Vmin is too small, particles may not explore sufficiently beyond local solutions.
- In many experiences with PSO, Vmax was often set at 10–20% of the dynamic range on each dimension.
- The constants C1and C2 pull each particle towards pbest and *gbest* positions.
- On the other hand, high values result in abrupt movement towards, or past, target regions.
- The acceleration constants C1 and C2 are often set to be 2.0 according to past experiences.
- Suitable selection of inertia weight *'ω'* provides a balance between global and local explorations. In general, the inertia weight *w* is set according to the following equation,

$$W = W_{max} - \left[\frac{W_{max} - W_{min}}{ITER_{max}}\right] \times ITER \quad \ldots (6)$$

Where w -is the inertia weighting factor
W_{max} - maximum value of weighting factor
W_{min} - minimum value of weighting factor
ITERmax - maximum number of iterations
ITER - current number of iteration

C. Flow Chart for Particle Swarm Optimization

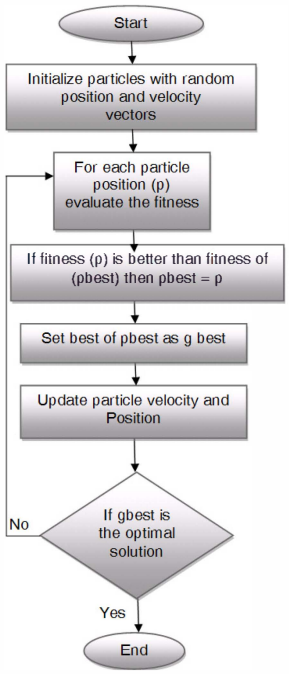


FIG. 1: FLOW CHART FOR PARTICLE SWARM OPTIMIZATION

IV. IMPLEMENTATION OF THE PROPOSED METHOD

Particle Swarm optimization (PSO) is a population based algorithm in which each particle is considered as solution in the multimodal optimization space. When economic load dispatch problem considered it can be classified in two different ways.

1. Economic load dispatch without considering the transmission line losses
2. Economic load dispatch considering the transmission line losses.

A. Economic Dispatch without Loss

Powers generated must be within the limit of maximum and minimum active power of each unit. The sequential steps of the proposed PSO method are given below.

Step 1: The velocities of the different particles are also randomly generated keeping the velocity within the maximum and minimum value of the velocities.

Step 2: Each set of solution in the space should satisfy the equality constraints. So equality constraints are checked.

Step 3: The evaluation function of each individual Pgi, is calculated in the population using the evaluation function F. Here F is

$$F = a \times (P_{gi})^2 + b \times P_{gi} + c \quad \ldots (7)$$

Where a, b, c are constants. The present value is set as the pbest value.

Step 4: Each pbest values are compared with the other pbest values in the population. The best evaluation value among the p-bests is denoted as gbest.

Step 5: The member velocity v of each individual Pg is modified according to the velocity update equation

$$V_{id}^{(u+1)} = w * V_i^{(u)} + C_1 * rand(\,) * (pbest_{id} - P_{gid}^{(u)}) + C_2 * rand(\,) * (gbest_{id} - P_{gid}^{(u)}) \quad \ldots (8)$$

Where u is the number of iteration.

Step 6: The velocity components constraint occurring in the limits from the following conditions are checked

$$Vd^{min} = -0.5 * P_{min}$$

$$Vd^{max} = +0.5 * P_{max}$$

Step 7: The position of each individual P_g is modified according to the position update equation

$$P_{gid}^{(u+1)} = P_{gid}^{(u)} + V_{id}^{(u+1)} \quad \ldots (9)$$

Step 8: If the evaluation value of each individual is better than previous *pbest,* the current value is set to be *pbest*. If the best *pbest* is better than *gbest*, the value is set to be *gbest*.

Step 9: If the number of iterations reaches the maximum, then go to step 10. Otherwise, go to step 2.

Step 10: The individual that generates the latest gbest is the optimal generation power of each unit with the minimum total generation cost.

B. Economic Dispatch with Loss

When the losses are considered the optimization process becomes little bit complicated. The P-loss can be found out by using the equation,

$$P_L = \sum_m \sum_n P_m B_{mn} P_n \quad \ldots (10)$$

Where B_{mn} are the loss co-efficient. The loss co-efficient can be calculated from the load flow equations or it may be given in the problem. The sequential steps to find the optimum solution are:

Step 1: The power of each unit, velocity of particles, is randomly generated which must be in the maximum and minimum limit.

Step 2: Each set of solution in the space should satisfy the following equation

$$\sum_{i=1}^{N} P_{gi} = P_D + P_L \quad \ldots (11)$$

The equality constraints are checked. If any combination doesn't satisfy the constraints then they are set according to the power balance equation.

$$P_d = P_D + P_L - \sum_{\substack{i=1 \\ i \neq d}}^{N} P_i \quad \ldots (12)$$

Step 3: The cost function of each individual P_{gi}, is calculated in the population using the evaluation function F. Here F is,

$$F = a \times (P_{gi})^2 + b \times P_{gi} + c \quad \ldots (13)$$

Where a, b, c are constants. The present value is set as the pbest value.

Step 4: Each pbest values are compared with the other pbest values in the population. The best evaluation value among the pbest is denoted as *gbest.*

Step 5: The member velocity v of each individual Pg is updated according to the velocity update equation.

$$V_{id}^{(u+1)} = w * V_i^{(u)} + C_1 * \text{rand}( ) * (\text{pbest}_{id} - P_{gid}^{(u)}) + C_2 * \text{rand}( ) * (\text{gbest}_{id} - P_{gid}^{(u)}) \quad \ldots (14)$$

Where u is the number of iteration.

