International Journal of Hybrid Information Technology
Vol.8, No.12 (2015), pp. 117-134
http://dx.doi.org/10.14257/ijhit.2015.8.12.07

Grey Wolf Optimization for Active Power Dispatch Planning Problem Considering Generator Constraints and Valve Point Effect

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Abstract

This research proposed an application of swarm inspired new meta heuristic algorithm Grey Wolf Optimization to solve active power dispatch problem imposing valve point effect and generator constraints. Grey Wolf optimization is based on mathematical approach whose solution convergence inspired by the leadership hierarchy and hunting mechanism of grey wolves. It explores search space as a multi-level decision mechanism and does not require gradient for search path. This approach converged to global optimal solution in spite of the non linearity added by valve point effect while solving the fitness function. Optimal scheduling of generators to minimize the total operating cost coupled with generator constraints and valve point effect to match load demand is implemented with proposed method and. Exploration, Computation and Convergence power are evaluated to track the computational efficiency of the proposed technique. The presented technique is tested on different test cases comprises three, six and thirteen test systems incorporating valve point effect. Test results are compared with other nature and bio inspired algorithms presented in literature .Analysis shows cut throat results as total operating cost turns out to be minimum as compared to other techniques which infers the effectiveness of proposed method and encourage to further explore the potential of proposed method to solve complex optimization problems in active power dispatch planning area.

Keywords: *Unit Commitment (UC), Active Power Dispatch (APD), Grey Wolf Optimization (GWO)*

1. Introduction

The Active Power Dispatch (APD) problem is one of the inherent issues of contemporary power system planning [1]. The goal of the APD is to find the efficient active power generation among different generators, so that the total fuel cost is minimized while keeping all the constraints satisfied. Conventional and heuristic algorithms have been applied to solve APD problem. In conventional methods, the cost curve is linear but in reality, the curve is highly nonlinear. Valsan, *et al.*, [2], proposed hope-field neural network for economic dispatch and unit commitment. Navpreet Singh Tung, *et al.*, [3], presented an implementation of fuzzy-logic controller to solve the unit-commitment and economic dispatch problem of thermal generation plant with the main objective of evaluating the total operating cost for each loading condition while subjected to a variety of constraints. Many evolutionary computing [4], based algorithms have been presented for economic dispatch. Happ [5], presented survey on optimal power dispatch considering different aspects. Rahman, *et al.*, [6] showed advancements in economic

ISSN: 1738-9968 IJHIT

dispatch. Solution to different constrained and unconstrained problem [7, 8], with genetic algorithm approached have been delivered. Nature and bio inspired techniques [9-12], have been successfully applied to APD problem for optimal solution. An application of Particle Swarm Optimization, Pattern Search and evolutionary programming [14-18], based approach is used for solving economic dispatch problem.

Recently, a new swarm based meta heuristic algorithm inspired by grey wolves Grey wolf optimization (GWO) has been introduced by Mirjalili, Seyedali, *et al.*, [13] in 2014 to solve complex optimization problem. Grey Wolf optimization is attracted by the mentorship hierarchy and hunting procedure of grey wolves. It has been successfully applied to many non linear engineering problems for optimal solution. In present context, an application of GWO has been proposed to solve active power dispatch problem considering valve point effect. As APD is highly non linear problem, GWO is evaluated and compared with other techniques to test its computation efficiency.

2. Problem Design

The APD problem [3] can be presented by minimizing the operating fuel cost of generator units subjected to various constraints. As the load demand is variable, the power generation has to be altered to equate the balance between loads and active power generation of a system. The APD model consists of n generating units online.
The APD problem can be expressed as.

A. Fuel Cost Model [3]
$C(P_{Gi})=\Sigma(a_i*P_{Gi}^2+ b_i*P_{Gi} +c_i)$Rs where i=1…..N(a,b,c are cost co-efficients)
B. Power Balance Constraints[3]

- $\Sigma P_{Gi}-P_D=0$(Power Generation=Power Demand)
- $P_{Gi,min}\leq P_{Gi}\leq P_{Gi,max}$ where i=1,2……N(Limits of Power Generation)

C. Total Operating Cost Minimization[3]
Total Operating Cost= $C(P_{Gi})$
D. Valve Point Effect [11]

The Input-output characteristic of a generator are approximated using quadratic or piecewise quadratic function, under the assumption that the incremental cost curves of the units are monotonically increasing piecewise-linear functions. However, real input-output characteristics display high order non linearities and discontinuities due to valve-point loading in fossil fuel burning plants. The generating units with multivalve steam turbines exhibit a greater variation in the fuel cost functions. The valve point effects introduce ripple in the heat rate curves. Mathematically ELD problem considering valve point loading is defined as:

$$C(P_{Gi})=\Sigma(a_i*P_{Gi}^2+ b_i*P_{Gi} +c_i)+e_i *\sin(f_i *(P_{Gi,min} - P_{Gi})$$

where, a,b,c, are cost coefficients of the i_{th} unit and e,f are constants of valve point effect of generators.

3. Grey Wolf Optimization

Grey wolf is a new population based method which is introduced in 2014 by Mirjalili, *et al.*, [13]. GWO algorithm is inspired by grey wolves. The technique follows the social hierarchy and hunting path of grey wolves. For simulating the leadership hierarchy in GWO algorithm, four groups are defined: alpha, beta, delta, and omega. Further, the three main steps of hunting, searching for prey, encircling prey, and attacking prey, are tested.

