Hgwo-RES: A Hybrid Algorithm with Improved Exploitation Capability For Profit Based Unit Commitment Problem

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Abstract: Deregulation of electrical power industries has produced the competition in electricity market among the suppliers of the electricity. This competition delivers the better reliability and business of electricity at inexpensive cost. So many electrical power companies are rising by executing their suitable utilities, proper roles and objectives. Profit based unit commitment problem (PBUCP) is the complicated, nonlinear and combinatorial optimization problem with some constraints in the research of power system. Now a days researchers used different types of evolutionary algorithms to solve the PBUCP. In this proposed research, the hybrid version of Grey Wolf Optimizer (GWO) and Random Exploratory Search (RES) algorithm has been applied to solve the PBUCP. The proposed hGWO-RES optimization technique is implemented to improve the phase of exploration with GWO and phase of exploitation with RES algorithm. The efficiency of the proposed algorithm has been tested on IEEE Test units consisting 10-generating units and results has been discussed with the overall generation cost of those units.

Keywords: Profit Based Unit Commitment Problem, Grey Wolf Optimizer (GWO), Random Exploratory Search (RES), Meta-Heuristics Search.

1. INTRODUCTION

The economic operation, planning and control of power generating units play a vital role in day-to-day operation of the electric power generation companies. Optimal scheduling of the power generating units plays a major role in profit and cost of electrical power system economy. Thus the better scheduling is essential to operate the generating unit status by minimizing the total operating cost and maximize the profit of generation companies which is known as profit based unit commitment. PBUCP is one of the complex problem which rise the nonlinearity related with some constraints. The maximization of the profit of generation companies depends upon unit data, demand of the system, reserve price and spot price with satisfying some constraints including spinning reserve, initial ON/OFF status, ramp limit, operating constraints, start-up and shut-down constraints, minimum up and down time constraints. In case of deregulated environment the load demand and spinning reserve constraints are measured as soft-constraints. The PBUCP involve two sub-problems for optimization. First one is unit commitment problem which chooses the committed or de-committed status of the power generating units and the second one is consists of economic load dispatch problem which decides optimal position of power to committed generating unit within power generating limits [1]. Profit Based Unit Commitment Problem is a part of system planning a schedule of 8-h to 24 hour planning is done before hand this duration is quite moderate, however it can very to very short term planning (next hour) to very long term panning (one week to few week). Basically, PBUCP is hierarchical problem it does not end with the achievement of bare on off patterns of units but economic factor is deeply incorporated with it. Next level of problem is allocation of real power in units that participated in load. So this problem can be subdivided into two sub problem Viz. optimum allocation (commitment) of generators at each stations for various load levels and “allocation of generation” to each station.

In the recent years, various types of meta-heuristics search algorithms has been applied to solve profit based unit commitment problems such as Biogeography based Optimizer [2], Moth Flame Optimizer [3] Ant Lion Optimizer [4], , Gravitational Search Algorithm [5], Expert System Algorithm [6] Branch and Bound Method [7], , Genetic Algorithm [8], Binary Gravitational Search Algorithm [9], Particle swarm optimization algorithm [10], Bat Algorithm [11]. But every algorithm has some drawbacks such as Branch and bound technique do not involve significance ordering of units and can be stretched to allow for probabilistic backup constraints. The trouble of this technique is the epidemic improvement in implementation time for frameworks of an extensive reasonable dimension [12]. The Lagrangian Relaxation approach takes care of the short UC issue that gives quicker procedure yet it neglects to acquire arrangement achievability and ends up simply confusing if the quantity of units are more [13]. The mixed integer programming strategies for the unit

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commitment issues fall flat if the investment of number of units rises since they need an expansive memory and experience the ill effects of computational delay [14]. The theory of fuzzy strategy utilizing set of fuzzy to understand about estimated stack plans, yet it experiences multifaceted nature [15]. The Hopfield neural system considers more supplies yet it might experience the ill effects of numerical meeting because of its preparation procedure [16]. The Artificial Neural Network (ANN) technique devours the upsides of providing great arrangement feature and fast meeting. The technique can suit further confounded unit wise limitations and offers mathematical meeting and arrangement nature of the issue.