Step 6: The velocity components constraint occurring in the limits from the following conditions are checked

$$V_{d\,min} = -0.5 * P_{min}$$

$$V_{dmax} = +0.5 * P_{max}$$

Step 7: The position of each individual Pg is modified according to the position update equation

$$P_{gid}^{(u+1)} = P_{gid}^{(u)} + V_{id}^{(u+1)} \quad \ldots (15)$$

Step 8: The cost function of each new is calculated. If the evaluation value of each individual is better than previous *pbest;* the current value is set to be *pbest*. If the best *pbest* is better than *gbest*, the value is set to be *gbest*.

Step 9: If the number of iterations reaches the maximum, then go to step 10. Otherwise, go to step 2.

Step 10: The individual that generates the latest gbest is the optimal generation power of each unit with the minimum total generation cost.

C. Results and Discussion

Particle Swarm Optimization algorithm has been tested on the three unit system and the numerical results obtained through the simulation and the cost curve obtained are as shown below.

1. *Three Unit System*

The three generating units considered are having different characteristic. Their cost function characteristics are given by following equations

$F_1 = 0.00533P_1^2 + 11.669P_1 + 213$ Rs/Hr

$F_2 = 0.00889P_2^2 + 10.333P_2 + 200$ Rs/Hr

$F_3 = 0.00741P_3^2 + 10.833P^3 + 240$ Rs/Hr

According to the constraints considered in this work among inequality constraints only active power constraints are constraints are considered. There operating limit of maximum and minimum power are also different. The unit operating ranges are:

$50 \text{ MW} \leq P_1 \leq 200 \text{ MW}$

$7.5 \text{ MW} \leq P_2 \leq 150 \text{ MW}$

$45 \text{ MW} \leq P_3 \leq 180 \text{ MW}$

The transmission line losses can be calculated by knowing the loss coefficient. The B_{mn} loss coefficient matrix is given by,

$$B_{mn} = \begin{matrix} 0.0218 & 0.0017 & 0.0028 \\ 0.0093 & 0.0228 & 0.0017 \\ 0.0028 & 0.0093 & 0.0179 \end{matrix}$$

This is the example we have taken for the testing this novel coding scheme on the three unit system.

Here $C_1 = 1.99$ and $C_2 = 1.99$. Here the maximum value of w is chosen 0.9 and minimum value is chosen 0.4.the velocity limits are selected as $V_{max} = 0.5 * P_{max}$ and the minimum velocity is selected as $V_{min} = -0.5 * P_{min}$. There are 10 no of particles selected in the population. For different value of C_1 and C_2 the cost curve converges in the different region. So, the best value is taken for the minimum cost of the problem.

2. Simulation Results—Solution of ED Problem

The solution for ED problem of the three unit system considered here is given below. The total demand taken here is about 200 MW and 700 MW.

```
out = 1.0e+003 *
        0.050000005801763
        0.079584818649999
        0.074549690507549
        2.977211011227124
P =  50.000005801763166
     79.584818649999349
     74.549690507549073

F =  2.977211011227124e+003
```

TABLE 1: COMBINED ECONOMIC AND EMISSION DISPATCH

Objective	*P1*	*P2*	*P3*	*P4*	*P5*	*P6*
Economic Dispatch	41.37485	19.56447	122.0292	95.8792	230.2597	215.0321
Emission Dispatch	86.2000	84.8309	110.9136	111.0101	161.7126	162.6996
Combined Economic	67.0226	64.0749	115.9380	119.4393	174.9152	177.2328

TABLE 2: TOTAL GENERATION USING DIFFERENT TECHNIQUES (AT 700 MW)

Objective	*Economic Dispatch*	*Emission Dispatch*	*Combined Economic and Emission Dispatch*
SA	40653.26	43962.26	66996.5396
PSO	40392.66	42998.72	66239.72

(c) Simulation Result—Cost Curve

The cost curve (the plot between the number of iterations and the cost) for the three unit system considered here is given below. The simulation output is given below.

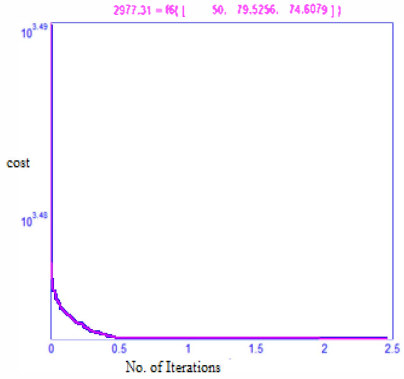


FIG. 2: SIMULATION RESULT—COST CURVE OF THE THREE UNIT SYSTEM

V. CONCLUSION

This project presents a new approach to the solution of ED using Particle Swarm Optimization with Simulated Annealing has been proposed. Through the proposed coding scheme, constraints of ED problems can be effectively released during the search process, therefore, the solution quality, as well as the calculation time, is greatly improved. The proposed approach has been demonstrated by three unit system and proven, including high quality solutions, stable convergence characteristics, and good computational efficiency. The encouraging simulation results showed that the proposed method is capable of obtaining more efficient, higher quality solutions for ED problems.

In future, the most problematic line flow constraints and security constraints will be considered which leads to the Security Constrained Economic Dispatch (SCED). For handling the line flow constraints, in addition to the Particle Swarm Optimization (PSO) algorithm with Simulated Annealing (SA), the Newton Raphson method (NR).Very fast simulated annealing technique(VFSA) will be used as well as for handling the security constraints also. Furthermore, the generating cost will be minimized and the Security Constrained Economic Dispatch will be targeted.

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