This algorithm requires a number of parameters to be set, namely, initialize alpha, beta, and delta, Number of search agents, Maximum number of iterations, number of sites selected for neighborhood search (out of n visited sites) and the stopping criterion.

The follow-up of grey wolf hunting are as follows:
1) Tracking, chasing, and approaching the victim.
2) Pursuing, encircling, and harassing the victim until it stops moving.
3) Attack towards the victim.

- **Social Hierarchy**

For modeling the social hierarchy of wolves until designing GWO, the fittest solution is considered as the alpha (α). Accordingly, the second and third best solutions are named beta (β) and delta (Δ) respectively. The rest of the candidate solutions are considered to be omega (w). The x wolves follow these three wolves.

- **Encircling Prey**

Next, for designing encircling behavior, some equations are considered:
$D= (C.X_p(t) - X(t))$
$X(t+1)=X_p(t) -A.D$

where t is the current iteration, A and C are coefficient vectors, $X_p(t)$ represents the position vector of the victim.
The vectors A and C can be calculated as below:

X=2.a.r1-a
C=2.r2

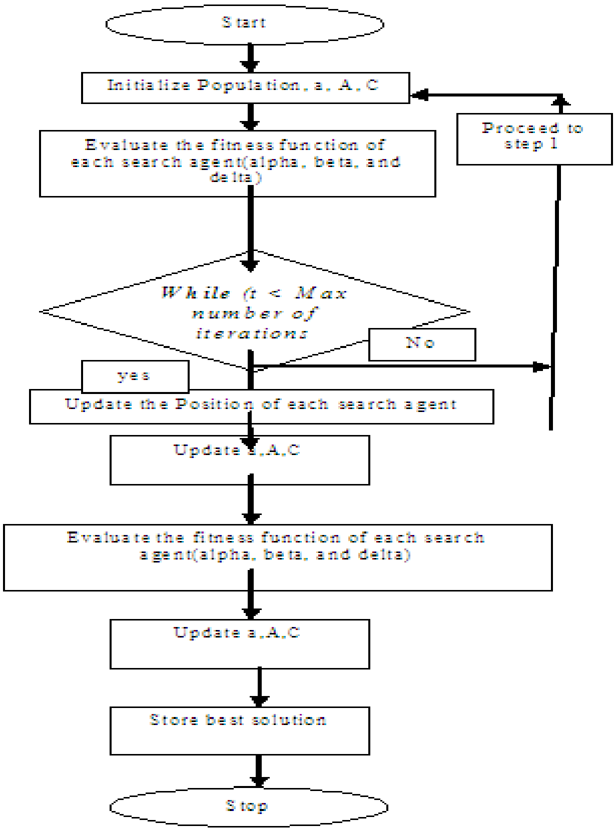
where a include are linearly decreased from 2 to 0 over the course of iterations and r1 and r2 are random vectors in the
range [0, 1].

- **Hunting**

In GWO, the first three best solutions obtained are stored so far and push the other search agents (including the omegas) to update their positions due to the position of the best search agents. The following equations are modeled.
$D_\alpha= (C_1.X_\alpha(t) - X(t))$
$D_\beta= (C_2.X_\beta (t) - X(t))$
$D_\Delta= (C_3.X_\Delta (t) - X(t))$
$X_1=X_\alpha - A_1. D_\alpha$
$X_2=X_\beta - A_2. D_\beta$
$X_3=X_\Delta - A_3. D_\Delta$
X(t+1)=X1+X2+X3/3;

The final position would be in a random position within a circle which is defined by the positions of alpha, beta, and delta in the search space. In other words alpha, beta, and delta estimate the victim position and other wolves update their positions randomly around the victim [13].

3.1 Design and Formulation of GWO



3.2 Pseudo Code

{Initialize the grey wolf population Xi (i = 1, 2, ..., n)
Initialize a, A, and C
Evaluate the fitness of each search agent
X_α=the best search agent
Xβ=the second best search agent
Xδ=the third best search agent
while *(t < Max number of iterations)*
for *each search agent*
Update the position of the current search agent
end for
Update a, A, and C
Calculate the fitness of all search agents
Update Xα, Xβ, and Xδ
t=t+1
end while
return X_α }

3.3 Simulation Flow

Step1: Feasible Boundary Location

Agents are randomly initialized and located between the minimum and maximum operating limits of generators. Each agent should match the system constraints.

Step 2: Objective Function

This evaluates for each agent(Xα, Xβ, and Xδ) while constraints are satisfied. Update position of each search agent.

Step 3: A,C,a coefficients

Value of coefficients A,C,a are updated.

Step 4: Update position of every agent

The position of every agent is updated (Xα, Xβ, and Xδ)

Step 5: Finishing criteria

Repeat process 2 to 5 until maximum number of iterations is reached.

4. Algorithms Numerical Settings

GWO: Population size =50, coefficient a=[0-2],Iterations=500

5. APD Formulation Using GWO

- Variables

Power Generation (PG) and cost coefficients (a,b,c) of units with fitness function as fuel cost, quadratic in nature and valve point effect. Power Generation variable should be initialized as starting point for initial solution in GWO.

- Constraints

Equality Constraints: Power Generation-Power Demand=0(P_G=P_d)

In-Equality Constraints: Power Generation should be between minimum and maximum limit of power generation.