Shuffled frog leaping algorithm is able of resolving continuous discrete, non-differentiable, multi modal & non-linear optimization difficulties with faster convergence speed. But have limitations in local searching ability and have non-uniform initial population and sometimes suffer from premature convergence [17]. Also, The No-Free-Lunch theorem for optimization allow developers to develop new algorithm or to improve the existing algorithm because, it logically proves that there is no such optimization algorithm which can solve all the optimization problems with equal efficiency for all. Some algorithm work best for few problems and worst for the rest of the problems. So, there is always a scope or improvement to develop the algorithm which could work well for most of the problems.

Abbreviations
PF_{MAX} = Maximum Profit
R_v = Revenue
TC = Total generation cost
∂_h = Energy price at hth sub-interval in $/MW-h
P_n^h = Power generation of nth unit at hth sub interval in MW
U_n^h = Unit status of nth unit at hth sub interval
FC_T = Total fuel cost
$FC_n(P_n^h)$ = Fuel cost of nth generating unit at hth hour
$SUC_{n,h}$ = Start-up cost of nth generating unit for hth hour
SDC_n = Shut-down cost of nth generating unit
HSC_n = Hot start cost of nth generating unit
CSC_n = Cold start cost of nth generating unit
$T_{n,down}$ = Minimum down time of nth unit
$T_{n,off}^h$ = Consecutive off time of nth unit
$T_{n,cold}$ = Cold start hour of the nth unit
$P_{W,h}$ = Power loss at hth hour
$P_{D,h}$ = Power demand at hth hour
SR_n^h = Spinning reserve of nth unit at hth hour

2. PROFIT BASED UNIT COMMITMENT PROBLEM FORMULATION

The Profit Based Unit commitment problem mathematically can be represented as per eqn.(1), which consists of revenue and total operating cost.

$$PF_{MAX}(n,h) = R_v(n,h) - TC(n,h) \tag{1}$$

$$R_v(n,h) = \sum_{h=1}^{H}\sum_{n=1}^{N} \partial_h \times P_n^h \times U_n^h \tag{2a}$$

$$TC(n,h) = \sum_{h=1}^{H}\sum_{n=1}^{N} FC_n(P_n^h) \times U_n^h + \mathrm{SU}\,C_{n,h} \tag{2b}$$

$$FC_T = \sum_{h=1}^{H}\sum_{n=1}^{N} FC_n(P_n^h)\,\mathrm{U}_n^h + U_n^h(1-\mathrm{U}_n^{h-1})\,\mathrm{SU}\,C_{n,h} + U_n^{h-1}(1-U_n^h)SDC_n \tag{3}$$

$$FC_n(P_n^h) = a_n(P_n^h)^2 + b_n(P_n^h) + c_n \tag{4}$$

$$SUC_{n,h} = \begin{Bmatrix} HSC_n & if & T_{n,down} \le T_{n,off}^h \le T_{n,down} + T_{n,cold} \\ CSC_n & if & T_{n,off}^h \ge T_{n,down} + T_{n,cold} \end{Bmatrix} \tag{5}$$

The aforementioned unit commitment problem is subjected to various equality and non-equality constraints and which are mathematically described below:

a) Power Operational constraints

$$\sum_{n=1}^{N} P_{n,h} + P_{W,h} - P_{D,h} = 0 \tag{6}$$

b) Spinning Reserve Constraint

$$SR_n^h = \min(\mathrm{P}_{n,\max} - P_{n,h}\,,\quad U_{R,h}\,T_l) \tag{7}$$

(c) Minimum up and down time constraints

$$\left(T_{n,h-1}^{on} - T_{n,\min}^{on}\right)\left(U_{n,h-1} - U_{n,h}\right) \ge 0 \tag{8}$$

$$\left(T_{n,h-1}^{off} - T_{n,\min}^{off}\right)\left(U_{n,h-1} - U_{n,h}\right) \ge 0 \tag{9}$$

