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Solution of Economic Load Dispatch Problem using Hybrid Particle Swarm and Grey Wolf Optimization Algorithm

Mahavir Kashyap[1], Anant Thakur[2]

PG Student [PS], Department of Electrical and Electronics Engineering, IES College of Technology, Bhopal, India[1]

Department of Electrical and Electronics Engineering, IES College of Technology, Bhopal, India[2]

ABSTRACT:In this paper, a hybrid algorithm based on particle swarm optimization (PSO) and grey wolf optimization (GWO) algorithm is used to solve economic load dispatch problem (ELDP). PSO is an efficient algorithm but it lacks global exploration and are often trapped in local minima while GWO efficiently handles global exploration. A hybrid PSO-GWO is proposed where initial population is updated by PSO and the updated solutions are again updated by GWO. The proposed algorithm eradicates the disadvantages of PSO and at the same time utilizes the advantages of GWO algorithm. To test the efficiency of the proposed algorithm, two different cases of standard test systems with diverse number of generating units are considered. The ELDP with smooth and non-smooth cost characteristics (considering valve-point loading) are taken into account for all cases. To prove the supremacy of the proposed algorithm, a comparative assessment for all cases is carried out by comparing the proposed algorithm with GWO and PSO algorithm. The results obtained prove the superior and efficient performance of the proposed algorithm in solving ELDP.

KEYWORDS: Cost minimization;economic load dispatch; equality and inequality constraints; grey wolf optimization; particle swarm optimization; valve-point loading effects.

I.INTRODUCTION

Due to increasing power demand, the modern power systems are getting interconnected with each other [1]. In this interconnected power system, the vital task is to schedule the total load demand among available generating units in such a way that the total cost incurred is minimum after all system constraints satisfied [2]. The above stated process is considered as economic load dispatch problem (ELDP) in power system [3].

In the past, various conventional techniques are applied in order to solve ELDP using mathematical programming and conventional optimization methods. Some of these conventional techniques are the lambda iteration (LI) method [1], branch and bound technique (BBT)[4], gradient method [5] etc. Out of these methods, the LI method has been applied prominently because of its easy implementation. The feasibility of all above mentioned methods are only for linear cost estimation. In practical, the power system has many discontinuities and inherent nonlinearities due to prohibited operating zones (POZ) [6], ramp rate limits (RRL) [7], valve-point loading (VPL) [8], and multi fuel options. Owing to these inherent discontinuities and nonlinearities, ELDP, in practical, is converted into a complex and non-convex optimization problem having both complex as well as non-convex features. So, practical ELDP will come across multiple minima which pose difficulty in obtaining global optima. In this scenario, the conventional techniques fail to attain global optimum solution.

The modern meta-heuristic optimization methods are well suitable in solving such problems. In the literature, many heuristic and meta-heuristic approaches are mentioned to be applied to the ELD problems such as dynamic programming (DP) [9], evolutionary programming (EP) [10], genetic algorithm (GA) [11], Tabu search (TS) [12], particle swarm optimization (PSO) [13], simulated annealing (SA) [14], differential evolution (DE) [15], bat algorithm (BA) [16], artificial bee colony (ABC) [17], grey wolf optimization (GWO) [18], cuckoo search (CS) algorithm [19],

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kinetic gas molecules optimization (KGMO) [20], exchange market algorithm (EMA) [21], back tracking search (BTS) algorithm [22] etc. A comprehensive literature survey of modern day evolutionary and swarm-based can be found in [23].

PSO is proposed in 1995 by Eberhart and Kennedy [24] and successfully applied to solve complex engineering problems. Mirjalili et al. in the year 2014 proposed GWO algorithm [25]. It is a meta-heuristic algorithm for global optimization. It was inspired by the hunting behaviour of grey wolves. A hybrid version of PSO and GWO algorithm is proposed in this study to solve practical ELDP with smooth and non-smooth cost characteristics satisfying different system constraints. The solution to the problem is carried out for system without transmission loss where two different standard test systems are considered. The results obtained from hybrid PSO-GWO are compared to the results obtained from GWO and PSO algorithm in order to test the supremacy and efficiency of the proposed algorithm.