Variables in constraints should be incorporated in GWO as feasible search boundary.

- Stopping Criteria

It is the maximum number of iteration for optimum solution.

6. Test System

To check the effectiveness of GWO for APD problems, four different case studies considering valve point effect [11, 12] are taken.

6.1. Three-Generating Unit System with Valve Point Effect [11]

This case study incorporates three generating units. Coefficients of fuel cost, valve point effect and the limits of the generation units are given in Table 1.

Table 1. Generator Data for Test System I

Unit	a	b	c	e	f	PG_{min}(MW)	PG_{max}(MW)
1	0.001562	7.92	561	300	0.00315	100	600
2	0.004820	7.97	78	150	0.063	50	200
3	0.001940	7.85	310	200	0.042	100	400

6.2. Six-Generating Unit System [12]

This case study incorporates six generating units. The coefficients of fuel cost and the limits of the generation units are given in Table 2.

Table 2. Generator Data for Test System II

Unit	a($/MW2)	b($/MW)	c($)	PG_{min}(MW)	PG_{max}(MW)
1	0.007	7	240	100	500
2	0.005	10	200	50	200
3	0.009	8.5	220	80	300
4	0.009	11	200	50	150
5	0.0080	10.5	220	50	200
6	0.0075	12	120	50	120

6.3. Three-Generating Unit System [12]

This case study incorporates three generating units. The coefficients of fuel cost and the capacities of the generation units are mentioned in Table 3.

Table 3. Generator Data for Test System III

Unit	a($/MW2)	b($/MW)	c($)	PG_{min}(MW)	PG_{max}(MW)
1	0.008	7	200	10	85
2	0.009	6.3	180	10	80
3	0.007	6.8	140	10	70

6.4. Thirteen Generating Unit System With Valve Point Effect[11]

This case study incorporates three generating units. The coefficients of fuel cost, valve point effect and the limits of the generation units are incorporated in Table 4.

Table 4. Generator Data for Test System IV

Unit	a	b	C	e	f	PG_{min}(MW)	PG_{max}(MW)
1	0.00028	8.10	550	300	0.035	0	680
2	0.00056	8.10	307	200	0.042	0	360
3	0.00056	8.10	309	150	0.042	0	360
4	0.00324	7.74	240	150	0.063	60	180
5	0.00324	7.74	240	150	0.063	60	180
6	0.00324	7.74	240	150	0.063	60	180
7	0.00324	7.74	240	150	0.063	60	180
8	0.00324	7.74	240	150	0.063	60	180
9	0.00324	7.74	240	150	0.063	60	180
10	0.00284	8.60	126	100	0.084	40	120
11	0.00284	8.60	126	100	0.084	40	120
12	0.00284	8.60	126	100	0.084	55	120
13	0.00284	8.60	126	100	0.084	55	120

7. Results and Discussions

7.1. Layout

- Test system comprises of three units, three units with valve point effect, six units and thirteen units system with valve point effect for variable power demand [11,12].
- Optimal Power generation (MW) for every test system is generated using GWO [13].
- Comparison of Total Operating Cost, Best Cost, Worst Cost, Mean Cost, Standard Deviation (SD) is presented for different test cases.

7.2. Simulation and Numerical Result

Proposed technique is tested on different benchmarks for simulation. Comparative analysis is demonstrated with other optimization techniques. In Table 5, Table 6 and Table 7, the optimum power generation for every unit, total operating cost (**8352.0153**($/hr)) and CPU computational time (**1.2 sec**) using proposed GWO technique on six unit system without valve point effect are given. In Table 7, comparative analysis is presented with other techniques like Cuckoo Search, Artificial Bee Colony, Firefly Algorithm, Particle Swarm Optimization, Harmony Search, Shuffled Frog Leaping, Bacterial Foraging Optimization, pattern search in terms of total operating cost. Total operating cost with proposed technique **GWO** is less as compared to other techniques. In Table 8, convergence and exploration potential of GWO is shown. Different costs like Worst, Mean and Best cost are less as compared to other techniques which proves the good solution quality and convergence variation with feasible search boundary. Standard Deviation (SD)- **0.000058** is again minimum as compared to other techniques shows robustness and exploration capability. Power generation and Cost Comparison with other techniques are reflected Figure 1 and Figure 2. Convergence of fitness function with iterations and feasible search boundary are shown in Figure 3.

Table 5. Power Generation, Total Cost and Computational Time using GWO on six unit System (Power Demand-700 MW) [12]

PG1 (MW)	PG2 (MW)	PG3 (MW)	PG4 (MW)	PG5 (MW)	PG6 (MW)	Cost ($/hr)	Computation Time(sec)
272.2641	**85.45712**	**168.5936**	**60.89443**	**73.64845**	**50.13542**	**8352.0153**	**1.2**

Table 6. Results Comparison with other Techniques on Six Unit System (Power Demand-700 MW) [12]

Parameters	**GWO**	CS[12]	ABC[12]	FA[12]
PG1 (MW)	**272.2641**	324.113	323.043	293.312
PG2 (MW)	**85.45712**	76.859	54.965	79.546
PG3 (MW)	**168.5936**	158.094	147.354	123.334
PG4 (MW)	**60.89443**	50.000	50.000	69.700
PG5 (MW)	**73.64845**	51.963	85.815	79.546
PG6 (MW)	**50.13542**	50.000	50.233	63.778
Cost ($/hr)	**8352.0153**	8356.06	8372.27	8388.45