(d) Maximum and Minimum Power Limit

$$P_n^{\min} \le P_{n,h} \le P_n^{\max} \tag{10}$$

3. CLASSICAL GREY WOLF OPTIMIZER

Mostly established Grey Wolf Optimizer, is a transformative design algorithm, based on the chasing factor and societal hierarchy of Grey Wolves in view of the three principles activities including chasing: assaulting victim, scanning for victim and encompassing victim and its statistically model which was measured in view point of pyramid of various types of grey wolves. Fittest solution was nominated as α. The second best solutions is named as β and third best solutions is named as δ. The hopeful solution are thought to be ω, κ and λ . For the fitness value calculation, the advancement (chasing) is guided by α, β and δ. The ω, κ and λ wolves trail the three wolves. The hunting mechanism of grey wolf is carryout by tracing, hunting and approaching toward the victim then pursuing, harassing and encircling the victim once the prey stops moving then attack toward the prey. In GWO, Encircling or Trapping of Prey was achieved by calculating $\vec{\mathrm{D}}$ and $\vec{\mathrm{X}}_{\mathrm{GWolf}}$ vectors described by equation numbers (11) and (12).

$$\vec{\mathrm{D}} = \left|\vec{\mathrm{C}}.\vec{\mathrm{X}}_{\mathrm{Prey}}(\mathrm{iteration}) - \vec{\mathrm{X}}_{\mathrm{GWolf}}(\mathrm{iteration})\right| \tag{11}$$

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$$\vec{X}_{GWolf}(\text{iteration}+1)=\vec{X}_{Prey}(\text{iteration})-\vec{A}.\vec{D} \quad (12)$$

Here, iteration demonstrates present iteration, coefficient vectors are $\vec{A}$ and $\vec{C}$, $\vec{X}_{Prey}$ is the location vector of the victim and $\vec{X}_{GWolf}$ shows the location vector of grey wolf and the calculation of vectors $\vec{A}$ and $\vec{C}$ are followed as:

$$\vec{A}=2\vec{a}.\vec{\mu}_1-\vec{a} \quad (13)$$

$$\vec{C}=2.\vec{\mu}_2 \quad (14)$$

Where, $\vec{\mu}_1,\vec{\mu}_2\in \text{rand}(0,1)$ and $\vec{a}$ decreases linearly from 2 to 0.

The hunting of victim are accomplished by calculating corresponding fitness score and locations of α, β and δ wolves by equation numbers (15), (16) and (17) separately and final position for attacking to the victim was intended by equation number (18).

$$\vec{D}_\alpha=|(\vec{C}_1.\vec{X}_\alpha-\vec{X})| \quad (15a)$$

$$\vec{X}_1=\vec{X}_\alpha-\vec{A}_1.\vec{D}_\alpha \quad (15b)$$

$$\vec{D}_\beta=|(\vec{C}_2.\vec{X}_\beta-\vec{X})| \quad (16a)$$

$$\vec{X}_2=\vec{X}_\beta-\vec{A}_2.\vec{D}_\beta \quad (16b)$$

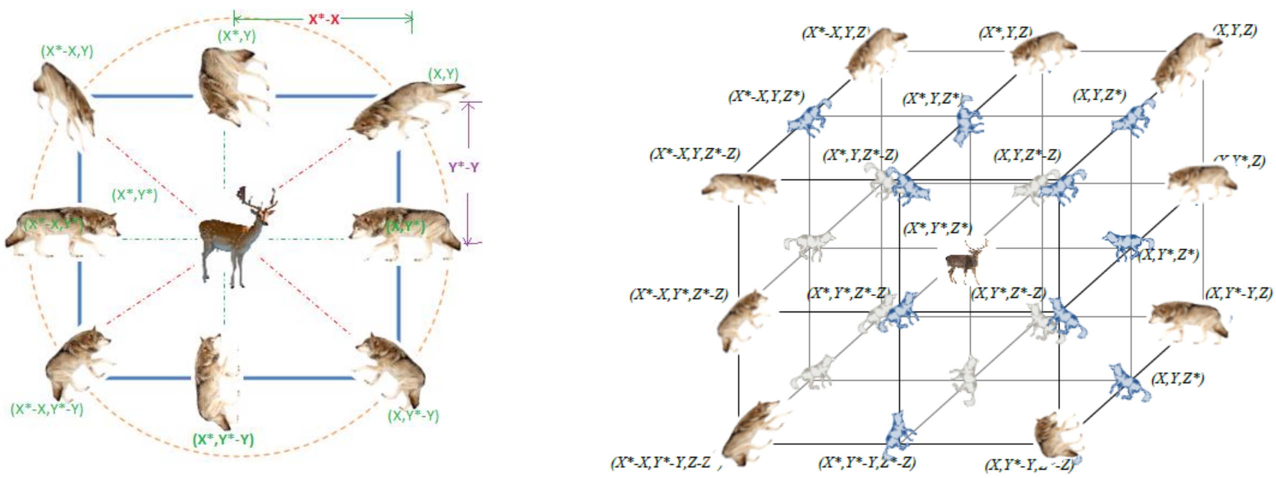
$$\vec{D}_\delta=|(\vec{C}_3.\vec{X}_\delta-\vec{X})| \quad (17a)$$