The rest of the paper is organized as follows. Section II discusses the problem definitions. The proposed algorithm is described in section III. Section IV discusses the simulation results. The work is concluded in section V.

II.PROBLEM DEFINITION

A. Generator operating cost

The overall cost of operation of plants consists of fuel cost, labour cost, maintenance and supplies. In general way, the labour cost, maintenance and supply do not change. Thus, the fuel costs are always taken into consideration for ELD problem. The objective of economic load dispatch is to minimize the total generation cost (including fuel cost, plus emission cost, plus operation/maintenance cost, plus network loss cost) by meeting operational constraints. In practical cases, the formulation of fuel cost of generators is taken in the form of quadratic function of generated output real power. However, the cost characteristic can be classified on the basis of smooth and non-smooth nature as smooth cost characteristic and non-smooth characteristic curve.

1) Smooth cost function

It depicts the simplest cost function. It can be mathematically expressed as a quadratic function

$$F_m\left(P_m\right) = a_m P_m^{\ 2} + b_m P_m + c_m \tag{1}$$

where, a_m , b_m and c_m are the cost coefficients of mth generating unit. P_m is the generated power of the mth unit.

2) Non-smooth cost function

It involves numerous non-differentiable positions to show the VPL effects that are present in EDP. VPL effect is a process that appears in power plants that generally consist of multiple valves for controlling the output power of the units. The steam entering valves in thermal units are first opened, then there is a abrupt increase in losses which leads to the appearance of ripples in cost characteristics curve. It can be formed as a quadratic and a sinusoidal function:

$$F_m\left(P_m\right) = a_m P_m^{\ 2} + b_m P_m + c_m + \left| e_m \sin\left(f_m \left(P_m^{\min} - P_m \right)\right)\right| \tag{2}$$

where, e_m and f_m are the fuel cost coefficients of the mth unit. $P_m^{\min}$ is the minimum generation limit of the mth unit.

The total generation cost (in $/hr) of the plant is given as

$$TC = \sum_{r=1}^{N} F_m\left(P_m\right) \tag{3}$$

where, TC is the total fuel cost of the plant and N is the total number of generating units in the plant.

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B. System Constraints

As it is stated before, the solution of ELD problem can be near to practical solution if the system constraints are satisfied. The system constraints are defined below.

1) Power balance constraint

The power generated has to be equal to the power demand required. It is defined as:

$$\sum_{r=1}^{N} P_m = P_D \tag{4}$$

where, P_D is the total power demand.

2) Generator limit constraint

The generating units of thermal power plants operate within their limits.

$$P_m^{\min} \le P_m \le P_m^{\max} \tag{5}$$

where, $P_m^{\min}$ and $P_m^{\max}$ are the minimum and maximum generating limits of the mth generating unit.

III.PROPOSED ALGORITHM

A. Particle Swarm optimization

PSO was developed by James Kennedy and Russell Eberhart in 1995 [24]. The inspiration behind PSO is the bird flocking behaviour. It is a population based algorithm and is categorized in nature-inspired optimization algorithms. In PSO, the initial population is subjected to fitness evaluation and the best solution is regarded as *pbest*. The other solution try to update their position based on *pbest* with certain velocity. After, some iteration, the better values are stored in archive and regarded as *gbest*. From the knowledge of *pbest* and *gbest*, the solution are modified at each iteration until global optima is found. The particle updates its velocity and positions with following equations based on *pbest* and *gbest*:

$$v_{r,j}^{new} = v_{r,j} + \left(c_1 \times rand() \times \left(pbest_{r,j} - x_{r,j}\right)\right) + \left(c_2 \times rand() \times \left(gbest_{r,j}\right) - x_{r,j}\right) \tag{6}$$

where, $v_{r,j}^{new}$ is the updated velocity of the jth decision variable of the rth population. $v_{r,j}$ is the old velocity of the jth decision variable of the rth population. c_1 and c_2 are the learning factors whose value is taken as 2. $rand()$ is any random number evenly distributed in the range $[0,1]$. $pbest_{r,j}$ and $gbest_{r,j}$ are the local and global best particle for jth decision variable of the rth population. $x_{r,j}$ is the present value of the particle.

