Optimal value of Economic Load Dispatch using Swarm Algorithm

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Abstract. In this paper space reduction particle swarm optimization(SRPSO) is proposed for solving single-objective optimization problems. Minimization of cost is considered as an objective in the economic dispatch problem. The valve point loading effect is incorporated with the cost function which transfigures to the nonlinear problem. To improve the convergence speed, space reduction is essential and parameter variation keeps away the stuck of local optima. Particle swarm optimization (PSO) emphasizes global search and is encountered as a stochastic population-based method. The proposed method is validated on a 26 bus system with 6 generators and the performance results are compared with the other existing techniques.

Index Terms — Valve point effect, Particle swarm optimization, Economic dispatch, optimal solution.

1. INTRODUCTION

The power system is associated with several optimization problems among which economic load dispatch is pivotal. In a power system, the planning and operation of thermal units is a crucial task. The main criteria of economic load dispatch (ELD) are the scheduling of power units to meet the load demand at the optimal value of cost maintaining equality and inequality constraints. The distribution of electrical loads among generating units with the objective of cost minimization is termed economic scheduling. ED problem incorporated with valve point loading effect represents as a nonlinear characteristic which becomes tedious in assessing the global value [1]. Due to the nonlinear characteristics of the power unit the associated cost function is nonconvex and not smooth. In general, the cost function of an individual unit is indicated in a quadratic form which requires mathematical methods [2].

Power units input and output characteristics are nonconvex due to valve point loadings, prohibited operating zones, etc. Practical ED problems cannot be solved by mathematical methods
directly because of the nonconvex. Many traditional optimization techniques are used for the optimal value of the load dispatch problem such as gradient method, lambda iteration, Newton method, quadratic programming [3], and linear programming [4]. The gradient method and lambda iteration method were rapid in predicting the optimal values in a noncomplex optimization problem but inadequate to the deregulated market of real applications. The deficiency associated with most of the traditional methods in predicting global optimum is tedious and is inadequate in solving a nonconvex optimization problem. To overcome the limitations of traditional methods researchers emphasized modern heuristic methods. This algorithm doesn’t require continuous and differentiable cost functions with their equality and inequality constraints. Some of the heuristic techniques are genetic algorithm [5], ant colony optimization [6], artificial immune system [7], tabu search [8] evolutionary programming [9], differential evolution (DE) [10]. Particle swarm optimization (PSO) [11], GA is satisfactorily applicable in solving complex optimization problems.

Later predicted the deficiency in the performance of GA i.e. repudiates the better fitness of analogous structure of child population and their mean fitness. The downside of DE is related to the convergence rate which doesn’t meet the expectation concerned with the high dimensional optimization problem. In the initial stage population move towards the optimal solution and in a later stage during parameter variation, the performance of the DE fails. Because of conveying mechanism and as well as sharing information swarm optimization techniques become more attractive, among PSO is a promising and popular modern heuristic algorithm. Compared with stochastic methods, PSO generates high convergence characteristics. To show the potential of PSO many researchers are still advance in solving a difficult and complex optimization problem. In this paper, PSO applied for the optimization problem with cost function as an objective, tested on 26 bus system with six generators. The valve point loading effect and transmission losses are considered along with equality and inequality constraints.

2. Problem Formulation

Formulation of the economic dispatch problem should be judicious from practical point of view. A single-objective optimization problem is formulated without [12] and with valve point loading effect [13]. The main objective of ED is to reduce the fuel cost by allocating the generating unit maintaining inequality and equality constraints. The economic dispatch problem is indicated with an objective function. The cost function is represented in quadratic form as described in equ (2).

\[
C = \sum_{i=1}^{n} F_i(P_{Gi})
\]

where 'C' is the total cost of the fuel represented in dollars per hour, PGl indicates the real power of 'l' generating unit.

\[
F_i(P_{Gl}) = (a_l + b_l P_{Gl} + c_l P_{Gl}^2)
\]

al, bl, and cl are the cost coefficients of ‘l’ thermal unit, Fl represents the fuel cost function expressed in quadratic form.