$$\vec{X}_3=\vec{X}_\delta-\vec{A}_3.\vec{D}_\delta \quad (17b)$$

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

4. HYBRID GWO-RES ALGORITHM

In the proposed hybrid Grey-Wolf Optimizer-Random Exploratory search (hybrid GWO-RES) algorithm, the position vector $\vec{X}_i$ is perturbed by Δ_i and new position vectors $(\vec{X}_i+\Delta_i)$ and $(\vec{X}_i-\Delta_i)$ has been obtained. The new fitness solutions $f^+\leftarrow f(X+\Delta)$ and $f^-\leftarrow f(X-\Delta)$ has been obtained along with previous fitness solution $f\leftarrow f(X)$ and final fitness has been evaluated taking minimum values out of these newly obtained solutions. The impact of newly obtained positions vectors as 2-Dimentional locations vector and conceivable neighbours are outlined in Fig.1. (a). As per Fig.1 (a), grey wolf poser of (*X*, *Y*) can apprise its location w.r.t. newly obtained position vectors $((X+\Delta),(Y+\Delta))$ and $((X-\Delta),(Y-\Delta))$ indicated by the position of the prey (*X**, *Y**) and exploit the search space in better way. Superior places nearby as well as can be predictable be come to regarding the present location by varying the approximation of $\vec{A}$ and $\vec{C}$ vectors. Fig. 1(a) shows the 2-D view of Position Vectors along with perturbed position vectors $(\vec{X}_i+\Delta_i)$, $(\vec{X}_i-\Delta_i)$ and probable next Location w.r.t. Victim. The 3-D view of position vectors along with perturbed position vectors $(\vec{X}_i+\Delta_i)$, $(\vec{X}_i-\Delta_i)$ and probable next position w.r.t. victim has been presented in Fig.1 (b).



(a) **(b)**

Fig.1: 2D and 3D view of Position Vectors along with perturbed Position Vector and probable next Position w.r.t. Prey

The exploration phase in hybrid GWO-RES is similar to GWO. , In order to explore the search space globally, vector $\vec{A}$ and $\vec{C}$ are used, which statistically model divergence. The absolute value of $\vec{A}$ > 1 which forces the grey wolves to deviate from the victim to optimistically find a suitable prey and has been depicted in the Fig.2 (a). The PSEUDO code of proposed hybrid GWO-RES algorithm has been presented in Fig.2 (b) and flow chart of the suggested hybrid algorithm is depicted in Fig.3.

```
Initialize the grey wolf population X_i (i=1, 2… n)
Initialize a, A and C
Calculate the fitness of each search agent
X_α =the best search agent
X_β =the second best search agent
X_δ =the third best search agent
while (t<max number of iteration)
    for each search agent
        Update the position of current search agent by equation (16)
    end for
    Update a, A and C
    Calculate the fitness for all search agents
    Update X_α , X_β and X_δ
    t=t+1
end while
return X_α
```

```
Initialize the grey wolf population X_i (i=1, 2… n)
Initialize a, A and C
Calculate the fitness of each search agent
X_α =the best search agent
X_β =the second best search agent
X_δ =the third best search agent
while (i<max number of iteration)
    for each search agent
        Update the position of current search agent by equation (16).
    end for
    Update a, A and C
    Calculate f⁺ ← f(X+Δ), f⁻ ← f(X−Δ) and f ← f(X) for all search agents
    Evaluate best fitness using fitness ← min(f⁺, f⁻, f)
    Update X_α , X_β and X_δ
    t=t+1
end while
return X_α
```

