Application of improved particle swarm optimization in economic dispatch of power system

G.Y. GNINKEU TCHAPDA[1], Z. WANG[1], Y. SUN[2]
[1]Department of Electrical and Mining Engineering, University of South Africa, Florida 1710, South Africa
[2]Department of Electrical and Electronic Engineering Science, University of Johannesburg, Auckland Park 2006, South Africa

Email: gygninkeu@yahoo.com, wangzengh@gmail.com, sunyanxia@gmail.com

***Abstract*. This paper introduces an improved particle swarm optimization to solve economic dispatch problems involving numerous constraints. Depending on the type of generating units, there are optimization constraints and practical operating constraints of generators such as prohibited operating zones and ramp rate limits. The algorithm is a hybrid technique made up of particle swarm optimization and bat algorithm. Particle swarm optimization as the main algorithm integrates bat algorithm in order to boost its velocity and adjust the improved solution. The new technique is firstly tested on five different cases of economic dispatch problems comprising 6, 13, 15, 40 and 140 generating units. The simulation results show that it performs better than both particle swarm and bat technique.**

Keywords: Economic dispatch, particle swarm optimization, bat algorithm, hybrid technique.

I. INTRODUCTION

Economic Dispatch (ED) can be defined as the determination of the optimal output power of a number of generating units, to satisfy the system load demand, at the lowest possible cost, for a short period usually one hour, considering equalities and inequalities constraints [1, 2]. This is an important optimization problem in electric power system, it aims to minimize as much as possible the total cost of production of electricity in consideration of the physical constraints of their generators [3].

To solve the ED problem, two categories of optimization methods are proposed. The first are the conventional methods also called classical or gradient based methods [5] such as lambda iteration [4], branch and bound [6], etc. they are applied on continuous and smooth objective functions [7]. The second are called metaheuristic methods; and they are popular for their abilities to deal easily with nonsmooth and discontinuous objective functions that practical ED problems encounter. They are classified into: evolutionary algorithm such as differential evolution [8]; immune algorithm such as genetic algorithm [9]; and swarm intelligence (SI) algorithm which have become a popular technique to solve ED problems. They imitate a collective behaviour of nature such as insects, birds, fishes, etc. [5]. SI techniques include particle swarm optimization (PSO), firefly algorithm [10], Bat Algorithm (BA) [7], differential search [11], and so on.

Kennedy and Eberhart first introduced PSO as a new heuristic method. They studied the social behaviours of bird flock and fish schools [12 - 13]. The algorithm is simple with only primitive mathematical operators effective to optimize wide range of functions at a cheap computational cost. An important advantage of PSO is its flexibility to be associated with other optimization techniques to form hybrid tools. The improved PSO proposed in this paper is a hybrid technique that integrates bat algorithm into PSO.

The rest of this paper is structured as follows. The next section describes the ED problem. Section 3 introduces PSO and BA. The proposed approach is then presented in section 4. Section 5 shows and analyses a series of simulation results of PSO, BA and hybrid PSO-BA algorithms with five cases of ED problems. Finally, section 6 concludes the paper.

II. ECONOMIC DISPATCH PROBLEM FORMULATION

Electrical economic dispatch aims to find the optimal output of generating units that participate in supplying the load. That is to minimize the total cost of generation of thermal power plants while satisfying the operational constraints of the system. The function that minimizes the total cost of the generating units is given by [7],

$$\min_{P\in R^{N_g}} F = \sum_{j=1}^{N_g} F_j(P_j) = \sum_{j=1}^{N_g} (a_j P_j^2 + b_j P_j + C_j) \quad (1)$$

where R is the set of real number and N_g is the total number of generating units. F_j (P_j) is the fuel cost of the jth generating unit in \$/hr, P_j is the power generated by the jth generating unit in MW, and a_j, b_j and c_j are cost coefficients of jth generating unit in \$/MW^2, \$/MW and \$ respectively.
An important constraint that influence the total cost is the valve-point effect. The valve point effect is due to the fact that the actual cost curve function of a large thermal plant is discontinuous and nonlinear [9].This because the valve-

opening process creates a wave- like effect in the heat rate curve of the generators. This opening will increase the fuel cost exponentially due to the wire drawing effect [10]. When the valve- point effect is considered, sinusoidal term is included to the quadratic cost function. The objective function therefore becomes:

$$\min_{P \in R^{N_g}} F = \sum_{j=1}^{N_g} F_j(P_j) = \sum_{j=1}^{N_g} (a_j P_j^2 + b_j P_j + C_j)$$

$$= \sum_{j=1}^{N_g} (a_j P_j^2 + b_j P_j + C_j) + \left| e_j \sin(f_j (P_j^{min} - P_j) \right| \quad (2)$$

Here e_j and f_j are constants of the valve point effect of generators in $ and rad/MW respectively.