Table 7. Results Comparison of Total Cost with other Techniques on Six Unit System (Power Demand-700 MW) [12]

Technique	**GWO**	CS[12]	ABC[12]	FA[12]	PSO[12]	SFL[12]	BFO[12]	HS[12]
Cost ($/hr)	**8352.0153**	8356.06	8372.27	8388.45	8401.45	8419.78	8428.69	8398.06

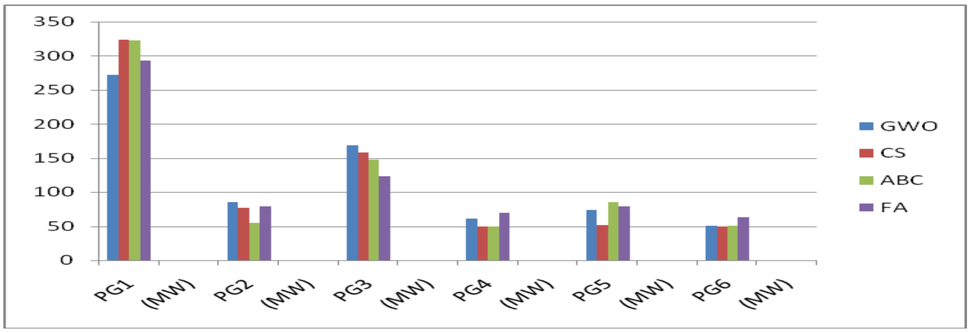


Figure 1. Power Generation Compariosn of GWO with other Techniques on Six Unit System 6

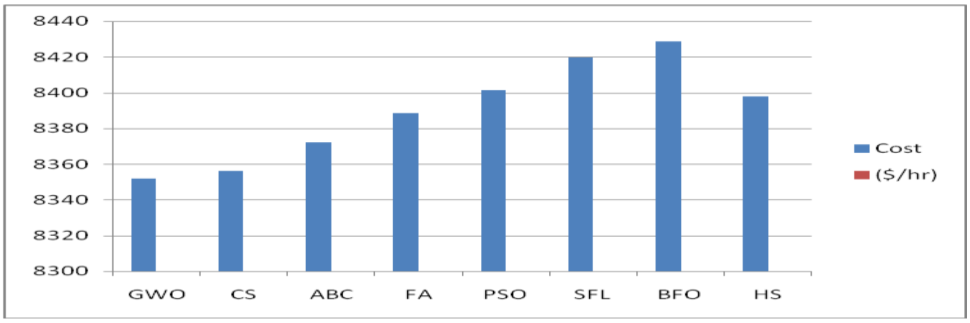


Figure 2. Comparison of Total Cost of GWO with other Techniques on Six Unit System

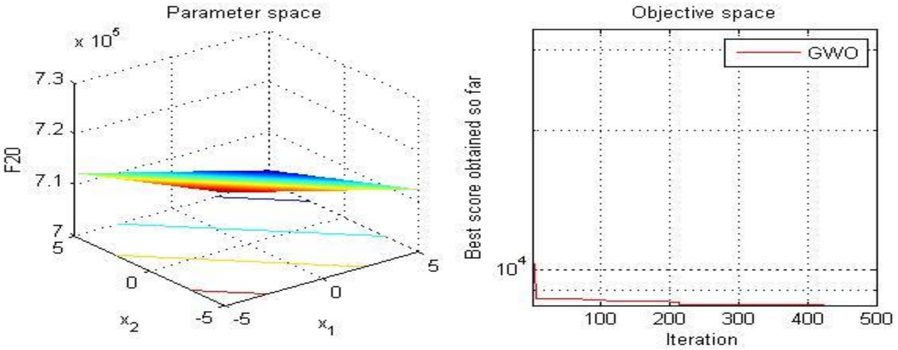


Figure 3. Convergence of Fitness Function with Iteration and Feasible Search Space Boundary on Six Unit System

Table 8. Convergence, Computation and Exploration Capability Comparison with other Techniques on Six Unit System [12]

Parameters	**Mean Cost($/hr)**	Standard Deviation	Worst Cost($/hr)	Best Cost($/hr)
CS[12]	8356.06	0.0008	8356.06	8356.06
ABC[12]	8457.16	57.726	8610.28	8372.27
FA[12]	8631.82	176.83	9082.00	8388.45
PSO[12]	8722.04	177.652	8912.16	8401.45
SFL[12]	8479.49	54.781	8604.29	8419.78
BFO[12]	8571.91	127.85	8909.85	8428.69
HS[12]	8541.72	99.531	8778.37	8398.06
GWO	**8352.0153**	**0.000058**	**8352.0153**	**8352.0153**

- To test the effectiveness of proposed method GWO on small scale, small system comprises three unit without valve point effect is considered. Comparative studies are carried out with other optimization techniques. Table 9 presents the optimum power generation for every unit, total operating cost (**1523.403**($/hr)) using proposed GWO technique on three unit system without valve point effect. Total operating cost with proposed technique is again less as compared to other techniques. In Table 10, convergence and exploration potential of GWO have been presented. Worst, Mean and Best cost are minimum as compared to other techniques which proves the sound solution quality and convergence variation within feasible search boundary. Standard Deviation (SD)**- 2.47e−6** is least among different set of costs contrast to other techniques shows robustness and exploration capability. In Figure 4, comparison of cost of proposed technique GWO with other techniques is presented on three unit system. Figure 5 shows the solution convergence with iteration and search space for three unit system.