(a) PSEUDO code of GWO algorithm (b) PSEUDO code of proposed hGWO-RES algorithm

Fig.2: PSEUDO code of GWO and proposed hybrid GWO-RES algorithm

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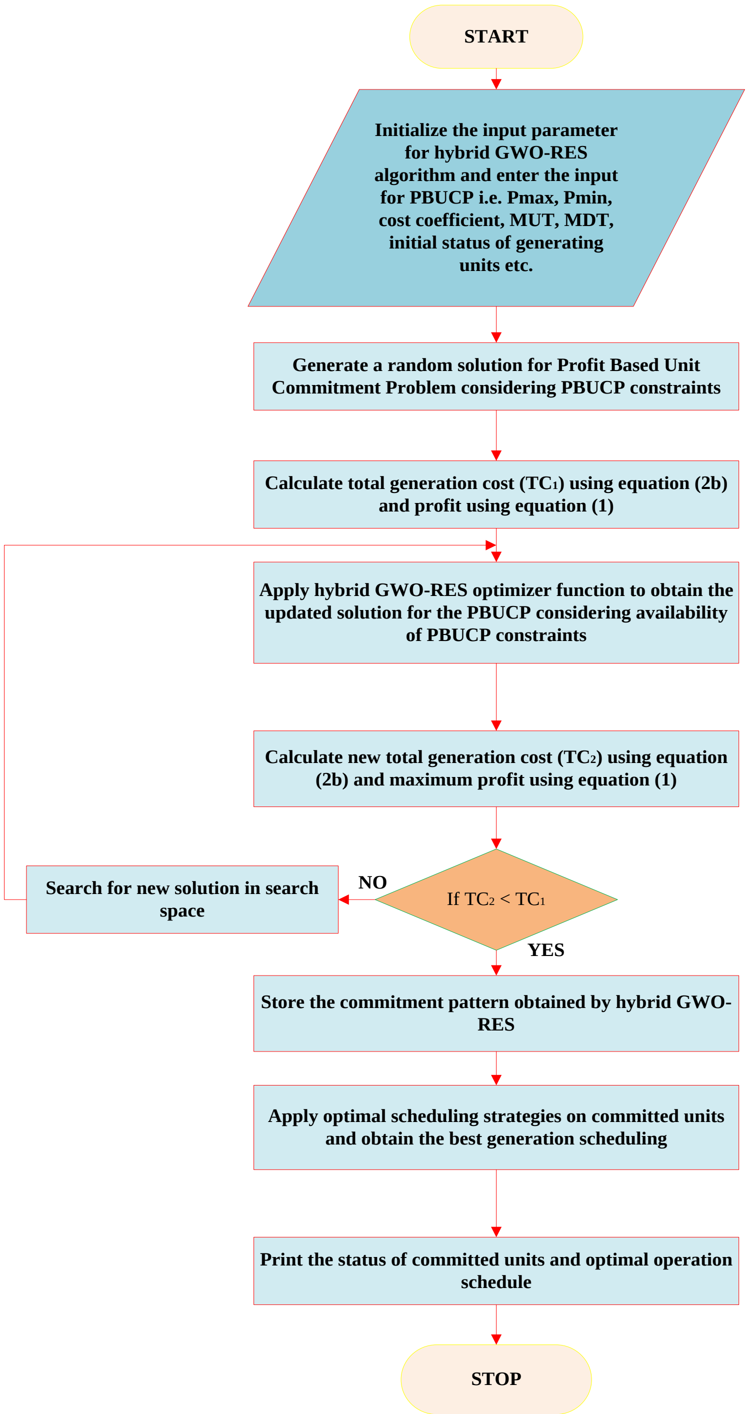

Fig.3: Flow chart for hybrid GWO-RES Algorithm

5. SOLUTION STRATEGY FOR PBUCP

In grey wolf optimizer, the search agent explore and exploit their updated position to a suitable real value in given search space considering various constraints impose upon them. Since profit based unit commitment problem is highly constraints in nature have both binary and discrete values. Thus mapping of continuous value of search agent updated to binary value is mandatory. Before solving PBUCP by using hybrid GWO-RES algorithm we represent agent as a binary string .each unit “ON state” as 1 and “OFF state” as a 0. So, unit state U is basically matrix of {N*H} following steps clarify modus operandi of unit commitment problem.