and

$$x_{r,j}^{new} = x_{r,j} + v_{r,j}^{new} \tag{7}$$

where, $x_{r,j}^{new}$ is the new particle that will take part in the next generation.

B. Grey wolf optimization

The GWO is introduced by Mirjalili*et al.*, [25]. This algorithm is inspired by the social behaviour and the hunting mechanism of grey wolves. It has been seen that in a pack of wolves, some wolves play the role leaders and the other follow their instructions. The leader wolves are called alpha. Next to these alpha wolves come next set wolves that are not the leaders but are very close to leaders. They are called beta. Then there comes a group of wolves who follows the commands of alpha and beta wolves and are called delta. The last level of wolves consists of child and old wolves and they are called omega. The GWO algorithm is provided in the mathematical forms as follows.

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1) Social hierarchy

In the design of GWO, the social hierarchy of wolves is considered. Alpha (α) is the leader of the pack of wolves so it is equivalent to the best solution. Similarly, beta (β) and delta (δ) which comes after alpha are equivalent to second and third best values respectively. The rest of solutions are assigned to be omega (ω).

2) Encircling prey

The encircling of prey by grey wolves is accomplished during the hunt. This encircling behavior can be mathematically expressed as follows.

$$\vec{M} = \left|\vec{N} * \vec{X}_r(t) - \vec{X}(t)\right| \quad (8)$$

$$\vec{X}(t+1) = \vec{X}_r(t) - \vec{L} * \vec{M} \quad (9)$$

where, t is the current iteration, $\vec{L}$ and $\vec{N}$ are coefficient vectors, $\vec{X}_r$ is the position vector of the prey (global solution), and $\vec{X}$ is the position vector of a gray wolf. The vectors $\vec{L}$ and $\vec{N}$ are evaluated as follows.

$$\vec{L} = 2\vec{l} * \vec{r}_1 - \vec{l} \quad (10)$$

$$\vec{N} = 2 * \vec{r}_2 \quad (11)$$

where, components of $\vec{l}$ are linearly decreased from 2 to 0 according to iterations and r_1, r_2 are random vectors in [0, 1].

3) Hunting

The hunting behavior is common in wolves. The hunt for a prey is initiated by alpha with the help of beta and delta wolves. The others wolves update their position accordingly. The update of their agent position can be formulated as follows.

$$\vec{M}_\alpha = \left|\vec{N}_1 \cdot \vec{X}_\alpha - \vec{X}_\alpha\right| \quad (12)$$

$$\vec{M}_\beta = \left|\vec{N}_1 \cdot \vec{X}_\beta - \vec{X}_\beta\right| \quad (13)$$

$$\vec{M}_\delta = \left|\vec{N}_1 \cdot \vec{X}_\delta - \vec{X}_\delta\right| \quad (14)$$

$$\vec{X}_1 = \vec{X}_\alpha - \vec{L}_1 \cdot \left(\vec{M}_\alpha\right) \quad (15)$$

$$\vec{X}_2 = \vec{X}_\beta - \vec{L}_1 \cdot \left(\vec{M}_\beta\right) \quad (16)$$

$$\vec{X}_3 = \vec{X}_\delta - \vec{L}_1 \cdot \left(\vec{M}_\delta\right) \quad (17)$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \quad (18)$$

4) Attacking prey and search for prey (exploitation and exploration):

It has been seen that the ability of any wolves can be rated on the basis of type of prey hunted. That means, the ability of algorithm lies in finding the optimal solution. Since the value of $\vec{l}$ is decreased from 2 to 0, $\vec{L}$ is also decreased by. In other words, $\vec{L}$ is a random value in the interval [-2l, 2l]. When $|L| < 1$, the prey has to be attacked by wolves. The search for prey is the exploration ability. The random values of $\vec{L}$ are utilized to oblige the search agent to diverge from the prey. When $|L| > 1$, the wolves are moved away from the prey.