Table 9. Results Comparison with other Techniques on Three Unit System 7 (Power Demand-150 MW) [12]

Parameters	**GSA**	CS[12]	ABC[12]	FA[12]
PG1 (MW)	23.7073	33.490	33.049	32.729
PG2 (MW)	83.7653	64.116	61.764	63.843
PG3 (MW)	44.5295	55.126	57.872	56.151
Cost ($/hr)	1526.7	1600.46	1600.51	1600.47

Table 10. Convergence, Computation and Exploration Capability Comparison with other Techniques on Three Unit System (Power Demand-150 MW) [12]

Parameters	**Mean Cost**($/hr)	Standard Deviation	Worst Cost($/hr)	Best Cost($/hr)
CS[12]	1600.46	2.7e−6	1600.46	1600.46
ABC[12]	1607.37	11.676	1620.60	1600.51
FA[12]	1617.34	10.746	1633.57	1600.47
PSO[12]	1609.13	8.231	1627.87	1600.60
SFL[12]	1602.06	1.519	1607.62	1600.67
BFO[12]	1604.28	3.1993	1611.35	1600.02
HS[12]	1610.10	9.415	1629.18	1600.58
GWO	**1523.403**	**2.47e−6**	**1523.403**	**1523.403**

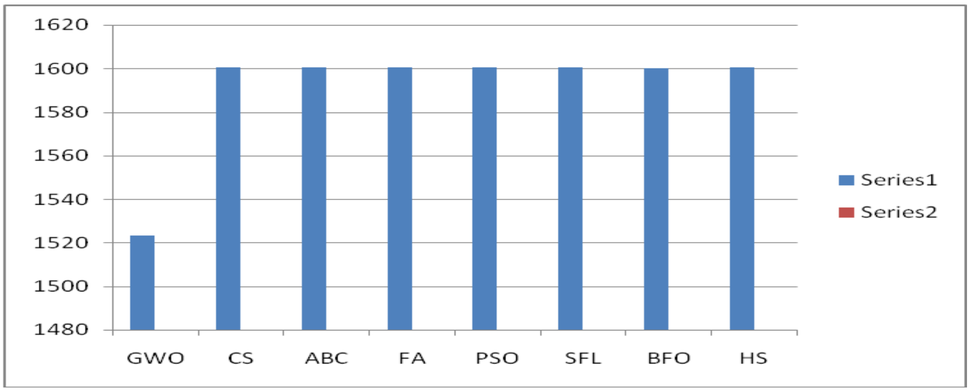


Figure 4. Comparison of Total Cost of GWO with Other Techniques on Three Unit System

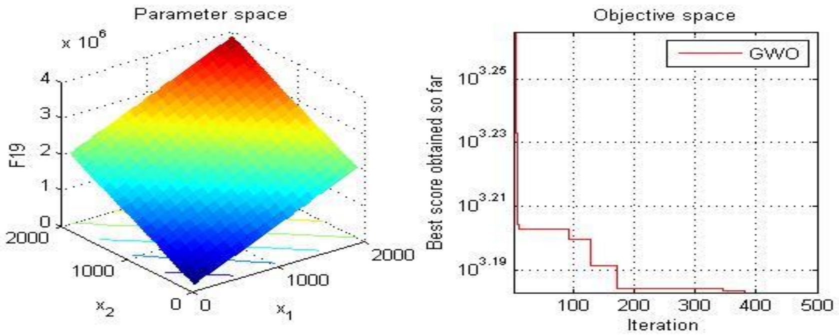


Figure 5. Convergence of Fitness Function with Iteration and Feasible Search Space Boundary on three Unit System 8

- In above test systems, testing are carried out without valve point effect. Proposed method GWO has outperformed other optimization techniques in literature in terms of cost, solution quality, robustness, and convergence and exploration capability. To consider the case of high non linearity, we take the effect of valve point. A valve point effect of generator adds high non linearity in the fitness function and adds couple of local minima peaks. As our suggested technique GWO always leads to global optimal solution till now. To further validate the result, we consider small test system with three units with valve point loading. In Table 11, the optimum power generation for every unit, total operating cost(**7716.7421($/hr))** using proposed GWO technique on three unit system with valve point effect subjected to power demand of 850 MW are presented. Comparative results are also shown in terms of total operating cost. In Table 11, comparative studies are tabulated with other techniques in terms of total operating cost. Total operating cost with proposed technique **GWO** turns out to be very less as compared to other techniques. Thus, total cost is minimum as compared to other technique which proves the sound solution quality and convergence variation within feasible search boundary directing robustness and exploration capability even in high non-linearity. In Figure 6, comparison of cost is shown imposing valve point effect. Convergence solution with iteration and search boundary are shown in Figure 7.