A. Cost function with valve point loading effect:

Real power balance is feasible with closing and opening of multiple valves available in the turbine of generating unit. Due to the valve point effect ripples are encountered in the cost function which represents into highly nonlinear function. With the effect of the valve point effect, the modified quadratic form is represented in equ (3).

\[
F_i(P_{Gl}) = a_l + b_l P_{Gl} + c_l P_{Gl}^2 + \epsilon_l (\sin(f_l(P_{Glmin} - P_{Gl})))
\]
where $e_l$ and $f_l$ indicate the coefficients of the generator with the effect of valve point loading. The objective function is subjected to inequality and equality constraints.

Fig 1: Incremental cost curve with a five-valve point.

**B. Constraints:**

**Power balance constraint:** The power generated from the power unit has to equate the summation of total load demand and power losses. This is an equality constraint that has to be satisfied in assessing the optimal solution.

$$\sum_{l=1}^{n} P_{Gl} = P_D + P_{LOSS} \quad (4)$$

where $P_D$ is the total demand in MW and $P_{LOSS}$ indicates the transmission losses.

$$P_{LOSS} = \sum_{o=1}^{n}\sum_{l=1}^{o} P_{Go}B_{ol}P_{Gl} + \sum_{l=1}^{n} P_{Gl}B_{lo} + B_{\|} \quad (5)$$

$B_{ol}$, $B_{lo}$, $B_{\|}$ are the transmission loss coefficients.

**Generation Limits:** The active power generated by the power units must be maintained within the range of limits which is termed generation limits.

$$P_{Glmin} \leq P_{Gl} \leq P_{Glmax} \quad (6)$$

$P_{Glmin}$ and $P_{Glmax}$ indicate the minimum and maximum limits of thermal generation.

3. **Methodology**

**Space Reduction Particle swarm optimization (SRPSO):** PSO was introduced in the category of combinatorial meta heuristic optimization which is a stochastic optimization method originated by Kennedy and Eberhart which stimulates the social behavior of birds or insects [14]. This earliest model applied to an optimization problem that is nonlinear and continuous. Later PSO was sophisticated in investigating the global solution of a complex optimization problem. Many researchers focused on PSO because of its simplicity, and each particle is accompanied by two vectors namely position and velocity vector. This technique initiates with a random generation of particles in a search space.

In achieving an optimal solution to an optimization problem, particle position and velocity will be updated in every iteration based on the parameter Gbest and Pbest. In $n$-dimensional search space, the velocity and position of an ‘$m$’ particle are configured as a vector of $P_m$={$P_{m1}, P_{m2}, P_{m3}$,.....$P_{mn}$} and corresponding velocity is $V_m$={$V_{m1}, V_{m2}, V_{m3}$,.....$V_{mn}$}. Let $G_{best}$={$P_{1best}, P_{2best}, P_{3best}$,.....$P_{nbest}$} and
$P_{bestm} = \{P_{m1best}, P_{m2best}, P_{m3best}, \ldots, P_{mnbest}\}$ be the neighbor best and particle ‘m’ best positions respectively.

$$V_{m}^{k+1} = K(W \ast v_{m}^{k} + C_{1} \ast rand \ast (P_{bestm} - P_{m}^{k}) + C_{2} \ast rand \ast (G_{bestm} - P_{m}^{k}))$$ (7)

$$P_{m}^{k+1} = P_{m}^{k} + V_{m}^{k+1}$$ (8)

where $v_{m}^{k}$ and $P_{m}^{k}$ represents velocity and position of ‘m’ particle at $k^{th}$ iteration, $C_{1}$, and $C_{2}$ indicate the acceleration coefficients, $W$ is the inertia weight, rand presents random number between 0 and 1. During the iteration process, the inertia weight decays and obtained as

$$W=W_{max}-(W_{max}-W_{min}) \ast iter/maxiter;$$ (9)