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C. Hybrid PSO-GWOalgorithm

The proposed hybrid PSO-GWO algorithm is formed by hybridization of basic PSO and GWO algorithm. The advantage of this hybridization is to eradicate the disadvantage associated with basic PSO algorithm and to use the advantage of GWO algorithm. The hybridized algorithm starts with the random initialization of the population. Then, the population is updated by the PSO algorithm and the better solution is selected. The selected solution are then fine-tuned and updated by then GWO algorithm. The better solution are selected and fed to the next iteration. This process is repeated until any termination criterion is met. The flowchart of proposed hybrid PSO-GWO algorithm is presented in Fig. 1.

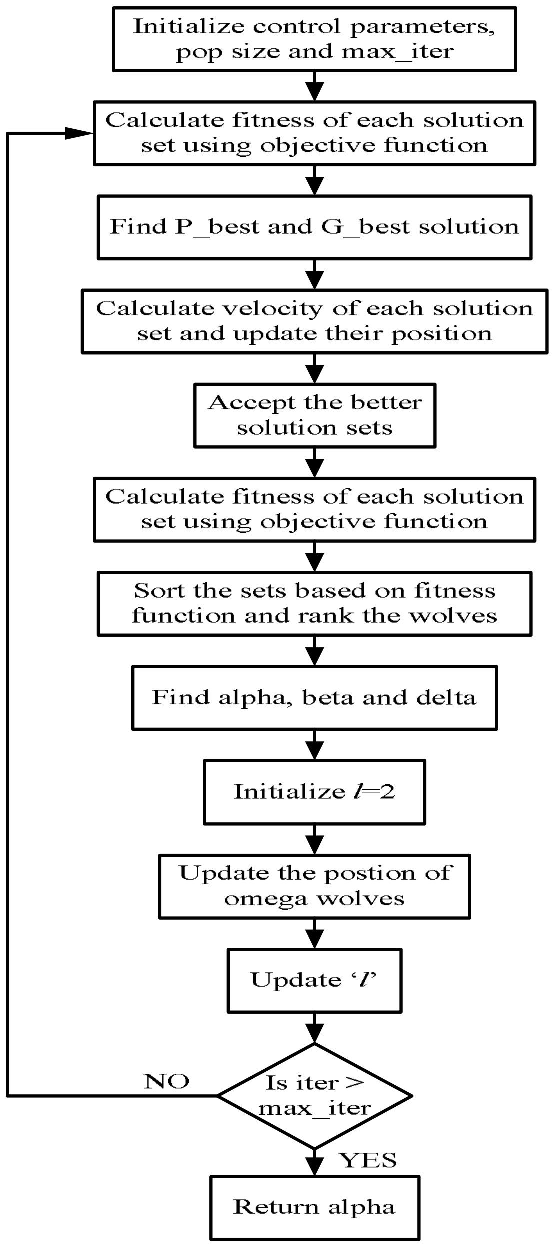

Fig. 1. Flowchart of hybrid PSO-GWO algorithm.

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D. Implementation of hybrid PSO-GWO algorithm to ELDP

Step 1: Read system data. Input population size and maximum iteration.