Table 11. Results Comparison of Power Generation and Cost with Other Techniques on Three Unit System Considering Valve Point Effect (Power Demand- 850MW)[11]

Parameters	PG1(MW)	PG2(MW)	P3(MW)	Cost($/hr)
GWO	**548.5753**	**174.6731**	**126.7337**	**7716.7421**
GA[14]	398.700	50.100	399.600	8222.07
EP[14]	300.264	149.736	400.000	8234.07
EP-SQP[14]	300.267	149.733	400.000	8234.07
PSO[14]	300.268	149.732	400.000	8234.07
PSOSQP[14]	300.267	149.733	400.000	8234.07
GAB[15]	300.267	149.733	400.000	8234.08
GAF[15]	300.267	149.733	400.000	8234.07
CEP[15]	300.267	149.733	400.000	8234.07
FEP[15]	300.267	149.733	400.000	8234.07
MFEP[15]	300.267	149.733	400.000	8234.08
IFEP[15]	300.267	149.733	400.000	8234.07
PS[16]	300.2663	149.7331	399.9996	8234.05
GSA[11]	300.2102	149.7953	399.9958	8234.10

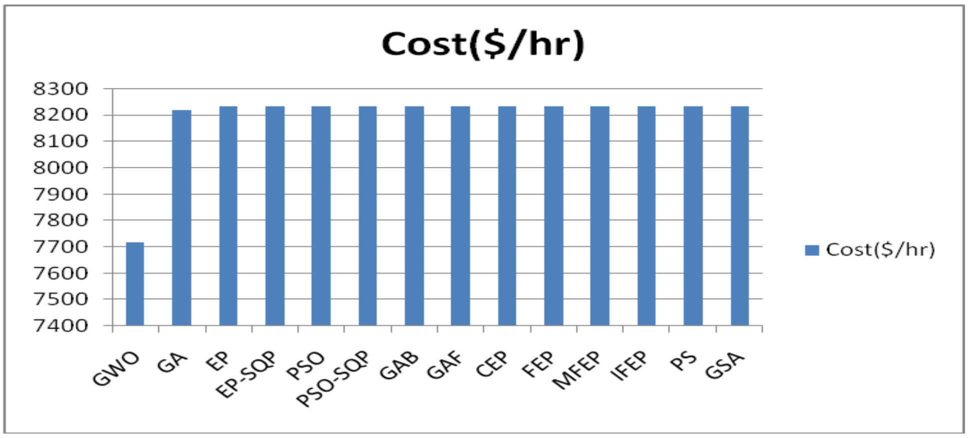


Figure 6. Comparison of Total Cost of GWO with Other Techniques on Three Unit System Considering Valve Point Effect 9

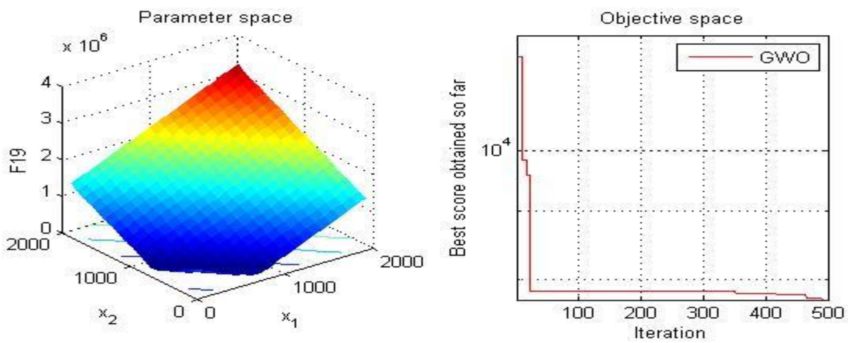


Figure 7. Convergence of Fitness Function with ITERATION and Feasible Search Space Boundary on three Unit System Considering Valve Point Effect

- To further validate the above results on large scale system, we consider large scale system having thirteen units with valve point loading. Variable power demand is considered to test the effectiveness. In Table 12 and 13 shows the power generation, computational time(**2.4 sec**) and total cost(**16413.9413 ($/hr)**) for power demand of 1800MW.Again, it overpowered other techniques ,which proves the sound solution quality and convergence variation within feasible search boundary directing robustness and exploration capability even in high non-linearity. In Figure 8 shows the convergence of fitness function with iteration and search boundary for large scale system. Cost comparison among different techniques on large scale system is presented in Figure 9.

Table 12. Results of Power Generation and Cost using GWO on Thirteen Unit System Considering Valve Point Effect (Power Demand-1800 MW) [11]

Power Generation	GWO
PG1(MW)	591.017
PG2(MW)	13.2194
PG3(MW)	205.5759
PG4(MW)	98.94354
PG5(MW)	177.3095
PG6(MW)	94.96122
PG7(MW)	91.138
PG8(MW)	91.4281
PG9(MW)	175.7487
PG10(MW)	53.37931
PG11(MW)	62.74387
PG12(MW)	68.1481
PG13(MW)	76.38201
Power Demand(MW)	1800
Cost($/hr)	16413.9413
Computation Time(sec)	2.4

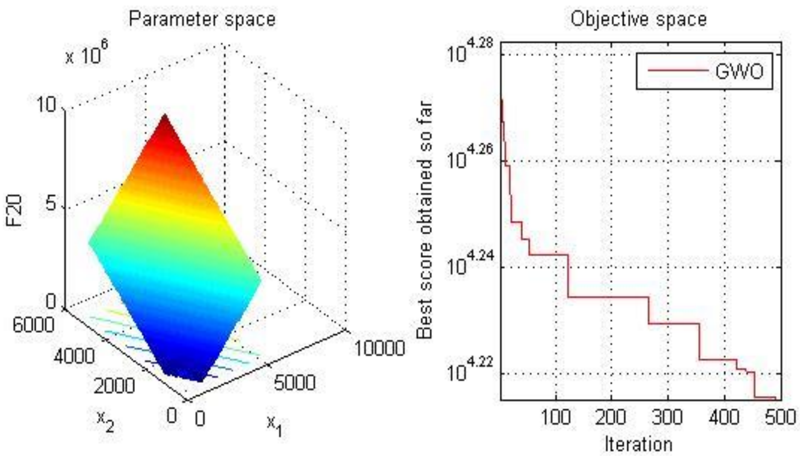


Figure 8. Convergence of Fitness Function with Iteration and Feasible Search Space Boundary on thirteen Unit System (Power Demand-1800 MW) 10