The ED problem involves different type of constraints: optimization constraints and practical operating constraints of generators.

- **Optimization constraints**

. The optimization constraints are the constraints related to the production of power. They include first, the real power balance constraints which balance the power between total system generation (P_D) and total system losses (P_L). And secondly the generator constraints, that is the output power of each generating unit should lies in between its lower and upper bounds. Each generating unit must not operate above its rating or below some minimum capacity

- **Practical operating constraints of generators**

The ED problem is usually expressed as a quadratic programming function that can easily be solved with classical or gradient based methods. However, realistic ED problems consider the nonlinear characteristic of generators which comprise the discontinuous prohibited operating zones and ramp rate limits [7]. Metaheuristic methods such as PSO are used to solve this type of problem.

Most constraints enumerated above need to be taken into consideration to solve a realistic ED problem. When they are all combined, the objective function of the ED problem becomes [6]:

$$\min_{P \in R^{N_g}} F = \sum_{j=1}^{N_g} F_j(P_j) = \sum_{j=1}^{N_g} (a_j P_j^2 + b_j P_j + C_j)$$

$$= \sum_{j=1}^{N_g} (a_j P_j^2 + b_j P_j + C_j) + \left| e_j \sin(f_j (P_j^{min} - P_j) \right| \quad (3)$$

Subject to $\sum_{j=1}^{N_g} P_j = P_D + P_L$

$$\max(P_j^{min}, P_j^0 - DR_j) \le P_j \le P_{j,1}^l$$

$$P_{j,k-1}^U \le P_j \le P_{j,k}^l, k = 2,3, \dots, n_j, j = 1,2, \dots N_g \quad (4)$$

$$P_{j,n_j}^U \le P_j \le \min(P_j^{max}, P_j^0 + UR_j)$$

III. RELATED WORKS

Since its first development in 1995, PSO has become one of the most popular nature inspired metaheuristic optimization algorithm [15]. The algorithm uses the behaviour of the bird flock in their search for space or for food. The bird relies on two types of information, its personal position and the position of its neighbour which is the closest to the food. Each particle during the search, adjusts its speed and position according to its own information, and the information received from other particle in the swarm. It thus uses the best position obtained by itself and its neighbours. That means in the search space, the next position of the particle is guided by its personal experience (pbest), the global experience (gbest) and the present movement of the particles. Pbest is the best position that the particle has achieved so far. It can be seen as the particle's memory [15]. The particle in PSO is an intelligent element that searches space based on its own experience and the experiences of peer particles: That is the simple concept around PSO algorithm [16, 17].

The particle swarm optimization formula involves only two model equations: position and velocity. The velocity update of each particle can be calculated using the current velocity with the inertia weight and distance from pbest to gbest [1]:

$$v_i^{k+1} = w v_i^k + c_1 r_1 (pbest_i^k - x_i^k) + c_2 r_2 (gbest^k - x_i^k) \quad (5)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (6)$$

There are many ways by which an optimization algorithm can be ameliorated such as modification of its parameters, study of the different constraints of the function, analyse the topological structure of the algorithm or else combine it with other techniques. An advantage of PSO is its flexibility to be associated with other techniques such as Bat Algorithm (BA) to form a hybrid tool. BA is a swarm intelligence algorithm proposed by Xin-She Yang in 2010 [7]. Bat uses echolocation to navigate and locate prey. As a type of sonar, echolocation is a technique used by bats, mainly micro bats, to locate objects by reflected sound. Micro bat computes its distance from the object by measuring the time it emitted the sound to the time the sound returns back to its ears after striking the object [7, 8]. Bat emits short pulses through frequency modulated signal to sense distance.

The bat algorithm logic takes into account the fact that bat is able to differentiate prey from any other obstacles. That permits it to hunt even in the darkness [18]. The detailed bat algorithm description can be find in Ref. [7].

IV. PROPOSED APPROACH

The improvement of the PSO algorithm is based on the integration of BA into the recently modified version of PSO in order to form a hybrid PSO-BA. The modified PSO uses the inertia weight. The inertia weight introduced at the velocity updating step is responsible for the momentum of each particle. It was proposed by Shi and Eberhart and it works by weighting the involvement of the previous velocity for the purpose of eliminating the requirement for velocity clamping [19]. It impacts positively on the performance of the PSO algorithm.

The idea comes from the consideration of the particle as micro bat in order to use its technique of echolocation to search for prey. Only two characteristics of micro bat are applied. The first characteristic is the frequency which is sent by the micro bat with a fixed value f_{min} and with a variable wavelength λ [20]. The PSO as the main optimizer uses frequency characteristic of BA in order to boost its velocity update by associating the two. The inertia weight is added on the velocity update equation of the BA in order to maintain the homogeneity of the algorithm.