Step 2: Initialize random population X of generated power of the units within their limits using following for each solution.

$$P_m = P_m^{\min} + rand()\left(P_m^{\max} - P_m^{\min}\right) \tag{19}$$

The resultant initial population X will be as follows.

$$X = \begin{pmatrix} P_{11} & \cdots & P_{1N} \\ \vdots & \ddots & \vdots \\ P_{N^{POP}1} & \cdots & P_{N^{POP}N} \end{pmatrix} \tag{20}$$

where, N^{POP} is the population and N is the number of units.

Step 3: Evaluate fitness function for each solution in the population using (3).

Step 4: Select *pbest* and *gbest* solutions.

Step 5: Update the velocity and position of the solution using (6)and (7), respectively.

Step 6: Select better solutions and evaluate objective function.

Step 4: Sort the solutions based on evaluated objective function and rank the dispatch solution.

Step 5: Determine alpha, beta and delta dispatch solution.

Step 6: Initialize $l = 2$ and obtain L.

Step 7: Update each solution using (18) depending upon the value of L.

Step 8: Select the better solution based on fitness function evaluation.

Step 9: Update l.

Step 10: Repeat steps 3 to 9 until any termination criteria is met.

IV. SIMULATION RESULTS AND DISCUSSION

In this paper, hybrid PSO-GWO algorithm is proposed to solve a non-convex ELDP neglecting transmission line losses. Throughout the study, a population size of 20 is considered while maximum iteration is taken to be 500. Two standard IEEE test systems of 3 generators and 13 generators with and without VPL are considered for the simulation and the results so obtained from the proposed algorithm are compared with PSO and GWO. The system data are taken from [26]. The social learning factors c_1 and c_2 are taken to be 2 and 2, respectively whereas inertia weight w is considered to be 0.9 for PSO algorithm. All simulation studies are studied in MATLAB environment.

A. A three generator system

In this system, the total load demand is 850 MW. Table I shows the ELD for the system without considering transmission losses and the VPL effects. The results obtained from hybrid PSO-GWO are compared with PSO and GWO for this system. From the table, it can be observed that the minimum total cost of generation i.e. 8194.4230 $/h is obtained with IGWO while GWO is incurring 8195.1897 $/h and PSO is incurring 8203.6415 $/h. This suggests that hybrid PSO-GWO is more superior to PSO and GWO in obtaining optimal power dispatch. Fig. 2 shows the convergence characteristics of the algorithms for the taken system. From the figure, it can be seen that hybrid PSO-GWO converges to minimum value faster in comparison to PSO and GWO.

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TABLE I. ECONOMIC LOAD DISPATCH FOR CASE A WITHOUT VPL

Generating Units	Economic Load dispatch in MW		
	PSO	*GWO*	*Hybrid PSO-GWO*
Unit 1	350.1190	398.4993	388.9467
Unit 2	341.5078	340.6964	338.0075
Unit 3	158.3733	110.8141	123.0472
Total cost of generation ($/h)	8203.6415	8195.1897	**8194.4230**

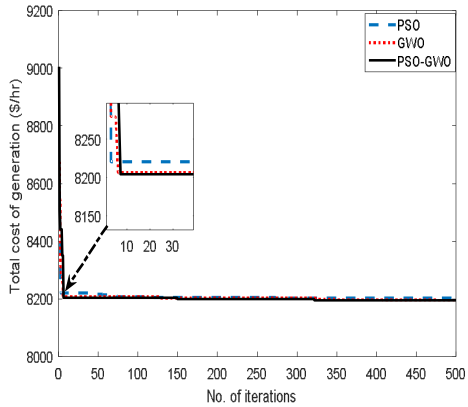

Fig. 2. Convergence characteristics for Case A without VPL effects

When the non-smooth nature of the cost is considered, the total cost of generation is ought to increase. Table II shows the comparative results obtained for ELD for the system considering the VPL effects with transmission losses neglected. From the table, it can be inferred that the minimum total cost of generation i.e. 8234.2826 $/h is obtained with hybrid PSO-GWO while GWO is incurring 8243.1671 $/h and PSO is incurring 8417.6868 $/h. This suggests that hybrid PSO-GWO is more superior to PSO and GWO in obtaining optimal power dispatch. Also in this case, it can be seen that the total cost of generation is increased with the inclusion of VPL effects in the problem. Fig. 3 shows the convergence characteristics of total generation cost. From the figure, it can be observed that hybrid PSO-GWO converges to minimum value faster in comparison to PSO and GWO.