Table 13. Results of Power Generation and Cost using GWO on Thirteen Unit System Considering Valve Point Effect (Power Demand-1800 MW) [11]

Technique	Cost($/hr)
GWO	**16413.9413**
CEP[15]	18048.21
PSO[14]	18030.72
MFEP[15]	18028.09
FEP[15]	18018.00
IFEP[15]	17994.07
EP-SQP[14]	17991.03
HDE[11]	17975.73
CGA-MU[11]	17975.34
PSO-SQP[14]	17969.93
PS[16]	17969.17
UHGA[11]	17964.81
QPSO[11]	17964
IGA_MU[11]	17963.98
ST-HDE[11]	17963.89
HGA[11]	17963.83
HQPSO[11]	17963.9571
DE[11]	17963.83
GSA[11]	17960.3684

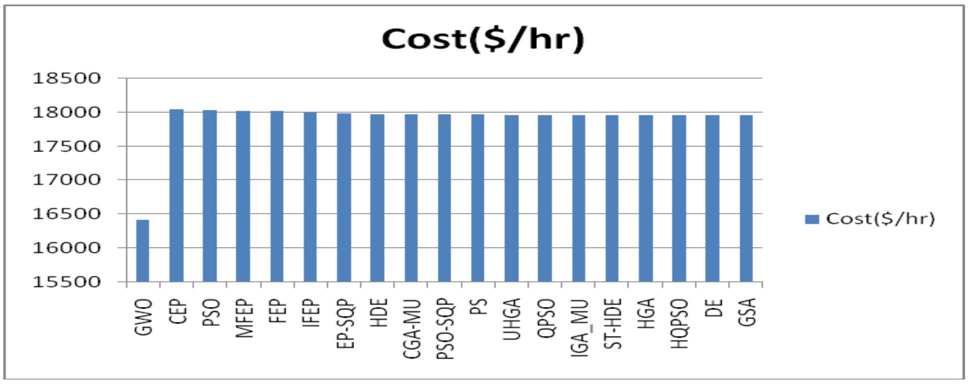


Figure 9. Comparison of Total Cost of GWO with other Techniques on Thirteen Unit System with Valve Point Effect (1800 MW Power Demand)

- Further, we consider different load demand of 2520 MW having thirteen units with valve point loading. Table 14 and Table 15, shows the power generation, computational time (**2.6 sec**) and total cost (**22783.0898($/hr)**) for power demand of 2520 MW. It has out-performed other techniques, again benchmarks the sound solution quality and convergence variation within feasible search boundary directing robustness and exploration capability even in high non-linearity. In Figure 10 and Figure 11, convergence of solution with iteration and cost comparison are shown for large scale system.

Table 14. Results of Power Generation and Cost using GWO on Thirteen Unit System Considering Valve Point Effect (Power Demand-2520 MW) [11]

Power Generation	GWO
PG1(MW)	**571.9089**
PG2(MW)	**341.143**
PG3(MW)	**351.1588**
PG4(MW)	**171.4505**
PG5(MW)	**159.6836**
PG6(MW)	**170.1981**
PG7(MW)	**115.0091**
PG8(MW)	**178.9071**
PG9(MW)	**176.4885**
PG10(MW)	**69.26004**
PG11(MW)	**64.16837**
PG12(MW)	**80.77308**
PG13(MW)	**69.86795**
Power Demand(MW)	**2520**
Cost**($/hr)**	**22783.0898**
Computation Time(sec)	**2.6**

Table 15. Results comparison of total Cost using GWO with other Techniques on Thirteen Unit System Considering Valve Point Effect (Power Demand-2520 MW) [11]

Technique	Cost($/hr)
GWO	**22783.0898**
SA[14]	24970.91
GA[14]	24398.23
GA-SA[14]	24275.71
EP-SQP[14]	24266.44
PSO-SQP[14]	24261.05
UHGA[11]	24172.25
GA-MU[11]	24170.755
IGAMU[11]	24169.979
ACO[11]	24169.93
HGA[11]	24169.92
EDSA[11]	24169.92
DE[11]	24169.9177
GSA[11]	24164.251357

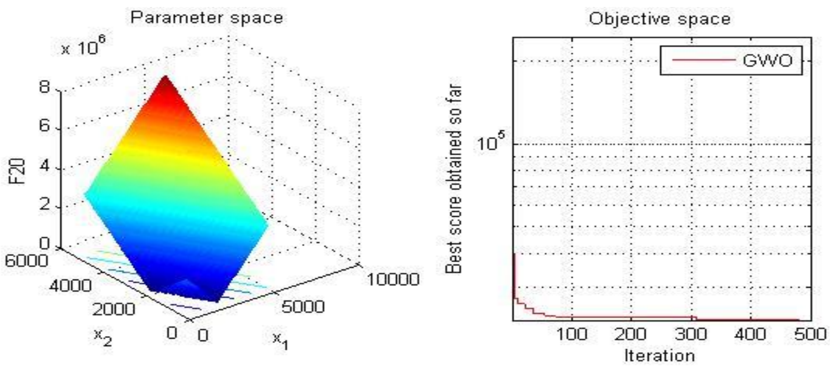


Figure 10. Convergence of Fitness Function with Iteration and Feasible Search Space Boundary on Thirteen Unit System (Power Demand-2520 MW) 12