Step-1: Solve the single area PBUCP, every individual is defined as units ON/OFF status showed as 1/0 correspondingly and commitment schedule display over the time horizon H. The ON/OFF unit schedule is stored U which is denoted as an integer-matrix, which is mathematically defined as:

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$$U_{NP}=\begin{bmatrix} u_1^1 & u_1^2 & \cdots & u_1^H \\ u_2^1 & u_2^2 & \cdots & u_2^H \\ \vdots & \vdots & \vdots & \vdots \\ u_G^1 & u_G^2 & \cdots & u_G^H \end{bmatrix},$$

Where, u_n^h is ON/OFF unit status of n^{th} unit at h^{th} hour (i.e. u_n^h =1/0 for ON/OFF).

Step-2: Generating units are prioritized according to their Average Full Load generation Capacity in descending order.

Step-3: Status of individual units is modified in the population to satisfy the spinning reserve constraints.

Step-4: Individual units in the population are repaired for MUT/ MDT violations

Step-5: Units of some search agents are de-committed in the population to decrease extreme SR due to MUT/MDT restoring

Step-6: Economic Load Dispatch Problem is then solved using MIQP and Fuel Cost is calculated for each hour.

Step-7: Calculate Start-up cost for each hour using eqn. (3).

Step-8: Overall generation cost for 1st position is evaluated and it is assumed as global fitness and its position as global position.

Step-9: Overall generation costs for all positions are then evaluated in the population and then local generation cost and local commitment schedule for whole population is determined.

Step-10: Overall global generation cost is compared with Local generation cost in whole population. If global generation cost is greater than local generation cost, replace global generation cost with local generation cost and take local commitment schedule as global commitment.

Step-11: Modify the individual position using hybrid GWO-RES algorithm and determine overall best generation cost and commitment schedule.

Step-12: If the maximum iteration number is reached, then go to next step (Step 14.)

Step-13: Otherwise, increase iteration number and go back to step 3.

Step-14: Stop and obtain the optimal solution of single area PBUCP from individual position in the population that generated the least total generation cost.

6. CONSTRAINTS HANDLING STRATEGY/ REPAIR MECHANISM OF CONSTRAINTS

The achieved major unit scheduling by hybrid GWO-RES may not fulfil the certain crucial constraints such as MDT, MUT, Spinning reserve etc. So, the constraints defilements are to be repaired. In this paper a heuristic search strategy is adopted to tackle such problem.

6.1 Handling strategy for MUT and MDT

MUT and MDT of specific unit is definite as connective hours that the unit is 'ON' or 'OFF 'when it 'on' or 'off'. any unit that is if 'on ' should not turned 'off' immediately without reaching to 'MUT' and similarly any unit which is once "off" should not turned "on" immediately without reaching to MDT. These constraints are calculated beforehand by using following recursive relation

$$T_{n.on}^{h}=\begin{cases} T_{n,on}^{h-1}+1 & if\ u_n^h=1 \\ 0 & if\ u_n^h=0 \end{cases} \tag{17}$$

$$T_{n,off}^{h}=\begin{cases} T_{n,off}^{h-1}+1 & if\ u_n^h=0 \\ 0 & if\ u_n^h=1 \end{cases} \tag{18}$$

Where $T_{n,on}^{h}$ and $T_{n,off}^{h}$ are number of continuous time when unit is on and off.

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When crowning load duration appreciably inferior to the minimum down time of particular system. Minimum up time (MUT) is despoiled. And constraint associated with MDT is despoiled at lower load level where lower load duration is considerable smaller than minimum up time. Since repapering of MDT, MUT, can lead to excessive spinning reserve , which results into high operating cost , thus if this remains whole the purpose of optimizing cost be defeated. Hence we again us heuristic technique to de commit excess of reserve.