TABLE II. ECONOMIC LOAD DISPATCH FOR CASE A WITH VPL

Generating Units	Economic Load dispatch in MW		
	PSO	*GWO*	*Hybrid PSO-GWO*
Unit 1	299.5854	499.6636	299.7240
Unit 2	350.8043	250.4032	400.1770
Unit 3	199.6103	99.9690	150.1042
Total cost of generation ($/h)	8417.6868	8243.1671	**8234.2826**

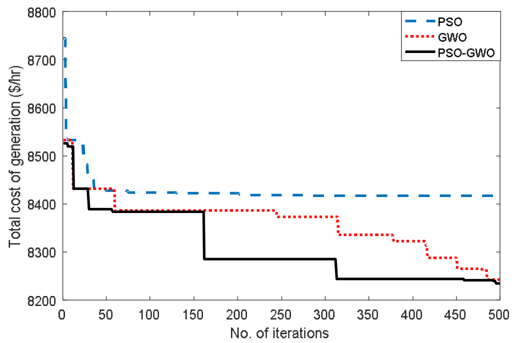

Fig. 3. Convergence characteristics for Case A with VPL effects.

B. A thirteen generator system

In this system, the total load demand is 1800 MW. Table III lists the ELD for the system without considering transmission losses and the VPL effects. The results obtained from hybrid PSO-GWO are compared with PSO and GWO in this case also. From this table, it can be clearly observed that the minimum total cost of generation i.e. 17936.1918 $/h is obtained with hybrid PSO-GWO while GWO is incurring 17972.8078 $/h and PSO is incurring 17987.1516 $/h. This suggests that hybrid PSO-GWO is more superior to PSO and GWO in obtaining optimal power dispatch. Fig. 4 shows the convergence characteristics of the algorithms for the taken system. From the figure, it can be inferred that the convergence rate of hybrid PSO-GWO is higher in comparison to PSO and GWO.

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TABLE III. ECONOMIC LOAD DISPATCH FOR CASE B WITHOUT VPL

Generating Units	Economic Load dispatch in MW		
	PSO	*GWO*	*Hybrid PSO-GWO*
Unit 1	453.8478	630.4293	512.6230
Unit 2	143.8530	53.0428	255.5768
Unit 3	236.0105	280.1076	218.9758
Unit 4	120.1254	93.4711	102.4349
Unit 5	126.0762	99.2055	125.4245
Unit 6	126.5154	129.0343	106.0419
Unit 7	102.8327	87.6559	96.2335
Unit 8	100.3922	98.5773	91.9451
Unit 9	133.3605	123.6202	101.7415
Unit 10	46.4585	48.0685	37.5856
Unit 11	79.5560	41.7148	40.0000
Unit 12	73.9108	59.9395	56.4998
Unit 13	57.0648	55.1975	55.0000
Total cost of generation ($/h)	17987.1516	17972.8078	**17936.1918**

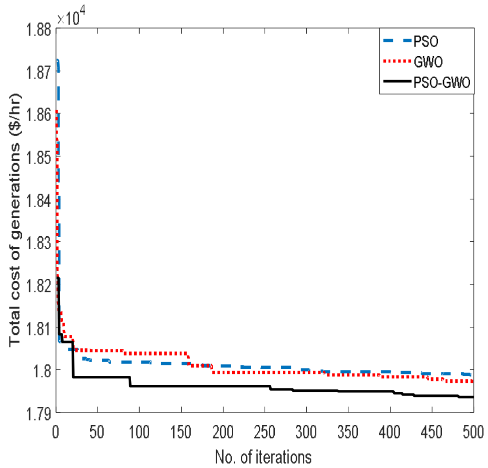

Fig. 4. Convergence characteristics for Case B without VPL effects.