The second characteristic applied is the loudness. Loudness is used to search for prey. PSO uses the loudness of BA in order to handle the boundary violation in case the solution improves. That is to adjust the improved solution by making sure that the sound is not too loud. The hybrid PSO-BA algorithm is as follow:

1) For each particle, initialize randomly the position and velocity vectors
2) Measure the fitness of each particle (pbest) and store the particle with the best fitness (gbest) value
3) Update the ameliorated velocity vectors using the following equations

$$f^i = f^{min} + r_1 \, (f^{max} \text{-} f^{min})$$
$$v1_i^{k+1} = wv_i^k + f^i\left(x_i^k - pbest_i^k\right)$$
$$v2_i^{k+1} = wv_i^k + c_1 r_1\left(pbest_i^k - x_i^k\right) + c_2 r_2\left(gbest^k - x_i^k\right)$$
$$v_i^{k+1} = (\, v1_i^{k+1} + v2_i^{k+1})/2 \qquad (7)$$

4) update the position vector using the PSO equation

$$x_i^{k+1} = x_i^k + v_i^{k+1} \qquad (8)$$

5) Evaluate fitness , update pbest if solution improves and not too loud
6) Update Gbest of population.
7) Repeat steps 2-6 until a termination criterion is satisfied.

The next paragraph shows the simulation of the hybrid PSO-BA and compares it with PSO and BA algorithms.

V. EXPERIMENTAL RESULTS

In order to confirm its improvement, the algorithm has been tested on five different cases of economic dispatch problems comprising 6, 13, 15, 40 and 140 generating units. The MATLAB R2010a software, installed on a personal computer with a 2.6GHz processor and 8GB RAM, running on windows 7, is used to program and simulate the algorithm.

To solve the ED problem and compare the performance of the improved PSO with its recently modified version, five different cases are proposed. 25 independent runs with 150 000 iterations are made. It is the standard number iterations proposed by the CEC 2011 competition on testing evolutionary algorithms on real world optimization problems [20], which provides the system data used for the experimentation The results of the best, mean, median, worst fuel cost and the standard deviation are used to evaluate the algorithms. All the cases include the valve point effect of generators. The constraints included for every test are as follow [19]:

- 6 generating units: power balance, capacity limits, ramp rate limit and prohibited operating zone(POZ)
- 13 generating units: power balance and capacity limits
- 15 generating units: power balance, capacity limits, ramp rate limit and POZ
- 40 generating units: power balance and capacity limits
- 140 generating units: : power balance, capacity limits, ramp rate limit and POZ

Table 1 shows that the improved PSO performs better than its current version. An improvement is observed when at least three criteria are met. The first case of 6 generating units shows the best results for all the five cases, while the other cases give the best value for four criteria. Moreover, the last case of 140 generating unit is the only case where the "best" criteria has it value lower than the one of the improved PSO. But the overall shows an improvement of all the five cases.

Table 1: Result of the 5 cases of generating units for the ED

Generating units	**Criteria**	**PSO**	**Improved PSO**
6 units	Best	15490.1	**15464.9**
	Mean	15587.3	**15527.0**
	Median	15580.9	**15522.8**
	Worst	15716.2	**15623.5**
	S.D	62.1	**39.0**
13 units	Best	18771.3	**18533.4**
	Mean	19292.3	**19189.1**
	Median	19272.6	**19219.2**
	Worst	19705.5	**19656.8**
	S.D	**225.6**	267.8
15 units	Best	38684.4	**38636.9**
	Mean	38904.1	**38845.0**
	Median	38848.1	**38805.1**
	Worst	**39177.9**	39313.3
	S.D	138.6	**136.0**
40 units	Best	131441.2	**130426.8**
	Mean	144429.8	**141211.0**
	Median	144537.8	**139795.4**
	Worst	**157086.3**	158797.7
	S.D	8115.5	**6522.5**

140 units	Best	**5728727.5**	5769300.5
	Mean	7832220.6	**7626462.1**
	Median	9298355.6	**7643879.4**
	Worst	9390437.0	**9344361.2**
	S.D	1747032.8	**1428972.2**

VI. CONCLUSION

The paper has presented an improved particle swarm optimization to deal with the economic dispatch problem. The improved PSO is based on an integration of bat algorithm frequency and loudness characteristics in order to boost the PSO performance and form a hybrid PSO-BA. The new algorithm is an assimilation of some characteristic of BA by PSO.The proposed algorithm is applied to 5 different cases of the economic dispatch problems. The results show that it performs better than the PSO and BA together. And it also has a smoother and faster convergence characteristic.

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