The methodology to adjust/repair defilement of constraints associated with MDT, MUT are done as given below:

Step1: Calculate the time duration of ON and OFF time of all units for the entire schedule time horizon.

Step2: set $h = 1$

Step 3: set iteration count $n = 1$

Step 4: $if\ u_n^h = 0$ and $u_n^{h-1} = 1$ and $T_{n,on}^{h-1} \leq MUT$ then set $u_n^h = 1$

Step5: if $u_n^h = 0$ and $u_n^{h-1} = 1$ and $h + MDT - 1 \leq T$ and $T_{n,off}^{off+MDT-1} \leq MDT$ SET $u_n^h = 1$

Step6: if $if\ u_n^h = 0$ and $u_n^{h-1} = 1$ and $t + MDT - 1 > T$ and $\sum_{n=h}^{H} u_n^h > 0$ set $u_n^h = 1$

Step 7: update the time period of ON/OFF times for unit i

Step8: Do $n = n + 1$ return to step 4.

Step9: $if\ h < H, h = h + 1,$ return to step 3,

Step 10: if condition at step 9, found false, stop.

7. TEST SYSTEM FOR PROFIT BASED UNIT COMMITMENT PROBLEM

In order to verify the effectiveness of the proposed memetic optimizer, 10-generating unit system with 24-hours load demand has been taken into consideration. In order to validate the efficacy and usefulness of the proposed algorithm, the robustness of the algorithm has been tested for 30 trial runs and algorithm is run for 500 iterations. The 30 search agents has been taken throughout the test study as number of population and best results are recoded in Table-3 and Table-4. The Power Demand, Energy Prices, forecasted market demand and reserve for 10-generatuing unit test system has been depicted in Fig.4.

Table 1: Unit Characteristics for 10-generating unit system

Unit Parameter	Generating Units									
	U1	**U2**	**U3**	**U4**	**U5**	**U6**	**U7**	**U8**	**U9**	**U10**
P_n^{MAX}	455	455	130	130	162	80	85	55	55	55
P_n^{MIN}	150	150	20	20	25	20	25	10	10	10
A_n	1000	970	700	680	450	370	480	660	665	670
B_n	16.19	17.26	16.6	16.5	19.7	22.26	27.74	25.92	27.27	27.79
C_n	0.00048	0.00031	0.002	0.00211	0.00398	0.00712	0.00079	0.00413	0.00222	0.00173
T_n^{UP}	8	8	5	5	6	3	3	1	1	1
T_n^{DW}	8	8	5	5	6	3	3	1	1	1
HSU_n	4500	5000	550	560	900	170	260	30	30	30
CSU_n	9000	10,000	1100	1120	1800	340	520	60	60	60
T_n^{COLD}	5	5	4	4	4	2	2	0	0	0
INS_n	8	8	-5	-5	-6	-3	-3	-1	-1	-1

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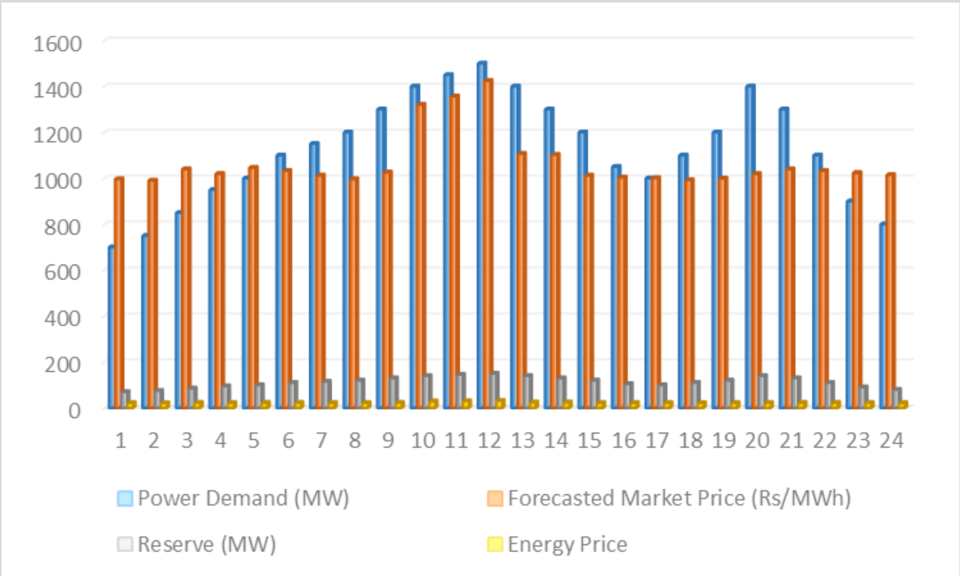