When the non-smooth nature of the cost is considered, the total cost of generation is ought to increase. Table IV shows the comparative results obtained for optimal power dispatch for the system considering the VPL effects with transmission losses neglected. From the table, it can be inferred that the minimum total cost of generation i.e. 18630.7654 $/h is obtained with hybrid PSO-GWO while GWO is incurring 18667.2100 $/h and PSO is incurring 18740.3033 $/h. This suggests that hybrid PSO-GWO is more superior to PSO and GWO in obtaining optimal power dispatch. Also in this case, it can be seen that the total cost of generation is increased with the inclusion of VPL effects in the problem. Fig. 5 shows the convergence characteristics of the algorithms for the studied system. From the figure, it can be observed that hybrid PSO-GWO converges to minimum value faster in comparison to PSO and GWO which again confirms the superior performance of the proposed algorithm over other.

TABLE IV. ECONOMIC LOAD DISPATCH FOR CASE B WITH VPL

Generating Units	Economic Load dispatch in MW		
	PSO	*GWO*	*Hybrid PSO-GWO*
Unit 1	658.4667	324.2137	407.8611
Unit 2	47.1279	213.2025	250.8120
Unit 3	157.7738	332.9281	79.5851
Unit 4	77.0871	153.5162	168.1617
Unit 5	91.5161	105.6721	163.1247
Unit 6	120.0854	110.0197	67.8759
Unit 7	92.5560	60.0000	141.4854
Unit 8	138.6376	103.7928	78.1028
Unit 9	95.8549	60.0000	117.5905
Unit 10	70.9015	103.0895	38.1364
Unit 11	94.1169	40.0000	86.7132
Unit 12	62.8156	112.4845	102.2184
Unit 13	94.4486	83.6138	102.8422
Total cost of generation ($/h)	18740.3033	18667.2100	**18630.7654**

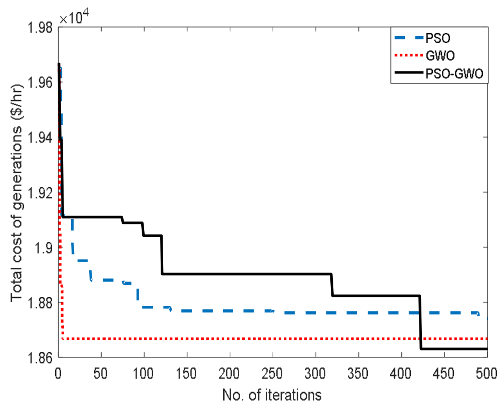

Fig. 5. Convergence characteristics for Case B with VPL effects.

V.CONCLUSION

In this work, a non-convex ELDP is solved with a novel proposed algorithm. The proposed algorithm is a hybrid version of particle swarm and grey wolf optimization. In PSO, the local search exploration was not that much convincing and it is often subjected to local minima trappings. However, GWO is found to be very much capable of

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local and global explorations. Thus, hybrid PSO-GWO algorithm is proposed by combining the two algorithms. To prove the efficiency of the proposed algorithm, two different cases of IEEE standard generator system with and without VPL effects are considered and the proposed algorithm is compared with GWO and PSO. The main conclusions are: (i) the hybridization of PSO and GWO enhances the local search exploration capability of the algorithm, (ii) The convergence rate of the algorithm is higher for hybrid PSO-GWO in comparison to GWO and PSO, (iii) hybrid PSO-GWO is well efficient in solving the ELD problem, since in all cases; the minimum total cost of generation is obtained from this algorithm, (iv) PSO algorithm is found to be the worst performer in comparison to others, and (v) the performance of hybrid PSO-GWO is not affected from the change in test systems.

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