$Iter$ is the current iteration and $maxiter$ is the maximum iteration and $W_{max}$is the final inertia weight and analogously acceleration coefficients are defined as

$$C_{1}=C_{1max}-(C_{1max}-C_{1min}) \ast iter/maxiter;$$

$$C_{2}=C_{2max}-(C_{2max}-C_{2min}) \ast iter/maxiter;$$ (10)

$$\theta=(C_{1}+C_{2});$$

$$K = \frac{2}{|2-\theta-\sqrt{\theta^2-4\theta}|}$$ (11)

To enhance the convergence speed of an optimal solution, a space minimization strategy is applied between Gbest and maximum and minimum power limits.

$$P_{m}^{k+1} = P_{max}^{k} + (P_{max}^{k} - G_{best}) \ast rand;$$

$$P_{m}^{k+1} = P_{min}^{k} + (P_{min}^{k} - G_{best}) \ast rand;$$ (12)

4. Results and Discussion

To evaluate the potential of SRPSO it has been tested on 26 bus system with six power units with and without transmission losses. The effect of valve point loading is incorporated with the cost function. Related cost coefficient and maximum and minimum power generation limits data are taken[15]. Parameters, number of particles is 50, maximum inertia weight 0.9 and minimum inertia weight 0.4, $C_{1max} = 2.075$, $C_{1min}=2.025$, $C_{2max} =2.025$; $C_{2min}=2$, constriction factor in range 0.6 to 0.95, maximum iteration 200, are initialised.

Test case1: In this case study, the test system consists of 6 power units with the incorporation of valve point loading effect, and transmission losses are included. The load demand was 1263 MW. The convergence speed can be improved by minimizing the search space which can be achieved with the new generation of power limits. The better optimal solution is obtained using SRPSO and made a comparison with the existing versions of PSO shown in table1.
TABLE 1. Comparison of generation cost and transmission losses with the proposed method.

| Method | MMPSO  | SA-PSO | GA-API | ESWPSO | SRPSO |
|--------|--------|--------|--------|--------|-------|
| PG1    | 447.4970 | 446.71 | 447.12 | 445.0993 | 448.5584 |
| PG2    | 173.3221 | 173.01 | 173.41 | 173.9688 | 172.8186 |
| PG3    | 263.4745 | 265.00 | 264.11 | 260.8106 | 264.3295 |
| PG4    | 139.0594 | 139.00 | 138.31 | 139.8351 | 129.6370 |
| PG5    | 165.4761 | 165.23 | 166.02 | 169.6363 | 169.2178 |
| PG6    | 87.1280  | 86.78  | 87.00  | 86.3246  | 90.5526 |
| Loss   | 12.9584  | 12.733 | 12.98  | 12.675   | 12.1139 |
| Total output(MW) | 1275.9571 | 1275.73 | 1275.97 | 1275.6747 | 1275.1139 |
| Demand (MW) | 1263     | 1263   | 1263   | 1263     | 1263   |
| Generation cost($/hr) | 15450    | 15447  | 15449  | 15446    | 15422.3800 |

In comparison with ESWPSO, SAPSO, MMPSO, GA-API with the proposed method SRPSO the transmission losses are reduced to 12.1139 (MW), and also generation cost was reduced to 15422.3800 ($/hr) and a miniature reduction obtained in the total output power which can be observed table1. Figure 1 illustrates the graph between cost and acceleration factors which indicates a constant cost value between 2.038 to 2.036 and later as the acceleration factor value reduces the cost value minimizes to an optimal value.

![Graph between cost and acceleration parameters.](image)

**Fig 2:** Graph between cost and acceleration parameters.

**5. Conclusion**

Space Reduction Particle Swarm Optimization was introduced in this paper, to improve the convergence speed, search space reduction is essential. The parameter variation avoids the struck of local optima. Nonlinear characteristics of a generator, valve point loading effect is considered in achieving global optima of an optimization problem. Results with the proposed technique show a better solution in generation cost, losses as well as generators output power with other literature methods. The proposed method shows good computational efficiency and stable convergence characteristics.
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