Fig.4: Power Demand, Reserve and Energy Price for 10-unit system

Table 2: Power demand and forecasted market price for 10-generating unit system

HOUR	Power Demand (MW)	Forecasted Market Price (Rs/MWh)
1	700	996.75
2	750	990
3	850	1039.5
4	950	1019.25
5	1000	1046.25
6	1100	1032.75
7	1150	1012.5
8	1200	996.75
9	1300	1026
10	1400	1320.75
11	1450	1356.75
12	1500	1424.25
13	1400	1107
14	1300	1102.5
15	1200	1012.5
16	1050	1003.5
17	1000	1001.25
18	1100	992.25
19	1200	999
20	1400	1019.25
21	1300	1039.5
22	1100	1032.75
23	900	1023.75
24	800	1014.75

8. RESULT AND DISCUSSION

To verify the performance of proposed hybrid algorithm hGWO-RES for PBUCP, the aforementioned algorithm has been tested for 24-hours load demand pattern and results are recorded with respected to

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scheduling of corresponding generating units for individual hours. The Table-3 depicts the scheduling and commitment pattern for 10 units system for first 12 hours and Table-4 represents the commitment and generation schedule for 10-unit system for last 12 hours during 24 hours load demand.

Table-3: Results for 10-generating units system using hGWO-RES (h1-h12) using hGWO-RES

Hour/Units	h1	h2	h3	h4	h5	h6	h7	h8	h9	h10	h11	h12
U1	455	455	455	455	455	455	455	455	455	455	455	455
U2	245	295	395	455	415	455	455	455	455	455	455	455
U3	0	0	0	0	0	0	0	0	130	130	130	130
U4	0	0	0	0	130	130	130	130	130	130	130	130
U5	0	0	0	0	0	0	0	0	0	162	162	162
U6	0	0	0	0	0	0	0	0	0	68	80	80
U7	0	0	0	0	0	0	0	0	0	0	0	0
U8	0	0	0	0	0	0	0	0	0	0	0	0
U9	0	0	0	0	0	0	0	0	0	0	0	0
U10	0	0	0	0	0	0	0	0	0	0	0	0

Table-4: Results for 10-generating units system using hGWO-RES (h13-h24) using hGWO-RES

Hour/Units	h13	h14	h15	h16	h17	h18	h19	h20	h21	h22	h23	h24
U1	455	455	455	455	455	455	455	455	455	455	455	455
U2	455	455	455	455	415	455	455	455	455	455	445	345
U3	130	130	0	0	0	0	0	0	0	0	0	0
U4	130	130	130	130	130	130	130	130	130	130	0	0
U5	162	130	160	0	0	0	0	0	0	0	0	0
U6	0	0	0	0	0	0	0	0	0	0	0	0
U7	0	0	0	0	0	0	0	0	0	0	0	0
U8	0	0	0	0	0	0	0	0	0	0	0	0
U9	0	0	0	0	0	0	0	0	0	0	0	0
U10	0	0	0	0	0	0	0	0	0	0	0	0

Experimentally, it has been observed that the overall fuel cost for 24-hours is $ 502372.74, overall start-up cost is $38090 and overall profit is $ 107702.57.

CONCLUSION

In the proposed research, the authors has successfully evaluated the performance of 10-generating unit test system for profit based unit commitment problem using random exploratory search based hybrid grey wolf optimizer, which represents an improved memetic variant of classical grey wolf optimizer and it had been experimentally found that the proposed algorithm endorse its effectiveness for profit based unit commitment problem as compared to other recently proposed optimizers.

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