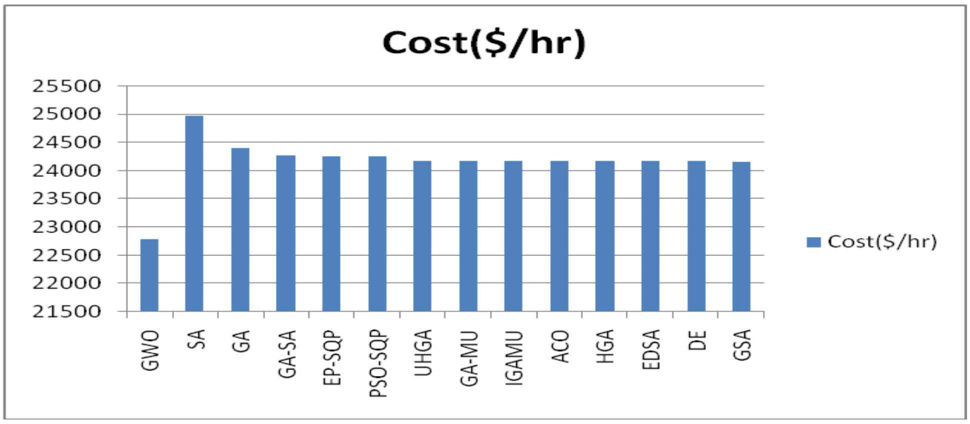


Figure 11. Comparison of Total Cost of GWO with Other Techniques on Thirteen Unit System with Valve Point Effect (2520 MW Power Demand)

- In nutshell, proposed technique GWO searches for best solution in feasible search boundary within bounds. GWO is successfully applied to different set of systems in small and large scale considering valve loading non linearity. Test results show the effectiveness of proposed technique both in linear and non linear system. In addition, the results substantiate the robustness, precise convergence and efficiency of this optimization algorithm. The main advantage of GWO is its core ability to converge at global solution among local minima values. From the results, it is concrete that GWO is a competitive technique for solving complex non smooth optimization problems in Active Power Dispatch Problem.

7.3. Comments

- **Global Minima Solution**

From convergence of fitness function with iterations and feasible search space boundary exploration, proposed technique achieves minima best solution through fast convergence with iterations solution.

- **Computational Power**

From results, we see that the proposed technique takes less computational time. This technique consumes less CPU memory as it is fast due to fast convergence from results. We observe that deviation of solution for this technique GWO is less as compared to other techniques for three and six unit system. Best, mean and worst cost with different set of iterations shows the computational efficiency of proposed method as they keep minima value as tested with other methods.

- **Convergence Precision Capability**

Convergence of solutions for iterations has been tested. It shows that, proposed methodology **GWO** grows towards global solutions and it maintains the solution convergence for many runs. Best, mean and worst cost solution are close approximation of each other for three and six test system, means the convergence precision is high and avoid all the local minima solutions among feasible solutions in search boundary as compared to other methods as these algorithms suffers from huge standard deviation among its best, mean, worst which shows lack of precision of convergence.

- **Exploration for Optimal Solution**

As the proposed method GWO explores solution in random initial population of generated powers through search space. GWO shows minimum mean cost solution and minimum standard deviation for three and six unit system when compared to other techniques for three and six unit system. It means average of all the solutions in feasible search space with different iterations carries the optimality when fly through the space for solution search. Further on, best cost also shows the promise of efficient exploration capability.SD goes down as the proposed method converge to optimal solution means the direction and boundary of solution search is best one.

8. Conclusion

In this work, potential of GWO is explored for solving APD problems considering valve point effect. The efficiency and effectiveness of the proposed technique is benchmarked for different test cases consisting of three, six and thirteen generating units with high non-linearity. The results of the GWO compared with that of other intelligence optimization algorithms in terms of operating cost of generators and power generation. Wide contrasting simulation results are observed with the other swarm, nature and bio inspired algorithms.GWO results in minimum operating cost, minimum standard deviation among best, mean and worst solution showing good explorability, fast convergence with iteration leads to robustness and good solution quality. It is concrete that GWO gives better results than other algorithms. GWO is simple to formulate and potential of reaching feasible global optimal solution.

Further on, the solution backs the robustness, accurate convergence and optimality of this optimization technique. From the results obtained it can be concluded that GWO has strong ability to solve complex non smooth optimization problems.

9. Future Suggestions

In future, the proposed technique can be effectively hybridized with other optimization techniques to solve convex and non-convex APD problems with incorporation of multi area objectives and constraints related to tie line, emission.

NOMENCLATURE

N	Number of units
P_D	Power Demand
P_{Gmax}	Maximum limit of Unit
P_{Gmin}	Minimum Limit of Unit
P_G	Power Generation

C Total Cost
P_L Power Losses
a,b,c Cost Coefficients
B Loss Coefficients

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